This is the Chainer documentation.
1.1 Before installing Chainer

We recommend these platforms.

- **Ubuntu** 14.04 LTS 64bit
- **CentOS** 7 64bit

Chainer is supported on Python 2.7.6+, 3.4.3+, 3.5.1+. Chainer uses C++ compiler such as g++. You need to install it before installing Chainer. This is typical installation method for each platform:

```bash
# Ubuntu 14.04
$ apt-get install g++

# CentOS 7
$ yum install gcc-c++
```

If you use old `setuptools`, upgrade it:

```bash
$ pip install -U setuptools
```

1.2 Install Chainer

Chainer depends on these Python packages:

- **NumPy** 1.9, 1.10, 1.11
- **Six** 1.9

CUDA support

- **CUDA** 6.5, 7.0, 7.5, 8.0
- **filelock**

cuDNN support

- **cuDNN** v2, v3, v4, v5, v5.1

Caffe model support

- **Protocol Buffers**
- protobuf>=3.0.0 is required for Py3
All these libraries are automatically installed with pip or setup.py. Image dataset is optional
- Pillow
HDF5 serialization is optional
- h5py 2.5.0

### 1.2.1 Install Chainer via pip
We recommend to install Chainer via pip:

```bash
$ pip install chainer
```

### 1.2.2 Install Chainer from source
You can use setup.py to install Chainer from source:

```bash
$ tar zxf chainer-x.x.x.tar.gz
$ cd chainer-x.x.x
$ python setup.py install
```

### 1.2.3 When an error occurs...
Use -vvvv option with pip command. That shows all logs of installation. It may helps you:

```bash
$ pip install chainer -vvvv
```

### 1.2.4 Install Chainer with CUDA
You need to install CUDA Toolkit before installing Chainer. If you have CUDA in a default directory or set CUDA_PATH correctly, Chainer installer finds CUDA automatically:

```bash
$ pip install chainer
```

**Note:** Chainer installer looks up CUDA_PATH environment variable first. If it is empty, the installer looks for nvcc command from PATH environment variable and use its parent directory as the root directory of CUDA installation. If nvcc command is also not found, the installer tries to use the default directory for Ubuntu /usr/local/cuda.

If you installed CUDA into a non-default directory, you need to specify the directory with CUDA_PATH environment variable:

```bash
$ CUDA_PATH=/opt/nvidia/cuda pip install chainer
```

**Warning:** If you want to use sudo to install Chainer, note that sudo command initializes all environment variables. Please specify CUDA_PATH environment variable inside sudo like this:

```bash
$ sudo CUDA_PATH=/opt/nvidia/cuda pip install chainer
```
1.2.5 Install Chainer with CUDA and cuDNN

cuDNN is a library for Deep Neural Networks that NVIDIA provides. Chainer can use cuDNN. If you want to enable cuDNN, install cuDNN and CUDA before installing Chainer. We recommend you to install cuDNN to CUDA directory. For example if you uses Ubuntu Linux, copy .h files to include directory and .so files to lib64 directory:

```bash
$ cp /path/to/cudnn.h $CUDA_PATH/include
$ cp /path/to/libcudnn.so* $CUDA_PATH/lib64
```

The destination directories depend on your environment.

If you want to use cuDNN installed in other directory, please use CFLAGS, LDFLAGS and LD_LIBRARY_PATH environment variables before installing Chainer:

```bash
export CFLAGS=-I/path/to/cudnn/include
export LDFLAGS=-L/path/to/cudnn/lib
export LD_LIBRARY_PATH=/path/to/cudnn/lib:$LD_LIBRARY_PATH
```

1.2.6 Install Chainer for developers

Chainer uses Cython (>=0.24). Developers need to use Cython to regenerate C++ sources from pyx files. We recommend to use pip with -e option for editable mode:

```bash
$ pip install -U cython
$ cd /path/to/chainer/source
$ pip install -e .
```

Users need not to install Cython as a distribution package of Chainer only contains generated sources.

1.2.7 Support image dataset

Install Pillow manually to activate image dataset. This feature is optional:

```bash
$ pip install pillow
```

1.2.8 Support HDF5 serialization

Install h5py manually to activate HDF5 serialization. This feature is optional:

```bash
$ pip install h5py
```

Before installing h5py, you need to install libhdf5. It depends on your environment:

- # Ubuntu 14.04
  ```bash
  $ apt-get install libhdf5-dev
  ```

- # CentOS 7
  ```bash
  $ yum -y install epel-release
  $ yum install hdf5-devel
  ```
1.3 Uninstall Chainer

Use pip to uninstall Chainer:

```bash
$ pip uninstall chainer
```

**Note:** When you upgrade Chainer, pip sometimes installed various version of Chainer in `site-packages`. Please uninstall it repeatedly until pip returns an error.

1.4 Upgrade Chainer

Just use pip with `-U` option:

```bash
$ pip install -U chainer
```

1.5 Reinstall Chainer

If you want to reinstall Chainer, please uninstall Chainer and then install it. We recommend to use `--no-cache-dir` option as pip sometimes uses cache:

```bash
$ pip uninstall chainer
$ pip install chainer --no-cache-dir
```

When you install Chainer without CUDA, and after that you want to use CUDA, please reinstall Chainer. You need to reinstall Chainer when you want to upgrade CUDA.

1.6 Run Chainer with Docker

We provide the official Docker image. Use `nvidia-docker` command to run Chainer image with GPU. You can login to the environment with bash, and run the Python interpreter:

```bash
$ nvidia-docker run -it chainer/chainer /bin/bash
```

Or, run the interpreter directly:

```bash
$ nvidia-docker run -it chainer/chainer /usr/bin/python
```

1.7 What “recommend” means?

We tests Chainer automatically with Jenkins. All supported environments are tested in this environment. We cannot guarantee that Chainer works on other environments.
1.8 FAQ

1.8.1 The installer says “hdf5.h is not found”

You don’t have libhdf5. Please install hdf5. See *Before installing Chainer*.

1.8.2 MemoryError happens

You maybe failed to install Cython. Please install it manually. See *When an error occurs*.

1.8.3 Examples says “cuDNN is not enabled”

You failed to build Chainer with cuDNN. If you don’t need cuDNN, ignore this message. Otherwise, retry to install Chainer with cuDNN. –vvvv option helps you. See *Install Chainer with CUDA and cuDNN*.
2.1 Introduction to Chainer

This is the first section of the Chainer Tutorial. In this section, you will learn about the following things:

- Pros and cons of existing frameworks and why we are developing Chainer
- Simple example of forward and backward computation
- Usage of links and their gradient computation
- Construction of chains (a.k.a. “model” in most frameworks)
- Parameter optimization
- Serialization of links and optimizers

After reading this section, you will be able to:

- Compute gradients of some arithmetics
- Write a multi-layer perceptron with Chainer

2.1.1 Core Concept

As mentioned on the front page, Chainer is a flexible framework for neural networks. One major goal is flexibility, so it must enable us to write complex architectures simply and intuitively.

Most existing deep learning frameworks are based on the “Define-and-Run” scheme. That is, first a network is defined and fixed, and then the user periodically feeds it with mini-batches. Since the network is statically defined before any forward/backward computation, all the logic must be embedded into the network architecture as data. Consequently, defining a network architecture in such systems (e.g. Caffe) follows a declarative approach. Note that one can still produce such a static network definition using imperative languages (e.g. torch.nn, Theano-based frameworks, and TensorFlow).

In contrast, Chainer adopts a “Define-by-Run” scheme, i.e., the network is defined on-the-fly via the actual forward computation. More precisely, Chainer stores the history of computation instead of programming logic. This strategy enables to fully leverage the power of programming logic in Python. For example, Chainer does not need any magic to introduce conditionals and loops into the network definitions. The Define-by-Run scheme is the core concept of Chainer. We will show in this tutorial how to define networks dynamically.

This strategy also makes it easy to write multi-GPU parallelization, since logic comes closer to network manipulation. We will review such amenities in later sections of this tutorial.
**Note:** In example codes of this tutorial, we assume for simplicity that the following symbols are already imported:

```python
import numpy as np
import chainer
from chainer import cuda, Function, gradient_check, report, training, utils, Variable
from chainer import datasets, iterators, optimizers, serializers
from chainer import Link, Chain, ChainList
import chainer.functions as F
import chainer.links as L
from chainer.training import extensions
```

These imports appear widely in Chainer’s codes and examples. For simplicity, we omit these imports in this tutorial.

### 2.1.2 Forward/Backward Computation

As described above, Chainer uses “Define-by-Run” scheme, so forward computation itself *defines* the network. In order to start forward computation, we have to set the input array to `Variable` object. Here we start with simple `ndarray` with only one element:

```python
>>> x_data = np.array([5], dtype=np.float32)
>>> x = Variable(x_data)
```

A Variable object has basic arithmetic operators. In order to compute \( y = x^2 - 2x + 1 \), just write:

```python
>>> y = x**2 - 2 * x + 1
```

The resulting `y` is also a Variable object, whose value can be extracted by accessing the `data` attribute:

```python
>>> y.data
array([ 16.], dtype=float32)
```

What `y` holds is not only the result value. It also holds the history of computation (or computational graph), which enables us to compute its differentiation. This is done by calling its `backward` method:

```python
>>> y.backward()
```

This runs *error backpropagation* (a.k.a. *backprop* or reverse-mode automatic differentiation). Then, the gradient is computed and stored in the `grad` attribute of the input variable `x`:

```python
>>> x.grad
array([ 8.], dtype=float32)
```

Also we can compute gradients of intermediate variables. Note that Chainer, by default, releases the gradient arrays of intermediate variables for memory efficiency. In order to preserve gradient information, pass the `retain_grad` argument to the backward method:

```python
>>> z = 2*x
>>> y = x**2 - z + 1
>>> y.backward(retain_grad=True)
>>> z.grad
array([-1.], dtype=float32)
```

All these computations are easily generalized to multi-element array input. Note that if we want to start backward computation from a variable holding a multi-element array, we must set the *initial error* manually. This is simply done by setting the `grad` attribute of the output variable:
>>> x = Variable(np.array([[1, 2, 3], [4, 5, 6]], dtype=np.float32))
>>> y = x**2 - 2*x + 1
>>> y.grad = np.ones((2, 3), dtype=np.float32)
>>> y.backward()
array([[ 0.,  2.,  4.],
       [ 6.,  8., 10.]], dtype=float32)

Note: Many functions taking Variable object(s) are defined in the functions module. You can combine them to realize complicated functions with automatic backward computation.

2.1.3 Links

In order to write neural networks, we have to combine functions with parameters and optimize the parameters. You can use links to do this. Link is an object that holds parameters (i.e. optimization targets).

The most fundamental ones are links that behave like regular functions while replacing some arguments by their parameters. We will introduce higher level links, but here think links just like functions with parameters.

One of the most frequently-used links is the Linear link (a.k.a. fully-connected layer or affine transformation). It represents a mathematical function \( f(x) = Wx + b \), where the matrix \( W \) and the vector \( b \) are parameters. This link is corresponding to its pure counterpart linear(), which accepts \( x, W, b \) as arguments. A linear link from three-dimensional space to two-dimensional space is defined by the following line:

```python
>>> f = L.Linear(3, 2)
```

Note: Most functions and links only accept mini-batch input, where the first dimension of input arrays is considered as the batch dimension. In the above Linear link case, input must have shape of (N, 3), where N is the mini-batch size.

The parameters of a link are stored as attributes. Each parameter is an instance of Variable. In the case of Linear link, two parameters, \( W \) and \( b \), are stored. By default, the matrix \( W \) is initialized randomly, while the vector \( b \) is initialized with zeros.

```python
>>> f.W.data
array([[ 1.01847613,  0.23103087,  0.56507462],
       [ 1.29378033,  1.07823515, -0.56423163]], dtype=float32)
>>> f.b.data
array([ 0.,  0.], dtype=float32)
```

An instance of the Linear link acts like a usual function:

```python
>>> x = Variable(np.array([[1, 2, 3], [4, 5, 6]], dtype=np.float32))
>>> y = f(x)
>>> y.data
array([[ 3.1757617 ,  1.75755572],
       [ 8.61950684,  7.18090773]], dtype=float32)
```

Gradients of parameters are computed by backward() method. Note that gradients are accumulated by the method rather than overwritten. So first you must clear gradients to renew the computation. It can be done by calling the cleargrads() method.

```python
>>> f.cleargrads()
```
Note: `cleargrads()` is introduced in v1.15 to replace `zerograds()` for efficiency. `zerograds()` is left only for backward compatibility.

Now we can compute the gradients of parameters by simply calling backward method.

```python
>>> y.grad = np.ones((2, 2), dtype=np.float32)
>>> y.backward()
```

```python
>>> f.W.grad
array([[ 5., 7., 9.],
       [ 5., 7., 9.]], dtype=float32)
```

```python
>>> f.b.grad
array([ 2., 2.], dtype=float32)
```

### 2.1.4 Write a model as a chain

Most neural network architectures contain multiple links. For example, a multi-layer perceptron consists of multiple linear layers. We can write complex procedures with parameters by combining multiple links like this:

```python
>>> l1 = L.Linear(4, 3)
>>> l2 = L.Linear(3, 2)
>>> def my_forward(x):
...     h = l1(x)
...     return l2(h)
```

Here the `L` indicates the `links` module. A procedure with parameters defined in this way is hard to reuse. More Pythonic way is combining the links and procedures into a class:

```python
>>> class MyProc(object):
...     def __init__(self):
...         self.l1 = L.Linear(4, 3)
...         self.l2 = L.Linear(3, 2)
...     def forward(self, x):
...         h = self.l1(x)
...         return self.l2(h)
```

In order to make it more reusable, we want to support parameter management, CPU/GPU migration support, robust and flexible save/load features, etc. These features are all supported by the `Chain` class in Chainer. Then, what we have to do here is just defining the above class as a subclass of Chain:

```python
>>> class MyChain(Chain):
...     def __init__(self):
...         super(MyChain, self).__init__(
...             l1=L.Linear(4, 3),
...             l2=L.Linear(3, 2),
...         )
...     def __call__(self, x):
...         h = self.l1(x)
...         return self.l2(h)
```

Note: We often define a single forward method of a link by `__call__` operator. Such links and chains are callable and behave like regular functions of Variables.
It shows how a complex chain is constructed by simpler links. Links like \( l_1 \) and \( l_2 \) are called child links of MyChain. Note that Chain itself inherits Link. It means we can define more complex chains that hold MyChain objects as their child links.

Another way to define a chain is using the ChainList class, which behaves like a list of links:

```python
>>> class MyChain2(ChainList):
...     def __init__(self):
...         super(MyChain2, self).__init__(
...             L.Linear(4, 3),
...             L.Linear(3, 2),
...         )
...
...     def __call__(self, x):
...         h = self[0](x)
...         return self[1](h)
```

ChainList is convenient to use an arbitrary number of links. If the number of links is fixed like the above case, the Chain class is recommended as a base class.

### 2.1.5 Optimizer

In order to get good values for parameters, we have to optimize them by the Optimizer class. It runs a numerical optimization algorithm given a link. Many algorithms are implemented in optimizers module. Here we use the simplest one, called Stochastic Gradient Descent (SGD):

```python
>>> model = MyChain()
>>> optimizer = optimizers.SGD()
>>> optimizer.use_cleargrads()
>>> optimizer.setup(model)
```

The method `use_cleargrads()` is for efficiency. See `use_cleargrads()` for detail.

The method `setup()` prepares for the optimization given a link.

Some parameter/gradient manipulations, e.g. weight decay and gradient clipping, can be done by setting hook functions to the optimizer. Hook functions are called after the gradient computation and right before the actual update of parameters. For example, we can set weight decay regularization by running the next line beforehand:

```python
>>> optimizer.add_hook(chainer.optimizer.WeightDecay(0.0005))
```

Of course, you can write your own hook functions. It should be a function or a callable object, taking the optimizer as the argument.

There are two ways to use the optimizer. One is using it via Trainer, which we will see in the following sections. The other way is using it directly. We here review the latter case. *If you are interested in getting able to use the optimizer in a simple way, skip this section and go to the next one.*

There are further two ways to use the optimizer directly. One is manually computing gradients and then call the `update()` method with no arguments. Do not forget to clear gradients beforehand!

```python
>>> x = np.random.uniform(-1, 1, (2, 4)).astype('f')
>>> model.cleargrads()
>>> # compute gradient here...
>>> loss = F.sum(model(chainer.Variable(x)))
>>> loss.backward()
>>> optimizer.update()
```

The other way is just passing a loss function to the `update()` method. In this case, `cleargrads()` is automatically called by the update method, so user do not have to call it manually.

2.1. Introduction to Chainer 13
>>> def lossfun(arg1, arg2):
...     # calculate loss
...     loss = F.sum(model(arg1 - arg2))
...     return loss
>>> arg1 = np.random.uniform(-1, 1, (2, 4)).astype('f')
>>> arg2 = np.random.uniform(-1, 1, (2, 4)).astype('f')
>>> optimizer.update(lossfun, chainer.Variable(arg1), chainer.Variable(arg2))

See `Optimizer.update()` for the full specification.

### 2.1.6 Trainer

When we want to train neural networks, we have to run training loops that update parameters many times. A typical training loop consists of following procedures:

1. Iterations over training datasets
2. Preprocessing of extracted mini-batches
3. Forward/backward computations of the neural networks
4. Parameter updates
5. Evaluations of the current parameters on validation datasets
6. Logging and printing of the intermediate results

Chainer provides a simple yet powerful way to make it easy to write such training processes. The training loop abstraction mainly consists of two components:

- **Dataset abstraction.** It implements 1 and 2 in the above list. The core components are defined in the `dataset` module. There are also many implementations of datasets and iterators in `datasets` and `iterators` modules, respectively.

- **Trainer.** It implements 3, 4, 5, and 6 in the above list. The whole procedure is implemented by `Trainer`. The way to update parameters (3 and 4) is defined by `Updater`, which can be freely customized. The 5 and 6 are implemented by instances of `Extension`, which appends an extra procedure to the training loop. Users can freely customize the training procedure by adding extensions. Users can also implement their own extensions.

We will see how to use Trainer in the example section below.

### 2.1.7 Serializer

Before proceeding to the first example, we introduce Serializer, which is the last core feature described in this page. Serializer is a simple interface to serialize or deserialize an object. `Link`, `Optimizer`, and `Trainer` supports serialization.

Concrete serializers are defined in the `serializers` module. It supports NumPy NPZ and HDF5 formats.

For example, we can serialize a link object into NPZ file by the `serializers.save_npz()` function:

```python
>>> serializers.save_npz('my.model', model)
```

It saves the parameters of `model` into the file `my.model` in NPZ format. The saved model can be read by the `serializers.load_npz()` function:

```python
>>> serializers.load_npz('my.model', model)
```
Note: Note that only the parameters and the persistent values are serialized by these serialization code. Other attributes are not saved automatically. You can register arrays, scalars, or any serializable objects as persistent values by the `Link.add_persistent()` method. The registered values can be accessed by attributes of the name passed to the `add_persistent` method.

The state of an optimizer can also be saved by the same functions:

```python
>>> serializers.save_npz('my.state', optimizer)
>>> serializers.load_npz('my.state', optimizer)
```

Note: Note that serialization of optimizer only saves its internal states including number of iterations, momentum vectors of MomentumSGD, etc. It does not save the parameters and persistent values of the target link. We have to explicitly save the target link with the optimizer to resume the optimization from saved states.

Support of the HDF5 format is enabled if the h5py package is installed. Serialization and deserialization with the HDF5 format are almost identical to those with the NPZ format; just replace `save_npz()` and `load_npz()` by `save_hdf5()` and `load_hdf5()`, respectively.

### 2.1.8 Example: Multi-layer Perceptron on MNIST

Now you can solve a multiclass classification task using a multi-layer perceptron. We use hand-written digits dataset called MNIST, which is one of the long-standing de facto “hello world” of machine learning. This MNIST example is also found in the examples/mnist directory of the official repository. We show how to use `Trainer` to construct and run the training loop in this section.

We first have to prepare the MNIST dataset. The MNIST dataset consists of 70,000 greyscale images of size 28x28 (i.e. 784 pixels) and corresponding digit labels. The dataset is divided into 60,000 training images and 10,000 test images by default. We can obtain the vectorized version (i.e., a set of 784 dimensional vectors) by `datasets.get_mnist()`.

```python
>>> train, test = datasets.get_mnist()
...```

This code automatically downloads the MNIST dataset and saves the NumPy arrays to the `$(HOME)/.chainer` directory. The returned `train` and `test` can be seen as lists of image-label pairs (strictly speaking, they are instances of `TupleDataset`).

We also have to define how to iterate over these datasets. We want to shuffle the training dataset for every epoch, i.e. at the beginning of every sweep over the dataset. In this case, we can use `iterators.SerialIterator`.

```python
>>> train_iter = iterators.SerialIterator(train, batch_size=100, shuffle=True)
```

On the other hand, we do not have to shuffle the test dataset. In this case, we can pass `shuffle=False` argument to disable the shuffling. It makes the iteration faster when the underlying dataset supports fast slicing.

```python
>>> test_iter = iterators.SerialIterator(test, batch_size=100, repeat=False, shuffle=False)
```

We also pass `repeat=False`, which means we stop iteration when all examples are visited. This option is usually required for the test/validation datasets; without this option, the iteration enters an infinite loop.

Next, we define the architecture. We use a simple three-layer rectifier network with 100 units per layer as an example.

```python
>>> class MLP(Chain):
...        def __init__(self, n_units, n_out):
...            super(MLP, self).__init__(
...                # the size of the inputs to each layer will be inferred
...```
l1=L.Linear(None, n_units),  # n_in -> n_units
l2=L.Linear(None, n_units),  # n_units -> n_units
l3=L.Linear(None, n_out),    # n_units -> n_out
)

def __call__(self, x):
    h1 = F.relu(self.l1(x))
    h2 = F.relu(self.l2(h1))
    y = self.l3(h2)
    return y

This link uses relu() as an activation function. Note that the 'l3' link is the final linear layer whose output corresponds to scores for the ten digits.

In order to compute loss values or evaluate the accuracy of the predictions, we define a classifier chain on top of the above MLP chain:

```python
>>> class Classifier(Chain):
...     def __init__(self, predictor):
...         super(Classifier, self).__init__(predictor=predictor)
...     def __call__(self, x, t):
...         y = self.predictor(x)
...         loss = F.softmax_cross_entropy(y, t)
...         accuracy = F.accuracy(y, t)
...         report({'loss': loss, 'accuracy': accuracy}, self)
...         return loss
```

This Classifier class computes accuracy and loss, and returns the loss value. The pair of arguments x and t corresponds to each example in the datasets (a tuple of an image and a label). softmax_cross_entropy() computes the loss value given prediction and ground truth labels. accuracy() computes the prediction accuracy. We can set an arbitrary predictor link to an instance of the classifier.

The report() function reports the loss and accuracy values to the trainer. For the detailed mechanism of collecting training statistics, see Reporter. You can also collect other types of observations like activation statistics in a similar ways.

Note that a class similar to the Classifier above is defined as chainer.links.Classifier. So instead of using the above example, we will use this predefined Classifier chain.

```python
>>> model = L.Classifier(MLP(100, 10))  # the input size, 784, is inferred
>>> optimizer = optimizers.SGD()
>>> optimizer.setup(model)
```

Now we can build a trainer object.

```python
>>> updater = training.StandardUpdater(train_iter, optimizer)
>>> trainer = training.Trainer(updater, (20, 'epoch'), out='result')
```

The second argument (20, 'epoch') represents the duration of training. We can use either epoch or iteration as the unit. In this case, we train the multi-layer perceptron by iterating over the training set 20 times.

In order to invoke the training loop, we just call the run() method.

```python
>>> trainer.run()
```

This method executes the whole training sequence.

The above code just optimizes the parameters. In most cases, we want to see how the training proceeds, where we can use extensions inserted before calling the run method.
These extensions perform the following tasks:

**Evaluator** Evaluates the current model on the test dataset at the end of every epoch.

**LogReport** Accumulates the reported values and emits them to the log file in the output directory.

**PrintReport** Prints the selected items in the LogReport.

**ProgressBar** Shows the progress bar.

There are many extensions implemented in the `chainer.training.extensions` module. The most important one that is not included above is `snapshot()`, which saves the snapshot of the training procedure (i.e., the Trainer object) to a file in the output directory.

The example code in the `examples/mnist` directory additionally contains GPU support, though the essential part is same as the code in this tutorial. We will review in later sections how to use GPU(s).

## 2.2 Recurrent Nets and their Computational Graph

In this section, you will learn how to write

- recurrent nets with full backprop,
- recurrent nets with truncated backprop,
- evaluation of networks with few memory.

After reading this section, you will be able to:

- Handle input sequences of variable length
- Truncate upper stream of the network during forward computation
- Use volatile variables to prevent network construction

### 2.2.1 Recurrent Nets

Recurrent nets are neural networks with loops. They are often used to learn from sequential input/output. Given an input stream $x_1, x_2, \ldots, x_t, \ldots$ and the initial state $h_0$, a recurrent net iteratively updates its state by $h_t = f(x_t, h_{t-1})$, and at some or every point in time $t$, it outputs $y_t = g(h_t)$. If we expand the procedure along the time axis, it looks like a regular feed-forward network except that same parameters are repeatedly used within the network.

Here we learn how to write a simple one-layer recurrent net. The task is language modeling: given a finite sequence of words, we want to predict the next word at each position without peeking the successive words. Suppose there are 1,000 different word types, and that we use 100 dimensional real vectors to represent each word (a.k.a. word embedding).

Let’s start from defining the recurrent neural net language model (RNNLM) as a chain. We can use the `chainer.links.LSTM` link that implements a fully-connected stateful LSTM layer. This link looks like an ordinary fully-connected layer. On construction, you pass the input and output size to the constructor:

```python
>>> l = L.LSTM(100, 50)
```
Then, call on this instance \( l(x) \) executes \emph{one step of LSTM layer}:

```python
>>> l.reset_state()
>>> x = Variable(np.random.randn(10, 100).astype(np.float32))
>>> y = l(x)
```

Do not forget to reset the internal state of the LSTM layer before the forward computation! Every recurrent layer holds its internal state (i.e. the output of the previous call). At the first application of the recurrent layer, you must reset the internal state. Then, the next input can be directly fed to the LSTM instance:

```python
>>> x2 = Variable(np.random.randn(10, 100).astype(np.float32))
>>> y2 = l(x2)
```

Based on this LSTM link, let’s write our recurrent network as a new chain:

```python
class RNN(Chain):
    def __init__(self):
        super(RNN, self).__init__ (
            embed=L.EmbedID(1000, 100), # word embedding
            mid=L.LSTM(100, 50), # the first LSTM layer
            out=L.Linear(50, 1000), # the feed-forward output layer
        )
    def reset_state(self):
        self.mid.reset_state()
    def __call__(self, cur_word):
        # Given the current word ID, predict the next word.
        x = self.embed(cur_word)
        h = self.mid(x)
        y = self.out(h)
        return y
rnn = RNN()
model = L.Classifier(rnn)
optimizer = optimizers.SGD()
optimizer.setup(model)
```

Here \emph{EmbedID} is a link for word embedding. It converts input integers into corresponding fixed-dimensional embedding vectors. The last linear link \emph{out} represents the feed-forward output layer.

The \emph{RNN} chain implements a \emph{one-step-forward computation}. It does not handle sequences by itself, but we can use it to process sequences by just feeding items in a sequence straight to the chain.

Suppose we have a list of word variables \( \text{x\_list} \). Then, we can compute loss values for the word sequence by simple for loop.

```python
def compute_loss(x_list):
    loss = 0
    for cur_word, next_word in zip(x_list, x_list[1:]):
        loss += model(cur_word, next_word)
    return loss
```

Of course, the accumulated loss is a Variable object with the full history of computation. So we can just call its \emph{backward()} method to compute gradients of the total loss according to the model parameters:

```python
# Suppose we have a list of word variables x\_list.
rnn.reset_state()
model.cleargrads()
loss = compute_loss(x_list)
```
Or equivalently we can use the `compute_loss` as a loss function:

```python
rnn.reset_state()
optimizer.update(compute_loss, x_list)
```

### 2.2.2 Truncate the Graph by Unchaining

Learning from very long sequences is also a typical use case of recurrent nets. Suppose the input and state sequence is too long to fit into memory. In such cases, we often truncate the backpropagation into a short time range. This technique is called *truncated backprop*. It is heuristic, and it makes the gradients biased. However, this technique works well in practice if the time range is long enough.

How to implement truncated backprop in Chainer? Chainer has a smart mechanism to achieve truncation, called *backward unchaining*. It is implemented in the `Variable.unchain_backward()` method. Backward unchaining starts from the `Variable` object, and it chops the computation history backwards from the variable. The chopped variables are disposed automatically (if they are not referenced explicitly from any other user object). As a result, they are no longer a part of computation history, and are not involved in backprop anymore.

Let’s write an example of truncated backprop. Here we use the same network as the one used in the previous subsection. Suppose we are given a very long sequence, and we want to run backprop truncated at every 30 time steps. We can write truncated backprop using the model defined above:

```python
loss = 0
count = 0
seqlen = len(x_list[1:])

rnn.reset_state()
for cur_word, next_word in zip(x_list, x_list[1:]):
    loss += model(cur_word, next_word)
count += 1
if count % 30 == 0 or count == seqlen:
    model.cleargrads()
    loss.backward()
    loss.unchain_backward()
    optimizer.update()
```

State is updated at `model()`, and the losses are accumulated to `loss` variable. At each 30 steps, backprop takes place at the accumulated loss. Then, the `unchain_backward()` method is called, which deletes the computation history backwards from the accumulated loss. Note that the last state of `model` is not lost, since the RNN instance holds a reference to it.

The implementation of truncated backprop is simple, and since there is no complicated trick on it, we can generalize this method to different situations. For example, we can easily extend the above code to use different schedules between backprop timing and truncation length.

### 2.2.3 Network Evaluation without Storing the Computation History

On evaluation of recurrent nets, there is typically no need to store the computation history. While unchaining enables us to walk through unlimited length of sequences with limited memory, it is a bit of a work-around.

As an alternative, Chainer provides an evaluation mode of forward computation which does not store the computation history. This is enabled by just passing `volatile` flag to all input variables. Such variables are called *volatile variables*. 
Volatile variable is created by passing `volatile='on'` at the construction:

```python
x_list = [Variable(..., volatile='on') for _ in range(100)]  # list of 100 words
loss = compute_loss(x_list)
```

Note that we cannot call `loss.backward()` to compute the gradient here, since the volatile variable does not remember the computation history.

Volatile variables are also useful to evaluate feed-forward networks to reduce the memory footprint.

Variable’s volatility can be changed directly by setting the `Variable.volatile` attribute. This enables us to combine a fixed feature extractor network and a trainable predictor network. For example, suppose we want to train a feed-forward network `predictor_func`, which is located on top of another fixed pre-trained network `fixed_func`. We want to train `predictor_func` without storing the computation history for `fixed_func`. This is simply done by following code snippets (suppose `x_data` and `y_data` indicate input data and label, respectively):

```python
x = Variable(x_data, volatile='on')
feat = fixed_func(x)
feat.volatile = 'off'
y = predictor_func(feat)
y.backward()
```

At first, the input variable `x` is volatile, so `fixed_func` is executed in volatile mode, i.e. without memorizing the computation history. Then the intermediate variable `feat` is manually set to non-volatile, so `predictor_func` is executed in non-volatile mode, i.e., with memorizing the history of computation. Since the history of computation is only memorized between variables `feat` and `y`, the backward computation stops at the `feat` variable.

**Warning:** It is not allowed to mix volatile and non-volatile variables as arguments to same function. If you want to create a variable that behaves like a non-volatile variable while can be mixed with volatile ones, use ‘`auto’ flag instead of ‘off’ flag.

### 2.2.4 Making it with Trainer

The above codes are written with plain Function/Variable APIs. When we write a training loop, it is better to use Trainer, since we can then easily add functionalities by extensions.

Before implementing it on Trainer, let’s clarify the training settings. We here use Penn Tree Bank dataset as a set of sentences. Each sentence is represented as a word sequence. We concatenate all sentences into one long word sequence, in which each sentence is separated by a special word `<eos>`, which stands for “End of Sequence”. This dataset is easily obtained by `chainer.datasets.get_ptb_words()`. This function returns train, validation, and test dataset, each of which is represented as a long array of integers. Each integer represents a word ID.

Our task is to learn a recurrent neural net language model from the long word sequence. We use words in different locations to form mini-batches. It means we maintain $B$ indices pointing to different locations in the sequence, read from these indices at each iteration, and increment all indices after the read. Of course, when one index reaches the end of the whole sequence, we turn the index back to 0.

In order to implement this training procedure, we have to customize the following components of Trainer:

- **Iterator.** Built-in iterators do not support reading from different locations and aggregating them into a mini-batch.

- **Update function.** The default update function does not support truncated BPTT.

When we write a dataset iterator dedicated to the dataset, the dataset implementation can be arbitrary; even the interface is not fixed. On the other hand, the iterator must support the `Iterator` interface. The important methods and attributes to implement are `batch_size`, `epoch`, `epoch_detail`, `is_new_epoch`, `iteration`, `__next__`, `serialize`. Following is a code from the official example in the `examples/ptb` directory.
from __future__ import division

class ParallelSequentialIterator(chainer.dataset.Iterator):
    def __init__(self, dataset, batch_size, repeat=True):
        self.dataset = dataset
        self.batch_size = batch_size
        self.epoch = 0
        self.is_new_epoch = False
        self.repeat = repeat
        self.offsets = [i * len(dataset) // batch_size for i in range(batch_size)]
        self.iteration = 0

    def __next__(self):
        length = len(self.dataset)
        if not self.repeat and self.iteration * self.batch_size >= length:
            raise StopIteration
        cur_words = self.get_words()
        self.iteration += 1
        next_words = self.get_words()
        epoch = self.iteration * self.batch_size // length
        self.is_new_epoch = self.epoch < epoch
        if self.is_new_epoch:
            self.epoch = epoch

        return list(zip(cur_words, next_words))

    @property
    def epoch_detail(self):
        return self.iteration * self.batch_size / len(self.dataset)

    def get_words(self):
        return [self.dataset[(offset + self.iteration) % len(self.dataset)]
                for offset in self.offsets]

    def serialize(self, serializer):
        self.iteration = serializer('iteration', self.iteration)
        self.epoch = serializer('epoch', self.epoch)

train_iter = ParallelSequentialIterator(train, 20)
val_iter = ParallelSequentialIterator(val, 1, repeat=False)

Although the code is slightly long, the idea is simple. First, this iterator creates offsets pointing to positions equally spaced within the whole sequence. The i-th examples of mini-batches refer the sequence with the i-th offset. The iterator returns a list of tuples of the current words and the next words. Each mini-batch is converted to a tuple of integer arrays by the concat_examples function in the standard updater (see the previous tutorial).

Backprop Through Time is implemented as follows.

```python
def update_bptt(updater):
    loss = 0
    for i in range(35):
        batch = train_iter.__next__()
        x, t = chainer.dataset.concat_example(batch)
        loss += model(chainer.Variable(x), chainer.Variable(t))

    model.cleargrads()
    loss.backward()
    loss.unchain_backward()  # truncate
```

2.2. Recurrent Nets and their Computational Graph 21
In this case, we update the parameters on every 35 consecutive words. The call of `unchain_backward` cuts the history of computation accumulated to the LSTM links. The rest of the code for setting up Trainer is almost same as one given in the previous tutorial.

In this section we have demonstrated how to write recurrent nets in Chainer and some fundamental techniques to manage the history of computation (a.k.a. computational graph). The example in the `examples/ptb` directory implements truncated backprop learning of a LSTM language model from the Penn Treebank corpus. In the next section, we will review how to use GPU(s) in Chainer.

### 2.3 Using GPU(s) in Chainer

In this section, you will learn about the following things:

- Relationship between Chainer and CuPy
- Basics of CuPy
- Single-GPU usage of Chainer
- Multi-GPU usage of model-parallel computing
- Multi-GPU usage of data-parallel computing

After reading this section, you will be able to:

- Use Chainer on a CUDA-enabled GPU
- Write model-parallel computing in Chainer
- Write data-parallel computing in Chainer

#### 2.3.1 Relationship between Chainer and CuPy

**Note:** As of the release of v1.3.0, Chainer changes its GPU backend from PyCUDA to CuPy. CuPy covers all features of PyCUDA used by Chainer, though their interfaces are not compatible.

Chainer uses *CuPy* as its backend for GPU computation. In particular, the *cupy.ndarray* class is the GPU array implementation for Chainer. CuPy supports a subset of features of NumPy with a compatible interface. It enables us to write a common code for CPU and GPU. It also supports PyCUDA-like user-defined kernel generation, which enables us to write fast implementations dedicated to GPU.

**Note:** The *chainer.cuda* module imports many important symbols from CuPy. For example, the cupy namespace is referred as `cuda.cupy` in the Chainer code. Note that the *chainer.cuda* module can be imported even if CUDA is not installed.

Chainer uses a memory pool for GPU memory allocation. As shown in the previous sections, Chainer constructs and destructs many arrays during learning and evaluating iterations. It is not well suited for CUDA architecture, since memory allocation and release in CUDA (i.e. `cudaMalloc` and `cudaFree` functions) synchronize CPU and GPU.
computations, which hurts performance. In order to avoid memory allocation and deallocation during the computation, Chainer uses CuPy’s memory pool as the standard memory allocator. Chainer changes the default allocator of CuPy to the memory pool, so user can use functions of CuPy directly without dealing with the memory allocator.

### 2.3.2 Basics of cupy.ndarray

**Note:** CuPy does not require explicit initialization, so `cuda.init()` function is deprecated.

CuPy is a GPU array backend that implements a subset of NumPy interface. The `cupy.ndarray` class is in its core, which is a compatible GPU alternative of `numpy.ndarray`. CuPy implements many functions on `cupy.ndarray` objects. See the reference for the supported subset of NumPy API. Understanding NumPy might help utilizing most features of CuPy. See the NumPy documentation for learning it.

The main difference of `cupy.ndarray` from `numpy.ndarray` is that the content is allocated on the device memory. The allocation takes place on the current device by default. The current device can be changed by `cupy.cuda.Device` object as follows:

```python
with cupy.cuda.Device(1):
    x_on_gpu1 = cupy.array([1, 2, 3, 4, 5])
```

Most operations of CuPy is done on the current device. Be careful that it causes an error to process an array on a non-current device.

Chainer provides some convenient functions to automatically switch and choose the device. For example, the `chainer.cuda.to_gpu()` function copies a `numpy.ndarray` object to a specified device:

```python
x_cpu = np.ones((5, 4, 3), dtype=np.float32)
x_gpu = cuda.to_gpu(x_cpu, device=1)
```

It is equivalent to the following code using CuPy:

```python
x_cpu = np.ones((5, 4, 3), dtype=np.float32)
with cupy.cuda.Device(1):
    x_gpu = cupy.array(x_cpu)
```

Moving a device array to the host can be done by `chainer.cuda.to_cpu()` as follows:

```python
x_cpu = cuda.to_cpu(x_gpu)
```

It is equivalent to the following code using CuPy:

```python
with x_gpu.device:
    x_cpu = x_gpu.get()
```

**Note:** The `with` statements in these codes are required to select the appropriate CUDA device. If user uses only one device, these device switching is not needed. `chainer.cuda.to_cpu()` and `chainer.cuda.to_gpu()` functions automatically switch the current device correctly.

Chainer also provides a convenient function `chainer.cuda.get_device()` to select a device. It accepts an integer, CuPy array, NumPy array, or None (indicating the current device), and returns an appropriate device object. If the argument is a NumPy array, then a dummy device object is returned. The dummy device object supports `with` statements like above which does nothing. Here are some examples:
cuda.get_device(1).use()
x_gpu1 = cupy.empty((4, 3), dtype='f')  # 'f' indicates float32

with cuda.get_device(1):
    x_gpu1 = cuda.empty((4, 3), dtype='f')

with cuda.get_device(x_gpu1):
    y_gpu1 = x_gpu1 + 1

Since it accepts NumPy arrays, we can write a function that accepts both NumPy and CuPy arrays with correct device switching:

def add1(x):
    with cuda.get_device(x):
        return x + 1

The compatibility of CuPy with NumPy enables us to write CPU/GPU generic code. It can be made easy by the chainer.cuda.get_array_module() function. This function returns the numpy or cupy module based on arguments. A CPU/GPU generic function is defined using it like follows:

# Stable implementation of log(1 + exp(x))
def softplus(x):
    xp = cuda.get_array_module(x)
    return xp.maximum(0, x) + xp.log1p(xp.exp(-abs(x)))

## 2.3.3 Run Neural Networks on a Single GPU

Single-GPU usage is very simple. What you have to do is transferring Link and input arrays to the GPU beforehand. In this subsection, the code is based on our first MNIST example in this tutorial.

A Link object can be transferred to the specified GPU using the to_gpu() method.

This time, we make the number of input, hidden, and output units configurable. The to_gpu() method also accepts a device ID like model.to_gpu(0). In this case, the link object is transferred to the appropriate GPU device. The current device is used by default.

If we use chainer.training.Trainer, what we have to do is just let the updater know the device ID to send each mini-batch.

updater = training.StandardUpdater(train_iter, optimizer, device=0)
trainer = training.Trainer(updater, (20, 'epoch'), out='result')

We also have to specify the device ID for an evaluator extension as well.
trainer.extend(extensions.Evaluator(test_iter, model, device=0))

When we write down the training loop by hand, we have to transfer each mini-batch to the GPU manually:

model.to_gpu()  
batchsize = 100  
datasize = len(x_train)
for epoch in range(20):
    print('epoch %d' % epoch)
    indexes = np.random.permutation(datasize)
    for i in range(0, datasize, batchsize):
        x = Variable(cuda.to_gpu(x_train[indexes[i : i + batchsize]]))
        t = Variable(cuda.to_gpu(y_train[indexes[i : i + batchsize]]))
        optimizer.update(model, x, t)
2.3.4 Model-parallel Computation on Multiple GPUs

Parallelization of machine learning is roughly classified into two types called “model-parallel” and “data-parallel”. Model-parallel means parallelizations of the computations inside the model. In contrast, data-parallel means parallelizations using data sharding. In this subsection, we show how to use the model-parallel approach on multiple GPUs in Chainer.

Recall the MNIST example. Now suppose that we want to modify this example by expanding the network to 6 layers with 2000 units each using two GPUs. In order to make multi-GPU computation efficient, we only make the two GPUs communicate at the third and sixth layer. The overall architecture looks like the following diagram:

```
|       (GPU0) input --> l1 --> l2 --> l3 --> l4 --> l5 --> l6 --> output |
|          |                |                |                |
| (GPU1)   +--> l1 --> l2 --> l3 --> l4 --> l5 --> l6 --> output |
```

We can use the above MLP chain as following diagram:

```
|       (GPU0) input --> mlp1 --> mlp2 --> output |
|          |                |                |
| (GPU1)   +--> mlp1 --> mlp2 --> |
```

Let’s write a link for the whole network.

```python
class ParallelMLP(Chain):
    def __init__(self):
        super(ParallelMLP, self).__init__:
            # the input size, 784, is inferred
            mlp1_gpu0=MLP(1000, 2000).to_gpu(0),
            mlp1_gpu1=MLP(1000, 2000).to_gpu(1),
            # the input size, 2000, is inferred
            mlp2_gpu0=MLP(1000, 10).to_gpu(0),
            mlp2_gpu1=MLP(1000, 10).to_gpu(1),

    def __call__(self, x):
        # assume x is on GPU 0
        z0 = self.mlp1_gpu0(x)
        z1 = self.mlp1_gpu1(F.copy(x, 1))

        # sync
        h0 = F.relu(z0 + F.copy(z1, 0))
        h1 = F.relu(z1 + F.copy(z0, 1))

        y0 = self.mlp2_gpu0(h0)
        y1 = self.mlp2_gpu1(h1)

        # sync
        y = y0 + F.copy(y1, 0)
        return y  # output is on GPU0
```

Recall that the Link.to_gpu() method returns the link itself. The copy() function copies an input variable to specified GPU device and returns a new variable on the device. The copy supports backprop, which just reversely transfers an output gradient to the input device.

Note: Above code is not parallelized on CPU, but is parallelized on GPU. This is because all the functions in the above code run asynchronously to the host CPU.
An almost identical example code can be found at examples/mnist/train_mnist_model_parallel.py.

### 2.3.5 Data-parallel Computation on Multiple GPUs with Trainer

Data-parallel computation is another strategy to parallelize online processing. In the context of neural networks, it means that a different device does computation on a different subset of the input data. In this subsection, we review the way to achieve data-parallel learning on two GPUs.

Suppose again our task is the MNIST example. This time we want to directly parallelize the three-layer network. The most simple form of data-parallelization is parallelizing the gradient computation for a distinct set of data. First, define a model and optimizer instances:

```python
model = L.Classifier(MLP(1000, 10))  # the input size, 784, is inferred
optimizer = optimizers.SGD()
optimizer.setup(model)
```

Recall that the MLP link implements the multi-layer perceptron, and the Classifier link wraps it to provide a classifier interface. We used StandardUpdater in the previous example. In order to enable data-parallel computation with multiple GPUs, we only have to replace it with ParallelUpdater.

```python
updater = training.ParallelUpdater(train_iter, optimizer,
                                   devices={'main': 0, 'second': 1})
```

The devices option specifies which devices to use in data-parallel learning. The device with name ’main’ is used as the main device. The original model is sent to this device, so the optimization runs on the main device. In the above example, the model is also cloned and sent to GPU 1. Half of each mini-batch is fed to this cloned model. After every backward computation, the gradient is accumulated into the main device, the parameter update runs on it, and then the updated parameters are sent to GPU 1 again.

See also the example code in examples/mnist/train_mnist_data_parallel.py.

### 2.3.6 Data-parallel Computation on Multiple GPUs without Trainer

We here introduce a way to write data-parallel computation without the help of Trainer. Most users can skip this section. If you are interested in how to write a data-parallel computation by yourself, this section should be informative. It is also helpful to, e.g., customize the ParallelUpdater class.

We again start from the MNIST example. At this time, we use a suffix like 
\_0 and 
\_1 to distinguish objects on each device. First, we define a model.

```python
model_0 = L.Classifier(MLP(1000, 10))  # the input size, 784, is inferred
optimizer = optimizers.SGD()
optimizer.setup(model_0)
```

We want to make two copies of this instance on different GPUs. The Link.to_gpu() method runs in place, so we cannot use it to make a copy. In order to make a copy, we can use Link.copy() method.

```python
import copy
model_1 = copy.deepcopy(model_0)
model_0.to_gpu(0)
model_1.to_gpu(1)
```

The Link.copy() method copies the link into another instance. It just copies the link hierarchy, and does not copy the arrays it holds.

Then, set up an optimizer:

```python
optimizer = optimizers.SGD()
optimizer.setup(model_0)
```
Here we use the first copy of the model as the master model. Before its update, gradients of model_1 must be aggregated to those of model_0.

Then, we can write a data-parallel learning loop as follows:

```python
batchsize = 100
data_size = len(x_train)
for epoch in range(20):
    print('epoch %d' % epoch)
    indexes = np.random.permutation(data_size)
    for i in range(0, data_size, batchsize):
        x_batch = x_train[indexes[i : i + batchsize]]
        y_batch = y_train[indexes[i : i + batchsize]]

        x0 = Variable(cuda.to_gpu(x_batch[:batchsize//2], 0))
        t0 = Variable(cuda.to_gpu(y_batch[:batchsize//2], 0))
        x1 = Variable(cuda.to_gpu(x_batch[batchsize//2:], 1))
        t1 = Variable(cuda.to_gpu(y_batch[batchsize//2:], 1))

        loss_0 = model_0(x0, t0)
        loss_1 = model_1(x1, t1)

        model_0.cleargrads()
        model_1.cleargrads()

        loss_0.backward()
        loss_1.backward()

        model_0.addgrads(model_1)
        optimizer.update()

        model_1.copyparams(model_0)
```

Do not forget to clear the gradients of both model copies! One half of the mini-batch is forwarded to GPU 0, the other half to GPU 1. Then the gradients are accumulated by the `Link.addgrads()` method. This method adds the gradients of a given link to those of the self. After the gradients are prepared, we can update the optimizer in usual way. Note that the update only modifies the parameters of `model_0`. So we must manually copy them to `model_1` using `Link.copyparams()` method.

**Note:** If the batch size used in one model remain the same, the scale of the gradient is roughly proportional to the number of models, when we aggregate gradients from all models by `chainer.Link.addgrads()`. So you need to adjust the batch size and/or learning rate of the optimizer accordingly.

Now you can use Chainer with GPUs. All examples in the examples directory support GPU computation, so please refer to them if you want to know more practices on using GPUs. In the next section, we will show how to define a differentiable (i.e. backpropable) function on Variable objects. We will also show there how to write a simple (elementwise) CUDA kernel using Chainer’s CUDA utilities.

## 2.4 Define your own function

In this section, you will learn about the following things:

- How to define a function on variables
2.4.1 Differentiable Functions

Chainer provides a collection of functions in the `functions` module. It covers typical use cases in deep learning, so many existing works can be implemented with them. On the other hand, deep learning is evolving rapidly and we cannot cover all possible functions to define unseen architectures. So it is important to learn how to define your own functions.

First, suppose we want to define an elementwise function $f(x, y, z) = x \cdot y + z$. While it is possible to implement this equation using a combination of the `*` and `+` functions, defining it as a single function may reduce memory consumption, so it is not only a toy example. Here we call this function `MulAdd`.

Let’s start with defining `MulAdd` working on the CPU. Any function must inherit the `Function` class. The skeleton of a function looks like:

```python
class MulAdd(Function):
    def forward_cpu(self, inputs):
        # do forward computation on CPU
        return some_tuple

    def backward_cpu(self, inputs, grad_outputs):
        # do backward computation on CPU
        return some_tuple
```

We must implement `forward_cpu()` and `backward_cpu()` methods. The non-self arguments of these functions are tuples of array(s), and these functions must return a tuple of array(s).

**Warning:** Be careful to return a tuple of arrays even if you have just one array to return.

`MulAdd` is simple and implemented as follows

```python
class MulAdd(Function):
    def forward_cpu(self, inputs):
        x, y, z = inputs
        w = x * y + z
        return w,

    def backward_cpu(self, inputs, grad_outputs):
        x, y, z = inputs
        gw, = grad_outputs
        gx = y * gw
        gy = x * gw
        gz = gw
        return gx, gy, gz
```

As per the warning above, the `forward_cpu` method returns a tuple of single element. Note that all arrays appearing in CPU functions are `numpy.ndarray`. The forward function is straightforward: It unpacks the input tuple, computes the output, and packs it into a tuple. The backward function is a bit more complicated. Recall the rule of...
differentiation of multiplication. This example just implements the rule. Look at the return values, the function just packs the gradient of each input in same order and returns them.

By just defining the core computation of forward and backward, Function class provides a chaining logic on it (i.e. storing the history of computation, etc.).

**Note:** Assuming we implement a (forward) function $y = f(x)$ which takes as input the vector $x \in \mathbb{R}^n$ and produces as output a vector $y \in \mathbb{R}^m$. Then the `backward` method has to compute

$$
\lambda_i = \sum_{j=1}^{m} \frac{\partial y_j}{\partial x_i} \gamma_j \text{ for } i = 1 \ldots n
$$

where $\gamma$ is the `grad_outputs`. Note, that the resulting vector $\lambda$ must have the same shape as the arguments of the `forward` method.

Now let’s define the corresponding GPU methods. You can easily predict that the methods we have to write are named `forward_gpu()` and `backward_gpu()`:

```python
class MulAdd(Function):
    def forward_cpu(self, inputs):
        ... 
    def backward_cpu(self, inputs, grad_outputs):
        ...
    def forward_gpu(self, inputs):
        x, y, z = inputs
        w = x * y + z
        return w,
    def backward_gpu(self, inputs, grad_outputs):
        x, y, z = inputs
        gw, = grad_outputs
        gx = y * gw
        gy = x * gw
        gz = gw
        return gx, gy, gz
```

In GPU methods, arrays are of type `cupy.ndarray`. We use arithmetic operators defined for this class. These operators implement the basic elementwise arithmetics.

You may find that the definitions of GPU methods are exactly same as those of CPU methods. In that case, we can reduce them to `forward()` and `backward()` methods:

```python
class MulAdd(Function):
    def forward(self, inputs):
        x, y, z = inputs
        w = x * y + z
        return w,
    def backward(self, inputs, grad_outputs):
        x, y, z = inputs
        gw, = grad_outputs
        gx = y * gw
        gy = x * gw
```

2.4. Define your own function 29
gz = gw

return gx, gy, gz

Since the `cupy.ndarray` class implements many methods of `numpy.ndarray`, we can write these unified methods in most cases.

The MulAdd function is used as follows:

```python
x = Variable(np.random.uniform(-1, 1, (3, 2)).astype(np.float32))
y = Variable(np.random.uniform(-1, 1, (3, 2)).astype(np.float32))
z = Variable(np.random.uniform(-1, 1, (3, 2)).astype(np.float32))
w = MulAdd()(x, y, z)
```

It looks a bit ugly: we have to explicitly instantiate MulAdd before applying it to variables. We also have to be careful that one instance of MulAdd must not be used multiple times, since it acts as a node in the computational graph. In Chainer, we often define a thin wrapper Python function that hide the instantiation:

```python
def muladd(x, y, z):
    return MulAdd()(x, y, z)

w = muladd(x, y, z)
```

### 2.4.2 Unified forward/backward methods with NumPy/CuPy functions

CuPy also implements many functions that are compatible to those of NumPy. We can write unified forward/backward methods with them. Consider that we want to write a backprop-able function $f(x, y) = \exp(x) + \exp(y)$. We name it `ExpAdd` here. It can be written straight-forward as follows:

```python
class ExpAdd(Function):
    def forward_cpu(self, inputs):
        x, y = inputs
        z = np.exp(x) + np.exp(y)
        return z,

    def backward_cpu(self, inputs, grad_outputs):
        x, y = inputs
        gz, = grad_outputs
        gx = gz * np.exp(x)
        gy = gz * np.exp(y)
        return gx, gy

    def forward_gpu(self, inputs):
        cupy = cuda.cupy
        x, y = inputs
        z = cupy.exp(x) + cupy.exp(y)
        return z,

    def backward_gpu(self, inputs, grad_outputs):
        cupy = cuda.cupy
        x, y = inputs
        gz, = grad_outputs
        gx = gz * cupy.exp(x)
        gy = gz * cupy.exp(y)
        return gx, gy
```
```python
def expadd(x, y):
    return ExpAdd()(x, y)
```

**Note:** Here we used `cuda.cupy` instead of directly accessing `cupy`. This is because the `cupy` module cannot be imported if the CUDA is not installed. In order to keep the implementation valid in non-CUDA environment, we have to defer the access to the `cupy` module. Note that the `chainer.cuda` module can be imported even if the CUDA is not installed. Of course, the module in such environment is almost useless, but if the interpreter does not run through the code accessing CUDA-dedicated functions, the code is still valid.

The CPU and GPU implementations are almost same, except that `numpy` is replaced by `cupy` in GPU methods. We can unify these functions using the `cuda.get_array_module()` function. This function accepts arbitrary number of arrays, and returns an appropriate module for them. See the following code

```python
class ExpAdd(Function):
    def forward(self, inputs):
        xp = cuda.get_array_module(*inputs)
        x, y = inputs
        z = xp.exp(x) + xp.exp(y)
        return z,

    def backward(self, inputs, grad_outputs):
        xp = cuda.get_array_module(*inputs)
        x, y = inputs
        gz, = grad_outputs
        gx = gz * xp.exp(x)
        gy = gz * xp.exp(y)
        return gx, gy

def expadd(x, y):
    return ExpAdd()(x, y)
```

Note that this code works correctly even if CUDA is not installed in the environment. If CUDA is not found, `get_array_module` function always returns `numpy`. We often use the name `xp` for the variadic module name, which is analogous to the abbreviation `np` for NumPy and `cp` for CuPy.

### 2.4.3 Write an Elementwise Kernel Function

Let’s turn back to the MulAdd example.

The GPU implementation of MulAdd as shown above is already fast and parallelized on GPU cores. However, it invokes two kernels during each of forward and backward computations. It might hurt performance, since the intermediate temporary arrays are read and written by possibly different GPU cores, which consumes much bandwidth. We can reduce the number of invocations by defining our own kernel. It also reduces the memory consumption.

Most functions only require elementwise operations like MulAdd. CuPy provides a useful tool to define elementwise kernels, the `cupy.elementwise.ElementwiseKernel` class, and Chainer wraps it by `cuda.elementwise()` function. Our MulAdd implementation can be improved as follows:

```python
class MulAdd(Function):
    def forward_cpu(self, inputs):
        ...

    def backward_cpu(self, self, inputs, grad_outputs):
        ...
```

## 2.4. Define your own function
def forward_gpu(self, inputs):
cupy = cuda.cupy
x, y, z = inputs
w = cuda.elementwise(
    'float32 x, float32 y, float32 z',
    'float32 w',
    'w = x * y + z',
    'muladd_fwd')(x, y, z)
return w,

def backward_gpu(self, inputs, grad_outputs):
x, y, z = inputs
gw, = grad_outputs
gx, gy = cuda.elementwise(
    'float32 x, float32 y, float32 gw',
    'float32 gx, float32 gy',
    '''
gx = y * gw;
gy = x * gw;
'''
    ,
    'muladd_bwd')(x, y, gw)
gz = gw
return gx, gy, gz

cuda.elementwise() function accepts the essential implementation of the kernel function, and returns a kernel invocation function (actually, it returns ElementwiseKernel object, which is callable). In typical usage, we pass four arguments to this function as follows:

1. Input argument list. This is a comma-separated string each entry of which consists of a type specification and an argument name.

2. Output argument list in the same format as the input argument list.

3. Body of parallel loop. We can use the input/output argument names as an element of these arrays.

4. Name of the kernel function, which is shown in debuggers and profilers.

Above code is not compiled on every forward/backward computation thanks to two caching mechanisms provided by cuda.elementwise() .

The first one is binary caching: cuda.elementwise() function caches the compiled binary in the $HOME/.cupy/kernel_cache directory with a hash value of the CUDA code, and reuses it if the given code matches the hash value. This caching mechanism is actually implemented in CuPy.

The second one is upload caching: Given a compiled binary code, we have to upload it to the current GPU in order to execute it. cuda.elementwise() function memoizes the arguments and the current device, and if it is called with the same arguments for the same device, it reuses the previously uploaded kernel code.

The above MulAdd code only works for float32 arrays. The ElementwiseKernel also supports the type-variadic kernel definition. In order to define variadic kernel functions, you can use type placeholder by placing a single character as type specifier:

class MulAdd(Function):
    def forward_cpu(self, inputs):
        ...
    
def backward_cpu(self, inputs, grad_outputs):
        ...
```python
def forward_gpu(self, inputs):
cupy = cuda.cupy
x, y, z = inputs
w = cuda.elementwise(
    'T x, T y, T z',
    'T w',
    'w = x * y + z',
    'muladd_fwd')(x, y, z)
return w,
def backward_gpu(self, inputs, grad_outputs):
x, y, z = inputs
gw, = grad_outputs
gx, gy = cuda.elementwise(
    'T x, T y, T gw',
    'T gx, T gy',
    '''
gx = y * gw;
gy = x * gw;
'''
    'muladd_bwd')(x, y, gw)
gz = gw
return gx, gy, gz
```

The type placeholder $T$ indicates an arbitrary data type that CuPy supports.
There are more functionalities on user-defined kernels in CuPy. See the CuPy documentation on user-defined kernels for more details.

### 2.4.4 Links that wrap functions

Some functions are meant to be combined with parameters. In such case, it is useful to write a small link that wraps the function. We have already seen how to define a chain that wraps other links (by inheriting Chain class). Here we study how to define a link that does not hold any other links.

As the first example, suppose that we want to implement elementwise product function between the input array and the parameter array. It can be defined as follows:

```python
class EltwiseParamProduct(Chain):
    def __init__(self, shape):
        # By passing a shape of the parameter, the initializer allocates a
        # parameter variable of the shape.
        super(EltwiseParamProduct, self).__init__(W=shape)
        self.W.data[...] = np.random.randn(*shape)

    def __call__(self, x):
        return self.W * x
```

We can also initialize the parameter after the initialization by the Link.add_param() method.

```python
class EltwiseParamProduct(Chain):
    def __init__(self, shape):
        super(EltwiseParamProduct, self).__init__()
        self.add_param('W', shape)
        self.W.data[...] = np.random.randn(*shape)
```

2.4. Define your own function
def __call__(self, x):
    return self.W * x

Note that the initializer and the add_param() method does not initialize elements of the parameter array. We have to manually initialize the elements by random values, zeros, etc.

For another example, assume we want to define a simple linear layer. It is already defined as Linear, so this is an educational example. The linear layer is divided into two parts: a function and its wrapper link. First, we have to define a function on variables:

class LinearFunction(Function):
    def forward(self, inputs):
        x, W, b = inputs
        return x.dot(W.T) + b,

    def backward(self, inputs, grad_outputs):
        x, W, b = inputs
        gy, = grad_outputs
        gx = gy.dot(W)
        gW = gy.T.dot(x)
        gb = gy.sum(axis=0)
        return gx, gW, gb

def linear(x, W, b):
    return LinearFunction()(x, W, b)

This function takes three arguments: input, weight, and bias. It can be used as a part of model definition, though is inconvenient since the user have to manage the weight and bias parameters directly. In order to make a convenient module, let’s wrap it into a link:

class Linear(Link):
    def __init__(self, in_size, out_size):
        super(Linear, self).__init__(W=(out_size, in_size), b=out_size)
        self.W.data[...] = np.random.randn(out_size, in_size) / math.sqrt(in_size)
        self.b.data.fill(0)

    def __call__(self, x):
        return linear(x, self.W, self.b)

This link hides the parameters of the linear layer.

Note: An advanced tip to implement functions: if you want to preserve some information between forward and backward computations (e.g. to cache some arrays), you can store it as attributes. Be careful that it might increase the memory consumption during the whole forward-backward computation. If you want to train very large networks on a GPU with limited memory, it is not recommended to cache arrays between forward and backward. There is one exception for this: caching the output arrays does not change the memory consumption, because they are also held by the output Variable objects.

Warning: You should not assume a one-to-one match of calls of forward and backward. Some users may call backward more than once after one forward call.
2.4.5 Testing Function

In order to isolate the cause of learning failure from implementation bugs, it is important to test function implementations. Chainer provides simple utilities to help writing unit tests. They are defined in the `gradient_check` module.

The most important test utility is the `numerical_grad()` function. This function computes the numerical gradient of given function using finite differences. It can be used as follows:

```python
x = np.random.randn(4, 3).astype(np.float32)
gy = np.ones((4, 3), dtype=np.float32)
f = lambda: (x * x,)
gx = gradient_check.numerical_grad(f, (x,), (gy,))
```

`f` is a closure that returns a tuple of array(s) computed from input arrays. The second and third arguments of `numerical_grad()` are tuples of input arrays and output gradient arrays, respectively. The code above computes the numerical gradients of `sum(f(x))`, where `sum` indicates the summation over all elements. The summation can be weighted by changing `gy.numerical_grad()` function also accepts additional `eps` argument, which indicates the quantization width of finite differences.

**Note:** `numerical_grad()` function accepts both CPU and GPU arrays. Note that we cannot mix CPU and GPU arrays.

Another utility is `chainer.testing.assert_allclose()` function. This is similar to `numpy.testing.assert_allclose()` function. The difference is that Chainer's version accepts CPU and GPU arrays as inputs. We can mix them in one invocation of `chainer.testing.assert_allclose()`. The default values of optional arguments are also different.

Here is a typical usage of gradient checking utilities. This is a test example of `functions.relu()` function:

```python
import unittest
from chainer import testing

class TestReLU(unittest.TestCase):
    def test_backward_cpu(self):
        x = Variable(np.random.randn(3, 2).astype(np.float32))
y = F.relu(x)
y.grad = np.random.randn(3, 2).astype(np.float32)
y.backward()

        f = lambda: (F.relu(x).data,)
gx, = gradient_check.numerical_grad(f, (x.data,), (y.grad,))

        testing.assert_allclose(gx, x.grad)
```

The first four lines of the test code are simple forward and backward computation of ReLU function. The next two lines compute numerical gradient using the same forward function without backward routine. And at last, we compare these two results elementwise. Note that the above test code can be easily modified to test GPU version just by replacing CPU arrays to GPU arrays.

You can find many examples of function tests under `tests/chainer_tests/function_tests` directory.

2.4. Define your own function
2.5 Type check

In this section, you will learn about the following things:

• Basic usage of type check
• Detail of type information
• Internal mechanism of type check
• More complicated cases
• Call functions
• Typical type check example

After reading this section, you will be able to:

• Write a code to check types of input arguments of your own functions

2.5.1 Basic usage of type check

When you call a function with an invalid type of array, you sometimes receive no error, but get an unexpected result by broadcasting. When you use CUDA with an illegal type of array, it causes memory corruption, and you get a serious error. These bugs are hard to fix. Chainer can check preconditions of each function, and helps to prevent such problems. These conditions may help a user to understand specification of functions.

Each implementation of Function has a method for type check, check_type_forward(). This function is called just before the forward() method of the Function class. You can override this method to check the condition on types and shapes of arguments.

def check_type_forward(self, in_types):
    ...

in_types is an instance of TypeInfoTuple, which is a sub-class of tuple. To get type information about the first argument, use in_types[0]. If the function gets multiple arguments, we recommend to use new variables for readability:

    x_type, y_type = in_types

In this case, x_type represents the type of the first argument, and y_type represents the second one.

We describe usage of in_types with an example. When you want to check if the number of dimension of x_type equals to 2, write this code:

    utils.type_check.expect(x_type.ndim == 2)

When this condition is true, nothing happens. Otherwise this code throws an exception, and the user gets a message like this:

    Traceback (most recent call last):
    ...
    InvalidType: Expect: in_types[0].ndim == 2
    Actual: 3 != 2

This error message means that “ndim of the first argument expected to be 2, but actually it is 3”.
2.5.2 Detail of type information

You can access three information of x_type.

- .shape is a tuple of ints. Each value is size of each dimension.
- .ndim is int value representing the number of dimensions. Note that ndim == len(shape)
- .dtype is numpy.dtype representing data type of the value.

You can check all members. For example, the size of the first dimension must be positive, you can write like this:

```python
globals().type_check.expect(x_type.shape[0] > 0)
```

You can also check data types with .dtype:

```python
globals().type_check.expect(x_type.dtype == np.float64)
```

And an error is like this:

```
Traceback (most recent call last):
  ...
InvalidType: Expect: in_types[0].dtype == <type 'numpy.float64'>
Actual: float32 != <type 'numpy.float64'>
```

You can also check kind of dtype. This code checks if the type is floating point:

```python
globals().type_check.expect(x_type.dtype.kind == 'f')
```

You can compare between variables. For example, the following code checks if the first argument and the second argument have the same length:

```python
globals().type_check.expect(x_type.shape[1] == y_type.shape[1])
```

2.5.3 Internal mechanism of type check

How does it show an error message like "in_types[0].ndim == 2"? If x_type is an object containing ndim member variable, we cannot show such an error message because this equation is evaluated as a boolean value by Python interpreter.

Actually x_type is a Expr objects, and doesn’t have a ndim member variable itself. Expr represents a syntax tree. x_type.ndim makes a Expr object representing (getattr, x_type, ’ndim’).x_type.ndim == 2 makes an object like (eq, (getattr, x_type, ’ndim’), 2).type_check.expect() gets a Expr object and evaluates it. When it is True, it causes no error and shows nothing. Otherwise, this method shows a readable error message.

If you want to evaluate a Expr object, call eval() method:

```python
actual_type = x_type.eval()
```

actual_type is an instance of TypeInfo, while x_type is an instance of Expr. In the same way, x_type.shape[0].eval() returns an int value.

2.5.4 More powerful methods

Expr class is more powerful. It supports all mathematical operators such as + and *. You can write a condition that the first dimension of x_type is the first dimension of y_type times four:
When \( x\_\text{type}.\text{shape}[0] == 3 \) and \( y\_\text{type}.\text{shape}[0] == 1 \), users can get the error message below:

```
Traceback (most recent call last):
...
InvalidType: Expect: \text{in\_types}[0].\text{shape}[0] == \text{in\_types}[1].\text{shape}[0] \times 4
Actual: 3 \neq 4
```

To compare a member variable of your function, wrap a value with `Variable` to show readable error message:

```
x\_\text{type}.\text{shape}[0] == \text{utils.type\_check.Variable}(\text{self.in\_size}, \"\text{in\_size}\")
```

This code can check the equivalent condition below:

```
x\_\text{type}.\text{shape}[0] == \text{self.in\_size}
```

However, the latter condition doesn’t know the meaning of this value. When this condition is not satisfied, the latter code shows unreadable error message:

```
InvalidType: Expect: \text{in\_types}[0].\text{shape}[0] == 4 \# \text{what\ does\ '4'\ mean?}
Actual: 3 \neq 4
```

Note that the second argument of `utils.type_check.Variable` is only for readability.

The former shows this message:

```
InvalidType: Expect: \text{in\_types}[0].\text{shape}[0] == \text{in\_size} \# \text{OK, \ 'in\_size'\ is\ a\ value\ that\ is\ given\ to\ the}
Actual: 3 \neq 4 \# \text{You\ can\ also\ check\ actual\ value\ here}
```

### 2.5.5 Call functions

How to check summation of all values of shape? `Expr` also supports function call:

```
\text{sum} = \text{utils.type\_check.Variable} (\text{np.sum, \"sum\"})
\text{utils.type\_check.expect}(\text{sum}(x\_\text{type}.\text{shape}) == 10)
```

Why do we need to wrap the function `numpy.sum` with `utils.type_check.Variable`? `x\_\text{type}.\text{shape}` is not a tuple but an object of `Expr` as we have seen before. Therefore, `numpy.sum(x\_\text{type}.\text{shape})` fails. We need to evaluate this function lazily.

The above example produces an error message like this:

```
Traceback (most recent call last):
...
InvalidType: Expect: \text{sum}(\text{in\_types}[0].\text{shape}) == 10
Actual: 7 \neq 10
```

### 2.5.6 More complicated cases

How to write a more complicated condition that can’t be written with these operators? You can evaluate `Expr` and get its result value with `eval()` method. Then check the condition and show warning message by hand:

```
x\_\text{shape} = x\_\text{type}.\text{shape}.\text{eval()} \# \text{get\ actual\ shape\ (int\ tuple)}
\text{if not more\_complicated\_condition}(x\_\text{shape}):
    \text{expect\_msg} = '\text{Shape\ is\ expected\ to\ be\ ...}'
    \text{actual\_msg} = '\text{Shape\ is\ ...}'
    \text{raise} \text{utils.type\_check.InvalidType}(\text{expect\_msg}, \text{actual\_msg})
```
Please write a readable error message. This code generates the following error message:

```python
Traceback (most recent call last):
...  
InvalidType: Expect: Shape is expected to be ...
Actual: Shape is ...
```

### 2.5.7 Typical type check example

We show a typical type check for a function.

First check the number of arguments:

```python
utils.type_check.expect(in_types.size() == 2)
```

`in_types.size()` returns a `Expr` object representing the number of arguments. You can check it in the same way.

And then, get each type:

```python
x_type, y_type = in_types
```

Don’t get each value before checking `in_types.size()`. When the number of argument is illegal, `type_check.expect` might output unuseful error messages. For example, this code doesn’t work when the size of `in_types` is 0:

```python
utils.type_check.expect(
    in_types.size() == 2,
    in_types[0].ndim == 3,
)
```

After that, check each type:

```python
utils.type_check.expect(
    x_type.dtype == np.float32,
    x_type.ndim == 3,
    x_type.shape[1] == 2,
)
```

The above example works correctly even when `x_type.ndim == 0` as all conditions are evaluated lazily.
3.1 Core functionalities

3.1.1 Variable

class chainer.Variable(data, volatile=OFF, name=None, grad=None)

Array with a structure to keep track of computation.

Every variable holds a data array of type either numpy.ndarray or cupy.ndarray.

A Variable object may be constructed in two ways: by the user or by some function. When a variable is created
by some function as one of its outputs, the variable holds a reference to that function. This reference is used in
error backpropagation (a.k.a. backprop). It is also used in backward unchaining. A variable that does not hold
a reference to its creator is called a root variable. A variable is root if it is created by the user, or if the reference
is deleted by unchain_backward().

Users can disable this chaining behavior by setting the volatile flag for the initial variables. When a function
gets volatile variables as its inputs, the output variables do not hold references to the function. This acts like
unchaining on every function application.

Parameters

• data (array) – Initial data array.
• volatile (Flag) – Volatility flag. String (‘on’, ‘off’, or ‘auto’) or boolean values can be
  used, too.
• name (str) – Name of the variable.
• grad (array) – Initial gradient array.

Variables

• data – Data array of type either numpy.ndarray or cupy.ndarray.
• grad – Gradient array.
• creator – The function who creates this variable. It is None if the variable is not created
  by any function.
• volatile – Ternary Flag object. If ‘ON’, the variable does not keep track of any func-
  tion applications. See Flag for the detail of ternary flags.

__abs__()  
Element-wise absolute.

Returns  Output variable.
Return type Variable

__add__ (rhs)
Element-wise addition.

Returns Output variable.

Return type Variable

__div__ (rhs)
Element-wise division

Returns Output variable.

Return type Variable

__getitem__ (x, slices)
Extract elements from array with specified shape, axes and offsets.

Parameters

• x (tuple of Variables) – Variable to be sliced.

• slices (int, slice, None or Ellipsis or tuple of them) – Basic slicing to slice a variable. It supports int, slice, newaxis (equivalent to None) and Ellipsis.

Returns Variable object which contains sliced array of x.

Return type Variable

Note: See NumPy document for details of indexing.

__len__ ()
Returns the number of elements of the data array.

Returns Number of elements of the data array.

Return type int

__matmul__ (rhs)
Matrix multiplication.

Returns Output variable.

Return type Variable

__mul__ (rhs)
Element-wise multiplication.

Returns Output variable.

Return type Variable

__neg__ ()
Element-wise negation.

Returns Output variable.

Return type Variable

__pow__ (rhs)
Element-wise power function.

Returns Output variable.
Return type: `Variable`

__radd__(rhs)
Element-wise addition.

Returns: Output variable.

Return type: `Variable`

__rdiv__(rhs)
Element-wise division.

Returns: Output variable.

Return type: `Variable`

__rmatmul__(rhs)
Matrix multiplication.

Returns: Output variable.

Return type: `Variable`

__rmul__(rhs)
Element-wise multiplication.

Returns: Output variable.

Return type: `Variable`

__rpow__(rhs)
Element-wise power function.

Returns: Output variable.

Return type: `Variable`

__rsub__(rhs)
Element-wise subtraction.

Returns: Output variable.

Return type: `Variable`

__rtruediv__(rhs)
Element-wise division.

Returns: Output variable.

Return type: `Variable`

__sub__(rhs)
Element-wise subtraction.

Returns: Output variable.

Return type: `Variable`

__truediv__(rhs)
Element-wise division.

Returns: Output variable.

Return type: `Variable`

addgrad(var)
Accumulates the gradient array from given source variable.

3.1. Core functionalities
This method just runs `self.grad += var.grad`, except that the accumulation is even done across
the host and different devices.

**Parameters**

`var (Variable)` – Source variable.

`backward(retain_grad=False)`

Runs error backpropagation (a.k.a. backprop) from this variable.

On backprop, `Function.backward()` is called on each `Function` object appearing in the backward
graph starting from this variable. The backward graph is represented by backward references from vari-
abless to their creators, and from functions to their inputs. The backprop stops at all root variables. Some
functions set `None` as gradients of some inputs, where further backprop does not take place at such input
variables.

This method uses `grad` as the initial error array. User can manually set a gradient array before calling
this method. If `data` contains only one element (i.e., it is scalar) and `grad` is `None`, then this method
automatically complements 1.0 as the initial error. This is useful on starting backprop from some scalar
loss value.

**Parameters**

`retain_grad (bool)` – If `True`, the gradient arrays of all intermediate variables
are kept. Otherwise, `grad` of the intermediate variables are set to `None` on appropriate
timing, which may reduce the maximum memory consumption.

In most cases of training some models, the purpose of backprop is to compute gradients of
parameters, not of variables, so it is recommended to set this flag `False`.

cleargrad()

Cleans the gradient array.

copydata(var)

Copies the data array from given source variable.

This method just copies the data attribute from given variable to this variable, except that the copy is even
done across the host and different devices.

**Parameters**

`var (Variable)` – Source variable.

debug_print()

Display a summary of the stored data and location of the Variable

label

Short text that represents the variable.

set_creator(gen_func)

Notifies the variable that the given function is its creator.

**Parameters**

`gen_func (Function)` – Function object that creates this variable as one of its
outputs.

to_cpu()

Copies the data and gradient arrays to CPU.

to_gpu(device=None)

Copies the data and gradient arrays to specified GPU.

**Parameters**

`device` – Target device specifier. If omitted, the current device is used.

unchain_backward()

Deletes references between variables and functions backward.

After this method completes, intermediate variables and functions that are not referenced from anywhere
are deallocated by reference count GC. Also this variable itself deletes the reference to its creator function,
i.e. this variable becomes root in the computation graph. It indicates that backprop after unchaining stops at this variable. This behavior is useful to implement truncated BPTT.

```
zerograd()
```

Initializes the gradient array by zeros.

Deprecated since version v1.15: Use `cleargrad()` instead.

### 3.1.2 Flag

```
class chainer.Flag
```

Ternary flag object for variables.

It takes three values: ON, OFF, and AUTO.

ON and OFF flag can be evaluated as a boolean value. These are converted to True and False, respectively. AUTO flag cannot be converted to boolean. In this case, `ValueError` is raised.

**Parameters**

```
name (str, bool, or None) – Name of the flag. Following values are allowed:
  • ’on’, ’ON’, or True for ON value
  • ’off’, ’OFF’, or False for OFF value
  • ’auto’, ’AUTO’, or None for AUTO value
```

```
chainer.ON = ON

Equivalent to Flag(’on’).
```

```
chainer.OFF = OFF

Equivalent to Flag(’off’).
```

```
chainer.AUTO = AUTO

Equivalent to Flag(’auto’).
```

```
class chainer.flag.aggregate_flags(flags)
```

Returns an aggregated flag given a sequence of flags.

If both ON and OFF are found, this function raises an error. Otherwise, either of ON and OFF that appeared is returned. If all flags are AUTO, then it returns AUTO.

**Parameters**

```
flags (sequence of Flag) – Input flags.
```

**Returns**

The result of aggregation.

**Return type**

Flag

### 3.1.3 Function

```
class chainer.Function
```

Function on variables with backpropagation ability.

All function implementations defined in `chainer.functions` inherit this class.

The main feature of this class is keeping track of function applications as a backward graph. When a function is applied to `Variable` objects, its `forward()` method is called on `data` fields of input variables, and at the same time it chains references from output variables to the function and from the function to its inputs.

**Note:** As of v1.5, a function instance cannot be used twice in any computational graphs. In order to reuse a function object multiple times, use `copy.copy()` before the function applications to make a copy of the instance.
This restriction also means that we cannot make a stateful function anymore. For example, it is now not allowed to let a function hold parameters. Define a function as a pure (stateless) procedure, and use Link to combine it with parameter variables.

### Example

Let \(x\) an instance of `Variable` and \(f\) an instance of `Function` taking only one argument. Then a line

```python
>>> import numpy, chainer, chainer.functions as F
>>> x = chainer.Variable(numpy.zeros(10))
>>> f = F.Identity()
>>> y = f(x)
```

computes a new variable \(y\) and creates backward references. Actually, backward references are set as per the following diagram:

```
x <--- f <--- y
```

If an application of another function \(g\) occurs as

```python
>>> g = F.Identity()
>>> z = g(x)
```

then the graph grows with a branch:

```
    |--- f <--- y
  x <--
    |--- g <--- z
```

Note that the branching is correctly managed on backward computation, i.e. the gradients from \(f\) and \(g\) are accumulated to the gradient of \(x\).

Every function implementation should provide `forward_cpu()`, `forward_gpu()`, `backward_cpu()` and `backward_gpu()`. Alternatively, one can provide `forward()` and `backward()` instead of separate methods. Backward methods have default implementations that just return `None`, which indicates that the function is non-differentiable.

### Variables

- **inputs** – A tuple or list of input variables.
- **outputs** – A tuple or list of output variables.
- **type_check_enable** – When it is `True`, the function checks types of input arguments. Set `CHAINER_TYPE_CHECK` environment variable `0` to disable type check, or set the variable directly in your own program.

```
__call__(*inputs)
```

Applies forward propagation with chaining backward references.

Basic behavior is expressed in documentation of `Function` class.

**Note:** If the `data` attribute of input variables exist on GPU device, then, before it calls `forward()` method, the appropriate device is selected, so in most cases implementers do not need to take care of device selection.
Parameters **inputs** – Tuple of input :class:`Variable`, :class:`numpy.ndarray` or :class:`cupy.ndarray` objects. The volatile flags of all input variables must agree. If the input is an :class:`numpy.ndarray` or a :class:`cupy.ndarray`, it is automatically wrapped with :class:`Variable`.

Returns One :class:`Variable` object or a tuple of multiple :class:`Variable` objects.

**add_hook** *(hook, name=None)*

Registers the function hook.

Parameters

- **hook** (:class:`FunctionHook`) – Function hook to be registered.
- **name** (:class:`str`) – Name of the function hook. name must be unique among function hooks registered to the function. If None, default name of the function hook is used.

**backward** *(inputs, grad_outputs)*

Applies backprop to output gradient arrays.

It delegates the procedure to :func:`backward_cpu()` or :func:`backward_gpu()` by default. Which it selects is determined by the type of input arrays and output gradient arrays. Implementations of *Function* must implement either CPU/GPU methods or this method, if the function is intended to be backprop-ed.

Parameters

- **inputs** – Tuple of input arrays.
- **grad_outputs** – Tuple of output gradient arrays.

Returns Tuple of input gradient arrays. Some or all of them can be :class:`None`, if the function is not differentiable on inputs.

Return type *tuple*

**Warning:** Implementations of *Function* must take care that the return value must be a tuple even if it returns only one array.

**backward_cpu** *(inputs, grad_outputs)*

Applies backprop to output gradient arrays on CPU.

Parameters

- **inputs** – Tuple of input :class:`numpy.ndarray` object(s).
- **grad_outputs** – Tuple of output gradient :class:`numpy.ndarray` object(s).

Returns Tuple of input gradient :class:`numpy.ndarray` object(s). Some or all of them can be :class:`None`, if the function is not differentiable on corresponding inputs.

Return type *tuple*

**Warning:** Implementations of *Function* must take care that the return value must be a tuple even if it returns only one array.

**backward_gpu** *(inputs, grad_outputs)*

Applies backprop to output gradient arrays on GPU.

Parameters

- **inputs** – Tuple of input :class:`cupy.ndarray` object(s).
- **grad_outputs** – Tuple of output gradient :class:`cupy.ndarray` object(s).
**Returns**  Tuple of input gradient `cupy.ndarray` object(s). Some or all of them can be `None`, if the function is not differentiable on corresponding inputs.

**Return type**  tuple

**Warning:** Implementations of `Function` must take care that the return value must be a tuple even if it returns only one array.

---

`check_type_forward`(*`in_types`*)

Checks types of input data before forward propagation.

Before `forward()` is called, this function is called. You need to validate types of input data in this function using the type checking utilities.

**Parameters**  

`in_types` (*TypeInfoTuple*) – The type information of input data for `forward()`.

---

`delete_hook`(*`name`*)

Unregisters the function hook.

**Parameters**  

`name` (*str*) – the name of the function hook to be unregistered.

---

`forward`(*`inputs`*)

Applies forward propagation to input arrays.

It delegates the procedure to `forward_cpu()` or `forward_gpu()` by default. Which it selects is determined by the type of input arrays. Implementations of `Function` must implement either CPU/GPU methods or this method.

**Parameters**  

`inputs` – Tuple of input array(s).

**Returns**  Tuple of output array(s).

**Warning:** Implementations of `Function` must take care that the return value must be a tuple even if it returns only one array.

---

`forward_cpu`(*`inputs`*)

Applies forward propagation to input arrays on CPU.

**Parameters**  

`inputs` – Tuple of `numpy.ndarray` object(s).

**Returns**  Tuple of `numpy.ndarray` object(s).

**Return type**  tuple

**Warning:** Implementations of `Function` must take care that the return value must be a tuple even if it returns only one array.

---

`forward_gpu`(*`inputs`*)

Applies forward propagation to input arrays on GPU.

**Parameters**  

`inputs` – Tuple of `cupy.ndarray` object(s).

**Returns**  Tuple of `cupy.ndarray` object(s).

**Return type**  tuple

**Warning:** Implementations of `Function` must take care that the return value must be a tuple even if it returns only one array.
**label**
Short text that represents the function.

The default implementation returns its type name. Each function should override it to give more information.

**local_function_hooks**
Ordered Dictionary of registered function hooks.

Contrary to `chainer.thread_local.function_hooks`, which registers its elements to all functions, Function hooks in this property is specific to this function.

**unchain()**
Purges in/out variables and this function itself from the graph.

This method is called from `Variable.unchain_backward()` method.

```python
chainer.force_backprop_mode(*args, **kwds)
```
Enable back-propagation for Variable whose volatile is auto.

When you want to enable back-propagation in `no_backprop_mode()`, call this method. In this context, `Variable` object whose `volatile` attribute is `auto` behaves like a `volatile` variable. That means you can disable `no_backprop_mode()` in this context.

If you call this method outside of `no_backprop_mode()` context, it changes nothing. `Variable` object with `volatile='auto'` behaves like a volatile variable by default.

In this example, the volatility of `x` and `y` is `auto`. In `no_backprop_mode()` context, `y` does not have a computational graph but in `force_backprop_mode()` it has a graph.

```python
>>> with chainer.no_backprop_mode():
...     # Variable with volatile='auto' behaves like volatile='on'
...     with chainer.force_backprop_mode():
...         # Variable with volatile='auto' behaves like volatile='off'
...         y = x + 1
```

See also:

See `no_backprop_mode()` for details of back-prop mode.

```python
chainer.no_backprop_mode(*args, **kwds)
```
Disable back-propagation for Variable whose volatile is auto.

In the default setting a `Variable` object whose `volatile` attribute is `auto` behaves like a `non-volatile` variable. That means such a `Variable` object builds a computational graph, consumes memory to store the graph, and you can execute back-propagation for it. With this context such a `Variable` object behaves like a `volatile` variable. So, you can easily switch training and evaluation.

In this example, the volatility of `x` and `y` is `auto`. So, `y` does not have a computational graph.

```python
>>> x = chainer.Variable(numpy.array([1,], 'f'), volatile='auto')
>>> with chainer.no_backprop_mode():
...     y = x + 1
```

### 3.1.4 Link and Chain

```python
class chainer.Link(**params)
```
Building block of model definitions.

Link is a building block of neural network models that support various features like handling parameters, defining network fragments, serialization, etc.
Link is the primitive structure for the model definitions. It supports management of parameter variables and persistent values that should be incorporated to serialization. Parameters are variables registered via the add_param() method, or given to the initializer method. Persistent values are arrays, scalars, or any other serializable values registered via the add_persistent() method.

**Note:** Whereas arbitrary serializable objects can be registered as persistent values, it is strongly recommended to just register values that should be treated as results of learning. A typical example of persistent values is ones computed during training and required for testing, e.g. running statistics for batch normalization.

Parameters and persistent values are referred by their names. They can be accessed as attributes of the links. Link class itself manages the lists of names of parameters and persistent values to distinguish parameters and persistent values from other attributes.

Link can be composed into more complex models. This composition feature is supported by child classes like Chain and ChainList. One can create a chain by combining one or more links. See the documents for these classes for details.

As noted above, Link supports the serialization protocol of the Serializer class. **Note that only parameters and persistent values are saved and loaded.** Other attributes are considered as a part of user program (i.e. a part of network definition). In order to construct a link from saved file, other attributes must be identically reconstructed by user codes.

### Example

This is a simple example of custom link definition. Chainer itself also provides many links defined under the links module. They might serve as examples, too.

Consider we want to define a simple primitive link that implements a fully-connected layer based on the linear() function. Note that this function takes input units, a weight variable, and a bias variable as arguments. Then, the fully-connected layer can be defined as follows:

```python
import chainer
import chainer.functions as F
import numpy as np

class LinearLayer(chainer.Link):
    
    def __init__(self, n_in, n_out):
        # Parameters are initialized as a numpy array of given shape.
        super(LinearLayer, self).__init__(
            W=(n_out, n_in),
            b=(n_out,),
        )
        self.W.data[...] = np.random.randn(n_out, n_in)
        self.b.data.fill(0)

    def __call__(self, x):
        return F.linear(x, self.W, self.b)
```

This example shows that a user can define arbitrary parameters and use them in any methods. Links typically implement the __call__ operator.

**Parameters** params – Names, shapes, and optional dtypes of initial parameters. The keywords are used as the parameter names and the corresponding values consist either of the shape or a tuple of shape and a dtype (shape, dtype). If only the shape is supplied, the default dtype will be used.
Variables

**name (str)** – Name of this link, given by the parent chain (if exists).

```python
add_param(name, shape, dtype=np.float32, initializer=None)
```

Registers a parameter to the link.

The registered parameter is saved and loaded on serialization and deserialization, and involved in the optimization. The data and gradient of the parameter are initialized by NaN arrays. If `initializer` is not `None`, the data is initialized by `initializer`.

If the supplied `name` argument corresponds to an uninitialized parameter (that is, one that was added with the `add_uninitialized_param()` method), `name` will be removed from the set of uninitialized parameters.

The parameter is set to an attribute of the link with the given name.

**Parameters**

- **name (str)** – Name of the parameter. This name is also used as the attribute name. Any uninitialized parameters with the same name will be removed.
- **shape (int or tuple of ints)** – Shape of the parameter array.
- **dtype** – Data type of the parameter array.
- **initializer (chainer.initializer.Initializer)** – If it is not `None`, the data is initialized with the given initializer. Note that in this case `dtype` argument is ignored.

```python
add_persistent(name, value)
```

Registers a persistent value to the link.

The registered value is saved and loaded on serialization and deserialization. The value is set to an attribute of the link.

**Parameters**

- **name (str)** – Name of the persistent value. This name is also used for the attribute name.
- **value** – Value to be registered.

```python
add_uninitialized_param(name)
```

Registers an uninitialized parameter to the link.

An uninitialized parameter is defined as a parameter that has a name but that does not yet have a shape. If the shape of a parameter depends on the shape of the inputs to the `__call__` operator, it can be useful to defer initialization (that is, setting the shape) until the first forward call of the link. Such parameters are intended to be defined as uninitialized parameters in the initializer and then initialized during the first forward call.

An uninitialized parameter is intended to be registered to a link by calling this method in the initializer method. Then, during the first forward call, the shape of the parameter will be determined from the size of the inputs and the parameter must be initialized by calling the `add_param()` method.

**Parameters**

- **name** – (str): Name of the uninitialized parameter.

```python
addgrads(link)
```

Accumulates gradient values from given link.

This method adds each gradient array of the given link to corresponding gradient array of this link. The accumulation is even done across host and different devices.

**Parameters**

- **link (Link)** – Source link object.
children()  
Returns a generator of all child links.

Returns A generator object that generates all child links.

cleargrads()  
Clears all gradient arrays.

This method should be called before the backward computation at every iteration of the optimization.

copy()  
Copies the link hierarchy to new one.

The whole hierarchy rooted by this link is copied. The copy is basically shallow, except that the parameter variables are also shallowly copied. It means that the parameter variables of copied one are different from ones of original link, while they share the data and gradient arrays.

The name of the link is reset on the copy, since the copied instance does not belong to the original parent chain (even if exists).

Returns Copied link object.

Return type Link

copyparams(link)  
Copies all parameters from given link.

This method copies data arrays of all parameters in the hierarchy. The copy is even done across the host and devices. Note that this method does not copy the gradient arrays.

Parameters link (Link) – Source link object.

has_uninitialized_params  
Check if the link has uninitialized parameters.

Returns True if the link has any uninitialized parameters. Otherwise returns False.

Return type bool

links(skipself=False)  
Returns a generator of all links under the hierarchy.

Parameters skipself (bool) – If True, then the generator skips this link and starts with the first child link.

Returns A generator object that generates all links.

namedlinks(skipself=False)  
Returns a generator of all (path, link) pairs under the hierarchy.

Parameters skipself (bool) – If True, then the generator skips this link and starts with the first child link.

Returns A generator object that generates all (path, link) pairs.

namedparams()  
Returns a generator of all (path, param) pairs under the hierarchy.

Returns A generator object that generates all (path, parameter) pairs. The paths are relative from this link.

params()  
Returns a generator of all parameters under the link hierarchy.

Returns A generator object that generates all parameters.
**serialize** *(serializer)*
Serializes the link object.

**Parameters**

**serializer** *(AbstractSerializer)* – Serializer object.

**to_cpu**
Copies parameter variables and persistent values to CPU.
This method does not handle non-registered attributes. If some of such attributes must be copied to CPU, the link implementation must override this method to do so.

Returns: self

**to_gpu**(device=None)
Copies parameter variables and persistent values to GPU.
This method does not handle non-registered attributes. If some of such attributes must be copied to GPU, the link implementation must override this method to do so.

**Parameters**

**device** – Target device specifier. If omitted, the current device is used.

Returns: self

**xp**
Array module for this link.
Depending on which of CPU/GPU this link is on, this property returns *numpy* or *cupy*.

**zerograds**
Initializes all gradient arrays by zero.
This method can be used for the same purpose of *cleargrads*, but less efficient. This method is left for backward compatibility.

Deprecated since version v1.15: Use *cleargrads()* instead.

```python
class chainer.Chain(**links)
```
Composable link with object-like interface.

Composability is one of the most important features of neural nets. Neural net models consist of many reusable fragments, and each model itself might be embedded into a larger learnable system. Chain enables us to write a neural net based on composition, without bothering about routine works like collecting parameters, serialization, copying the structure with parameters shared, etc.

This class actually provides a way to compose one or more links into one structure. A chain can contain one or more child links. Child link is a link registered to the chain with its own name. The child link is stored to an attribute of the chain with the name. User can write a whole model or a fragment of neural nets as a child class of Chain.

Each chain itself is also a link. Therefore, one can combine chains into higher-level chains. In this way, links and chains construct a link hierarchy. Link hierarchy forms a tree structure, where each node is identified by the path from the root. The path is represented by a string like a file path in UNIX, consisting of names of nodes on the path, joined by slashes `/`.

**Example**

This is a simple example of custom chain definition. Chainer itself also provides some chains defined under the *links* module. They might serve as examples, too.

Consider we want to define a multi-layer perceptron consisting of two hidden layers with rectifiers as activation functions. We can use the *Linear* link as a building block:
import chainer
import chainer.functions as F
import chainer.links as L

class MultiLayerPerceptron(chainer.Chain):
    def __init__(self, n_in, n_hidden, n_out):
        # Create and register three layers for this MLP
        super(MultiLayerPerceptron, self).__init__ (  
            layer1=L.Linear(n_in, n_hidden),
            layer2=L.Linear(n_hidden, n_hidden),
            layer3=L.Linear(n_hidden, n_out),
        )

    def __call__(self, x):
        # Forward propagation
        h1 = F.relu(self.layer1(x))
        h2 = F.relu(self.layer2(h1))
        return self.layer3(h2)

Child links are registered via the initializer method. They also can be registered by the `add_link()` method. The forward propagation is often implemented as the `__call__` operator as the above example, though it is not mandatory.

Parameters

- **links** – Child links. The keywords are used as their names. The names are also set to the links.

- **__getitem__(name)**
  Equivalent to `getattr`.

- **add_link(name, link)**
  Registers a child link to this chain.
  The registered link is saved and loaded on serialization and deserialization, and involved in the optimization. The registered link is called a child. The child link is set to an attribute of the chain with the given name.
  This method also sets the `name` attribute of the registered link. If the given link already has the name attribute set, then it raises an error.

  **Parameters**

  - name (str) – Name of the child link. This name is also used as the attribute name.
  - link (Link) – The link object to be registered.

class chainer.ChainList(*links)
Composable link with list-like interface.

This is another example of compositional link. Unlike `Chain`, this class can be used like a list of child links. Each child link is indexed by a non-negative integer, and it maintains the current number of registered child links. The `add_link()` method inserts a new link at the end of the list. It is useful to write a chain with arbitrary number of child links, e.g. an arbitrarily deep multi-layer perceptron.

Note that this class does not implement all methods of `list`.

Parameters

- **links** – Initial child links.

- **__getitem__(index)**
  Returns the child at given index.
Parameters `index` *(int)* – Index of the child in the list.

Returns The `index`-th child link.

Return type `Link`

`__len__` ()
Returns a number of children.

`add_link` *(link)*
Registers a child link to this chain.

The registered link is saved and loaded on serialization and deserialization, and involved in the optimization. The registered link is called a child. The child link is accessible via `children()` generator, which returns a generator running through the children in registered order.

This method also sets the `name` attribute of the registered link. If the given link already has the name attribute set, then it raises an error.

Parameters `link` *(Link)* – The link object to be registered.

3.1.5 Optimizer

class `chainer.Optimizer`
Base class of all numerical optimizers.

This class provides basic features for all optimization methods. It optimizes parameters of a target link. The target link is registered via the `setup()` method, and then the `update()` method updates its parameters based on a given loss function.

Each optimizer implementation must be defined as a child class of Optimizer. It must override `update()` method. An optimizer can use internal states each of which is tied to one of the parameters. State is a dictionary of serializable values (typically arrays of size same as the corresponding parameters). In order to use state dictionaries, the optimizer must override `init_state()` method (or its CPU/GPU versions, `init_state_cpu()` and `init_state_gpu()`).

If the optimizer is based on single gradient computation (like most first-order methods), then it should inherit `GradientMethod`, which adds some features dedicated for the first order methods.

Optimizer instance also supports hook functions. Hook function is registered by the `add_hook()` method. Each hook function is called in registration order in advance of the actual parameter update.

Variables

- `target` – Target link object. It is set by the `setup()` method.
- `t` – Number of update steps. It must be incremented by the `update()` method.
- `epoch` – Current epoch. It is incremented by the `new_epoch()` method.

`accumulate_grads` *(grads)*
Accumulates gradients from other source.

This method just adds given gradient arrays to gradients that this optimizer holds. It is typically used in data-parallel optimization, where gradients for different shards are computed in parallel and aggregated by this method. This method correctly treats multiple GPU devices.

Parameters `grads` *(Iterable)* – Iterable of gradient arrays to be accumulated.

Deprecated since version v1.5: Use the `chainer.Link.addgrads()` method of the target link instead.
add_hook (hook, name=None)
Registers a hook function.

Hook function is typically called right after the gradient computation, though the timing depends on the optimization method.

Parameters

• hook (function) – Hook function. It accepts the optimizer object.
• name (str) – Name of the registration. If omitted, hook.name is used by default.

call_hooks()
Invokes hook functions in registration order.

clip_grads (maxnorm)
Clips the norm of whole gradients up to the threshold.

Parameters maxnorm (float) – Threshold of gradient L2 norm.

Deprecated since version v1.5: Use the GradientClipping hook function instead.

compute_grads_norm()
Computes the norm of whole gradients.

Returns L2 norm of whole gradients, i.e. square root of sum of square of all gradient elements.

Return type float

Warning: This method returns a CPU-computed value, which means that this method synchronizes between CPU and GPU if at least one of the gradients reside on the GPU.

Deprecated since version v1.5.

init_state (param, state)
Initializes the optimizer state corresponding to the parameter.

This method should add needed items to the state dictionary. Each optimizer implementation that uses its own states should override this method or CPU/GPU dedicated versions (init_state_cpu() and init_state_gpu()).

Parameters

• param (Variable) – Parameter variable.
• state (dict) – State dictionary.

See also:

init_state_cpu(), init_state_gpu()

init_state_cpu (param, state)
Initializes the optimizer state on CPU.

This method is called from init_state() by default.

Parameters

• param (Variable) – Parameter variable. Its data array is of type numpy.ndarray.
• state (dict) – State dictionary.

See also:

init_state()
**init_state_gpu** *(param, state)*

Initializes the optimizer state on GPU.

This method is called from *init_state()* by default.

**Parameters**

- **param** *(Variable)* – Parameter variable. Its data array is of type *cupy.ndarray*.
- **state** *(dict)* – State dictionary.

**See also:**

*init_state()*

**new_epoch()**

Starts a new epoch.

This method increments the *epoch* count. Note that if the optimizer depends on the epoch count, then user should call this method appropriately at the beginning of each epoch.

**prepare()**

Prepares for an update.

This method initializes missing optimizer states (e.g. for newly added parameters after the set up), and copies arrays in each state dictionary to CPU or GPU according to the corresponding parameter array.

**remove_hook**(name)

Removes a hook function.

**Parameters**

- **name** *(str)* – Registered name of the hook function to remove.

**serialize**(serializer)

Serializes or deserializes the optimizer.

It only saves or loads the following things:

- Optimizer states
- Global states (*t* and *epoch*)

**It does not saves nor loads the parameters of the target link.** They should be separately saved or loaded.

**Parameters**

- **serializer** *(AbstractSerializer)* – Serializer or deserializer object.

**setup**(link)

Sets a target link and initializes the optimizer states.

Given link is set to the *target* attribute. It also prepares the optimizer state dictionaries corresponding to all parameters in the link hierarchy. The existing states are discarded.

**Parameters**

- **link** *(Link)* – Target link object.

**update**(lossfun=None, *args, **kwds)

Updates the parameters and optimizer states.

This method updates the parameters of the target link and corresponding optimizer states. The behavior of this method is different for the cases either *lossfun* is given or not.

If *lossfun* is given, then this method initializes the gradients by zeros, calls it with given extra arguments, and calls the *backward()* method of its output to compute the gradients. The implementation might call *lossfun* more than once.

If *lossfun* is not given, then this method assumes that the gradients of all parameters are already computed. An implementation that requires multiple gradient computations might raise an error on this case.

In both cases, this method invokes the update procedure for all parameters.
Parameters

- `lossfun (function)` – Loss function. It accepts arbitrary arguments and returns one `Variable` object that represents the loss (or objective) value. This argument can be omitted for single gradient-based methods. In this case, this method assumes gradient arrays computed.

- `kwds (args,)` – Arguments for the loss function.

`weight_decay (decay)`
Applies weight decay to the parameter/gradient pairs.

**Parameters**
- `decay (float)` – Coefficient of weight decay.

Deprecated since version v1.5: Use the `WeightDecay` hook function instead.

`zero_grads ()`
Fills all gradient arrays by zeros.

Deprecated since version v1.5: Use the `chainer.Link.cleargrads()` method for the target link instead.

class `chainer.GradientMethod`
Base class of all single gradient-based optimizers.

This is an extension of the `Optimizer` class. Typical gradient methods that just require the gradient at the current parameter vector on an update can be implemented as its child class.

An implementation of a gradient method must override the following methods:

- `init_state ()` or both `init_state_cpu ()` and `init_state_gpu ()`
- `update_one ()` or both `update_one_cpu ()` and `update_one_gpu ()`

**Note:** It is recommended to call `use_cleargrads ()` after creating a `GradientMethod` object for efficiency.

`update (lossfun=None, *args, **kwds)`
Updates parameters based on a loss function or computed gradients.

This method runs in two ways.

- If `lossfun` is given, then use it as a loss function to compute gradients.
- Otherwise, this method assumes that the gradients are already computed.

In both cases, the computed gradients are used to update parameters. The actual update routines are defined by the `update_one ()` method (or its CPU/GPU versions, `update_one_cpu ()` and `update_one_gpu ()`).

`update_one (param, state)`
Updates a parameter based on the corresponding gradient and state.

This method calls appropriate one from `update_param_cpu ()` or `update_param_gpu ()`.

**Parameters**

- `param (Variable)` – Parameter variable.
- `state (dict)` – State dictionary.

`update_one_cpu (param, state)`
Updates a parameter on CPU.
Parameters

- **param** ([Variable]) – Parameter variable.
- **state** ([dict]) – State dictionary.

`update_one_gpu(param, state)`

Updates a parameter on GPU.

Parameters

- **param** ([Variable]) – Parameter variable.
- **state** ([dict]) – State dictionary.

`use_cleargrads(use=True)`

Enables or disables use of `cleargrads()` in `update`.

Parameters **use** ([bool]) – If True, this function enables use of `cleargrads`. If False, disables use of `cleargrads` (`zerograd` is used).

Note: Note that `update()` calls `zerograd()` by default for backward compatibility. It is recommended to call this method before first call of `update` because `cleargrads` is more efficient than `zerograd`.

Hook functions

class chainer.optimizer.WeightDecay(rate)

Optimizer hook function for weight decay regularization.

This hook function adds a scaled parameter to the corresponding gradient. It can be used as a regularization.

Parameters **rate** ([float]) – Coefficient for the weight decay.

Variables **rate** ([float]) – Coefficient for the weight decay.

class chainer.optimizer.Lasso(rate)

Optimizer hook function for Lasso regularization.

This hook function adds a scaled parameter to the sign of each weight. It can be used as a regularization.

Parameters **rate** ([float]) – Coefficient for the weight decay.

Variables **rate** ([float]) – Coefficient for the weight decay.

class chainer.optimizer.GradientClipping(threshold)

Optimizer hook function for gradient clipping.

This hook function scales all gradient arrays to fit to the defined L2 norm threshold.

Parameters **threshold** ([float]) – L2 norm threshold.

Variables **threshold** ([float]) – L2 norm threshold of gradient norm.

class chainer.optimizer.GradientNoise(eta, noise_func=<function exponential_decay_noise>)

Optimizer hook function for adding gradient noise.

This hook function simply adds noise generated by the `noise_func` to the gradient. By default it adds time-dependent annealed Gaussian noise to the gradient at every training step:

\[ g_t \leftarrow g_t + \mathcal{N}(0, \sigma^2_t) \]
where

\[ \sigma_t^2 = \frac{\eta}{(1 + t)^\gamma} \]

with \( \eta \) selected from \{0.01, 0.3, 1.0\} and \( \gamma = 0.55 \).

**Parameters**

- \texttt{eta} (float) – Parameter that defines the scale of the noise, which for the default noise function is recommended to be either 0.01, 0.3 or 1.0.
- \texttt{noise_func} (function) – Noise generating function which by default is given by Adding Gradient Noise Improves Learning for Very Deep Networks.

### 3.1.6 Serializer

**class** chainer.AbstractSerializer

Abstract base class of all serializers and deserializers.

**__call__**(key, value)

Serializes or deserializes a value by given name.

This operator saves or loads a value by given name.

If this is a serializer, then the value is simply saved at the key. Note that some type information might be missed depending on the implementation (and the target file format).

If this is a deserializer, then the value is loaded by the key. The deserialization differently works on scalars and arrays. For scalars, the \texttt{value} argument is used just for determining the type of restored value to be converted, and the converted value is returned. For arrays, the restored elements are directly copied into the \texttt{value} argument. String values are treated like scalars. If the \texttt{value} argument is \texttt{None}, the type of the restored value will typically be a numpy array but can depend on the particular subclass implementation.

**Parameters**

- \texttt{key} (str) – Name of the serialization entry.
- \texttt{value} (scalar, array, None, or str) – Object to be (de)serialized. \texttt{None} is only supported by deserializers.

**Returns** Serialized or deserialized value.

**__getitem__**(key)

Gets a child serializer.

This operator creates a _child_ serializer represented by the given key.

**Parameters** \texttt{key} (str) – Name of the child serializer.

**class** chainer.Serializer

Base class of all serializers.

**save**(obj)

Saves an object by this serializer.

This is equivalent to \texttt{obj.serialize(self)}.

**Parameters** \texttt{obj} – Target object to be serialized.

**class** chainer.Deserializer

Base class of all deserializers.
load(obj)
Loads an object from this deserializer.

This is equivalent to obj.serialize(self).

**Parameters**

obj – Target object to be serialized.

### 3.1.7 Dataset abstraction

Chainer has a support of common interface of training and validation datasets. The dataset support consists of three components: datasets, iterators, and batch conversion functions.

**Dataset** represents a set of examples. The interface is only determined by combination with iterators you want to use on it. The built-in iterators of Chainer requires the dataset to support `__getitem__` and `__len__` method. In particular, the `__getitem__` method should support indexing by both an integer and a slice. We can easily support slice indexing by inheriting `DatasetMixin`, in which case users only have to implement `get_example()` method for indexing. Some iterators also restrict the type of each example. Basically, datasets are considered as *stateless* objects, so that we do not need to save the dataset as a checkpoint of the training procedure.

**Iterator** iterates over the dataset, and at each iteration, it yields a mini batch of examples as a list. Iterators should support the `Iterator` interface, which includes the standard iterator protocol of Python. Iterators manage where to read next, which means they are *stateful*.

**Batch conversion function** converts the mini batch into arrays to feed to the neural nets. They are also responsible to send each array to an appropriate device. Chainer currently provides `concat_example()` as the only example of batch conversion functions.

These components are all customizable, and designed to have a minimum interface to restrict the types of datasets and ways to handle them. In most cases, though, implementations provided by Chainer itself are enough to cover the usages.

Chainer also has a light system to download, manage, and cache concrete examples of datasets. All datasets managed through the system are saved under the *dataset root directory*, which is determined by the `CHAINER_DATASET_ROOT` environment variable, and can also be set by the `set_dataset_root()` function.

**Dataset representation**

See *Dataset examples* for dataset implementations.

```python
class chainer.dataset.DatasetMixin
    Default implementation of dataset indexing.

DatasetMixin provides the `__getitem__` operator. The default implementation uses `get_example()` to extract each example, and combines the results into a list. This mixin makes it easy to implement a new dataset that does not support efficient slicing.

Dataset implementation using DatasetMixin still has to provide the `__len__` operator explicitly.

    __getitem__(index)
    Returns an example or a sequence of examples.

    It implements the standard Python indexing. It uses the `get_example()` method by default, but it may be overridden by the implementation to, for example, improve the slicing performance.

    __len__()
    Returns the number of data points.

    get_example(i)
    Returns the i-th example.
```
Implementations should override it. It should raise `IndexError` if the index is invalid.

**Parameters**

- `i` (*int*) -- The index of the example.

**Returns**

The `i`-th example.

---

**Iterator interface**

See *Iterator examples* for dataset iterator implementations.

**class** `chainer.dataset.Iterator`

Base class of all dataset iterators.

Iterator iterates over the dataset, yielding a minibatch at each iteration. Minibatch is a list of examples. Each implementation should implement an iterator protocol (e.g., the `__next__()` method).

Note that, even if the iterator supports setting the batch size, it does not guarantee that each batch always contains the same number of examples. For example, if you let the iterator to stop at the end of the sweep, the last batch may contain a fewer number of examples.

The interface between the iterator and the underlying dataset is not fixed, and up to the implementation.

Each implementation should provide the following attributes (not needed to be writable).

- `batch_size`: Number of examples within each minibatch.
- `epoch`: Number of completed sweeps over the dataset.
- `epoch_detail`: Floating point number version of the epoch. For example, if the iterator is at the middle of the dataset at the third epoch, then this value is 2.5.
- `is_new_epoch`: True if the epoch count was incremented at the last update.

Each implementation should also support serialization to resume/suspend the iteration.

```
__iter__(self)

Returns self.

__next__(self)

Returns the next batch.

This is a part of the iterator protocol of Python. It may raise the `StopIteration` exception when it stops the iteration.

finalize(self)

Finalizes the iterator and possibly releases the resources.

This method does nothing by default. Implementation may override it to better handle the internal resources.

next(self)

Python2 alternative of `__next__`

It calls `__next__()` by default.

serialize(serializer)

Serializes the internal state of the iterator.

This is a method to support serializer protocol of Chainer.

**Note:** It should only serialize the internal state that changes over the iteration. It should not serializes what is set manually by users such as the batch size.
Batch conversion function

```python
chainer.dataset.concat_examples(batch, device=None, padding=None)
```

Concatenates a list of examples into array(s).

Dataset iterator yields a list of examples. If each example is an array, this function concatenates them along the newly-inserted first axis (called `batch dimension`) into one array. The basic behavior is same for examples consisting of multiple arrays, i.e., corresponding arrays of all examples are concatenated.

For instance, consider each example consists of two arrays \((x, y)\). Then, this function concatenates \(x\)’s into one array, and \(y\)’s into another array, and returns a tuple of these two arrays. Another example: consider each example is a dictionary of two entries whose keys are ‘\(x\)’ and ‘\(y\)’, respectively, and values are arrays. Then, this function concatenates \(x\)’s into one array, and \(y\)’s into another array, and returns a dictionary with two entries \(x\) and \(y\) whose values are the concatenated arrays.

When the arrays to concatenate have different shapes, the behavior depends on the `padding` value. If `padding` is `None` (default), it raises an error. Otherwise, it builds an array of the minimum shape that the contents of all arrays can be substituted to. The padding value is then used to the extra elements of the resulting arrays.

**Parameters**

- `batch` (`list`) – A list of examples. This is typically given by a dataset iterator.
- `device` (`int`) – Device ID to which each array is sent. Negative value indicates the host memory (CPU). If it is omitted, all arrays are left in the original device.
- `padding` – Scalar value for extra elements. If this is `None` (default), an error is raised on shape mismatch. Otherwise, an array of minimum dimensionalities that can accommodate all arrays is created, and elements outside of the examples are padded by this value.

**Returns**
Array, a tuple of arrays, or a dictionary of arrays. The type depends on the type of each example in the batch.

Dataset management

```python
chainer.dataset.get_dataset_root()
```

Gets the path to the root directory to download and cache datasets.

**Returns**
The path to the dataset root directory.

**Return type** `str`

```python
chainer.dataset.set_dataset_root(path)
```

Sets the root directory to download and cache datasets.

There are two ways to set the dataset root directory. One is by setting the environment variable `CHAINER_DATASET_ROOT`. The other is by using this function. If both are specified, one specified via this function is used. The default dataset root is `$HOME/.chainer/dataset`.

**Parameters**
- `path` (`str`) – Path to the new dataset root directory.

```python
chainer.dataset.cached_download(url)
```

Downloads a file and caches it.

It downloads a file from the URL if there is no corresponding cache. After the download, this function stores a cache to the directory under the dataset root (see `get_dataset_root()`). If there is already a cache for the given URL, it just returns the path to the cache without downloading the same file.

**Parameters**
- `url` (`str`) – URL to download from.
Returns Path to the downloaded file.

Return type str

cghainer.dataset.cache_or_load_file(path, creator, loader)
Caches a file if it does not exist, or loads it otherwise.

This is a utility function used in dataset loading routines. The creator creates the file to given path, and returns the content. If the file already exists, the loader is called instead, and it loads the file and returns the content.

Note that the path passed to the creator is temporary one, and not same as the path given to this function. This function safely renames the file created by the creator to a given path, even if this function is called simultaneously by multiple threads or processes.

Parameters

• path (str) – Path to save the cached file.
• creator – Function to create the file and returns the content. It takes a path to temporary place as the argument. Before calling the creator, there is no file at the temporary path.
• loader – Function to load the cached file and returns the content.

Returns It returns the returned values by the creator or the loader.

3.1.8 Training loop abstraction

Chainer provides a standard implementation of the training loops under the chainer.training module. It is built on top of many other core features of Chainer, including Variable and Function, Link/Chain/ChainList, Optimizer, Dataset, and Reporter/Summary. Compared to the training loop abstraction of other machine learning toolkits, Chainer’s training framework aims at maximal flexibility, while keeps the simplicity for the typical usages. Most components are pluggable, and users can overwrite the definition.

The core of the training loop abstraction is Trainer, which implements the training loop itself. The training loop consists of two parts: one is Updater, which actually updates the parameters to train, and the other is Extension for arbitrary functionalities other than the parameter update.

Updater and some extensions use dataset and Iterator to scan the datasets and load mini batches. The trainer also uses Reporter to collect the observed values, and some extensions use DictSummary to accumulate them and computes the statistics.

You can find many examples for the usage of this training utilities from the official examples. You can also search the extension implementations from Trainer extensions.

Trainer

class chainer.training.Trainer (updater, stop_trigger=None, out='result')
The standard training loop in Chainer.

Trainer is an implementation of a training loop. Users can invoke the training by calling the run() method.

Each iteration of the training loop proceeds as follows.

• Update of the parameters. It includes the mini-batch loading, forward and backward computations, and an execution of the update formula. These are all done by the update object held by the trainer.

• Invocation of trainer extensions in the descending order of their priorities. A trigger object is attached to each extension, and it decides at each iteration whether the extension should be executed. Trigger objects
are callable objects that take the trainer object as the argument and return a boolean value indicating whether the extension should be called or not.

Extensions are callable objects that take the trainer object as the argument. There are two ways to define custom extensions: inheriting the `Extension` class, and decorating functions by `make_extension()`. See `Extension` for more details on custom extensions.

Users can register extensions to the trainer by calling the `extend()` method, where some configurations can be added.

- **Trigger object**, which is also explained above. In most cases, `IntervalTrigger` is used, in which case users can simply specify a tuple of the interval length and its unit, like `(1000, 'iteration')` or `(1, 'epoch')`.

- The order of execution of extensions is determined by their priorities. Extensions of higher priorities are invoked earlier. There are three standard values for the priorities:
  - `PRIORITY_WRITER`: This is the priority for extensions that write some records to the observation dictionary. It includes cases that the extension directly adds values to the observation dictionary, or the extension uses the `chainer.report()` function to report values to the observation dictionary.
  - `PRIORITY_EDITOR`: This is the priority for extensions that edit the observation dictionary based on already reported values.
  - `PRIORITY_READER`: This is the priority for extensions that only read records from the observation dictionary. This is also suitable for extensions that do not use the observation dictionary at all.

- Extensions with `invoke_before_training` flag on are also invoked at the beginning of the training loop. Extensions that update the training status (e.g., changing learning rates) should have this flag to be `True` to ensure that resume of the training loop correctly recovers the training status.

The current state of the trainer object and objects handled by the trainer can be serialized through the standard serialization protocol of Chainer. It enables us to easily suspend and resume the training loop.

**Note:** The serialization does not recover everything of the training loop. It only recovers the states which change over the training (e.g. parameters, optimizer states, the batch iterator state, extension states, etc.). You must initialize the objects correctly before deserializing the states.

On the other hand, it means that users can change the settings on deserialization. For example, the exit condition can be changed on the deserialization, so users can train the model for some iterations, suspend it, and then resume it with larger number of total iterations.

During the training, it also creates a `Reporter` object to store observed values on each update. For each iteration, it creates a fresh observation dictionary and stores it in the `observation` attribute.

Links of the target model of each optimizer are registered to the reporter object as observers, where the name of each observer is constructed as the format `<optimizer name><link name>`. The link name is given by the `chainer.Link.namedlink()` method, which represents the path to each link in the hierarchy. Other observers can be registered by accessing the reporter object via the `reporter` attribute.

The default trainer is `plain`, i.e., it does not contain any extensions.

**Parameters**

- `updater (Updater)` – Updater object. It defines how to update the models.
- `stop_trigger` – Trigger that determines when to stop the training loop. If it is not callable, it is passed to `IntervalTrigger`. 

3.1. Core functionalities
Variables

- **updater** – The updater object for this trainer.
- **stop_trigger** – Trigger that determines when to stop the training loop. The training loop stops at the iteration on which this trigger returns `True`.
- **observation** – Observation of values made at the last update. See the `Reporter` class for details.
- **out** – Output directory.
- **reporter** – Reporter object to report observed values.

**elapsed_time**
Total time used for the training.

The time is in seconds. If the training is resumed from snapshot, it includes the time of all the previous training to get the current state of the trainer.

**extend**(extension, name=None, trigger=None, priority=None, invoke_before_training=None)
Registers an extension to the trainer.

*Extension* is a callable object which is called after each update unless the corresponding trigger object decides to skip the iteration. The order of execution is determined by priorities: extensions with higher priorities are called earlier in each iteration. Extensions with the same priority are invoked in the order of registrations.

If two or more extensions with the same name are registered, suffixes are added to the names of the second to last extensions. The suffix is `_N` where N is the ordinal of the extensions.

See **Extension** for the interface of extensions.

**Parameters**

- **extension** – Extension to register.
- **name** (`str`) – Name of the extension. If it is omitted, the `default_name` attribute of the extension is used instead. Note that the name would be suffixed by an ordinal in case of duplicated names as explained above.
- **trigger** (`tuple` or `Trigger`) – Trigger object that determines when to invoke the extension. If it is `None`, `extension.trigger` is used instead. If the trigger is not callable, it is passed to `IntervalTrigger` to build an interval trigger.
- **priority** (`int`) – Invocation priority of the extension. Extensions are invoked in the descending order of priorities in each iteration. If this is `None`, `extension.priority` is used instead.
- **invoke_before_training** (`bool` or `None`) – If `True`, the extension is also invoked just before entering the training loop. If this is `None`, `extension.invoke_before_training` is used instead. This option is mainly used for extensions that alter the training configuration (e.g., learning rates); in such a case, resuming from snapshots require the call of extension to recover the configuration before any updates.

**get_extension**(name)
Returns the extension of a given name.

**Parameters**

- **name** (`str`) – Name of the extension.

**Returns** Extension.
run()

Executes the training loop.

This method is the core of Trainer. It executes the whole loop of training the models.

Note that this method cannot run multiple times for one trainer object.

### Updater

class chainer.training.Updater

Interface of updater objects for trainers.

TODO(beam2d): document it.

**connect_trainer** *(trainer)*

Connects the updater to the trainer that will call it.

The typical usage of this method is to register additional links to the reporter of the trainer. This method is called at the end of the initialization of Trainer. The default implementation does nothing.

Parameters:

- **trainer** *(Trainer)* – Trainer object to which the updater is registered.

**finalize** *

Finalizes the updater object.

This method is called at the end of training loops. It should finalize each dataset iterator used in this updater.

**get_all_optimizers** *

Gets a dictionary of all optimizers for this updater.

- **Returns** Dictionary that maps names to optimizers.
- **Return type** dict

**get_optimizer** *(name)*

Gets the optimizer of given name.

Updater holds one or more optimizers with names. They can be retrieved by this method.

- **Parameters** name *(str)* – Name of the optimizer.
- **Returns** Optimizer of the name.
- **Return type** Optimizer

**serialize** *(serializer)*

Serializes the current state of the updater object.

**update** *

Updates the parameters of the target model.

This method implements an update formula for the training task, including data loading, forward/backward computations, and actual updates of parameters.

This method is called once at each iteration of the training loop.

**connect_trainer** *(trainer)*

Connects the updater to the trainer that will call it.

The typical usage of this method is to register additional links to the reporter of the trainer. This method is called at the end of the initialization of Trainer. The default implementation does nothing.

Parameters:

- **trainer** *(Trainer)* – Trainer object to which the updater is registered.
batch is converted to input arrays by `concat_examples()` by default, which can also be manually set by `converter` argument.

**Parameters**

- **iterator** – Dataset iterator for the training dataset. It can also be a dictionary of iterators. If this is just an iterator, then the iterator is registered by the name ‘main’.
- **optimizer** – Optimizer to update parameters. It can also be a dictionary of optimizers. If this is just an optimizer, then the optimizer is registered by the name ‘main’.
- **converter** – Converter function to build input arrays. Each batch extracted by the main iterator and the `device` option are passed to this function. `concat_examples()` is used by default.
- **device** – Device to which the training data is sent. Negative value indicates the host memory (CPU).
- **loss_func** – Loss function. The target link of the main optimizer is used by default.

**Variables**

- **converter** – Converter function.
- **loss_func** – Loss function. If it is `None`, the target link of the main optimizer is used instead.
- **device** – Device to which the training data is sent.
- **iteration** – Current number of completed updates.

**get_iterator(name)**

Gets the dataset iterator of given name.

**Parameters**

- **name** (`str`) – Name of the dataset iterator.

**Returns**

Corresponding dataset iterator.

**Return type**

`Iterator`

**class chainer.training.ParallelUpdater(iterator, optimizer, converter=<function concat_examples>, models=None, devices=None, loss_func=None)**

Implementation of a parallel GPU Updater.

This is an implementation of `Updater` that uses multiple GPUs. It behaves similarly to `StandardUpdater`. The update routine is modified to support data-parallel computation on multiple GPUs in one machine. It is based on synchronous parallel SGD: it parallelizes the gradient computation over a mini-batch, and updates the parameters only in the main device.

**Parameters**

- **iterator** – Dataset iterator for the training dataset. It can also be a dictionary of iterators. If this is just an iterator, then the iterator is registered by the name ‘main’.
- **optimizer** – Optimizer to update parameters. It can also be a dictionary of optimizers. If this is just an optimizer, then the optimizer is registered by the name ‘main’.
- **converter** – Converter function to build input arrays. Each batch extracted by the main iterator is split equally between the devices and then passed with corresponding `device` option to this function. `concat_examples()` is used by default.
- **models** – Dictionary of models. The main model should be the same model attached to the ‘main’ optimizer.
• **devices** – Dictionary of devices to which the training data is sent. The devices should be arranged in a dictionary with the same structure as `models`.

• **loss_func** – Loss function. The model is used as a loss function by default.

**Extension**

class chainer.training.Extension
Base class of trainer extensions.

Extension of Trainer is a callable object that takes the trainer object as the argument. It also provides some default configurations as its attributes, e.g. the default trigger and the default priority. This class provides a set of typical default values for these attributes.

There are two ways to define users’ own extensions: inheriting this class, or decorating closures by `make_extension()`. Decorator can slightly reduce the overhead and is much easier to use, while this class provides more flexibility (for example, it can have methods to configure the behavior).

**Variables**

• **trigger** – Default value of trigger for this extension. It is set to `(1, 'iteration')` by default.

• **priority** – Default priority of the extension. It is set to `PRIORITY_READER` by default.

• **invoke_before_training** – Default flag to decide whether this extension should be invoked before the training starts. The default value is `False`.

__call__(trainer)
Invokes the extension.

Implementations should override this operator. This method is called at iterations which the corresponding trigger accepts.

**Parameters**

trainer (Trainer) – Trainer object that calls this operator.

default_name
Default name of the extension.

It is the name of the class by default. Implementation can override this property, or provide a class attribute to hide it.

finalize()
Finalizes the extension.

This method is called at the end of the training loop.

serialize(serializer)
Serializes the extension state.

It is called when a trainer that owns this extension is serialized. It serializes nothing by default.

chainer.training.make_extension(trigger=None, default_name=None, priority=None, invoke_before_training=False, finalizer=None)
Decorator to make given functions into trainer extensions.

This decorator just adds some attributes to a given function. The value of the attributes are given by the arguments of this decorator.

See Extension for details of trainer extensions. Most of the default values of arguments also follow those for this class.

**Parameters**
• **trigger** – Default trigger of the extension.

• **default_name** – Default name of the extension. The name of a given function is used by default.

• **priority** (*int*) – Default priority of the extension.

• **invoke_before_training** (*bool*) – Default flag to decide whether the extension should be invoked before any training.

• **finalizer** – Finalizer function of this extension. The finalizer is called at the end of the training loop.

### Trigger

Trigger is a callable object to decide when to process some specific event within the training loop. It takes a Trainer object as the argument, and returns True if some event should be fired.

It is mainly used to determine when to call an extension. It is also used to determine when to quit the training loop.

**chainer.training.get_trigger**(trigger)

Gets a trigger object.

Trigger object is a callable that accepts a Trainer object as an argument and returns a boolean value. When it returns True, various kinds of events can occur depending on the context in which the trigger is used. For example, if the trigger is passed to the Trainer as the stop trigger, the training loop breaks when the trigger returns True. If the trigger is passed to the extend() method of a trainer, then the registered extension is invoked only when the trigger returns True.

This function returns a trigger object based on the argument. If trigger is already a callable, it just returns the trigger. If trigger is None, it returns a trigger that never fires. Otherwise, it passes the value to IntervalTrigger.

**Parameters**

- **trigger** – Trigger object. It can be either an already built trigger object (i.e., a callable object that accepts a trainer object and returns a bool value), or a tuple. In latter case, the tuple is passed to IntervalTrigger.

**Returns**

- trigger if it is a callable, otherwise a IntervalTrigger object made from trigger.

### 3.1.9 Debug mode

In debug mode, Chainer checks values of variables on runtime and shows more detailed error messages. It helps you to debug your programs. Instead it requires additional overhead time.

In debug mode, Chainer checks all results of forward and backward computation, and if it founds a NaN value, it raises RuntimeError. Some functions and links also check validity of input values.

**chainer.is_debug**()

Get the debug mode.

**Returns**

- Return True if Chainer is in debug mode.

**Return type**

- **bool**

**chainer.set_debug**(debug)

Set the debug mode.
Note: This method changes global state. When you use this method on multi-threading environment, it may affects other threads.

Parameters debug (bool) – New debug mode.

class chainer.DebugMode (debug)

Debug mode context.

This class provides a context manager for debug mode. When entering the context, it sets the debug mode to the value of debug parameter with memorizing its original value. When exiting the context, it sets the debug mode back to the original value.

Parameters debug (bool) – Debug mode used in the context.

3.1.10 FunctionSet (deprecated)

class chainer.FunctionSet (**links)

Set of links (as “parameterized functions”).

FunctionSet is a subclass of Chain. Function registration is done just by adding an attribute to object.

Deprecated since version v1.5: Use Chain instead.

Note: FunctionSet was used for manipulation of one or more parameterized functions. The concept of parameterized function is gone, and it has been replaced by Link and Chain.

__getitem__(key)

Returns an attribute by name.

Parameters key (str) – Name of the attribute.

Returns Attribute.

Example

```python
>>> model = chainer.FunctionSet(l1=L.Linear(10, 10), ... 12=L.Linear(10, 10))

>>> ll = model['ll']  # equivalent to ll = model.ll
```

collect_parameters ()

Returns a tuple of parameters and gradients.

Returns Tuple (pair) of two tuples. The first element is a tuple of parameter arrays, and the second is a tuple of gradient arrays.

copy_parameters_from (params)

Copies parameters from another source without reallocation.

Parameters params (Iterable) – Iterable of parameter arrays.

gradients

Tupel of gradient arrays of all registered functions.

The order of gradients is consistent with parameters() property.
parameters
Tuples of parameter arrays of all registered functions.
The order of parameters is consistent with parameters() property.

3.2 Utilities

3.2.1 CUDA utilities

Device, context and memory management on CuPy.

Chainer uses CuPy (with very thin wrapper) to exploit the speed of GPU computation. Following modules and classes are imported to cuda module for convenience (refer to this table when reading chainer’s source codes).

<table>
<thead>
<tr>
<th>imported name</th>
<th>original name</th>
</tr>
</thead>
<tbody>
<tr>
<td>chainer.cuda.cupy</td>
<td>cupy</td>
</tr>
<tr>
<td>chainer.cuda.ndarray</td>
<td>cupy.ndarray</td>
</tr>
<tr>
<td>chainer.cuda.cupy.cuda</td>
<td>cupy.cuda</td>
</tr>
<tr>
<td>chainer.cuda.Device</td>
<td>cupy.cuda.Device</td>
</tr>
<tr>
<td>chainer.cuda.Event</td>
<td>cupy.cuda.Event</td>
</tr>
<tr>
<td>chainer.cuda.Stream</td>
<td>cupy.cuda.Stream</td>
</tr>
</tbody>
</table>

Chainer replaces the default allocator of CuPy by its memory pool implementation. It enables us to reuse the device memory over multiple forward/backward computations, and temporary arrays for consecutive elementwise operations.

Devices

chainer.cuda.get_device(*args)
gets the device from a device object, an ID integer or an array object.

This is a convenient utility to select a correct device if the type of arg is unknown (i.e., one can use this function on arrays that may be on CPU or GPU). The returned device object supports the context management protocol of Python for the with statement.

Parameters args – Values to specify a GPU device. The first device object, integer or cupy.ndarray object is used to select a device. If it is a device object, it is returned. If it is an integer, the corresponding device is returned. If it is a CuPy array, the device on which this array reside is returned. If any arguments are neither integers nor CuPy arrays, a dummy device object representing CPU is returned.

Returns Device object specified by given args.

See also:
See cupy.cuda.Device for the device selection not by arrays.

CuPy array allocation and copy

Note: As of v1.3.0, the following array construction wrappers are marked as deprecated. Use the corresponding functions of the cupy module instead. The main difference of them is that the default dtype is changed from float32 to float64.
### Deprecated functions

<table>
<thead>
<tr>
<th>Deprecated functions</th>
<th>Recommended functions</th>
</tr>
</thead>
<tbody>
<tr>
<td>chainer.cuda.empty</td>
<td>cupy.empty()</td>
</tr>
<tr>
<td>chainer.cuda.empty_like</td>
<td>cupy.empty_like()</td>
</tr>
<tr>
<td>chainer.cuda.zeros</td>
<td>cupy.zeros()</td>
</tr>
<tr>
<td>chainer.cuda.zeros_like</td>
<td>cupy.zeros_like()</td>
</tr>
<tr>
<td>chainer.cuda.ones</td>
<td>cupy.ones()</td>
</tr>
<tr>
<td>chainer.cuda.ones_like</td>
<td>cupy.ones_like()</td>
</tr>
<tr>
<td>chainer.cuda.full</td>
<td>cupy.full()</td>
</tr>
<tr>
<td>chainer.cuda.full_like</td>
<td>cupy.full_like()</td>
</tr>
</tbody>
</table>

---

**chainer.cuda.copy** *(array, out=None, out_device=None, stream=None)*

Copies a `cupy.ndarray` object using the default stream.

This function can copy the device array to the destination array on another device.

**Parameters**

- **array** (`cupy.ndarray`) – Array to be copied.
- **out** (`cupy.ndarray`) – Destination array. If it is not `None`, then `out_device` argument is ignored.
- **out_device** – Destination device specifier. Actual device object is obtained by passing this value to `get_device()`.
- **stream** (`cupy.cuda.Stream`) – CUDA stream.

**Returns**

Copied array.

If `out` is not specified, then the array is allocated on the device specified by `out_device` argument.

**Return type** `cupy.ndarray`

**chainer.cuda.to_cpu** *(array, stream=None)*

Copies the given GPU array to host CPU.

**Parameters**

- **array** – Array to be sent to CPU.
- **stream** (`cupy.cuda.Stream`) – CUDA stream.

**Returns**

Array on CPU.

If given `array` is already on CPU, then this function just returns `array` without performing any copy.

**Return type** `numpy.ndarray`

**chainer.cuda.to_gpu** *(array, device=None, stream=None)*

Copies the given CPU array to specified device.

**Parameters**

- **array** – Array to be sent to GPU.
- **device** – Device specifier.
- **stream** (`cupy.cuda.Stream`) – CUDA stream. If not `None`, the copy runs asynchronously.
Returns
Array on GPU.
If array is already on GPU, then this function just returns array without performing any copy. Note that this function does not copy cupy.ndarray into specified device.

Return type cupy.ndarray

Kernel definition utilities
chainer.cuda.memoize(for_each_device=False)
Makes a function memoizing the result for each argument and device.
This is a similar version of cupy.memoize(). The difference is that this function can be used in the global scope even if CUDA is not available. In such case, this function does nothing.

Note: This decorator acts as a dummy if CUDA is not available. It cannot be used for general purpose memoization even if for_each_device is set to False.

chainer.cuda.clear_memo()
Clears the memoized results for all functions decorated by memoize.
This function works like cupy.clear_memo() as a counterpart for chainer.cuda.memoize(). It can be used even if CUDA is not available. In such a case, this function does nothing.

chainer.cuda.elementwise()
Creates an elementwise kernel function.
This function uses memoize() to cache the kernel object, i.e. the resulting kernel object is cached for each argument combination and CUDA device.
The arguments are the same as those for cupy.ElementwiseKernel, except that the name argument is mandatory.

chainer.cuda.reduce()
Creates a global reduction kernel function.
This function uses memoize() to cache the resulting kernel object, i.e. the resulting kernel object is cached for each argument combination and CUDA device.
The arguments are the same as those for cupy.ReductionKernel, except that the name argument is mandatory.

CPU/GPU generic code support
chainer.cuda.get_array_module(*args)
Gets an appropriate one from numpy or cupy.
This is almost equivalent to cupy.get_array_module(). The only difference is that this function can be used even if CUDA is not available.

Parameters args – Values to determine whether NumPy or CuPy should be used.
Returns cupy or numpy is returned based on the types of the arguments.
Return type module
cuDNN support

`chainer.cuda.set_max_workspace_size(size)`
Sets the workspace size for cuDNN.

Check “cuDNN Library User Guide” for detail.

**Parameters**
- `size` – The workspace size for cuDNN.

`chainer.cuda.get_max_workspace_size()`
Gets the workspace size for cuDNN.

Check “cuDNN Library User Guide” for detail.

**Returns**
The workspace size for cuDNN.

**Return type** `int`

3.2.2 Common algorithms

```ipython
class chainer.utils.WalkerAlias(probs)
    Implementation of Walker’s alias method.
    This method generates a random sample from given probabilities \( p_1, \ldots, p_n \) in \( O(1) \) time. It is more efficient than `choice()`.
    This class works on both CPU and GPU.

    **Parameters**
    - `probs` (`float list`) – Probabilities of entries. They are normalized with \( \sum(probs) \).

    See: Wikipedia article

    `sample(shape)`
    Generates a random sample based on given probabilities.

    **Parameters**
    - `shape` (`tuple of int`) – Shape of a return value.

    **Returns**
    Returns a generated array with the given shape. If a sampler is in CPU mode the return value is a `numpy.ndarray` object, and if it is in GPU mode the return value is a `cupy.ndarray` object.

    `to_gpu()`
    Make a sampler GPU mode.
```

3.2.3 Reporter

**Reporter**

`class chainer.Reporter`
Object to which observed values are reported.

Reporter is used to collect values that users want to watch. The reporter object holds a mapping from value names to the actually observed values. We call this mapping `observations`.

When a value is passed to the reporter, an object called `observer` can be optionally attached. In this case, the name of the observer is added as the prefix of the value name. The observer name should be registered beforehand.

See the following example:
```python
>>> from chainer import Reporter, report, report_scope

>>> reporter = Reporter()

>>> observer = object()  # it can be an arbitrary (reference) object

>>> reporter.add_observer('my_observer:', observer)

>>> observation = {}

>>> with reporter.scope(observation):
...    reporter.report({'x': 1}, observer)
...    ...

>>> observation
{'my_observer:x': 1}
```

There are also a global API to add values:

```python
>>> observation = {}

>>> with report_scope(observation):
...    report({'x': 1}, observer)
...    ...

>>> observation
{'my_observer:x': 1}
```

The most important application of `Reporter` is to report observed values from each link or chain in the training and validation procedures. `Trainer` and some extensions prepare their own `Reporter` object with the hierarchy of the target link registered as observers. We can use `report()` function inside any links and chains to report the observed values (e.g., training loss, accuracy, activation statistics, etc.).

**Variables**

- **observation** — Dictionary of observed values.

**__enter__**

- Makes this reporter object current.

**__exit__** *(exc_type, exc_value, traceback)*

- Recovers the previous reporter object to the current.

**add_observer**(name, observer)

- Registers an observer of values.

Observer defines a scope of names for observed values. Values observed with the observer are registered with names prefixed by the observer name.

**Parameters**

- **name** *(str)* — Name of the observer.

- **observer** — The observer object. Note that the reporter distinguishes the observers by their object ids (i.e., `id(owner)`), rather than the object equality.

**add_observers**(prefix, observers)

- Registers multiple observers at once.

This is a convenient method to register multiple objects at once.

**Parameters**

- **prefix** *(str)* — Prefix of each name of observers.

- **observers** — Iterator of name and observer pairs.

**report**(values, observer=None)

- Reports observed values.

The values are written with the key, prefixed by the name of the observer object if given.

**Parameters**

- **values** — Values to report.

- **observer** *(optional)* — Observer object.
• **values** (*dict*) – Dictionary of observed values.

• **observer** – Observer object. Its object ID is used to retrieve the observer name, which is used as the prefix of the registration name of the observed value.

**scope** (*args*, **kwds*)

Creates a scope to report observed values to observation.

This is a context manager to be passed to `with` statements. In this scope, the observation dictionary is changed to the given one.

It also makes this reporter object current.

**Parameters**

- **observation** (*dict*) – Observation dictionary. All observations reported inside the `with` statement are written to this dictionary.

**chainer.get_current_reporter**()

Returns the current reporter object.

**chainer.report** (*values*, **observer=None**)

Reports observed values with the current reporter object.

Any reporter object can be set current by the `with` statement. This function calls the `Report.report()` method of the current reporter. If no reporter object is current, this function does nothing.

### Example

The most typical example is a use within links and chains. Suppose that a link is registered to the current reporter as an observer (for example, the target link of the optimizer is automatically registered to the reporter of the `Trainer`). We can report some values from the link as follows:

```python
class MyRegressor(chainer.Chain):
    def __init__(self, predictor):
        super(MyRegressor, self).__init__(predictor=predictor)

    def __call__(self, x, y):
        # This chain just computes the mean absolute and squared errors between the prediction and y.
        pred = self.predictor(x)
        abs_error = F.sum(F.abs(pred - y)) / len(x.data)
        loss = F.mean_squared_error(pred, y)

        # Report the mean absolute and squared errors.
        report({'abs_error': abs_error, 'squared_error': loss}, self)

        return loss
```

If the link is named ‘main’ in the hierarchy (which is the default name of the target link in the `StandardUpdater`), these reported values are named ‘main/abs_error’ and ‘main/squared_error’. If these values are reported inside the `Evaluator` extension, ‘validation/’ is added at the head of the link name, thus the item names are changed to ‘validation/main/abs_error’ and ‘validation/main/squared_error’ (‘validation’ is the default name of the `Evaluator` extension).

**Parameters**

- **values** (*dict*) – Dictionary of observed values.

- **observer** – Observer object. Its object ID is used to retrieve the observer name, which is used as the prefix of the registration name of the observed value.
chainer.report_scope(*args, **kwds)
    Returns a report scope with the current reporter.

    This is equivalent to get_current_reporter().scope(observation), except that it does not make
    the reporter current redundantly.

Summary and DictSummary

class chainer.Summary
    Online summarization of a sequence of scalars.

    Summary computes the statistics of given scalars online.

    add(value)
        Adds a scalar value.

        Parameters value – Scalar value to accumulate. It is either a NumPy scalar or a zero-
        dimensional array (on CPU or GPU).

    compute_mean()
        Computes the mean.

    make_statistics()
        Computes and returns the mean and standard deviation values.

        Returns Mean and standard deviation values.

        Return type tuple

class chainer.DictSummary
    Online summarization of a sequence of dictionaries.

    DictSummary computes the statistics of a given set of scalars online. It only computes the statistics for scalar
    values and variables of scalar values in the dictionaries.

    add(d)
        Adds a dictionary of scalars.

        Parameters d (dict) – Dictionary of scalars to accumulate. Only elements of scalars, zero-
        dimensional arrays, and variables of zero-dimensional arrays are accumulated.

    compute_mean()
        Creates a dictionary of mean values.

        It returns a single dictionary that holds a mean value for each entry added to the summary.

        Returns Dictionary of mean values.

        Return type dict

    make_statistics()
        Creates a dictionary of statistics.

        It returns a single dictionary that holds mean and standard deviation values for every entry added to the
        summary. For an entry of name ‘key’, these values are added to the dictionary by names ‘key’ and
        ‘key.std’, respectively.

        Returns Dictionary of statistics of all entries.

        Return type dict
3.3 Assertion and Testing

Chainer provides some facilities to make debugging easy.

3.3.1 Type checking utilities

*Function* uses a systematic type checking of the `chainer.utils.type_check` module. It enables users to easily find bugs of forward and backward implementations. You can find examples of type checking in some function implementations.

```python
class chainer.utils.type_check.Expr(priority)
    Abstract syntax tree of an expression.
```

It represents an abstract syntax tree, and isn’t a value. You can get its actual value with `eval()` function, and get syntax representation with the `__str__()` method. Each comparison operator (e.g. `==`) generates a new `Expr` object which represents the result of comparison between two expressions.

**Example**

Let `x` and `y` be instances of `Expr`, then

```python
>>> x = Variable(1, 'x')
>>> y = Variable(1, 'y')
>>> c = (x == y)
```

is also an instance of `Expr`. To evaluate and get its value, call `eval()` method:

```python
>>> c.eval()
True
```

Call `str` function to get a representation of the original equation:

```python
>>> str(c)
'x == y'
```

You can actually compare an expression with a value:

```python
>>> (x == 1).eval()
True
```

Note that you can’t use boolean operators such as `and`, as they try to cast expressions to boolean values:

```python
>>> z = Variable(1, 'z')
>>> x == y and y == z  # raises an error
Traceback (most recent call last):
    RuntimeError: Don’t convert Expr to bool. Please call Expr.eval method to evaluate expression.
```

**eval()**

Evaluates the tree to get actual value.

Behavior of this function depends on an implementation class. For example, a binary operator `+` calls the `__add__` function with the two results of `eval()` function.

**chainer.utils.type_check.expect(*bool_exprs)**

Evaluates and tests all given expressions.

This function evaluates given boolean expressions in order. When at least one expression is evaluated as `False`, that means the given condition is not satisfied. You can check conditions with this function.
Parameters **bool_exprs** *(tuple of Bool expressions)* – Bool expressions you want to evaluate.

**class** `chainer.utils.type_check.TypeInfo(shape, dtype)`

Type information of an input/gradient array.

It contains type information of an array, such as the shape of array and the number of dimensions. This information is independent of CPU or GPU array.

**class** `chainer.utils.type_check.TypeInfoTuple`

Type information of input/gradient tuples.

It is a sub-class of tuple containing `TypeInfo`. The i-th element of this object contains type information of the i-th input/gradient data. As each element is `Expr`, you can easily check its validity.

**size()**

Returns an expression representing its length.

Returns An expression object representing length of the tuple.

Return type `Expr`

### 3.3.2 Gradient checking utilities

Most function implementations are numerically tested by *gradient checking*. This method computes numerical gradients of forward routines and compares their results with the corresponding backward routines. It enables us to make the source of issues clear when we hit an error of gradient computations. The `chainer.gradient_check` module makes it easy to implement the gradient checking.

`chainer.gradient_check.check_backward(func, x_data, y_grad, params=(), eps=0.001, atol=1e-05, rtol=0.0001, no_grads=None, dtype=None)`

Test backward procedure of a given function.

This function automatically check backward-process of given function. For example, when you have a `Function` class `MyFunc`, that gets two arguments and returns one value, you can make its test like this:

```python
>>> def test_my_func(self):
...     func = MyFunc()
...     x1_data = xp.array(...)  
...     x2_data = xp.array(...)  
...     gy_data = xp.array(...)  
...     check_backward(func, (x1_data, x2_data), gy_data)
```

This method creates `Variable` objects with `x_data` and calls `func` with the `Variable`s to get its result as `Variable`. Then, it sets `y_grad` array to `grad` attribute of the result and calls `backward` method to get gradients of the inputs. To check correctness of the gradients, the function calls `numerical_grad()` to calculate numerically the gradients and compares the types of gradients with `chainer.testing.assert_allclose()`. If input objects (`x1_data` or/and `x2_data` in this example) represent integer variables, their gradients are ignored.

You can simplify a test when `MyFunc` gets only one argument:

```python
>>> check_backward(func, x1_data, gy_data)
```

If `MyFunc` is a loss function which returns a zero-dimensional array, pass `None` to `gy_data`. In this case, it sets 1 to `grad` attribute of the result:

```python
>>> check_backward(my_loss_func, (x1_data, x2_data), None)
```

If `MyFunc` returns multiple outputs, pass all gradients for outputs as a tuple:
You can also test a Link. To check gradients of parameters of the link, set a tuple of the parameters to `params` arguments:

```python
>> check_backward(my_link, (x1_data, x2_data), gy_data,
   (my_link.W, my_link.b))
```

Note that `params` are not `ndarray`s, but `Variables`s.

Function objects are acceptable as `func` argument:

```python
>> check_backward(lambda x1, x2: f(x1, x2),
   (x1_data, x2_data), gy_data)
```

Note: `func` is called many times to get numerical gradients for all inputs. This function doesn’t work correctly when `func` behaves randomly as it gets different gradients.

### Parameters

- **func** (*callable*) – A function which gets `Variables` and returns `Variables`. `func` must returns a tuple of `Variables` or one `Variable`. You can use `Function` object, `Link` object or a function satisfying the condition.

- **x_data** (*ndarray or tuple of ndarrays*) – A set of `ndarray`s to be passed to `func`. If `x_data` is one `ndarray` object, it is treated as `(x_data,)`.

- **y_grad** (*ndarray or tuple of ndarrays or None*) – A set of `ndarray`s representing gradients of return-values of `func`. If `y_grad` is one `ndarray` object, it is treated as `(y_grad,)`. If `func` is a loss-function, `y_grad` should be set to `None`.

- **params** (*Variable*) – A set of `Variable`s whose gradients are checked. When `func` is a `Link` object, set its parameters as `params`. If `params` is one `Variable` object, it is treated as `(params,)`.

- **eps** (*float*) – Epsilon value to be passed to `numerical_grad()`.

- **atol** (*float*) – Absolute tolerance to be passed to `chainer.testing.assert_allclose()`.

- **rtol** (*float*) – Relative tolerance to be passed to `chainer.testing.assert_allclose()`.

- **no_grads** (*list of bool*) – Flag to skip variable for gradient assertion. It should be same length as `x_data`.

- **dtype** (*dtype*) – `x_data` and `y_grad` are casted to this `dtype` when calculating numerical gradients. Only float types and `None` are allowed.

See: `numerical_grad()`

```python
chainer.gradient_check.numerical_grad(f, inputs, grad_outputs, eps=0.001)
```

Computes numerical gradient by finite differences.

This function is used to implement gradient check. For usage example, see unit tests of `chainer.functions`. 3.3. Assertion and Testing
Parameters

- \( f(\text{function}) \) – Python function with no arguments that runs forward computation and returns the result.
- **inputs** *(tuple of arrays)* – Tuple of arrays that should be treated as inputs. Each element of them is slightly modified to realize numerical gradient by finite differences.
- **grad_outputs** *(tuple of arrays)* – Tuple of arrays that are treated as output gradients.
- **eps** *(float)* – Epsilon value of finite differences.

Returns Numerical gradient arrays corresponding to inputs.

Return type tuple

### 3.3.3 Standard Assertions

The assertions have same names as NumPy’s ones. The difference from NumPy is that they can accept both `numpy.ndarray` and `cupy.ndarray`.

```python
chainer.testing.assert_allclose(x, y, atol=1e-05, rtol=0.0001, verbose=True)
```

Asserts if some corresponding element of \( x \) and \( y \) differs too much.

This function can handle both CPU and GPU arrays simultaneously.

Parameters

- **x** – Left-hand-side array.
- **y** – Right-hand-side array.
- **atol** *(float)* – Absolute tolerance.
- **rtol** *(float)* – Relative tolerance.
- **verbose** *(bool)* – If True, it outputs verbose messages on error.

### 3.3.4 Function testing utilities

Chainer provides some utilities for testing its functions.

```python
chainer.testing.unary_math_function_unittest(func, func_expected=None, label_expected=None, make_data=None)
```

Decorator for testing unary mathematical Chainer functions.

This decorator makes test classes test unary mathematical Chainer functions. Tested are forward and backward computations on CPU and GPU across parameterized `shape` and `dtype`.

Parameters

- **func** *(Function)* – Chainer function to be tested by the decorated test class.
- **func_expected** – Function used to provide expected values for testing forward computation. If not given, a corresponding numpy function for `func` is implicitly picked up by its class name.
- **label_expected** *(string)* – String used to test labels of Chainer functions. If not given, the class name of `func` lowered is implicitly used.
• **make_data** – Function to customize input and gradient data used in the tests. It takes `shape` and `dtype` as its arguments, and returns a tuple of input and gradient data. By default, uniform distribution ranged \([-1, 1]\) is used for both.

The decorated test class tests forward and backward computations on CPU and GPU across the following `parameterize()` ed parameters:

- \textbf{shape}: rank of zero, and rank of more than zero
- \textbf{dtype}: `numpy.float16`, `numpy.float32`, and `numpy.float64`

Additionally, it tests the label of the Chainer function.

Chainer functions tested by the test class decorated with the decorator should have the following properties:

- \textbf{Unary}, taking one parameter and returning one value
- \textbf{dtype} of input and output are the same
- \textbf{Elementwise} operation for the supplied `ndarray`

**Example**

The following code defines a test class that tests \texttt{sin()} Chainer function, which takes a parameter with `dtype` of float and returns a value with the same `dtype`.

```python
>>> import unittest
>>> from chainer import testing
>>> from chainer import functions as F

>>> @testing.unary_math_function_unittest(F.Sin())
... class TestSin(unittest.TestCase):
...     pass
```

Because the test methods are implicitly injected to `TestSin` class by the decorator, it is enough to place `pass` in the class definition.

Now the test is run with `nose` module.

```python
>>> import nose
>>> nose.run(
...     defaultTest=__name__, argv=['', '-a', '!gpu'], exit=False)
True
```

To customize test data, `make_data` optional parameter can be used. The following is an example of testing \texttt{sqrt} Chainer function, which is tested in positive value domain here instead of the default input.

```python
>>> import numpy

>>> def make_data(shape, dtype):
...     x = numpy.random.uniform(0.1, 1, shape).astype(dtype)
...     gy = numpy.random.uniform(-1, 1, shape).astype(dtype)
...     return x, gy

>>> @testing.unary_math_function_unittest(F.Sqrt(), make_data=make_data)
... class TestSqrt(unittest.TestCase):
...     pass

>>> nose.run(
...     defaultTest=__name__, argv=['', '-a', '!gpu'], exit=False)
True
```
make_data function which returns input and gradient data generated in proper value domains with given shape and dtype parameters is defined, then passed to the decorator's make_data parameter.

### 3.4 Standard Function implementations

Chainer provides basic Function implementations in the chainer.functions package. Most of them are wrapped by plain Python functions, which users should use.

**Note:** As of v1.5, the concept of parameterized functions are gone, and they are replaced by corresponding Link implementations. They are still put in the functions namespace for backward compatibility, though it is strongly recommended to use them via the chainer.links package.

#### 3.4.1 Activation functions

**clipped_relu**

chainer.functions.clipped_relu(x, z=20.0)

Clipped Rectifier Unit function.

This function is expressed as \( ClippedReLU(x, z) = \min(\max(0, x), z) \), where \( z(> 0) \) is a clipping value.

**Parameters**

- \( x \) (Variable) – Input variable.
- \( z \) (float) – Clipping value. (default = 20.0)

**Returns** Output variable.

**Return type** Variable

**crelu**

chainer.functions.crelu(x, axis=1)

Concatenated Rectified Linear Unit function.

This function is expressed as \( f(x) = (\max(0, x), \max(0, -x)) \), where two output values are concatenated along an axis.

See: http://arxiv.org/abs/1603.05201

**Parameters**

- \( x \) (Variable) – Input variable.
- \( axis \) (int) – Axis that the output values are concatenated along

**Returns** Output variable.

**Return type** Variable
elu

\texttt{chainer.functions.elu(x, alpha=1.0)}

Exponential Linear Unit function.

This function is expressed as

\[ f(x) = \begin{cases} 
  x & \text{if } x \geq 0 \\
  \alpha(\exp(x) - 1) & \text{if } x < 0,
\end{cases} \]

where \( \alpha \) is a parameter. See: \url{http://arxiv.org/abs/1511.07289}

- **Parameters**
  - \texttt{x (Variable)} – Input variable.
  - \texttt{alpha (float)} – Parameter \( \alpha \).

- **Returns** Output variable.

- **Return type** \texttt{Variable}

hard_sigmoid

\texttt{chainer.functions.hard_sigmoid(x)}

Elementwise hard-sigmoid function.

This function is defined as

\[ f(x) = \begin{cases} 
  0 & \text{if } x < -0.25 \\
  0.2x + 0.5 & \text{if } -0.25 < x < 0.25 \\
  1 & \text{if } 0.25 < x.
\end{cases} \]

- **Parameters** \texttt{x (Variable)} – Input variable.

- **Returns** Output variable.

- **Return type** \texttt{Variable}

leaky_relu

\texttt{chainer.functions.leaky_relu(x, slope=0.2)}

Leaky Rectified Linear Unit function.

This function is expressed as \( f(x) = \max(x, ax) \), where \( a \) is a configurable slope value.

- **Parameters**
  - \texttt{x (Variable)} – Input variable.
  - \texttt{slope (float)} – Slope value \( a \).

- **Returns** Output variable.

- **Return type** \texttt{Variable}
log_softmax

chainer.functions.log_softmax(x, use_cudnn=True)

Channelwise log-softmax function.

This function computes its logarithm of softmax along the second axis. Let \( i = (i_1, i_2, \ldots, i_d)^T \) be the \( d \)-dimensional index array and \( x = f(i) \) be the corresponding \( d \)-dimensional input array. For each index \( i \) of the input array \( f(i) \), it computes the logarithm of the probability \( \log p(x) \) defined as

\[
p(i) = \frac{\exp(f(i))}{\sum_{i'} \exp(f(i'))},
\]

where \( i' = (i_1, i'_2, \ldots, i_d) \).

\[
p(x) = \frac{\exp(f(x))}{\sum_{x'} \exp(f(x'))}.
\]

This method is theoretically equivalent to \( \log(\text{softmax}(x)) \) but is more stable.

**Note:** \( \log(\text{softmax}(x)) \) may cause underflow when \( x \) is too small, because \( \text{softmax}(x) \) may return 0. \( \log\text{softmax} \) method is more stable.

**Parameters**

- \( x \) (Variable) – Input variable.
- \( \text{use}_\text{cudnn} \) (bool) – If True, cuDNN is enabled and cuDNN ver. 3 or later is used, then this function uses cuDNN as the core implementation.

**Returns** Output variable.

**Return type** Variable

**See also:** softmax()

lstm

chainer.functions.lstm(c_prev, x)

Long Short-Term Memory units as an activation function.

This function implements LSTM units with forget gates. Let the previous cell state \( c_{\text{prev}} \) and the incoming signal \( x \).

First, the incoming signal \( x \) is split into four arrays \( a, i, f, o \) of the same shapes along the second axis. It means that \( x \) ’s second axis must have 4 times the length of \( c_{\text{prev}} \).

The split input signals are corresponding to:

- \( a \) : sources of cell input
- \( i \) : sources of input gate
- \( f \) : sources of forget gate
- \( o \) : sources of output gate
Second, it computes outputs as:

\[ c = \tanh(a)\text{sigmoid}(i) + c_{\text{prev}}\text{sigmoid}(f), \]
\[ h = \tanh(c)\text{sigmoid}(o). \]

These are returned as a tuple of two variables.

This function supports variable length inputs. The mini-batch size of the current input must be equal to or smaller than that of the previous one. When mini-batch size of \( x \) is smaller than that of \( c \), this function only updates \( c[0:|x|] \) and doesn’t change the rest of \( c, c[|x|:] \). So, please sort input sequences in descending order of lengths before applying the function.

**Parameters**

- **c_prev** (Variable) – Variable that holds the previous cell state. The cell state should be a zero array or the output of the previous call of LSTM.

- **x** (Variable) – Variable that holds the incoming signal. It must have the second dimension four times of that of the cell state,

**Returns** Two Variable objects \( c \) and \( h \). \( c \) is the updated cell state. \( h \) indicates the outgoing signal.

**Return type** tuple

See the original paper proposing LSTM with forget gates: Long Short-Term Memory in Recurrent Neural Networks.

**Example**

Assuming \( y \) is the current input signal, \( c \) is the previous cell state, and \( h \) is the previous output signal from an lstm function. Each of \( y, c \) and \( h \) has \( n \_\text{units} \) channels. Most typical preparation of \( x \) is:

```python
>>> n_units = 100
>>> y = chainer.Variable(np.zeros((1, n_units), 'f'))
>>> h = chainer.Variable(np.zeros((1, n_units), 'f'))
>>> c = chainer.Variable(np.zeros((1, n_units), 'f'))
>>> model = chainer.Chain(w=F.Linear(n_units, 4 * n_units),
...                         v=F.Linear(n_units, 4 * n_units),)
>>> x = model.w(y) + model.v(h)
>>> c, h = F.lstm(c, x)
```

It corresponds to calculate the input sources \( a, i, f, o \) from the current input \( y \) and the previous output \( h \). Different parameters are used for different kind of input sources.

**maxout**

chainer.functions.maxout \( (x, \text{pool}_{-}\text{size}, \text{axis}=1) \)

Maxout activation function.

It accepts an input tensor \( x \), reshapes the \( \text{axis} \) dimension (say the size being \( M \times \text{pool}_{-}\text{size} \)) into two dimensions \( (M, \text{pool}_{-}\text{size}) \), and takes maximum along the \( \text{axis} \) dimension. The output of this function is same as \( x \) except that \( \text{axis} \) dimension is transformed from \( M \times \text{pool}_{-}\text{size} \) to \( M \).

Typically, \( x \) is the output of a linear layer or a convolution layer. The following is the example where we use maxout () in combination with a Linear link.
>>> in_size, out_size, pool_size = 100, 100, 100
>>> l = L.Linear(in_size, out_size * pool_size)
>>> x = chainer.Variable(np.zeros((1, in_size), 'f'))  # prepare data
>>> x = l(x)
>>> y = F.maxout(x, pool_size)

**Parameters**  
`x` *(Variable)* – Input variable. Its first dimension is assumed to be the *minibatch dimension*. The other dimensions are treated as one concatenated dimension.

**Returns**  
Output variable.

**Return type**  
`Variable`

---

**prelu**

`chainer.functions.prelu(x, W)`  
Parametric ReLU function.

It accepts two arguments: an input `x` and a weight array `W` and computes the output as $PReLU(x) = \max(x, W \ast x)$, where $\ast$ is an elementwise multiplication for each sample in the batch.

When the PReLU function is combined with two-dimensional convolution, the elements of parameter $a$ are typically shared across the same filter of different pixels. In order to support such usage, this function supports the shape of parameter array that indicates leading dimensions of input arrays except the batch dimension.

For example, $W$ has the shape of $(2, 3, 4)$, $x$ must have the shape of $(B, 2, 3, 4, S1, ..., SN)$ where $B$ is batch size and the number of trailing $S$’s is arbitrary non-negative integer.

**Parameters**

- `x` *(Variable)* – Input variable. Its first argument is assumed to be the minibatch dimension.
- `W` *(Variable)* – Weight variable.

**Returns**  
Output variable.

**Return type**  
`Variable`

---

**relu**

`chainer.functions.relu(x, use_cudnn=True)`  
Rectified Linear Unit function $f(x) = \max(0, x)$.

**Parameters**

- `x` *(Variable)* – Input variable.
- `use_cudnn` *(bool)* – If `True` and cuDNN is enabled, then this function uses cuDNN as the core implementation.

**Returns**  
Output variable.
Return type  \texttt{Variable}

\texttt{sigmoid}

\texttt{chainer.functions.sigmoid(x, use\_cudnn=True)}

Elementwise sigmoid logistic function $f(x) = (1 + \exp(-x))^{-1}$.

- \texttt{x (Variable)} – Input variable.
- \texttt{use\_cudnn (bool)} – If True and cuDNN is enabled, then this function uses cuDNN as the core implementation.

Returns  Output variable.  
Return type  \texttt{Variable}

\texttt{slstm}

\texttt{chainer.functions.slstm(c\_prev1, c\_prev2, x1, x2)}

S-LSTM units as an activation function.

This function implements S-LSTM unit. It is an extension of LSTM unit applied to tree structures. The function is applied to binary trees. Each node has two child nodes. It gets four arguments, previous cell states $c_1$ and $c_2$, and incoming signals $x_1$ and $x_2$.

First both input signals $x_1$ and $x_2$ are split into eight arrays $a_1, i_1, f_1, o_1, a_2, i_2, f_2, o_2$. They have the same shape along the second axis. It means that $x_1$ and $x_2$'s second axis must have 4 times the length of $c_{1\text{prev}}$ and $c_{2\text{prev}}$.

The split input signals are corresponding to:
- $a_i$: sources of cell input
- $i_i$: sources of input gate
- $f_i$: sources of forget gate
- $o_i$: sources of output gate

It computes outputs as:

\begin{align*}
    c &= \tanh(a_1 + a_2)\sigma(i_1 + i_2) + c_{1\text{prev}}\sigma(f_1) + c_{2\text{prev}}\sigma(f_2), \\
    h &= \tanh(c)\sigma(o_1 + o_2),
\end{align*}

where $\sigma$ is the elementwise sigmoid function. The function returns $c$ and $h$ as a tuple.

Parameters
- \texttt{c\_prev1 (Variable)} – Variable that holds the previous cell state of the first child node. The cell state should be a zero array or the output of the previous call of LSTM.
- \texttt{c\_prev2 (Variable)} – Variable that holds the previous cell state of the second child node.
- \texttt{x1 (Variable)} – Variable that holds the incoming signal from the first child node. It must have the second dimension four times of that of the cell state,
- \texttt{x2 (Variable)} – Variable that holds the incoming signal from the second child node.

Returns  Two \texttt{Variable} objects $c$ and $h$. $c$ is the cell state. $h$ indicates the outgoing signal.
Return type: tuple

See detail in paper: Long Short-Term Memory Over Tree Structures.

**softmax**

```python
chainer.functions.softmax(x, use_cudnn=True)
```

Channelwise softmax function.

This function computes its softmax along the second axis. Let \( x = (x_1, x_2, \ldots, x_d)^T \) be the d dimensional index array and \( f(x) \) be the d dimensional input array. For each index \( x \) of the input array \( f(x) \), it computes the probability \( p(x) \) defined as

\[
p(x) = \frac{\exp(f(x))}{\sum_{x_2} \exp(f(x))}.
\]

Parameters

- \( x \) (Variable) – Input variable.
- \( use_cudnn \) (bool) – If True and cuDNN is enabled, then this function uses cuDNN as the core implementation.

Returns: Output variable.

Return type: Variable

**softplus**

```python
chainer.functions.softplus(x, beta=1.0)
```

Elementwise softplus function.

This function is expressed as \( f(x) = \frac{1}{\beta} \log(1 + \exp(\beta x)) \), where \( \beta \) is a parameter.

Parameters

- \( x \) (Variable) – Input variable.
- \( beta \) (float) – Parameter \( \beta \).

Returns: Output variable.

Return type: Variable

**tanh**

```python
chainer.functions.tanh(x, use_cudnn=True)
```

Elementwise hyperbolic tangent function.

Parameters

- \( x \) (Variable) – Input variable.
- \( use_cudnn \) (bool) – If True and cuDNN is enabled, then this function uses cuDNN as the core implementation.

Returns: Output variable.

Return type: Variable
3.4.2 Array manipulations

**broadcast**

chainer.functions.broadcast(*args)

Broadcast given variables.

Parameters

- **args** (*Variables*) – Variables to be broadcasted.

Returns

Tuple of *Variable* objects which are broadcasted from given arguments.

Return type

tuple

**broadcast_to**

chainer.functions.broadcast_to(x, shape)

Broadcast a given variable to a given shape.

Parameters

- **x** (*Variable*) – Variable to be broadcasted.
- **shape** (*tuple of int*) – The shape of the output variable.

Returns

Output variable broadcasted to the given shape.

Return type

*Variable*

**cast**

chainer.functions.cast(x, typ)

Cast an input variable to a given type.

Parameters

- **x** (*Variable*) – Input variable.
- **typ** (*str of dtype*) – Typecode or data type to cast.

Returns

Variable holding a casted array.

Return type

*Variable*

**concat**

chainer.functions.concat(xs, axis=1)

Concatenates given variables along an axis.

Parameters

- **xs** (*tuple of Variables*) – Variables to be concatenated.
- **axis** (*int*) – Axis that the input arrays are concatenated along.

Returns

Output variable.

Return type

*Variable*
copy

```
chainer.functions.copy(x, dst)
```

Copies the input variable onto the specified device.

This function copies the array of input variable onto the device specified by `dst`. When `dst == -1`, it copies the array onto the host memory. This function supports copies from host to device, from device to device and from device to host.

**Parameters**

- `x (Variable)` – Variable to be copied.
- `dst` – Target device specifier.

**Returns**

Output variable.

**Return type** `Variable`

dstack

```
chainer.functions.dstack(xs)
```

Concatenate variables along third axis (depth wise).

**Parameters**

- `xs (list of chainer.Variable)` – Variables to be concatenated.

**Returns**

Output variable.

**Return type** `Variable`

expand_dims

```
chainer.functions.expand_dims(x, axis)
```

Expands dimensions of an input variable without copy.

**Parameters**

- `x (Variable)` – Input variable.
- `axis (int)` – Position where new axis is to be inserted.

**Returns**

Variable that holds a expanded input.

**Return type** `Variable`

flatten

```
chainer.functions.flatten(x)
```

Flatten a given array.

**Parameters**

- `x (Variable)` – Input variable.

**Returns**

Output variable.

**Return type** `Variable`
get_item

chainer.functions.get_item(x, slices)
Extract elements from array with specified shape, axes and offsets.

Parameters

- x (tuple of Variables) – Variable to be sliced.
- slices (int, slice, None or Ellipsis or tuple of them) – Basic slicing to slice a variable. It supports int, slice, newaxis (equivalent to None) and Ellipsis.

Returns Variable object which contains sliced array of x.

Return type Variable

Note: See NumPy document for details of indexing.

hstack

chainer.functions.hstack(xs)
Concatenate variables horizontally (column wise).

Parameters xs (list of chainer.Variable) – Variables to be concatenated.

Returns Output variable.

Return type Variable

permutate

chainer.functions.permute(x, indices, axis=0, inv=False)
Permutates a given variable along an axis.

This function permutate x with given indices. That means y[i] = x[indices[i]] for all i. Note that this result is same as y = x.take(indices). indices must be a permutation of [0, 1, ..., len(x) - 1].

When inv is True, indices is treated as its inverse. That means y[indices[i]] = x[i].

Parameters

- x (Variable) – Variable to permutate.
- indices (Variable) – Indices to extract from the variable.
- axis (int) – Axis that the input array is permutate along.
- inv (bool) – If True, indices is treated as its inverse.

Returns Output variable.

Return type Variable
**reshape**

`chainer.functions.reshape(x, shape)`

Reshapes an input variable without copy.

**Parameters**

- `x` ([Variable](#variable)) – Input variable.
- `shape` ([tuple of ints](#tuple)) – Target shape.

**Returns**

Variable that holds a reshaped version of the input variable.

**return type** `Variable`

**rollaxis**

`chainer.functions.rollaxis(x, axis, start=0)`

Roll the axis backwards to the given position.

**Parameters**

- `x` ([Variable](#variable)) – Input variable.
- `axis` ([int](#int)) – The axis to roll backwards.
- `start` ([int](#int)) – The place to which the axis is moved.

**Returns**

Variable whose axis is rolled.

**Return type** `Variable`

**select_item**

`chainer.functions.select_item(x, t)`

Select elements stored in given indices.

This function returns `t.choose(x.T)`, that means `y[i] == x[i, t[i]]` for all `i`.

**Parameters**

- `x` ([Variable](#variable)) – Variable storing arrays.
- `t` ([Variable](#variable)) – Variable storing index numbers.

**Returns**

Variable that holds `t`-th element of `x`.

**Return type** `Variable`

**separate**

`chainer.functions.separate(x, axis=0)`

Separates an array along a given axis.

This function separates an array along a given axis. For example, shape of an array is `(2, 3, 4)`. When it separates the array with `axis=1`, it returns three `(2, 4)` arrays.

This function is an inverse of `chainer.functions.stack()`.

**Parameters**

- `x` ([chainer.Variable](#variable)) – Variable to be separated.
• **axis** *(int)* – Axis along which variables are separated.

**Returns** Output variables.

**Return type** tuple of chainer.Variable

**See also:**

chainer.functions.stack()

---

**split_axis**

chainer.functions.split_axis(*x, indices_or_sections, axis, force_tuple=False*)

Splits given variables along an axis.

**Parameters**

- **x** *(tuple of Variables)* – Variables to be split.
- **indices_or_sections** *(int or 1-D array)* – If this argument is an integer, N, the array will be divided into N equal arrays along axis. If it is a 1-D array of sorted integers, it indicates the positions where the array is split.
- **axis** *(int)* – Axis that the input array is split along.
- **force_tuple** *(bool)* – If True, this method returns a tuple even when the number of outputs is one.

**Returns** Tuple of Variable objects if the number of outputs is more than 1 or Variable otherwise. When force_tuple is True, returned value is always a tuple regardless of the number of outputs.

**Return type** tuple or Variable

---

**Note:** This function raises `ValueError` if at least one of the outputs is split to zero-size (i.e. axis-th value of its shape is zero).

---

**squeeze**

chainer.functions.squeeze(*x, axis=None*)

Remove dimensions of size one from the shape of a ndarray.

**Parameters**

- **x** *(chainer.Variable or :class:`numpy.ndarray` or cupy.ndarray)* – Input data.
- **axis** *(None or int or tuple of ints)* – A subset of the single-dimensional entries in the shape to remove. If None is supplied, all of them are removed. The dimension index starts at zero. If an axis with dimension greater than one is selected, an error is raised.

**Returns** Variable whose dimensions of size 1 are removed.

**Return type** Variable

---

**stack**

chainer.functions.stack(*xs, axis=0*)

Concatenate variables along a new axis.
Parameters

- `xs (list of chainer.Variable)` – Variables to be concatenated.
- `axis (int)` – Axis of result along which variables are stacked.

Returns Output variable.

Return type Variable

swapaxes

chainer.functions.swapaxes(x, axis1, axis2)

Swap two axes of a variable.

Parameters

- `x (Variable)` – Input variable.
- `axis1 (int)` – The first axis to swap.
- `axis2 (int)` – The second axis to swap.

Returns Variable whose axes are swapped.

Return type Variable

tile

chainer.functions.tile(x, reps)

Construct an array by tiling a given array.

Parameters

- `x (chainer.Variable or numpy.ndarray or cupy.ndarray)` – Input data.
- `reps (int or tuple of ints)` – The number of times for each axis with which x is replicated.

Returns Variable tiled the given array.

Return type Variable

transpose

chainer.functions.transpose(x, axes=\text{None})

Permute the dimensions of an input variable without copy.

Parameters

- `x (Variable)` – Input variable.
- `axes (tuple of ints)` – By default, reverse the dimensions, otherwise permute the axes according to the values given.

Returns Variable whose axes are permuted.

Return type Variable
transpose_sequence

chainer.functions.transpose_sequence(xs)
Transpose a list of Variables.
This function transposes a list of Variables and returns a list of Variables. For example a user gives 
\[(0, 1, 2, 3), (4, 5), (6)\], the function returns 
\[(0, 4, 6), (1, 5), (2), (3)\]. Note that a given list needs to be sorted by each length of Variable.

Parameters `xs` (list of ~chainer.Variable) – Variables to transpose.

Returns Transposed list.

Return type tuple or Variable

vstack

chainer.functions.vstack(xs)
Concatenate variables vertically (row wise).

Parameters `xs` (list of chainer.Variable) – Variables to be concatenated.

Returns Output variable.

Return type Variable

where

chainer.functions.where(condition, x, y)
Choose elements depending on condition.

This function choose values depending on a given condition. All condition, x, and y must have the same shape.

Parameters
• `condition` (Variable) – Variable containing the condition. Only boolean array is permitted.
• `x` (Variable) – Variable chosen when condition is True.
• `y` (Variable) – Variable chosen when condition is False.

Returns Variable containing chosen values.

Return type Variable

3.4.3 Neural network connections

bilinear

chainer.functions.bilinear(e1, e2, W, V1=None, V2=None, b=None)
Applies a bilinear function based on given parameters.

This is a building block of Neural Tensor Network (see the reference paper below). It takes two input variables and one or four parameters, and outputs one variable.

To be precise, denote six input arrays mathematically by
\[ e^1 \in \mathbb{R}^{I \cdot J}, e^2 \in \mathbb{R}^{I \cdot K}, W \in \mathbb{R}^{J \cdot K \cdot L}, V^1 \in \mathbb{R}^{J \cdot L}, V^2 \in \mathbb{R}^{K \cdot L}, \text{ and } b \in \mathbb{R}^{L}, \text{ where } I \text{ is mini-batch size. In this document, we call } V^1, V^2, \text{ and } b \text{ linear parameters. } \]
The output of forward propagation is calculated as

\[ y_{il} = \sum_{jk} e_{ij}^1 e_{ik}^2 W_{jkl} + \sum_{j} e_{ij}^1 V_{1jkl}^1 + \sum_{k} e_{ik}^2 V_{2kli}^2 + b_l. \]

Note that \( V_1, V_2, b \) are optional. If these are not given, then this function omits the last three terms in the above equation.

**Note:** This function accepts an input variable \( e_1 \) or \( e_2 \) of a non-matrix array. In this case, the leading dimension is treated as the batch dimension, and the other dimensions are reduced to one dimension.

**Note:** In the original paper, \( J \) and \( K \) must be equal and the author denotes \( [V^1 V^2] \) (concatenation of matrices) by \( V \).

**Parameters**

- \( e_1 \) (Variable) – Left input variable.
- \( e_2 \) (Variable) – Right input variable.
- \( W \) (Variable) – Quadratic weight variable.
- \( V_1 \) (Variable) – Left coefficient variable.
- \( V_2 \) (Variable) – Right coefficient variable.
- \( b \) (Variable) – Bias variable.

**Returns** Output variable.

**Return type** Variable

**See:** Reasoning With Neural Tensor Networks for Knowledge Base Completion [Socher+, NIPS2013].

### convolution_2d

chainer.functions.convolution_2d(x, W, b=None, stride=1, pad=0, use_cudnn=True, cover_all=False, deterministic=False)

Two-dimensional convolution function.

This is an implementation of two-dimensional convolution in ConvNets. It takes three variables: the input image \( x \), the filter weight \( W \), and the bias vector \( b \).

**Notation:** here is a notation for dimensionalities.

- \( n \) is the batch size.
- \( c_I \) and \( c_O \) are the number of the input and output channels, respectively.
- \( h \) and \( w \) are the height and width of the input image, respectively.
- \( k_H \) and \( k_W \) are the height and width of the filters, respectively.

**Parameters**

- \( x \) (Variable) – Input variable of shape \((n, c_I, h, w)\).
- \( W \) (Variable) – Weight variable of shape \((c_O, c_I, k_H, k_W)\).
• **b** (*Variable*) – Bias variable of length \(c_O\) (optional).
• **stride** (*int or pair of ints*) – Stride of filter applications. \(\text{stride}=s\) and \(\text{stride}=(s, s)\) are equivalent.
• **pad** (*int or pair of ints*) – Spatial padding width for input arrays. \(\text{pad}=p\) and \(\text{pad}=(p, p)\) are equivalent.
• **use_cudnn** (*bool*) – If True, then this function uses cuDNN if available.
• **cover_all** (*bool*) – If True, all spatial locations are convoluted into some output pixels.
  It may make the output size larger.
• **deterministic** (*bool*) – The output of this function can be non-deterministic when it uses cuDNN.
  If this option is True, then it forces cuDNN to use a deterministic algorithm.
  This option is only available for cuDNN version \(\geq v4\).

**Returns** Output variable.

**Return type** *Variable*

The two-dimensional convolution function is defined as follows. Then the \texttt{Convolution2D} function computes correlations between filters and patches of size \((k_H, k_W)\) in \(x\). Note that correlation here is equivalent to the inner product between expanded vectors. Patches are extracted at positions shifted by multiples of \texttt{stride} from the first position \(-\text{pad}\) for each spatial axis. The right-most (or bottom-most) patches do not run over the padded spatial size.

Let \((s_Y, s_X)\) be the stride of filter application, and \((p_H, p_W)\) the spatial padding size. Then, the output size \((h_O, w_O)\) is determined by the following equations:

\[
\begin{align*}
  h_O &= \left( h + 2p_H - k_H \right) / s_Y + 1, \\
  w_O &= \left( w + 2p_W - k_W \right) / s_X + 1.
\end{align*}
\]

If the bias vector is given, then it is added to all spatial locations of the output of convolution.

**See also:**

\texttt{Convolution2D}

\texttt{convolution_nd}

\texttt{chainer.functions.convolution_nd(x, W, b=None, stride=1, pad=0, use_cudnn=True, cover_all=False)}

N-dimensional convolution function.

This is an implementation of N-dimensional convolution which is generalized two-dimensional convolution in ConvNets. It takes three variables: the input \(x\), the filter weight \(W\) and the bias vector \(b\).

**Notation:** here is a notation for dimensionalities.

• \(N\) is the number of spatial dimensions.
• \(n\) is the batch size.
• \(c_I\) and \(c_O\) are the number of the input and output channels, respectively.
• \(d_1, d_2, ..., d_N\) are the size of each axis of the input’s spatial dimensions, respectively.
• \(k_1, k_2, ..., k_N\) are the size of each axis of the filters, respectively.

**Parameters**

• **x** (*Variable*) – Input variable of shape \((n, c_I, d_1, d_2, ..., d_N)\).
• **W (Variable)** – Weight variable of shape \( (c_O, c_I, k_1, k_2, \ldots, k_N) \).

• **b (Variable)** – One-dimensional bias variable with length \( c_O \) (optional).

• **stride (int or tuple of ints)** – Stride of filter applications \( (s_1, s_2, \ldots, s_N) \). \( \text{stride}=s \) is equivalent to \( (s, s, \ldots, s) \).

• **pad (int or tuple of ints)** – Spatial padding width for input arrays \( (p_1, p_2, \ldots, p_N) \). \( \text{pad}=p \) is equivalent to \( (p, p, \ldots, p) \).

• **use_cudnn (bool)** – If \text{True}, then this function uses cuDNN if available. See below for the exact conditions.

• **cover_all (bool)** – If \text{True}, all spatial locations are convoluted into some output pixels. It may make the output size larger. \text{cover_all} needs to be \text{False} if you want to use cuDNN.

**Returns**  
Output variable.

**Return type**  
\text{Variable}

This function uses cuDNN implementation for its forward and backward computation if ALL of the following conditions are satisfied:

• \( \text{cuda.cudnn_enabled is True} \)

• \( \text{use_cudnn is True} \)

• The number of spatial dimensions is more than one.

• \( \text{cover_all is False} \)

• The input’s dtype is equal to the filter weight’s.

• The dtype is FP32, FP64 or FP16 (cuDNN version is equal to or greater than v3)

**See also:**  
\text{ConvolutionND, convolution\_2d()}

deconvolution\_2d

\text{chainer.functions.deconvolution\_2d(x, W, b=None, stride=1, pad=0, outsize=None, use_cudnn=True, deterministic=False)}

Two dimensional deconvolution function.

This is an implementation of two-dimensional deconvolution. It takes three variables: input image \( x \), the filter weight \( W \), and the bias vector \( b \).

**Parameters**

• **x (Variable)** – Input variable of shape \( (n, c_I, h, w) \).

• **W (Variable)** – Weight variable of shape \( (c_I, c_O, k_H, k_W) \).

• **b (Variable)** – Bias variable of length \( c_O \) (optional).

• **stride (int or pair of ints)** – Stride of filter applications. \( \text{stride}=s \) and \( \text{stride}=(s, s) \) are equivalent.

• **pad (int or pair of ints)** – Spatial padding width for input arrays. \( \text{pad}=p \) and \( \text{pad}=(p, p) \) are equivalent.

• **outsize (tuple)** – Expected output size of deconvolutional operation. It should be pair of height and width \( (out_H, out_W) \). Default value is \text{None} and the outsize is estimated by input size, stride and pad.
• **use_cudnn** *(bool)* – If True, then this function uses cuDNN if available.

• **deterministic** *(bool)* – The output of this function can be non-deterministic when it uses cuDNN. If this option is True, then it forces cuDNN to use a deterministic algorithm. This option is only available for cuDNN version >= v4.

The filter weight has four dimensions \((c_I, c_O, k_H, k_W)\) which indicate the number of input channels, output channels, height and width of the kernels, respectively.

The bias vector is of size \(c_O\).

Let \(X\) be the input tensor of dimensions \((n, c_I, h, w)\), \((s_Y, s_X)\) the stride of filter application, and \((p_H, p_W)\) the spatial padding size. Then, the output size \((h_O, w_O)\) is determined by the following equations:

\[
h_O = s_Y(h - 1) + k_H - 2p_H, \\
w_O = s_X(w - 1) + k_W - 2p_W.
\]

---

### deconvolution_nd

chainer.functions.deconvolution_nd(x, W, b=None, stride=1, pad=0, outsize=None, use_cudnn=True)

N-dimensional deconvolution function.

This is an implementation of N-dimensional deconvolution which generalizes two-dimensional one. It takes three variables: input \(x\), the filter weight \(W\), and the bias vector \(b\).

**Parameters**

- **x** *(chainer.Variable or numpy.ndarray or cupy.ndarray)* – Input data of shape \((n, c_I, d_1, d_2, ..., d_N)\).
- **W** *(chainer.Variable or numpy.ndarray or cupy.ndarray)* – Weight data of shape \((c_I, c_O, k_1, k_2, ..., k_N)\).
- **b** *(chainer.Variable or numpy.ndarray or cupy.ndarray)* – Bias vector of length \(c_O\) (optional).
- **stride** *(int or tuple of ints)* – Stride of filter applications \((s_1, s_2, ..., s_N)\). \(stride=s\) is equivalent to \((s, s, ..., s)\).
- **pad** *(int or tuple of ints)* – Spatial padding size for input arrays \((p_1, p_2, ..., p_N)\). \(pad=p\) is equivalent to \((p, p, ..., p)\).
- **outsize** *(tuple of ints)* – Expected output size of deconvolutional operation. It should be a tuple of ints \((out_1, out_2, ..., out_N)\). Default value is None and the outsize is estimated by input size, stride and pad.
- **use_cudnn** *(bool)* – If True, then this function uses cuDNN if available. Note that cuDNN supports more than one-dimensional deconvolutional operations only.

**Returns** Output variable.

**Return type** **Variable**

The filter weight has the following dimensions \((c_I, c_O, k_1, k_2, ..., k_N)\) which indicate the number of input channels, that of output channels and the filter’s spatial sizes, respectively.

The one-dimensional bias vector is of size \(c_O\).

Let \(X\) be the input tensor of dimensions \((n, c_I, d_1, d_2, ..., d_N)\), \((s_1, s_2, ..., s_N)\) the stride of filter applications, and \((p_1, p_2, ..., p_N)\) the spatial padding size. Then the output size \((out_1, out_2, ..., out_N)\) is determined by the
following equations:

\[\begin{align*}
  \text{out}_1 &= s_1(d_1 - 1) + k_1 - 2p_1, \\
  \text{out}_2 &= s_2(d_2 - 1) + k_2 - 2p_2, \\
  &\vdots \\
  \text{out}_N &= s_N(d_N - 1) + k_N - 2p_N.
\end{align*}\]

See also:

links.DeconvolutionND, deconvolution_2d()

dilated_convolution_2d

```
chainer.functions.dilated_convolution_2d(x, W, b=None, stride=1, pad=0, dilate=1,
                                       use_cudnn=True, cover_all=False)
```

Two-dimensional dilated convolution function.

This is an implementation of two-dimensional dilated convolution in ConvNets. It takes three variables: the input image `x`, the filter weight `W`, and the bias vector `b`.

Notation: here is a notation for dimensionalities.

- `n` is the batch size.
- `c_I` and `c_O` are the number of the input and output, respectively.
- `h` and `w` are the height and width of the input image, respectively.
- `k_H` and `k_W` are the height and width of the filters, respectively.

**Parameters**

- `x (Variable)` – Input variable of shape `(n, c_I, h, w)`.
- `W (Variable)` – Weight variable of shape `(c_O, c_I, k_H, k_W)`.
- `b (Variable)` – Bias variable of length `c_O` (optional).
- `stride (int or pair of ints)` – Stride of filter applications. `stride=s` and `stride=(s, s)` are equivalent.
- `pad (int or pair of ints)` – Spatial padding width for input arrays. `pad=p` and `pad=(p, p)` are equivalent.
- `dilate (int or pair of ints)` – Dilation factor of filter applications. `dilate=d` and `dilate=(d, d)` are equivalent.
- `use_cudnn (bool)` – If `True`, then this function uses cuDNN if available.
- `cover_all (bool)` – If `True`, all spatial locations are convoluted into some output pixels.
  It may make the output size larger.

**Returns** Output variable.

**Return type** `Variable`

The two-dimensional dilated convolution function is defined as follows. Then the DilatedConvolution2D function computes correlations between filters and patches of size `(k_H, k_W)` in `x`. Patches here are extracted at intervals of the dilation factor. Note that correlation here is equivalent to the inner product between expanded vectors. Patches are extracted at intervals of the dilation factor and at positions shifted by multiples of `stride`.
from the first position -pad for each spatial axis. The right-most (or bottom-most) patches do not run over the padded spatial size.

Let \((s_Y, s_X)\) be the stride of filter application, \((p_H, p_W)\) the spatial padding size, and \((d_Y, d_X)\) the dilation factor of filter application. Then, the output size \((h_O, w_O)\) is determined by the following equations:

\[
\begin{align*}
  h_O &= (h + 2p_H - k_H - (k_H - 1) * (d_Y - 1))/s_Y + 1, \\
  w_O &= (w + 2p_W - k_W - (k_W - 1) * (d_X - 1))/s_X + 1.
\end{align*}
\]

If the bias vector is given, then it is added to all spatial locations of the output of convolution.

**See also:**

DilatedConvolution2D

**embed_id**

chainer.functions.embed_id(x, W, ignore_label=None)

Efficient linear function for one-hot input.

This function implements so called word embedding. It takes two arguments: a set of IDs (words) \(x\) in \(B\) dimensional integer vector, and a set of all ID (word) embeddings \(\hat{W}\) in \(V \times d\) float32 matrix. It outputs \(B \times d\) matrix whose \(i\)-th column is the \(x[i]\)-th column of \(\hat{W}\).

This function is only differentiable on the input \(\hat{W}\).

**Parameters**

- **x** (Variable) – Batch vectors of IDs.
- **W** (Variable) – Representation of each ID (a.k.a. word embeddings).
- **ignore_label** (int or None) – If ignore_label is an int value, \(i\)-th column of return value is filled with 0.

**Returns** Output variable.

**Return type** Variable

**See also:**

EmbedID

**linear**

chainer.functions.linear(x, W, b=None)

Linear function, or affine transformation.

It accepts two or three arguments: an input minibatch \(x\), a weight matrix \(W\), and optionally a bias vector \(b\). It computes \(Y = xW^T + b\).

**Parameters**

- **x** (Variable) – Input variable. Its first dimension is assumed to be the minibatch dimension. The other dimensions are treated as concatenated one dimension whose size must be \(N\).
- **W** (Variable) – Weight variable of shape \((M, N)\).
- **b** (Variable) – Bias variable (optional) of shape \((M,)\).

**Returns** Output variable.
3.4.4 Evaluation functions

**accuracy**

chainer.functions.accuracy(y, t, ignore_label=None)

Computes muticlass classification accuracy of the minibatch.

Parameters

- **y** (Variable) – Variable holding a matrix whose (i, j)-th element indicates the score of the class j at the i-th example.
- **t** (Variable) – Variable holding an int32 vector of ground truth labels.
- **ignore_label** (int or None) – Skip calculating accuracy if the true label is ignore_label.

Returns

A variable holding a scalar array of the accuracy.

Return type **Variable**

Note: This function is non-differentiable.

3.4.5 Loss functions

**bernoulli_nll**

chainer.functions.bernoulli_nll(x, y)

Computes the negative log-likelihood of a Bernoulli distribution.

This function calculates the negative log-likelihood of a Bernoulli distribution.

\[-B(x; p) = - \sum_i x_i \log(p_i) + (1 - x_i) \log(1 - p_i),\]

where \(p = \sigma(y)\), and \(\sigma(\cdot)\) is a sigmoid function.

Note: As this function uses a sigmoid function, you can pass a result of fully-connected layer (that means Linear) to this function directly.

Parameters

- **x** (Variable) – Input variable.
- **y** (Variable) – A variable representing the parameter of Bernoulli distribution.

Returns

A variable representing negative log-likelihood.

Return type **Variable**
black_out

**chainer.functions.black_out** *(x, t, W, samples)*
BlackOut loss function.

BlackOut loss function is defined as

$$- \log(p(t)) - \sum_{s \in S} \log(1 - p(s)),$$

where *t* is the correct label, *S* is a set of negative examples and *p(·)* is likelihood of a given label. And, *p* is defined as

$$p(y) = \frac{\exp(W^T_y x)}{\sum_{s \in \text{samples}} \exp(W^T_s x)}.$$

**Parameters**
- *x* *(Variable)* – Batch of input vectors.
- *t* *(Variable)* – Vector of ground truth labels.
- *W* *(Variable)* – Weight matrix.
- *samples* *(Variable)* – Negative samples.

**Returns** Loss value.

**Return type** *Variable*

See: BlackOut: Speeding up Recurrent Neural Network Language Models With Very Large Vocabularies

See also: BlackOut.

connectionist_temporal_classification

**chainer.functions.connectionist_temporal_classification** *(x, t, blank_symbol, input_length=None, label_length=None)*

Connectionist Temporal Classification loss function.

Connectionist Temporal Classification (CTC) [Graves2006] is a loss function of sequence labeling where the alignment between the inputs and target is unknown. See also [Graves2012]

**Parameters**
- *x* *(sequence of Variable)* – RNN output at each time. *x* must be a list of Variables. Each element of *x*, *x[i]* is a Variable representing output of RNN at time *i*.
- *t* *(Variable)* – Expected label sequence.
- *blank_symbol* *(int)* – Index of blank_symbol. This value must be non-negative.
- *input_length* *(Variable)* – Length of valid sequence for each of mini batch *x* (optional). If *input_length* is skipped, it regards that all of *x* is valid input.
- *label_length* *(Variable)* – Length of valid sequence for each of mini batch *t* (optional). If *label_length* is skipped, it regards that all of *t* is valid input.

**Returns** A variable holding a scalar value of the CTC loss.
Return type: Variable

Note: You need to input \( x \) without applying to activation functions (e.g., softmax function), because this function applies softmax functions to \( x \) before calculating CTC loss to avoid numerical limitations. You also need to apply softmax function to forwarded values before you decode it.

Note: This function is differentiable only by \( x \).

Note: This function supports (batch, sequence, 1-dimensional input)-data.

**contrastive**

`chainer.functions.contrastive(x0, x1, y, margin=1)`

Computes contrastive loss.

It takes a pair of variables and a label as inputs. The label is 1 when those two input variables are similar, or 0 when they are dissimilar. Let \( N \) and \( K \) denote mini-batch size and the dimension of input variables, respectively. The shape of both input variables should be \((N, K)\).

\[
L = \frac{1}{2N} \left( \sum_{n=1}^{N} y_n d_n^2 + (1 - y_n) \max(margin - d_n, 0)^2 \right)
\]

where \( d_n = \|x_{0n} - x_{1n}\|_2 \). \( N \) denotes the mini-batch size. Input variables, \( x_0 \) and \( x_1 \), have \( N \) vectors, and each vector is \( K \)-dimensional. Therefore, \( x_{0n} \) and \( x_{1n} \) are \( n \)-th \( K \)-dimensional vectors of \( x_0 \) and \( x_1 \).

**Parameters**

- \( x_0 \) (Variable) – The first input variable. The shape should be \((N, K)\), where \( N \) denotes the mini-batch size, and \( K \) denotes the dimension of \( x_0 \).
- \( x_1 \) (Variable) – The second input variable. The shape should be the same as \( x_0 \).
- \( y \) (Variable) – Labels. All values should be 0 or 1. The shape should be \((N,)\), where \( N \) denotes the mini-batch size.
- \( margin \) (float) – A parameter for contrastive loss. It should be positive value.

**Returns** A variable holding a scalar that is the loss value calculated by the above equation.

**Return type** Variable

Note: This cost can be used to train siamese networks. See *Learning a Similarity Metric Discriminatively, with Application to Face Verification* for details.

**crf1d**

`chainer.functions.crf1d(cost, xs, ys)`

Calculates negative log-likelihood of linear-chain CRF.
It takes a transition cost matrix, a sequence of costs, and a sequence of labels. Let $c_{st}$ be a transition cost from a label $s$ to a label $t$, $x_{it}$ be a cost of a label $t$ at position $i$, and $y_i$ be an expected label at position $i$. The negative log-likelihood of linear-chain CRF is defined as

$$L = -\left(\sum_{i=1}^{l} x_{iy_i} + \sum_{i=1}^{l-1} c_{y_i y_{i+1}} - \log(Z)\right),$$

where $l$ is the length of the input sequence and $Z$ is the normalizing constant called partition function.

**Note:** When you want to calculate the negative log-likelihood of sequences which have different lengths, sort the sequences in descending order of lengths and transpose the sequences. For example, you have three input sequences:

```python
>>> a1 = a2 = a3 = a4 = np.random.uniform(-1, 1, 3).astype('f')
>>> b1 = b2 = b3 = np.random.uniform(-1, 1, 3).astype('f')
>>> c1 = c2 = np.random.uniform(-1, 1, 3).astype('f')
```

```python
>>> a = [a1, a2, a3, a4]
>>> b = [b1, b2, b3]
>>> c = [c1, c2]
```

where `$a$` and all other variables are arrays with $(K,)$ shape. Make a transpose of the sequences:

```python
>>> x1 = np.stack([a1, b1, c1])
>>> x2 = np.stack([a2, b2, c2])
>>> x3 = np.stack([a3, b3])
>>> x4 = np.stack([a4])
```

and make a list of the arrays:

```python
>>> xs = [x1, x2, x3, x4]
```

You need to make label sequences in the same fashion. And then, call the function:

```python
>>> cost = chainer.Variable(
...    np.random.uniform(-1, 1, (3, 3)).astype('f'))
>>> ys = [np.zeros(x.shape[0:1], dtype='i') for x in xs]
>>> loss = F.crf1d(cost, xs, ys)
```

It calculates sum of the negative log-likelihood of the three sequences.

**Parameters**

- `cost` (*Variable*) - A $K \times K$ matrix which holds transition cost between two labels, where $K$ is the number of labels.

- `xs` (*list of Variable*) - Input vector for each label. `len(xs)` denotes the length of the sequence, and each `Variable` holds a $B \times K$ matrix, where $B$ is mini-batch size, $K$ is the number of labels. Note that $B$ s in all the variables are not necessary the same, i.e., it accepts the input sequences with different lengths.

- `ys` (*list of Variable*) - Expected output labels. It needs to have the same length as `xs`. Each `Variable` holds a $B$ integer vector. When $x$ in `xs` has the different $B$, corresponding $y$ has the same $B$. In other words, `ys` must satisfy `ys[i].shape == xs[i].shape[0:1]` for all $i$.

**Returns** A variable holding the average negative log-likelihood of the input sequences.

**Return type** `Variable`
chainer.functions.argmax_crf1d(cost, xs)
Computes a state that maximizes a joint probability of the given CRF.

Parameters

- `cost` (Variable) – A $K \times K$ matrix which holds transition cost between two labels, where $K$ is the number of labels.
- `xs` (list of Variable) – Input vector for each label. len(xs) denotes the length of the sequence, and each Variable holds a $B \times K$ matrix, where $B$ is mini-batch size, $K$ is the number of labels. Note that $B$ s in all the variables are not necessary the same, i.e., it accepts the input sequences with different lengths.

Returns A tuple of Variable object $s$ and a list $ps$. The shape of $s$ is $(B,)$, where $B$ is the mini-batch size. i-th element of $s, s[i]$, represents log-likelihood of i-th data. $ps$ is a list of numpy.ndarray or cupy.ndarray, and denotes the state that maximizes the point probability. len(ps) is equal to len(xs), and shape of each $ps[i]$ is the mini-batch size of the corresponding $xs[i]$. That means, $ps[i].shape == xs[i].shape[0:1]$.

Return type tuple

cross_covariance

chainer.functions.cross_covariance(y, z)
Computes the sum-squared cross-covariance penalty between $y$ and $z$

Parameters

- `y` (Variable) – Variable holding a matrix where the first dimension corresponds to the batches.
- `z` (Variable) – Variable holding a matrix where the first dimension corresponds to the batches.

Returns A variable holding a scalar of the cross covariance loss.

Return type Variable

Note: This cost can be used to disentangle variables. See http://arxiv.org/abs/1412.6583v3 for details.

gaussian_kl_divergence

chainer.functions.gaussian_kl_divergence(mean, ln_var)
Computes the KL-divergence of Gaussian variables from the standard one.

Given two variable mean representing $\mu$ and ln_var representing $\log(\sigma^2)$, this function returns a variable representing the KL-divergence between the given multi-dimensional Gaussian $N(\mu, S)$ and the standard Gaussian $N(0, I)$

\[
D_{KL}(N(\mu, S)\|N(0, I)),
\]

where $S$ is a diagonal matrix such that $S_{ii} = \sigma^2$ and $I$ is an identity matrix.
Parameters

- **mean** ([Variable]) – A variable representing mean of given gaussian distribution, \( \mu \).
- **ln_var** ([Variable]) – A variable representing logarithm of variance of given gaussian distribution, \( \log(\sigma^2) \).

**Returns** A variable representing KL-divergence between given gaussian distribution and the standard gaussian.

**Return type** [Variable]

gaussian_nll

chainer.functions.gaussian_nll(x, mean, ln_var)

Computes the negative log-likelihood of a Gaussian distribution.

Given two variable **mean** representing \( \mu \) and **ln_var** representing \( \log(\sigma^2) \), this function returns the negative log-likelihood of \( x \) on a Gaussian distribution \( N(\mu, S) \),

\[
-\log N(x; \mu, \sigma^2) = \log \left( \sqrt{(2\pi)^D |S|} \right) + \frac{1}{2} (x - \mu)^T S^{-1} (x - \mu),
\]

where \( D \) is a dimension of \( x \) and \( S \) is a diagonal matrix where \( S_{ii} = \sigma_i^2 \).

**Parameters**

- **x** ([Variable]) – Input variable.
- **mean** ([Variable]) – A variable representing mean of a Gaussian distribution, \( \mu \).
- **ln_var** ([Variable]) – A variable representing logarithm of variance of a Gaussian distribution, \( \log(\sigma^2) \).

**Returns** A variable representing the negative log-likelihood.

**Return type** [Variable]

hinge

chainer.functions.hinge(x, t, norm='L1')

Computes the hinge loss for a one-of-many classification task.

\[
L = \frac{1}{N} \sum_{n=1}^{N} \sum_{k=1}^{K} \left[ \max(0, 1 - \delta\{l_n = k\} t_{nk}) \right]^p
\]

where \( N \) denotes the batch size, \( K \) is the number of classes of interest,

\[
\delta\{\text{condition}\} = \begin{cases} 
1 & \text{if condition} \\
-1 & \text{otherwise}, 
\end{cases}
\]

and

\[
p = \begin{cases} 
1 & \text{if norm = 'L1'} \\
2 & \text{if norm = 'L2'}. 
\end{cases}
\]

**Parameters**

- **x** ([Variable]) – Input variable. The shape of \( x \) should be \((N, K)\).
t (Variable) – The \(N\)-dimensional label vector \(l\) with values \(l_n \in \{0, 1, 2, \ldots, K - 1\}\). The shape of \(t\) should be \((N,)\).

norm (string) – Specifies norm type. Only either ‘L1’ or ‘L2’ is acceptable.

Returns A variable object holding a scalar array of the hinge loss \(L\).

Return type Variable

huber_loss

chainer.functions.huber_loss(x, t, delta)

Loss function which is less sensitive to outliers in data than MSE.

\[
\begin{align*}
  a &= x - t \\
  L_\delta(a) &= \begin{cases}
    \frac{1}{2}a^2 & \text{if } |a| \leq \delta \\
    \delta(|a| - \frac{1}{2}\delta) & \text{otherwise}
  \end{cases}
\end{align*}
\]

Parameters

- x (Variable) – Input variable. The shape of \(x\) should be \((N, K)\).
- t (Variable) – Target variable for regression. The shape of \(t\) should be \((N, K)\).
- delta (float) – Constant variable for huber loss function as used in definition.

Returns A variable object holding a scalar array of the huber loss \(L_\delta\).

Return type Variable

See: Huber loss - Wikipedia.

mean_squared_error

chainer.functions.mean_squared_error(x0, x1)

Mean squared error function.

This function computes mean squared error between two variables. The mean is taken over the minibatch. Note that the error is not scaled by 1/2.

negative_sampling

chainer.functions.negative_sampling(x, t, W, sampler, sample_size)

Negative sampling loss function.

In natural language processing, especially language modeling, the number of words in a vocabulary can be very large. Therefore, you need to spend a lot of time calculating the gradient of the embedding matrix.

By using the negative sampling trick you only need to calculate the gradient for a few sampled negative examples.

The objective function is below:

\[
f(x, p) = \log \sigma(x^T w_p) + kE_{i \sim p(i)}[\log \sigma(-x^T w_i)],
\]
where $\sigma(\cdot)$ is a sigmoid function, $w_i$ is the weight vector for the word $i$, and $p$ is a positive example. It is approximated with $k$ examples $N$ sampled from probability $P(i)$, like this:

$$f(x, p) \approx \log \sigma(x^Tw_p) + \sum_{n \in N} \log \sigma(-x^Tw_n).$$

Each sample of $N$ is drawn from the word distribution $P(w)$. This is calculated as $P(w) = \frac{1}{Z} c(w)^\alpha$, where $c(w)$ is the unigram count of the word $w$, $\alpha$ is a hyper-parameter, and $Z$ is the normalization constant.

**Parameters**
- $x$ (Variable) – Batch of input vectors.
- $t$ (Variable) – Vector of ground truth labels.
- $W$ (Variable) – Weight matrix.
- sampler (FunctionType) – Sampling function. It takes a shape and returns an integer array of the shape. Each element of this array is a sample from the word distribution. A WalkerAlias object built with the power distribution of word frequency is recommended.
- sample_size (int) – Number of samples.

See: Distributed Representations of Words and Phrases and their Compositionality
See also: NegativeSampling.

**sigmoid_cross_entropy**

chainer.functions.sigmoid_cross_entropy(x, t, use_cudnn=True, normalize=True)

Computes cross entropy loss for pre-sigmoid activations.

**Parameters**
- $x$ (Variable) – A variable object holding a matrix whose $(i, j)$-th element indicates the unnormalized log probability of the $j$-th unit at the $i$-th example.
- $t$ (Variable) – Variable holding an int32 vector of ground truth labels. If $t[i] == -1$, corresponding $x[i]$ is ignored. Loss is zero if all ground truth labels are $-1$.
- normalize (bool) – Variable holding a boolean value which determines the normalization constant. If true, this function normalizes the cross entropy loss across all instances. If else, it only normalizes along a batch size.

**Returns** A variable object holding a scalar array of the cross entropy loss.

**Return type** Variable

**Note:** This function is differentiable only by $x$.

**softmax_cross_entropy**

chainer.functions.softmax_cross_entropy(x, t, use_cudnn=True, normalize=True, cache_score=True)

Computes cross entropy loss for pre-softmax activations.

**Parameters**
- $x$ (Variable) – A variable object holding a matrix whose $(i, j)$-th element indicates the unnormalized log probability of the $j$-th unit at the $i$-th example.
- $t$ (Variable) – Variable holding an int32 vector of ground truth labels. If $t[i] == -1$, corresponding $x[i]$ is ignored. Loss is zero if all ground truth labels are $-1$.
- normalize (bool) – Variable holding a boolean value which determines the normalization constant. If true, this function normalizes the cross entropy loss across all instances. If else, it only normalizes along a batch size.

**Returns** A variable object holding a scalar array of the cross entropy loss.

**Return type** Variable
• **x** (*Variable*) – Variable holding a multidimensional array whose element indicates un-normalized log probability: the first axis of the variable represents the number of samples, and the second axis represents the number of classes. While this function computes a usual softmax cross entropy if the number of dimensions is equal to 2, it computes a cross entropy of the replicated softmax if the number of dimensions is greater than 2.

• **t** (*Variable*) – Variable holding an int32 vector of ground truth labels. If \( t[i] == -1 \), corresponding \( x[i] \) is ignored.

• **normalize** (*bool*) – If True, this function normalizes the cross entropy loss across all instances. If False, it only normalizes along a batch size.

• **cache_score** (*bool*) – When it is True, the function stores result of forward computation to use it on backward computation. It reduces computational cost though consumes more memory.

**Returns** A variable holding a scalar array of the cross entropy loss.

**Return type** *Variable*

---

**Note:** This function is differentiable only by \( x \).

---

**triplet**

*chainer.functions.triplet*(anchor, positive, negative, margin=0.2)

Computes triplet loss.

It takes a triplet of variables as inputs, \( a, p \) and \( n \): anchor, positive example and negative example respectively. The triplet defines a relative similarity between samples. Let \( N \) and \( K \) denote mini-batch size and the dimension of input variables, respectively. The shape of all input variables should be \((N, K)\).

\[
L(a, p, n) = \frac{1}{N} \left( \sum_{i=1}^{N} \max\{d(a_i, p_i) - d(a_i, n_i) + \text{margin}, 0\} \right)
\]

where \( d(x_i, y_i) = \|x_i - y_i\|_2^2 \).

**Parameters**

• **anchor** (*Variable*) – The anchor example variable. The shape should be \((N, K)\), where \( N \) denotes the minibatch size, and \( K \) denotes the dimension of the anchor.

• **positive** (*Variable*) – The positive example variable. The shape should be the same as anchor.

• **negative** (*Variable*) – The negative example variable. The shape should be the same as anchor.

• **margin** (*float*) – A parameter for triplet loss. It should be a positive value.

**Returns** A variable holding a scalar that is the loss value calculated by the above equation.

**Return type** *Variable*

---

**Note:** This cost can be used to train triplet networks. See Learning Fine-grained Image Similarity with Deep Ranking for details.
3.4.6 Mathematical functions

arccos

chainer.functions.arccos(x)
Elementwise arccosine function.

\[ y_i = \arccos x_i. \]

Parameters  
\( x \) (Variable) – Input variable.

Returns  
Output variable.

Return type  
Variable

arcsin

chainer.functions.arcsin(x)
Elementwise arcsine function.

\[ y_i = \arcsin x_i. \]

Parameters  
\( x \) (Variable) – Input variable.

Returns  
Output variable.

Return type  
Variable

arctan

chainer.functions.arctan(x)
Elementwise arctangent function.

\[ y_i = \arctan x_i. \]

Parameters  
\( x \) (Variable) – Input variable.

Returns  
Output variable.

Return type  
Variable

argmax

chainer.functions.argmax(x, axis=None)
Returns index which holds maximum of array elements over a given axis.

Parameters

- \( x \) (Variable) – Array to find maximum elements.
- \( \text{axis} \) (None or int) – Axis over which a max is performed. The default (axis = None) is perform a max over all the dimensions of the input array.

Returns  
Output variable.

Return type  
Variable
argmin

\texttt{chainer.functions.argmin}(x, axis=\texttt{None})

Returns index which holds minimum of array elements over a given axis.

\textbf{Parameters}

- \texttt{x} (Variable) – Array to find minimum elements.
- \texttt{axis} (\texttt{None or int}) – Axis over which a min is performed. The default (axis = \texttt{None}) is perform a min over all the dimensions of the input array.

\textbf{Returns} Output variable.

\textbf{Return type} \texttt{Variable}

batch_inv

\texttt{chainer.functions.batch_inv}(a)

Computes the inverse of a batch of square matrices.

\textbf{Parameters} \texttt{a} (Variable) – Input array to compute the inverse for. Shape of the array should be \((m, n, n)\) where \(m\) is the number of matrices in the batch, and \(n\) is the dimensionality of a square matrix.

\textbf{Returns} Inverse of every matrix in the batch of matrices.

\textbf{Return type} \texttt{Variable}

batch_l2_norm_squared

\texttt{chainer.functions.batch_l2_norm_squared}(x)

L2 norm (a.k.a. Euclidean norm) squared.

This function implements the square of L2 norm on a vector. No reduction along batch axis is done.

\textbf{Parameters} \texttt{x} (Variable) – Input variable. The first dimension is assumed to be the \textit{minibatch} dimension. If \(x\) has more than two dimensions all but the first dimension are flattened to one dimension.

\textbf{Returns} Two dimensional output variable.

\textbf{Return type} \texttt{Variable}

batch_matmul

\texttt{chainer.functions.batch_matmul}(a, b, transa=\texttt{False}, transb=\texttt{False})

Computes the batch matrix multiplications of two sets of arrays.

\textbf{Parameters}

- \texttt{a} (Variable) – The left operand of the batch matrix multiplications. A 2-D array of shape \((B, N)\) is considered as \(B \times N\) matrices. A 3-D array of shape \((B, M, N)\) is considered as \(B \times M \times N\) matrices.
- \texttt{b} (Variable) – The right operand of the batch matrix multiplications. Its array is treated as matrices in the same way as \(a\)’s array.
- \texttt{transa} (\texttt{bool}) – If True, transpose each matrix in \(a\).
transb

If True, transpose each matrix in b.

Returns: The result of the batch matrix multiplications as a 3-D array.

Return type: Variable

bias

chainer.functions.bias(x, y, axis=1)

Elementwise summation with broadcasting.

Computes a elementwise summation of two input variables, with the shape of the latter variable broadcasted to match the shape of the former. axis is the first axis of the first variable along which the second variable is applied.

The term “broadcasting” here comes from Caffe’s bias layer so the “broadcasting” with the following arguments:

| x | 100 x 3 x 40 x 60 |
| y | 3 x 40 |
| axis | 1 |

is equivalent to the following numpy broadcasting:

| x | 100 x 3 x 40 x 60 |
| y | 1 x 3 x 40 x 1 |

Note that how the axis indicates to which axis of x we apply y.

Parameters

- x (Variable) – Input variable to be summed.
- y (Variable) – Input variable to sum, broadcasted.
- axis (int) – The first axis of x along which y is applied.

Returns: Output variable.

Return type: Variable

ceil

chainer.functions.ceil(x)

Elementwise ceil function.

\[ y_i = \lceil x_i \rceil \]

Parameters: x (Variable) – Input variable.

Returns: Output variable.

Return type: Variable

clip

chainer.functions.clip(x, x_min, x_max)

Clips (limits) elements of input variable.

Given an interval \([x_{\text{min}}, x_{\text{max}}]\), elements outside the interval are clipped to the interval edges.

Parameters
• \(x\) (Variable) – Input variable to be clipped.
• \(x_{\text{min}}\) (float) – Minimum value.
• \(x_{\text{max}}\) (float) – Maximum value.

**Returns**  Output variable.
**Return type**  Variable

### cos

\[ \text{chainer.functions.cos}(x) \]
Elementwise cos function.

### cosh

\[ \text{chainer.functions.cosh}(x) \]
Elementwise hyperbolic cosine function.

\[ y_i = \cosh x_i. \]

**Parameters**  \(x\) (Variable) – Input variable.
**Returns**  Output variable.
**Return type**  Variable

### exp

\[ \text{chainer.functions.exp}(x) \]
Elementwise exponential function.

### floor

\[ \text{chainer.functions.floor}(x) \]
Elementwise floor function.

\[ y_i = \lfloor x_i \rfloor \]

**Parameters**  \(x\) (Variable) – Input variable.
**Returns**  Output variable.
**Return type**  Variable

### identity

\[ \text{chainer.functions.identity}(*\text{inputs}) \]
Just returns input variables.
inv

\texttt{chainer.functions.inv}(a)

Computes the inverse of square matrix.

\textbf{Parameters}\ a (Variable) – Input array to compute the inverse for. Shape of the array should be \((n, n)\) where \(n\) is the dimensionality of a square matrix.

\textbf{Returns}\ Matrix inverse of \(a\).

\textbf{Return type}\ Variable

linear_interpolate

\texttt{chainer.functions.linear_interpolate}(p, x, y)

Elementwise linear-interpolation function.

This function is defined as

\[ f(p, x, y) = px + (1 - p)y. \]

\textbf{Parameters}

- \(p\) (Variable) – Input variable.
- \(x\) (Variable) – Input variable.
- \(y\) (Variable) – Input variable.

\textbf{Returns}\ Output variable.

\textbf{Return type}\ Variable

log

\texttt{chainer.functions.log}(x)

Elementwise natural logarithm function.

log10

\texttt{chainer.functions.log10}(x)

Elementwise logarithm function to the base 10.

\[ y_i = \log_{10} x_i. \]

\textbf{Parameters}\ x (Variable) – Input variable.

\textbf{Returns}\ Output variable.

\textbf{Return type}\ Variable

log1p

\texttt{chainer.functions.log1p}(x)

Elementwise natural logarithm plus one function.
**log2**

chainer.functions.log2(x)

Elementwise logarithm function to the base 2.

\[ y_i = \log_2 x_i. \]

**Parameters**
- **x** (*Variable*) – Input variable.

**Returns**
Output variable.

**Return type** *Variable*

**logsumexp**

chainer.functions.logsumexp(x, axis=None)

Log-sum-exp of array elements over a given axis.

This function calculates logarithm of sum of exponential of array elements.

\[ y_i = \log \left( \sum_j \exp(x_{ij}) \right) \]

**Parameters**
- **x** (*Variable*) – Elements to log-sum-exp.
- **axis** (*None, int, or tuple of int*) – Axis which a sum is performed. The default (axis = None) is perform a sum over all the dimensions of the input array.

**Returns**
Output variable.

**Return type** *Variable*

**matmul**

chainer.functions.matmul(a, b, transa=False, transb=False)

Computes the matrix multiplication of two arrays.

**Parameters**
- **a** (*Variable*) – The left operand of the matrix multiplication. A 1-D array of shape \((N, )\) is considered as an \(N \times 1\) matrix. A 2-D array of shape \((M, N)\) is considered as an \(M \times N\) matrix.
- **b** (*Variable*) – The right operand of the matrix multiplication. Its array is treated as a matrix in the same way as a’s array.
- **transa** (*bool*) – If True, transpose a.
- **transb** (*bool*) – If True, transpose b.

**Returns**
The result of the matrix multiplication as a 2-D array.

**Return type** *Variable*
max

chainer.functions.max(x, axis=None, keepdims=False)

Maximum of array elements over a given axis.

Parameters

- `x` (Variable) – Array to be maximized.
- `axis` (None, int, or tuple of int) – Axis over which a max is performed. The default (axis = None) is perform a max over all the dimensions of the input array.

Returns Output variable.

Return type `Variable`

maximum

chainer.functions.maximum(x1, x2)

Element-wise maximum of input variables.

Parameters

- `x1` (Variable) – Input variables to be compared.
- `x2` (Variable) – Input variables to be compared.

Returns Output variable.

Return type `Variable`

min

chainer.functions.min(x, axis=None, keepdims=False)

Minimum of array elements over a given axis.

Parameters

- `x` (Variable) – Array to be minimized.
- `axis` (None, int, or tuple of int) – Axis over which a min is performed. The default (axis = None) is perform a min over all the dimensions of the input array.

Returns Output variable.

Return type `Variable`

minimum

chainer.functions.minimum(x1, x2)

Element-wise minimum of input variables.

Parameters

- `x1` (Variable) – Input variables to be compared.
- `x2` (Variable) – Input variables to be compared.

Returns Output variable.

Return type `Variable`
rsqrt

chainer.functions.rsqrt(x)
Computes elementwise reciprocal of square root of input $x_i$.

\[ y_i = \frac{1}{\sqrt{x_i}}. \]

Parameters

- **x (Variable)** – Input variable.

Returns

Output variable.

Return type **Variable**

See also:

- sqrt()

scale

chainer.functions.scale(x, y, axis=1)
Elementwise product with broadcasting.

Computes a elementwise product of two input variables, with the shape of the latter variable broadcasted to match the shape of the former. **axis** is the first axis of the first variable along which the second variable is applied.

The term “broadcasting” here comes from Caffe’s scale layer so the “broadcasting” with the following arguments:

\[
\begin{align*}
x & : 100 \times 3 \times 40 \times 60 \\
y & : 3 \times 40 \\
axis & : 1
\end{align*}
\]

is equivalent to the following numpy broadcasting:

\[
\begin{align*}
x & : 100 \times 3 \times 40 \times 60 \\
y & : 1 \times 3 \times 40 \times 1
\end{align*}
\]

Note that how the **axis** indicates to which axis of $x$ we apply $y$.

Parameters

- **x (Variable)** – Input variable to be scaled.
- **y (Variable)** – Input variable to scale, broadcasted.
- **axis (int)** – The first axis of $x$ along which $y$ is applied.

Returns

Output variable.

Return type **Variable**

sin

chainer.functions.sin(x)
Elementwise sin function.
**sinh**

chainer.functions.sinh(x)

Elementwise hyperbolic sine function.

\[ y_i = \sinh x_i. \]

**Parameters**

- **x** *(Variable)* – Input variable.

**Returns**

Output variable.

**Return type**

Variable

**sqrt**

chainer.functions.sqrt(x)

Elementwise square root function.

\[ y_i = \sqrt{x_i}. \]

If the value of \(x_i\) is negative, it returns \(\text{Nan}\) for \(y_i\) respect to underlying numpy and cupy specification.

**Parameters**

- **x** *(Variable)* – Input variable.

**Returns**

Output variable.

**Return type**

Variable

**square**

chainer.functions.square(x)

Elementwise square function.

\[ y_i = x_i^2. \]

**Parameters**

- **x** *(chainer.Variable or numpy.ndarray or cupy.ndarray)* – Input variable.

**Returns**

Output variable.

**Return type**

Variable

**squared_difference**

chainer.functions.squared_difference(x1, x2)

Squared difference of input variables.

**Parameters**

- **x1** *(Variable)* – Input variables to be compared.
- **x2** *(Variable)* – Input variables to be compared.

**Returns**

\((x1 - x2) ** 2\) element-wise.

**Return type**

Variable
**sum**

`chainer.functions.sum(x, axis=None)`

Sum of array elements over a given axis.

**Parameters**

- **x (Variable)** – Elements to sum.
- **axis (None, int, or tuple of int)** – Axis which a sum is performed. The default (axis = None) is perform a sum over all the dimensions of the input array.

**Returns** Output variable.

**Return type** Variable

**tanh**

Hyperbolic tangent function is described in “Activation functions” section.

**See also:**

`tanh()`

**tan**

`chainer.functions.tan(x)`

Elementwise tan function.

### 3.4.7 Noise injections

**dropout**

`chainer.functions.dropout(x, ratio=0.5, train=True)`

Drops elements of input variable randomly.

This function drops input elements randomly with probability ratio and scales the remaining elements by factor $1 / (1 - \text{ratio})$. In testing mode, it does nothing and just returns $x$.

**Parameters**

- **x (Variable)** – Input variable.
- **ratio (float)** – Dropout ratio.
- **train (bool)** – If True, executes dropout. Otherwise, does nothing.

**Returns** Output variable.

**Return type** Variable

See the paper by G. Hinton: Improving neural networks by preventing co-adaptation of feature detectors.

**gaussian**

`chainer.functions.gaussian(mean, ln_var)`

Gaussian sampling function.

It takes mean $\mu$ and logarithm of variance $\log(\sigma^2)$ as input and output a sample drawn from gaussian $N(\mu, \sigma)$. 
Parameters

- **mean (Variable)** – Input variable representing mean \( \mu \).
- **ln_var (Variable)** – Input variable representing logarithm of variance \( \log(\sigma^2) \).

Returns

Output variable.

Return type

Variable

### 3.4.8 Normalization functions

**batch_normalization**

chainer.functions.batch_normalization(x, gamma, beta, eps=2e-05, running_mean=None, running_var=None, decay=0.9, use_cudnn=True)

Batch normalization function.

It takes the input variable \( x \) and two parameter variables \( \gamma \) and \( \beta \). The input must have the batch size and the features (or channels) as the first two dimensions of its shape. The input can have more than two dimensions, where the remaining dimensions are considered as spatial dimensions, which are considered as a part of the batch size. That is, the total batch size will be considered to be the product of all dimensions except the second dimension.

Note: If this function is called, it will not be possible to access the updated running mean and variance statistics, because they are members of the function object, which cannot be accessed by the caller. If it is desired to access the updated running statistics, it is necessary to get a new instance of the function object, call the object, and then access the running_mean and/or running_var attributes. See the corresponding Link class for an example of how to do this.

Parameters

- **x (Variable)** – Input variable.
- **gamma (Variable)** – Scaling parameter of normalized data.
- **beta (Variable)** – Shifting parameter of scaled normalized data.
- **eps (float)** – Epsilon value for numerical stability.
- **running_mean (array)** – Running average of the mean. This is a running average of the mean over several mini-batches using the decay parameter. If \( \text{None} \), the running average is not computed. If this is \( \text{None} \), then running_var must also be \( \text{None} \).
- **running_var (array)** – Running average of the variance. This is a running average of the variance over several mini-batches using the decay parameter. If \( \text{None} \), the running average is not computed. If this is \( \text{None} \), then running_mean must also be \( \text{None} \).
- **decay (float)** – Decay rate of moving average. It is used during training.
- **use_cudnn (bool)** – If \( \text{True} \) and cuDNN is enabled, then this function uses cuDNN as the core implementation.

See: Batch Normalization: Accelerating Deep Network Training by Reducing Internal Covariate Shift

See also:

links.BatchNormalization

3.4. Standard Function implementations
fixed_batch_normalization

chainer.functions.fixed_batch_normalization(x, gamma, beta, mean, var, eps=2e-05, use_cudnn=True)

Batch normalization function with fixed statistics.

This is a variant of batch normalization, where the mean and variance statistics are given by the caller as fixed variables. This is used on testing mode of the batch normalization layer, where batch statistics cannot be used for prediction consistency.

Parameters

- x (Variable) – Input variable.
- gamma (Variable) – Scaling parameter of normalized data.
- beta (Variable) – Shifting parameter of scaled normalized data.
- mean (Variable) – Shifting parameter of input.
- var (Variable) – Square of scaling parameter of input.
- eps (float) – Epsilon value for numerical stability.
- use_cudnn (bool) – If True and cuDNN is enabled, then this function uses cuDNN as the core implementation.

See also:

functions.batch_normalization(), links.BatchNormalization

local_response_normalization

chainer.functions.local_response_normalization(x, n=5, k=2, alpha=0.0001, beta=0.75)

Local response normalization across neighboring channels.

This function implements normalization across channels. Let $x$ an input image with $N$ channels. Then, this function computes an output image $y$ by following formula:

$$y_i = \frac{x_i}{\left( k + \alpha \sum_{j=\max(1, i-n/2)}^{\min(N, i+n/2)} x_j^2 \right)^{\beta}}.$$ 

Parameters

- x (Variable) – Input variable.
- n (int) – Normalization window width.
- k (float) – Smoothing parameter.
- alpha (float) – Normalizer scaling parameter.
- beta (float) – Normalizer power parameter.

Returns Output variable.

Return type Variable

See: Section 3.3 of ImageNet Classification with Deep Convolutional Neural Networks
normalize

chainer.functions.normalize(x, eps=1e-05)
L2 norm squared (a.k.a. Euclidean norm).

This function implements L2 normalization on a 1D vector. No reduction is done along the batch axis. Let $x$ be an input vector of dimension $(N, K)$, where $N$ and $K$ denote mini-batch size and the dimension of the input variable. Then, this function computes an output vector $y$ by the following equation:

$$y_i = \frac{x_i}{\|x_i\|_2}$$

$\epsilon$ is used to avoid division by zero when $x_i = 0$

**Parameters**
- $x$ (Variable) – Two dimensional output variable. The first dimension is assumed to be the mini-batch dimension.
- $\epsilon$ (float) – Epsilon value for numerical stability.

**Returns** Two dimensional output variable, the same shape as $x$.

**Return type** Variable

### 3.4.9 Spatial pooling

average_pooling_2d

chainer.functions.average_pooling_2d(x, ksize=None, stride=None, pad=0, use_cudnn=True)
Spatial average pooling function.

This function acts similarly to Convolution2D, but it computes the average of input spatial patch for each channel without any parameter instead of computing the inner products.

**Parameters**
- $x$ (Variable) – Input variable.
- ksize (int or pair of ints) – Size of pooling window. ksize=k and ksize=(k, k) are equivalent.
- stride (int or pair of ints or None) – Stride of pooling applications. stride=s and stride=(s, s) are equivalent. If None is specified, then it uses same stride as the pooling window size.
- pad (int or pair of ints) – Spatial padding width for the input array. pad=p and pad=(p, p) are equivalent.
- use_cudnn (bool) – If True and cuDNN is enabled, then this function uses cuDNN as the core implementation.

**Returns** Output variable.

**Return type** Variable

**Note:** This function currently does not support cover_all mode as max_pooling_2d(). Average pooling runs in non-cover-all mode.
**max_pooling_2d**

```python
chainer.functions.max_pooling_2d(x, ksize, stride=None, pad=0, cover_all=True, use_cudnn=True)
```

Spatial max pooling function.

This function acts similarly to Convolution2D, but it computes the maximum of input spatial patch for each channel without any parameter instead of computing the inner products.

**Parameters**

- **x (Variable)** – Input variable.
- **ksize (int or pair of ints)** – Size of pooling window. ksize=k and ksize=(k, k) are equivalent.
- **stride (int or pair of ints or None)** – Stride of pooling applications. stride=s and stride=(s, s) are equivalent. If None is specified, then it uses same stride as the pooling window size.
- **pad (int or pair of ints)** – Spatial padding width for the input array. pad=p and pad=(p, p) are equivalent.
- **cover_all (bool)** – If True, all spatial locations are pooled into some output pixels. It may make the output size larger.
- **use_cudnn (bool)** – If True and cuDNN is enabled, then this function uses cuDNN as the core implementation.

**Returns** Output variable.

**Return type** Variable

---

**roi_pooling_2d**

```python
chainer.functions.roi_pooling_2d(x, rois, outh, outw, spatial_scale)
```

Spatial Region of Interest (ROI) pooling function.

This function acts similarly to MaxPooling2D, but it computes the maximum of input spatial patch for each channel with the region of interest.

**Parameters**

- **x (Variable)** – Input variable. The shape is expected to be 4 dimensional: (n: batch, c: channel, h, height, w: width).
- **rois (Variable)** – Input roi variable. The shape is expected to be (n: data size, 5), and each datum is set as below: (batch_index, x_min, y_min, x_max, y_max).
- **outh (int)** – Height of output image after pooled.
- **outw (int)** – Width of output image after pooled.
- **spatial_scale (float)** – Scale of the roi is resized.

**Returns** Output variable.

**Return type** Variable

See the original paper proposing ROIPooling: Fast R-CNN.
spatial_pyramid_pooling_2d

chainer.functions.spatial_pyramid_pooling_2d(x, pyramid_height, pooling_class, use_cudnn=True)

Spatial pyramid pooling function.

It outputs a fixed-length vector regardless of input feature map size.

It performs pooling operation to the input 4D-array x with different kernel sizes and padding sizes, and then flattens all dimensions except first dimension of all pooling results, and finally concatenates them along second dimension.

At i-th pyramid level, the kernel size \((k_h^{(i)}, k_w^{(i)})\) and padding size \((p_h^{(i)}, p_w^{(i)})\) of pooling operation are calculated as below:

\[
\begin{align*}
    k_h^{(i)} &= \lceil b_h / 2^i \rceil, \\
    k_w^{(i)} &= \lceil b_w / 2^i \rceil, \\
    p_h^{(i)} &= (2^i k_h^{(i)} - b_h) / 2, \\
    p_w^{(i)} &= (2^i k_w^{(i)} - b_w) / 2,
\end{align*}
\]

where \(\lceil \cdot \rceil\) denotes the ceiling function, and \(b_h, b_w\) are height and width of input variable \(x\), respectively. Note that index of pyramid level \(i\) is zero-based.


Parameters

- \(x\) (Variable) – Input variable. The shape of \(x\) should be \((\text{batchsize}, \# \text{ of channels}, \text{height}, \text{width})\).
- \(\text{pyramid_height}\) (int) – Number of pyramid levels
- \(\text{pooling_class}\) (MaxPooling2D or AveragePooling2D) – Only MaxPooling2D class can be available for now.
- \(\text{use_cudnn}\) (bool) – If True and cuDNN is enabled, then this function uses cuDNN as the core implementation.

Returns

Output variable. The shape of the output variable will be \((\text{batchsize}, c \sum_{h=0}^{H-1} 2^h, 1, 1)\), where \(c\) is the number of channels of input variable \(x\) and \(H\) is the number of pyramid levels.

Return type

Variable

Note:
This function uses some pooling classes as components to perform spatial pyramid pooling. Now it supports only MaxPooling2D as elemental pooling operator so far.

unpooling_2d

chainer.functions.unpooling_2d(x, ksize, stride=None, pad=0, outsize=None, cover_all=True)

Inverse operation of pooling for 2d array.

This function acts similarly to \text{Deconvolution2D}, but it spreads input 2d array’s value without any parameter instead of computing the inner products.

Parameters

- \(x\) (Variable) – Input variable.
• **ksize** (*int or pair of ints*) — Size of pooling window. `ksize=k` and `ksize=(k, k)` are equivalent.

• **stride** (*int, pair of ints or None*) — Stride of pooling applications. `stride=s` and `stride=(s, s)` are equivalent. If None is specified, then it uses same stride as the pooling window size.

• **pad** (*int or pair of ints*) — Spatial padding width for the input array. `pad=p` and `pad=(p, p)` are equivalent.

• **outsize** (*None or pair of ints*) — Expected output size (height, width) of array after the operation. If None, the size (height or width) is estimated from the size of input array in first batch with `get_deconv_outsize()`. If `outsize` is not None, the result of `outsize` applied to `get_conv_outsize()` must be equal to the shape of the 2d array in the input batch.

• **cover_all** (*bool*) — If True, the output size may be smaller than the size if `cover_all` is False. This flag serves to align behavior to the pooling functions which can cover all input locations, see `max_pooling_2d()` and `convolution_2d()`.

**Returns** Output variable.

**Return type** `Variable`

### 3.4.10 Utility functions

#### forget

```python
cranel.functions.forget(func, *xs)
```

Call a function without storing internal results.

On a forward propagation Chainer stores all internal results of `Function` on a computational graph as they are required on backward-propagation. These results consume too much memory when the internal results are too large. This method `forgets` such internal results on forward propagation, and still supports back-propagation with recalculation.

In a forward propagation, this method calls a given function with given variables without creating a computational graph. That means, no internal results are stored. In a backward propagation this method calls the given function again to create a computational graph to execute back-propagation.

This method reduces internal memory usage. Instead it requires more calculation time as it calls the function twice.

**Example**

Let `f` be a function defined as:

```python
>>> def f(a, b):
...   return a + b + a
```

and, `x` and `y` be `Variable`:

```python
>>> x = chainer.Variable(np.random.uniform(-1, 1, 5).astype('f'))
>>> y = chainer.Variable(np.random.uniform(-1, 1, 5).astype('f'))
```

When `z` is calculated as `z = f(x, y)`, its internal result `x + y` is stored in memory. Instead if you call `f` with `forget()`:

```python
```
```python
>>> z = F.forget(f, x, y)
```

internal $x + y$ is forgotten.

**Note:** The method does not support functions behaving randomly, such as `dropout()` and `negative_sampling()`. It is because first results of these function differ from the second one.

**Parameters**

- `func (callable)` - A function to call. It needs to be called with `Variable` object(s) and to return a `Variable` object or a tuple of `Variable` objects.
- `xs (Variable)` - Argument variables of the function.

**Returns** A variable `func` returns. If it returns a tuple, the method returns a tuple too.

**Return type** `Variable`

### 3.5 Standard Link implementations

Chainer provides many `Link` implementations in the `chainer.links` package.

**Note:** Some of the links are originally defined in the `chainer.functions` namespace. They are still left in the namespace for backward compatibility, though it is strongly recommended to use them via the `chainer.links` package.

#### 3.5.1 Learnable connections

**Bias**

```python
class chainer.links.Bias(axis=1, shape=None)
```

Broadcasted elementwise summation with learnable parameters.

Computes a elementwise summation as `bias()` function does except that its second input is a learnable bias parameter $b$ the link has.

**Parameters**

- `axis (int)` - The first axis of the first input of `bias()` function along which its second input is applied.
- `shape (tuple of ints)` - Shape of the learnable bias parameter. If `None`, this link does not have learnable parameters so an explicit bias needs to be given to its `__call__` method’s second input.

**See also:**

See `bias()` for details.

**Variables** $b (Variable)$ - Bias parameter if `shape` is given. Otherwise, no attributes.
__call__(*xs)
Applies broadcasted elementwise summation.

Parameters

**xs** (list of Variables) – Input variables whose length should be one if the
link has a learnable bias parameter, otherwise should be two.

Bilinear

class chainer.links.Bilinear(left_size, right_size, out_size, nobias=False, initialW=None, initial_bias=None)

Bilinear layer that performs tensor multiplication.

Bilinear is a primitive link that wraps the *bilinear()* functions. It holds parameters \(W, V_1, V_2,\) and \(b\) corresponding to the arguments of *bilinear()*.

Parameters

- **left_size** (int) – Dimension of input vector \(e^1 (J)\)
- **right_size** (int) – Dimension of input vector \(e^2 (K)\)
- **out_size** (int) – Dimension of output vector \(y (L)\)
- **nobias** (bool) – If True, parameters \(V_1, V_2,\) and \(b\) are omitted.
- **initialW** (3-D numpy array) – Initial value of \(W\). Shape of this argument must be \(\text{(left_size, right_size, out_size)}\). If None, \(W\) is initialized by centered Gaussian distribution properly scaled according to the dimension of inputs and outputs. May also be a callable that takes numpy.ndarray or cupy.ndarray and edits its value.
- **initial_bias** (tuple) – Initial values of \(V_1, V_2,\) and \(b\). The length this argument must be 3. Each element of this tuple must have the shapes of \(\text{(left_size, output_size)}, \text{(right_size, output_size)}\), and \(\text{(output_size,)}\), respectively. If None, \(V_1\) and \(V_2\) is initialized by scaled centered Gaussian distributions and \(b\) is set to 0. May also be a tuple of callables that take numpy.ndarray or cupy.ndarray and edit its value.

See also:

See *chainer.functions.bilinear()* for details.

Variables

- **W** (Variable) – Bilinear weight parameter.
- **V1** (Variable) – Linear weight parameter for the first argument.
- **V2** (Variable) – Linear weight parameter for the second argument.
- **b** (Variable) – Bias parameter.

__call__(e1, e2)
Applies the bilinear function to inputs and the internal parameters.

Parameters

- **e1** (Variable) – Left input.
- **e2** (Variable) – Right input.

Returns

Output variable.

Return type

Variable
**Convolution2D**

```python
class chainer.links.Convolution2D(in_channels, out_channels, ksize, stride=1, pad=0, wscale=1, bias=0, nobias=False, use_cudnn=True, initialW=None, initial_bias=None, deterministic=False)
```

Two-dimensional convolutional layer.

This link wraps the `convolution_2d()` function and holds the filter weight and bias vector as parameters.

**Parameters**

- `in_channels (int)` – Number of channels of input arrays. If `None`, parameter initialization will be deferred until the first forward data pass at which time the size will be determined.
- `out_channels (int)` – Number of channels of output arrays.
- `ksize (int or pair of ints)` – Size of filters (a.k.a. kernels). `ksize=k` and `ksize=(k, k)` are equivalent.
- `stride (int or pair of ints)` – Stride of filter applications. `stride=s` and `stride=(s, s)` are equivalent.
- `pad (int or pair of ints)` – Spatial padding width for input arrays. `pad=p` and `pad=(p, p)` are equivalent.
- `wscale (float)` – Scaling factor of the initial weight.
- `bias (float)` – Initial bias value.
- `nobias (bool)` – If True, then this link does not use the bias term.
- `use_cudnn (bool)` – If True, then this link uses cuDNN if available.
- `initialW (4-D array)` – Initial weight value. If `None`, then this function uses to initialize `wscale`. May also be a callable that takes `numpy.ndarray` or `cupy.ndarray` and edits its value.
- `initial_bias (1-D array)` – Initial bias value. If `None`, then this function uses to initialize `bias`. May also be a callable that takes `numpy.ndarray` or `cupy.ndarray` and edits its value.
- `deterministic (bool)` – The output of this link can be non-deterministic when it uses cuDNN. If this option is True, then it forces cuDNN to use a deterministic algorithm. This option is only available for cuDNN version >= v4.

See also:

See `chainer.functions.convolution_2d()` for the definition of two-dimensional convolution.

**Variables**

- `W (Variable)` – Weight parameter.
- `b (Variable)` – Bias parameter.

```python
__call__(x)
```

Applies the convolution layer.

**Parameters**

- `x (Variable)` – Input image.

**Returns**

Output of the convolution.

**Return type**

`Variable`
class chainer.links.ConvolutionND(ndim, in_channels, out_channels, ksize, stride=1, pad=0, initialW=None, initial_bias=None, use_cudnn=True, cover_all=False)

N-dimensional convolution layer.

This link wraps the `convolution_nd()` function and holds the filter weight and bias vector as parameters.

**Parameters**

- `ndim (int)` – Number of spatial dimensions.
- `in_channels (int)` – Number of channels of input arrays.
- `out_channels (int)` – Number of channels of output arrays.
- `ksize (int or tuple of ints)` – Size of filters (a.k.a. kernels). `ksize=k` and `ksize=(k, k, ..., k)` are equivalent.
- `stride (int or tuple of ints)` – Stride of filter application. `stride=s` and `stride=(s, s, ..., s)` are equivalent.
- `pad (int or tuple of ints)` – Spatial padding width for input arrays. `pad=p` and `pad=(p, p, ..., p)` are equivalent.
- `initialW` – Value used to initialize the filter weight. May be an initializer instance or another value that `init_weight()` helper function can take.
- `initial_bias` – Value used to initialize the bias vector. May be an initializer instance or another value except `None` that `init_weight()` helper function can take. If `None` is given, this link does not use the bias vector.
- `use_cudnn (bool)` – If `True`, then this link uses cuDNN if available. See `convolution_nd()` for exact conditions of cuDNN availability.
- `cover_all (bool)` – If `True`, all spatial locations are convoluted into some output pixels. It may make the output size larger. `cover_all` needs to be `False` if you want to use cuDNN.

See also:

See `convolution_nd()` for the definition of N-dimensional convolution. See `convolution_2d()` for the definition of two-dimensional convolution.

**Variables**

- `W (Variable)` – Weight parameter.
- `b (Variable)` – Bias parameter. If `initial_bias` is `None`, set to `None`.

**`__call__`(x)**

Applies N-dimensional convolution layer.

**Parameters** `x (Variable)` – Input image.

**Returns** Output of convolution.

**Return type** `Variable`
Deconvolution2D

class chainer.links.Deconvolution2D(in_channels, out_channels, ksize, stride=1, pad=0, wscale=1, bias=0, nobias=False, outsize=None, use_cudnn=True, initialW=None, initial_bias=None, deterministic=False)

Two dimensional deconvolution function.

This link wraps the deconvolution_2d() function and holds the filter weight and bias vector as parameters.

Parameters

- in_channels (int) – Number of channels of input arrays. If None, parameter initialization will be deferred until the first forward data pass at which time the size will be determined.

- out_channels (int) – Number of channels of output arrays.

- ksize (int or pair of ints) – Size of filters (a.k.a. kernels). ksize=k and ksize=(k, k) are equivalent.

- stride (int or pair of ints) – Stride of filter applications. stride=s and stride=(s, s) are equivalent.

- pad (int or pair of ints) – Spatial padding width for input arrays. pad=p and pad=(p, p) are equivalent.

- wscale (float) – Scaling factor of the initial weight.

- bias (float) – Initial bias value.

- nobias (bool) – If True, then this function does not use the bias term.

- outsize (tuple) – Expected output size of deconvolutional operation. It should be pair of height and width (out_H, out_W). Default value is None and the outsize is estimated by input size, stride and pad.

- use_cudnn (bool) – If True, then this function uses cuDNN if available.

- initialW (4-D array) – Initial weight value. If None, then this function uses to initialize wscale. May also be a callable that takes numpy.ndarray or cupy.ndarray and edits its value.

- initial_bias (1-D array) – Initial bias value. If None, then this function uses to initialize bias. May also be a callable that takes numpy.ndarray or cupy.ndarray and edits its value.

- deterministic (bool) – The output of this link can be non-deterministic when it uses cuDNN. If this option is True, then it forces cuDNN to use a deterministic algorithm. This option is only available for cuDNN version >= v4.

The filter weight has four dimensions (c_I, c_O, k_H, k_W) which indicate the number of input channels, output channels, height and width of the kernels, respectively. The filter weight is initialized with i.i.d. Gaussian random samples, each of which has zero mean and deviation $\sqrt{1/(c_I k_H k_W)}$ by default. The deviation is scaled by wscale if specified.

The bias vector is of size c_O. Its elements are initialized by bias argument. If nobias argument is set to True, then this function does not hold the bias parameter.

See also:

See chainer.functions.deconvolution_2d() for the definition of two-dimensional convolution.
DeconvolutionND

```python
class chainer.links.DeconvolutionND(ndim, in_channels, out_channels, ksize, stride=1, pad=0, outsize=None, initialW=None, initial_bias=0, use_cudnn=True)
```

N-dimensional deconvolution function.

This link wraps `deconvolution_nd()` function and holds the filter weight and bias vector as its parameters.

**Parameters**

- `ndim (int)` – Number of spatial dimensions.
- `in_channels (int)` – Number of channels of input arrays.
- `out_channels (int)` – Number of channels of output arrays.
- `ksize (int or tuple of ints)` – Size of filters (a.k.a. kernels). `ksize=k` and `ksize=(k, k, ..., k)` are equivalent.
- `stride (int or tuple of ints)` – Stride of filter application. `stride=s` and `stride=(s, s, ..., s)` are equivalent.
- `pad (int or tuple of ints)` – Spatial padding width for input arrays. `pad=p` and `pad=(p, p, ..., p)` are equivalent.
- `outsize (tuple of ints)` – Expected output size of deconvolutional operation. It should be a tuple of ints that represents the output size of each dimension. Default value is `None` and the outsize is estimated with input size, stride and pad.
- `initialW` – Value used to initialize the filter weight. May be an initializer instance of another value the same with that `init_weight()` function can take.
- `initial_bias` – Value used to initialize the bias vector. May be an initializer instance or another value except `None` the same with that `init_weight()` function can take. If `None` is supplied, this link does not use the bias vector.
- `use_cudnn (bool)` – If `True`, then this link uses cuDNN if available.

**See also:**

`deconvolution_nd()`

**Variables**

- `W (Variable)` – Weight parameter.
- `b (Variable)` – Bias parameter. If `initial_bias` is `None`, set to `None`.

DilatedConvolution2D

```python
class chainer.links.DilatedConvolution2D(in_channels, out_channels, ksize, stride=1, pad=0, dilate=1, wscale=1, bias=0, nobias=False, use_cudnn=True, initialW=None, initial_bias=None)
```

Two-dimensional dilated convolutional layer.

This link wraps the `dilated_convolution_2d()` function and holds the filter weight and bias vector as parameters.

**Parameters**
• **in_channels** (*int*) – Number of channels of input arrays. If None, parameter initialization will be deferred until the first forward data pass at which time the size will be determined.

• **out_channels** (*int*) – Number of channels of output arrays.

• **ksize** (*int or pair of ints*) – Size of filters (a.k.a. kernels). ksize=k and ksize=(k, k) are equivalent.

• **stride** (*int or pair of ints*) – Stride of filter applications. stride=s and stride=(s, s) are equivalent.

• **pad** (*int or pair of ints*) – Spatial padding width for input arrays. pad=p and pad=(p, p) are equivalent.

• **dilate** (*int or pair of ints*) – Dilation factor of filter applications. dilate=d and dilate=(d, d) are equivalent.

• **wscale** (*float*) – Scaling factor of the initial weight.

• **bias** (*float*) – Initial bias value.

• **nobias** (*bool*) – If True, then this link does not use the bias term.

• **use_cudnn** (*bool*) – If True, then this link uses cuDNN if available.

• **initialW** (*4-D array*) – Initial weight value. If None, then this function uses to initialize wscale. May also be a callable that takes numpy.ndarray or cupy.ndarray and edits its value.

• **initial_bias** (*1-D array*) – Initial bias value. If None, then this function uses to initialize bias. May also be a callable that takes numpy.ndarray or cupy.ndarray and edits its value.

See also:

See chainer.functions.dilated_convolution_2d() for the definition of two-dimensional dilated convolution.

Variables

• W (*Variable*) – Weight parameter.

• b (*Variable*) – Bias parameter.

```python
__call__(x)
```

Applies the convolution layer.

Parameters

**x** (*Variable*) – Input image.

Returns

Output of the convolution.

Return type

*Variable*

---

**EmbedID**

class chainer.links.EmbedID (*in_size, out_size, initialW=None, ignore_label=None*)

Efficient linear layer for one-hot input.

This is a link that wraps the embed_id() function. This link holds the ID (word) embedding matrix \( \mathbf{W} \) as a parameter.

Parameters
• **in_size** (*int*) – Number of different identifiers (a.k.a. vocabulary size).
• **out_size** (*int*) – Size of embedding vector.
• **initialW** (*2-D array*) – Initial weight value. If None, then the matrix is initialized from the standard normal distribution. May also be a callable that takes `numpy.ndarray` or `cupy.ndarray` and edits its value.
• **ignore_label** (*int or None*) – If ignore_label is an int value, i-th column of return value is filled with 0.

See also:

`chainer.functions.embed_id()`

**Variables**

*W* (*Variable*) – Embedding parameter matrix.

**__call__**(*x*)

Extracts the word embedding of given IDs.

**Parameters**

*x* (*Variable*) – Batch vectors of IDs.

**Returns**

Batch of corresponding embeddings.

**Return type**

*Variable*

**GRU**

```python
class chainer.links.GRU(n_units, n_inputs=None, init=None, inner_init=None, bias_init=0)
```

Stateless Gated Recurrent Unit function (GRU).

GRU function has six parameters $W_r, W_z, W, U_r, U_z$, and $U$. All these parameters are $n \times n$ matrices, where $n$ is the dimension of hidden vectors.

Given two inputs a previous hidden vector $h$ and an input vector $x$, GRU returns the next hidden vector $h'$ defined as

$$
    r = \sigma(W_r x + U_r h), \quad z = \sigma(W_z x + U_z h), \quad \bar{h} = \tanh(W x + U(r \odot h)), \quad h' = (1 - z) \odot h + z \odot \bar{h},
$$

where $\sigma$ is the sigmoid function, and $\odot$ is the element-wise product.

GRU does not hold the value of hidden vector $h$. So this is stateless. Use `StatefulGRU` as a stateful GRU.

**Parameters**

• **n_units** (*int*) – Dimension of hidden vector $h$.

• **n_inputs** (*int*) – Dimension of input vector $x$. If None, it is set to the same value as n_units.

See:

• On the Properties of Neural Machine Translation: Encoder-Decoder Approaches [Cho+, SSST2014].
• Empirical Evaluation of Gated Recurrent Neural Networks on Sequence Modeling [Chung+NIPS2014 DLWorkshop].

See also:

StatefulGRU

Highway

class chainer.links.Highway(in_out_size, nobias=False, activate=<function relu>, init_Wh=None, init_Wt=None, init_bh=None, init_bt=-1)

Highway module.

In highway network, two gates are added to the ordinal non-linear transformation \( H(x) = \text{activate}(W_h x + b_h) \). One gate is the transform gate \( T(x) = \sigma(W_t x + b_t) \), and the other is the carry gate \( C(x) \). For simplicity, the author defined \( C = 1 - T \). Highway module returns \( y \) defined as

\[
y = \text{activate}(W_h x + b_h) \odot \sigma(W_t x + b_t) + x \odot (1 - \sigma(W_t x + b_t))
\]

The output array has the same spatial size as the input. In order to satisfy this, \( W_h \) and \( W_t \) must be square matrices.

Parameters

• \textbf{in\_out\_size (int)} – Dimension of input and output vectors.

• \textbf{nobias (bool)} – If True, then this function does not use the bias.

• \textbf{activate} – Activation function of plain array. \texttt{tanh} is also available.

• \textbf{init\_Wh (2-D array)} – Initial weight value of plain array. If None, then this function uses it to initialize \texttt{wscale}. May also be a callable that takes \texttt{numpy.ndarray} or \texttt{cupy.ndarray} and edits its value.

• \textbf{init\_bh (1-D array)} – Initial bias value of plain array. If None, then this function uses it to initialize zero vector. May also be a callable that takes \texttt{numpy.ndarray} or \texttt{cupy.ndarray} and edits its value.

• \textbf{init\_Wt (2-D array)} – Initial weight value of transform array. If None, then this function uses it to initialize \texttt{wscale}. May also be a callable that takes \texttt{numpy.ndarray} or \texttt{cupy.ndarray} and edits its value.

• \textbf{init\_bt (1-D array)} – Initial bias value of transform array. Default value is -1 vector. May also be a callable that takes \texttt{numpy.ndarray} or \texttt{cupy.ndarray} and edits its value. Negative value is recommended by the author of the paper. (e.g. -1, -3, ...).

See: Highway Networks.

\_\_call\_\_ (x)

Computes the output of the Highway module.

Parameters \textbf{x (Variable)} – Input variable.

Returns Output variable. Its array has the same spatial size and the same minibatch size as the input array.

Return type \texttt{Variable}

3.5. Standard Link implementations 137
Inception

```python
class chainer.links.Inception(in_channels, out1, proj3, out3, proj5, out5, proj_pool,
                        conv_init=None, bias_init=None)
```

Inception module of GoogLeNet.

It applies four different functions to the input array and concatenates their outputs along the channel dimension. Three of them are 2D convolutions of sizes 1x1, 3x3 and 5x5. Convolution paths of 3x3 and 5x5 sizes have 1x1 convolutions (called projections) ahead of them. The other path consists of 1x1 convolution (projection) and 3x3 max pooling.

The output array has the same spatial size as the input. In order to satisfy this, Inception module uses appropriate padding for each convolution and pooling.

See: Going Deeper with Convolutions.

Parameters

- **in_channels (int)** – Number of channels of input arrays.
- **out1 (int)** – Output size of 1x1 convolution path.
- **proj3 (int)** – Projection size of 3x3 convolution path.
- **out3 (int)** – Output size of 3x3 convolution path.
- **proj5 (int)** – Projection size of 5x5 convolution path.
- **out5 (int)** – Output size of 5x5 convolution path.
- **proj_pool (int)** – Projection size of max pooling path.
- **conv_init** – A callable that takes `numpy.ndarray` or `cupy.ndarray` and edits its value. It is used for initialization of the convolution matrix weights. Maybe be `None` to use default initialization.
- **bias_init** – A callable that takes `numpy.ndarray` or `cupy.ndarray` and edits its value. It is used for initialization of the convolution bias weights. Maybe be `None` to use default initialization.

```python
__call__(x)
```

Computes the output of the Inception module.

Parameters **x (Variable)** – Input variable.

Returns Output variable. Its array has the same spatial size and the same minibatch size as the input array. The channel dimension has size `out1 + out3 + out5 + proj_pool`.

Return type **Variable**

InceptionBN

```python
class chainer.links.InceptionBN(in_channels, out1, proj3, out3, proj33, out33, pooltype,
                        proj_pool=None, stride=1, conv_init=None, dtype=<type 'numpy.float32'>)
```

Inception module of the new GoogLeNet with BatchNormalization.

This chain acts like Inception, while InceptionBN uses the BatchNormalization on top of each convolution, the 5x5 convolution path is replaced by two consecutive 3x3 convolution applications, and the pooling method is configurable.


Parameters
• **in_channels** *(int)* – Number of channels of input arrays.
• **out1** *(int)* – Output size of the 1x1 convolution path.
• **proj3** *(int)* – Projection size of the single 3x3 convolution path.
• **out3** *(int)* – Output size of the single 3x3 convolution path.
• **proj33** *(int)* – Projection size of the double 3x3 convolutions path.
• **out33** *(int)* – Output size of the double 3x3 convolutions path.
• **pooltype** *(str)* – Pooling type. It must be either ’max’ or ’avg’.
• **proj_pool** *(bool)* – If True, do projection in the pooling path.
• **stride** *(int)* – Stride parameter of the last convolution of each path.
• **conv_init** – A callable that takes `numpy.ndarray` or `cupy.ndarray` and edits its value. It is used for initialization of the convolution matrix weights. Maybe be `None` to use default initialization.
• **dtype** *(`numpy.dtype`)* – Type to use in `~batch_normalization.BatchNormalization`.

See also:

*Inception*

**Variables**

• **train** *(bool)* – If True, then batch normalization layers are used in training mode. If False, they are used in testing mode.

*Linear*

class `chainer.links.Linear(in_size, out_size, wscale=1, bias=0, nobias=False, initialW=None, initial_bias=None)`

Linear layer (a.k.a. fully-connected layer).

This is a link that wraps the `linear()` function, and holds a weight matrix $W$ and optionally a bias vector $b$ as parameters.

The weight matrix $W$ is initialized with i.i.d. Gaussian samples, each of which has zero mean and deviation $\sqrt{1/n}$

Parameters

• **in_size** *(int)* – Dimension of input vectors. If None, parameter initialization will be deferred until the first forward data pass at which time the size will be determined.
• **out_size** *(int)* – Dimension of output vectors.
• **wscale** *(float)* – Scaling factor of the weight matrix.
• **bias** *(float)* – Initial bias value.
• **nobias** *(bool)* – If True, then this function does not use the bias.
• **initialW** *(2-D array)* – Initial weight value. If None, then this function uses to initialize wscale. May also be a callable that takes `numpy.ndarray` or `cupy.ndarray` and edits its value.
• **initial_bias** *(1-D array)* – Initial bias value. If None, then this function uses to initialize bias. May also be a callable that takes `numpy.ndarray` or `cupy.ndarray` and edits its value.

See also:

*linear()

**Variables**

• **W** *(Variable)* – Weight parameter.
• **b** *(Variable)* – Bias parameter.
__call__(x)
Applies the linear layer.

Parameters

- **x** (*Variable*) – Batch of input vectors.

Returns

Output of the linear layer.

Return type

*Variable*

## LSTM

**class chainer.links.LSTM(in_size, out_size, **kwargs)**

Fully-connected LSTM layer.

This is a fully-connected LSTM layer as a chain. Unlike the `lstm()` function, which is defined as a stateless activation function, this chain holds upward and lateral connections as child links.

It also maintains states, including the cell state and the output at the previous time step. Therefore, it can be used as a *stateful LSTM*.

This link supports variable length inputs. The mini-batch size of the current input must be equal to or smaller than that of the previous one. The mini-batch size of \(c\) and \(h\) is determined as that of the first input \(x\). When mini-batch size of \(i\)-th input is smaller than that of the previous input, this link only updates \(c[0:len(x)]\) and \(h[0:len(x)]\) and doesn’t change the rest of \(c\) and \(h\). So, please sort input sequences in descending order of lengths before applying the function.

**Parameters**

- **in_size** (*int*) – Dimension of input vectors. If None, parameter initialization will be deferred until the first forward data pass at which time the size will be determined.

- **out_size** (*int*) – Dimensionality of output vectors.

- **lateral_init** – A callable that takes *ndarray* and edits its value. It is used for initialization of the lateral connections. Maybe be None to use default initialization.

- **upward_init** – A callable that takes *ndarray* and edits its value. It is used for initialization of the upward connections. Maybe be None to use default initialization.

- **bias_init** – A callable that takes *ndarray* and edits its value. It is used for initialization of the biases of cell input, input gate and output gate and gates of the upward connection. Maybe a scalar, in that case, the bias is initialized by this value. Maybe be None to use default initialization.

- **forget_bias_init** – A callable that takes *ndarray* and edits its value. It is used for initialization of the biases of the forget gate of the upward connection. Maybe a scalar, in that case, the bias is initialized by this value. Maybe be None to use default initialization.

**Variables**

- **upward** (*Linear*) – Linear layer of upward connections.

- **lateral** (*Linear*) – Linear layer of lateral connections.

- **c** (*Variable*) – Cell states of LSTM units.

- **h** (*Variable*) – Output at the previous time step.

__call__(x)
Updates the internal state and returns the LSTM outputs.
Parameters $x$ (Variable) – A new batch from the input sequence.

Returns Outputs of updated LSTM units.

Return type Variable

reset_state ()
Resets the internal state.
It sets None to the $c$ and $h$ attributes.

set_state $(c, h)$
Sets the internal state.
It sets the $c$ and $h$ attributes.

Parameters

- $c$ (Variable) – A new cell states of LSTM units.
- $h$ (Variable) – A new output at the previous time step.

MLPConvolution2D

class chainer.links.MLPConvolution2D (in_channels, out_channels, ksize, stride=1, pad=0, wscale=1, activation=<function relu>, use_cudnn=True, conv_init=None, bias_init=None)

Two-dimensional MLP convolution layer of Network in Network.

This is an “mlpconv” layer from the Network in Network paper. This layer is a two-dimensional convolution layer followed by 1x1 convolution layers and interleaved activation functions.

Note that it does not apply the activation function to the output of the last 1x1 convolution layer.

Parameters

- in_channels (int) – Number of channels of input arrays.
- out_channels (tuple of ints) – Tuple of number of channels. The i-th integer indicates the number of filters of the i-th convolution.
- ksize (int or pair of ints) – Size of filters (a.k.a. kernels) of the first convolution layer. ksize=k and ksize=(k, k) are equivalent.
- stride (int or pair of ints) – Stride of filter applications at the first convolution layer. stride=s and stride=(s, s) are equivalent.
- pad (int or pair of ints) – Spatial padding width for input arrays at the first convolution layer. pad=p and pad=(p, p) are equivalent.
- activation (function) – Activation function for internal hidden units. Note that this function is not applied to the output of this link.
- use_cudnn (bool) – If True, then this link uses cuDNN if available.
- conv_init – An initializer of weight matrices passed to the convolution layers.
- bias_init – An initializer of bias vectors passed to the convolution layers.


Variables activation (function) – Activation function.

__call__ $(x)$
Computes the output of the mlpconv layer.
Parameters $x$ (Variable) – Input image.

Returns Output of the mlpconv layer.

Return type Variable

Scale

```python
class chainer.links.Scale(axis=1, W_shape=None, bias_term=False, bias_shape=None)
    Broadcasted elementwise product with learnable parameters.
    Computes a elementwise product as scale() function does except that its second input is a learnable weight parameter $W$ the link has.

    Parameters
    • axis (int) – The first axis of the first input of scale() function along which its second input is applied.
    • W_shape (tuple of ints) – Shape of learnable weight parameter. If None, this link does not have learnable weight parameter so an explicit weight needs to be given to its __call__ method’s second input.
    • bias_term (bool) – Whether to also learn a bias (equivalent to Scale link + Bias link).
    • bias_shape (tuple of ints) – Shape of learnable bias. If W_shape is None, this should be given to determine the shape. Otherwise, the bias has the same shape W_shape with the weight parameter and bias_shape is ignored.

    See also:
    See scale() for details.

    Variables
    • W (Variable) – Weight parameter if W_shape is given. Otherwise, no W attribute.
    • bias (Bias) – Bias term if bias_term is True. Otherwise, no bias attribute.

    __call__(*xs)
    Applies broadcasted elementwise product.
    Parameters xs (list of Variables) – Input variables whose length should be one if the link has a learnable weight parameter, otherwise should be two.
```

StatefulGRU

```python
class chainer.links.StatefulGRU(in_size, out_size, init=None, inner_init=None, bias_init=0)
    Stateful Gated Recurrent Unit function (GRU).
    Stateful GRU function has six parameters $W_r$, $W_z$, $W$, $U_r$, $U_z$, and $U$. All these parameters are $n \times n$ matrices, where $n$ is the dimension of hidden vectors.
```
Given input vector $x$, Stateful GRU returns the next hidden vector $h'$ defined as

\[ r = \sigma(W_r x + U_r h), \]
\[ z = \sigma(W_z x + U_z h), \]
\[ \overline{h} = \tanh(W x + U (r \odot h)), \]
\[ h' = (1 - z) \odot h + z \odot \overline{h}, \]

where $h$ is current hidden vector.

As the name indicates, StatefulGRU is stateful, meaning that it also holds the next hidden vector $h'$ as a state. Use GRU as a stateless version of GRU.

**Parameters**

- **in_size (int)** – Dimension of input vector $x$.
- **out_size (int)** – Dimension of hidden vector $h$.
- **init** – A callable that takes `numpy.ndarray` or `cupy.ndarray` and edits its value. It is used for initialization of the GRU’s input units ($W$). Maybe be `None` to use default initialization.
- **inner_init** – A callable that takes `numpy.ndarray` or `cupy.ndarray` and edits its value. It is used for initialization of the GRU’s inner recurrent units ($U$). Maybe be `None` to use default initialization.
- **bias_init** – A callable or scalar used to initialize the bias values for both the GRU’s inner and input units. Maybe be `None` to use default initialization.

**Variables**

- **h (Variable)** – Hidden vector that indicates the state of StatefulGRU.

**See also:**

GRU

**StatefulPeepholeLSTM**

```python
class chainer.links.StatefulPeepholeLSTM(in_size, out_size)
```

Fully-connected LSTM layer with peephole connections.

This is a fully-connected LSTM layer with peephole connections as a chain. Unlike the LSTM link, this chain holds `peep_i`, `peep_f` and `peep_o` as child links besides `upward` and `lateral`.  

3.5. Standard Link implementations

143
Given a input vector \( x \), Peephole returns the next hidden vector \( h' \) defined as

\[
\begin{align*}
    a &= \tanh(upward x + lateral h), \\
    i &= \sigma(upward x + lateral h + peep_i c), \\
    f &= \sigma(upward x + lateral h + peep_f c), \\
    c' &= a \odot i + f \odot c, \\
    o &= \sigma(upward x + lateral h + peep_o c'), \\
    h' &= o \tanh(c'),
\end{align*}
\]

where \( \sigma \) is the sigmoid function, \( \odot \) is the element-wise product, \( c \) is the current cell state, \( c' \) is the next cell state and \( h \) is the current hidden vector.

**Parameters**

- **in_size** (int) – Dimension of the input vector \( x \).
- **out_size** (int) – Dimension of the hidden vector \( h \).

**Variables**

- **upward** (Linear) – Linear layer of upward connections.
- **lateral** (Linear) – Linear layer of lateral connections.
- **peep_i** (Linear) – Linear layer of peephole connections to the input gate.
- **peep_f** (Linear) – Linear layer of peephole connections to the forget gate.
- **peep_o** (Linear) – Linear layer of peephole connections to the output gate.
- **c** (Variable) – Cell states of LSTM units.
- **h** (Variable) – Output at the current time step.

**__call__(x)**

Updates the internal state and returns the LSTM outputs.

- **Parameters** \( x \) (Variable) – A new batch from the input sequence.
- **Returns** Outputs of updated LSTM units.
- **Return type** Variable

**reset_state()**

Resets the internal states.

It sets \( \text{None} \) to the \( c \) and \( h \) attributes.

**StatelessLSTM**

```python
class chainer.links.StatelessLSTM(in_size, out_size, lateral_init=None, upward_init=None, bias_init=0, forget_bias_init=0)
```

Stateless LSTM layer.
This is a fully-connected LSTM layer as a chain. Unlike the lstm() function, this chain holds upward and lateral connections as child links. This link doesn’t keep cell and hidden states.

**Parameters**

- `in_size (int)` – Dimension of input vectors. If None, parameter initialization will be deferred until the first forward data pass at which time the size will be determined.
- `out_size (int)` – Dimensionality of output vectors.

**Variables**

- `upward (chainer.links.Linear)` – Linear layer of upward connections.
- `lateral (chainer.links.Linear)` – Linear layer of lateral connections.

__call__(c, h, x)

Returns new cell state and updated output of LSTM.

**Parameters**

- `c (Variable)` – Cell states of LSTM units.
- `h (Variable)` – Output at the previous time step.
- `x (Variable)` – A new batch from the input sequence.

**Returns**

Returns `(c_new, h_new)`, where `c_new` represents new cell state, and `h_new` is updated output of LSTM units.

**Return type**

tuple of ~chainer.Variable

### 3.5.2 Activation/loss/normalization functions with parameters

**BatchNormalization**

class chainer.links.BatchNormalization(size, decay=0.9, eps=2e-05, dtype=\<type ‘numpy.float32’>, use_gamma=True, use_beta=True, initial_gamma=None, initial_beta=None, use_cudnn=True)

Batch normalization layer on outputs of linear or convolution functions.

This link wraps the batch_normalization() and fixed_batch_normalization() functions.

It runs in three modes: training mode, fine-tuning mode, and testing mode.

In training mode, it normalizes the input by batch statistics. It also maintains approximated population statistics by moving averages, which can be used for instant evaluation in testing mode.

In fine-tuning mode, it accumulates the input to compute population statistics. In order to correctly compute the population statistics, a user must use this mode to feed mini-batches running through whole training dataset.

In testing mode, it uses pre-computed population statistics to normalize the input variable. The population statistics is approximated if it is computed by training mode, or accurate if it is correctly computed by fine-tuning mode.

**Parameters**

- `size (int or tuple of ints)` – Size (or shape) of channel dimensions.
- `decay (float)` – Decay rate of moving average. It is used on training.
- `eps (float)` – Epsilon value for numerical stability.
- `dtype (numpy.dtype)` – Type to use in computing.
• **use_gamma**(bool) – If True, use scaling parameter. Otherwise, use unit(1) which makes no effect.

• **use_beta**(bool) – If True, use shifting parameter. Otherwise, use unit(0) which makes no effect.

• **use_cudnn**(bool) – If True, then this link uses cuDNN if available.

See: Batch Normalization: Accelerating Deep Network Training by Reducing Internal Covariate Shift
See also:

`batch_normalization()`, `fixed_batch_normalization()`

**Variables**

• **gamma**(Variable) – Scaling parameter.

• **beta**(Variable) – Shifting parameter.

• **avg_mean**(Variable) – Population mean.

• **avg_var**(Variable) – Population variance.

• **N**(int) – Count of batches given for fine-tuning.

• **decay**(float) – Decay rate of moving average. It is used on training.

• **eps**(float) – Epsilon value for numerical stability. This value is added to the batch variances.

• **use_cudnn**(bool) – If True, then this link uses cuDNN if available.

```python
__call__(x, test=False, finetune=False)
```

Invokes the forward propagation of BatchNormalization.

BatchNormalization accepts additional arguments, which controls three different running mode.

**Parameters**

• **x**(Variable) – Input variable.

• **test**(bool) – If True, BatchNormalization runs in testing mode; it normalizes the input using pre-computed statistics.

• **finetune**(bool) – If finetune is True and test is False, BatchNormalization runs in fine-tuning mode; it accumulates the input array to compute population statistics for normalization, and normalizes the input using batch statistics.

If test is False, then BatchNormalization runs in training mode; it computes moving averages of mean and variance for evaluation during training, and normalizes the input using batch statistics.

```python
start_finetuning()
```

Resets the population count for collecting population statistics.

This method can be skipped if it is the first time to use the fine-tuning mode. Otherwise, this method should be called before starting the fine-tuning mode again.

**BinaryHierarchicalSoftmax**

class chainer.links.BinaryHierarchicalSoftmax(in_size, tree)

Hierarchical softmax layer over binary tree.
In natural language applications, vocabulary size is too large to use softmax loss. Instead, the hierarchical softmax uses product of sigmoid functions. It costs only \( O(\log(n)) \) time where \( n \) is the vocabulary size in average.

At first a user need to prepare a binary tree whose each leaf is corresponding to a word in a vocabulary. When a word \( x \) is given, exactly one path from the root of the tree to the leaf of the word exists. Let \( \text{path}(x) = ((e_1, b_1), \ldots, (e_m, b_m)) \) be the path of \( x \), where \( e_i \) is an index of \( i \)-th internal node, and \( b_i \in \{-1, 1\} \) indicates direction to move at \( i \)-th internal node (-1 is left, and 1 is right). Then, the probability of \( x \) is given as below:

\[
P(x) = \prod_{(e_i, b_i) \in \text{path}(x)} P(b_i | e_i)
= \prod_{(e_i, b_i) \in \text{path}(x)} \sigma(b_i \cdot x^\top w_{e_i}),
\]

where \( \sigma(\cdot) \) is a sigmoid function, and \( w \) is a weight matrix.

This function costs \( O(\log(n)) \) time as an average length of paths is \( O(\log(n)) \), and \( O(n) \) memory as the number of internal nodes equals \( n - 1 \).

**Parameters**

- `in_size (int)` – Dimension of input vectors.
- `tree` – A binary tree made with tuples like \(((1, 2), 3)\).

**Variables**

- `W (Variable)` – Weight parameter matrix.

See: Hierarchical Probabilistic Neural Network Language Model [Morin+, AISTAT2005].

**__call__** \((x, t)\)

Computes the loss value for given input and ground truth labels.

**Parameters**

- `x (Variable)` – Input to the classifier at each node.
- `t (Variable)` – Batch of ground truth labels.

**Returns** Loss value.

**Return type** Variable

**static create_huffman_tree** \((\text{word_counts})\)

Makes a Huffman tree from a dictionary containing word counts.

This method creates a binary Huffman tree, that is required for BinaryHierarchicalSoftmax. For example, \{0: 8, 1: 5, 2: 6, 3: 4\} is converted to \(((3, 1), (2, 0))\).

**Parameters**

- `word_counts (dict of int key and int or float values)` – Dictionary representing counts of words.

**Returns** Binary Huffman tree with tuples and keys of \( \text{word_counts} \).

**BlackOut**

**class** `chainer.links.BlackOut (in_size, counts, sample_size)`

BlackOut loss layer.

See also:

- `black_out()` for more detail.
Parameters

- **in_size (int)** – Dimension of input vectors.
- **counts (int list)** – Number of each identifiers.
- **sample_size (int)** – Number of negative samples.

Variables

- **W (Variable)** – Weight parameter matrix.

**CRF1d**

```python
class chainer.links.CRF1d(n_label)
```

Linear-chain conditional random field loss layer.

This link wraps the `crf1d()` function. It holds a transition cost matrix as a parameter.

Parameters

- **n_label (int)** – Number of labels.

See also:

`crf1d()` for more detail.

Variables

- **cost (Variable)** – Transition cost parameter.

**argmax (xs)**

Computes a state that maximizes a joint probability.

Parameters

- **xs (list of Variable)** – Input vector for each label.

Returns

A tuple of `Variable` representing each log-likelihood and a list representing the argmax path.

Return type

`tuple`

See also:

See `crf1d_argmax()` for more detail.

**PReLU**

```python
class chainer.links.PReLU(shape=(), init=0.25)
```

Parametric ReLU function as a link.

Parameters

- **shape (tuple of ints)** – Shape of the parameter array.
- **init (float)** – Initial parameter value.

See the paper for details: Delving Deep into Rectifiers: Surpassing Human-Level Performance on ImageNet Classification.

See also:

`chainer.functions.prelu()`

Variables

- **W (Variable)** – Coefficient of parametric ReLU.

**__call__ (x)**

Applies the parametric ReLU activation function.
Parameters \( x (\text{Variable}) \) – Input variable.

Returns Output of the parametric ReLU function.

Return type \( \text{Variable} \)

Maxout

class chainer.links.Maxout(\( \text{in\_size}, \text{out\_size}, \text{pool\_size}, \text{wscale}=1, \text{initialW}=\text{None}, \text{initial\_bias}=0 \))

Fully-connected maxout layer.

Let \( M, P \) and \( N \) be an input dimension, a pool size, and an output dimension, respectively. For an input vector \( x \) of size \( M \), it computes

\[
Y_i = \max_j (W_{ij} x + b_{ij}).
\]

Here \( W \) is a weight tensor of shape \( (M, P, N) \), \( b \) an optional bias vector of shape \( (M, P) \) and \( W_{ij} \) is a sub-vector extracted from \( W \) by fixing first and second dimensions to \( i \) and \( j \), respectively. Minibatch dimension is omitted in the above equation.

As for the actual implementation, this chain has a Linear link with a \( (M * P, N) \) weight matrix and an optional \( M * P \) dimensional bias vector.

Parameters

- \( \text{in\_size} (\text{int}) \) – Dimension of input vectors.
- \( \text{out\_size} (\text{int}) \) – Dimension of output vectors.
- \( \text{pool\_size} (\text{int}) \) – Number of channels.
- \( \text{wscale} (\text{float}) \) – Scaling factor of the weight matrix.
- \( \text{initialW} (\text{3-D array or None}) \) – Initial weight value. If \( \text{None} \), then this function uses \( \text{wscale} \) to initialize.
- \( \text{initial\_bias} (\text{2-D array, float or None}) \) – Initial bias value. If it is float, initial bias is filled with this value. If \( \text{None} \), bias is omitted.

Variables \( \text{linear} (\text{Link}) \) – The Linear link that performs affine transformation.

See also:

maxout()

See also:


__call__(x)

Applies the maxout layer.

Parameters \( x (\text{Variable}) \) – Batch of input vectors.

Returns Output of the maxout layer.

Return type \( \text{Variable} \)
NegativeSampling

class chainer.links.NegativeSampling(in_size, counts, sample_size, power=0.75)
Negative sampling loss layer.

This link wraps the negative_sampling() function. It holds the weight matrix as a parameter. It also builds a sampler internally given a list of word counts.

Parameters

• in_size (int) – Dimension of input vectors.
• counts (int list) – Number of each identifiers.
• sample_size (int) – Number of negative samples.
• power (float) – Power factor $\alpha$.

See also:

negative_sampling() for more detail.

Variables W (Variable) – Weight parameter matrix.

__call__(x, t)
Computes the loss value for given input and ground truth labels.

Parameters

• x (Variable) – Input of the weight matrix multiplication.
• t (Variable) – Batch of ground truth labels.

Returns Loss value.

Return type Variable

3.5.3 Machine learning models

Classifier

class chainer.links.Classifier(predictor, lossfun=<function softmax_cross_entropy>, accfunc=<function accuracy>)
A simple classifier model.

This is an example of chain that wraps another chain. It computes the loss and accuracy based on a given input/label pair.

Parameters

• predictor (Link) – Predictor network.
• lossfun (function) – Loss function.
• accfun (function) – Function that computes accuracy.

Variables

• predictor (Link) – Predictor network.
• lossfun (function) – Loss function.
• accfun (function) – Function that computes accuracy.
• \texttt{y (Variable)} – Prediction for the last minibatch.
• \texttt{loss (Variable)} – Loss value for the last minibatch.
• \texttt{accuracy (Variable)} – Accuracy for the last minibatch.
• \texttt{compute\_accuracy (bool)} – If True, compute accuracy on the forward computation. The default value is True.

__call__(\*args)
Computes the loss value for an input and label pair.
It also computes accuracy and stores it to the attribute.

\textbf{Parameters} \texttt{args (list of \texttt{-chainer.Variable})} – Input minibatch.
The all elements of \texttt{args} but last one are features and the last element corresponds to ground truth labels.
It feeds features to the predictor and compare the result with ground truth labels.

\textbf{Returns} Loss value.

\textbf{Return type} Variable

### 3.5.4 Deprecated links

\textbf{Parameter}

\textbf{class} \texttt{chainer.links.Parameter (array)}
Link that just holds a parameter and returns it.
Depreciated since version v1.5: The parameters are stored as variables as of v1.5. Use them directly instead.

\textbf{Parameters} \texttt{array} – Initial parameter array.

\textbf{Variables} \texttt{W (Variable)} – Parameter variable.

__call__(\texttt{volatile='off'})
Returns the parameter variable.

\textbf{Parameters} \texttt{volatile (Flag)} – The volatility of the returned variable.

\textbf{Returns} A copy of the parameter variable with given volatility.

\textbf{Return type} Variable

### 3.6 Optimizers

\textbf{class} \texttt{chainer.optimizers.AdaDelta (rho=0.95, eps=1e-06)}
Zeiler’s ADADELTA.

\textbf{class} \texttt{chainer.optimizers.Adam (alpha=0.001, beta1=0.9, beta2=0.999, eps=1e-08)}
Adam optimization algorithm.
See: http://arxiv.org/abs/1412.6980v8
class chainer.optimizers.MomentumSGD \( (lr=0.01, momentum=0.9) \)

Classical momentum SGD.

class chainer.optimizers.NesterovAG \( (lr=0.01, momentum=0.9) \)

Nesterov’s Accelerated Gradient.

Formulated as the linear combination coefficients of the velocity and gradient contributions at each iteration.


class chainer.optimizers.RMSProp \( (lr=0.01, alpha=0.99, eps=1e-08) \)

Hinton’s RMSProp.

class chainer.optimizers.RMSPropGraves \( (lr=0.0001, alpha=0.95, momentum=0.9, eps=0.0001) \)

Alex Graves’s RMSProp.

See http://arxiv.org/abs/1308.0850

class chainer.optimizers.SGD \( (lr=0.01) \)

Vanilla Stochastic Gradient Descent.

class chainer.optimizers.SMORMS3 \( (lr=0.001, eps=1e-16) \)

Simon Funk’s SMORMS3.


### 3.7 Serializers

#### 3.7.1 Serialization in NumPy NPZ format

NumPy serializers can be used in arbitrary environments that Chainer runs with. It consists of asymmetric serial-izer/deserializer due to the fact that `numpy.savez()` does not support online serialization. Therefore, serialization requires two-step manipulation: first packing the objects into a flat dictionary, and then serializing it into npz format.

class chainer.serializers.DictionarySerializer \( (target=None, path='') \)

Serializer for dictionary.

This is the standard serializer in Chainer. The hierarchy of objects are simply mapped to a flat dictionary with keys representing the paths to objects in the hierarchy.

**Note:** Despite of its name, this serializer DOES NOT serialize the object into external files. It just build a flat dictionary of arrays that can be fed into `numpy.savez()` and `numpy.savez_compressed()`. If you want to use this serializer directly, you have to manually send a resulting dictionary to one of these functions.

**Parameters**

- **target (dict)** – The dictionary that this serializer saves the objects to. If target is None, then a new dictionary is created.

- **path (str)** – The base path in the hierarchy that this serializer indicates.

**Variables**

- **target (dict)** – The target dictionary. Once the serialization completes, this dictionary can be fed into `numpy.savez()` or `numpy.savez_compressed()` to serialize it in the NPZ format.

class chainer.serializers.NpzDeserializer \( (npz, path='') \)

Deserializer for NPZ format.
This is the standard deserializer in Chainer. This deserializer can be used to read an object serialized by `save_npz()`.

**Parameters**
- `npz` – `npz` file object.
- `path` – The base path that the deserialization starts from.

```python
chainer.serializers.save_npz(filename, obj, compression=True)
```
Saves an object to the file in NPZ format.

This is a short-cut function to save only one object into an NPZ file.

**Parameters**
- `filename` (`str`) – Target file name.
- `obj` – Object to be serialized. It must support serialization protocol.
- `compression` (`bool`) – If True, compression in the resulting zip file is enabled.

```python
chainer.serializers.load_npz(filename, obj)
```
Loads an object from the file in NPZ format.

This is a short-cut function to load from an `.npz` file that contains only one object.

**Parameters**
- `filename` (`str`) – Name of the file to be loaded.
- `obj` – Object to be deserialized. It must support serialization protocol.

### 3.7.2 Serialization in HDF5 format

```python
class chainer.serializers.HDF5Serializer(group, compression=4)
```
Serializer for HDF5 format.

This is the standard serializer in Chainer. The chain hierarchy is simply mapped to HDF5 hierarchical groups.

**Parameters**
- `group` (`h5py.Group`) – The group that this serializer represents.
- `compression` (`int`) – Gzip compression level.

```python
class chainer.serializers.HDF5Deserializer(group)
```
Deserializer for HDF5 format.

This is the standard deserializer in Chainer. This deserializer can be used to read an object serialized by `HDF5Serializer`.

**Parameters**
- `group` (`h5py.Group`) – The group that the deserialization starts from.

```python
chainer.serializers.save_hdf5(filename, obj, compression=4)
```
Saves an object to the file in HDF5 format.

This is a short-cut function to save only one object into an HDF5 file. If you want to save multiple objects to one HDF5 file, use `HDF5Serializer` directly by passing appropriate `h5py.Group` objects.

**Parameters**
- `filename` (`str`) – Target file name.
- `obj` – Object to be serialized. It must support serialization protocol.
- `compression` (`int`) – Gzip compression level.
chainer.serializers.load_hdf5(filename, obj)

Loads an object from the file in HDF5 format.

This is a short-cut function to load from an HDF5 file that contains only one object. If you want to load multiple objects from one HDF5 file, use HDF5Deserializer directly by passing appropriate h5py.Group objects.

Parameters

- **filename** (str) – Name of the file to be loaded.
- **obj** – Object to be deserialized. It must support serialization protocol.

3.8 Function hooks

Chainer provides a function-hook mechanism that enriches the behavior of forward and backward propagation of Function.

3.8.1 Base class

class chainer.function.FunctionHook

Base class of hooks for Functions.

FunctionHook is a callback object that is registered to Function. Registered function hooks are invoked before and after forward and backward operations of each function.

Function hooks that derive FunctionHook are required to implement four methods: forward_preprocess(), forward_postprocess(), backward_preprocess(), and backward_postprocess(). By default, these methods do nothing.

Specifically, when __call__() method of some function is invoked, forward_preprocess() (resp. forward_postprocess()) of all function hooks registered to this function are called before (resp. after) forward propagation.

Likewise, when backward() of some Variable is invoked, backward_preprocess() (resp. backward_postprocess()) of all function hooks registered to the function which holds this variable as a gradient are called before (resp. after) backward propagation.

There are two ways to register FunctionHook objects to Function objects.

First one is to use with statement. Function hooks hooked in this way are registered to all functions within with statement and are unregistered at the end of with statement.

The following code is a simple example in which we measure the elapsed time of a part of forward propagation procedure with TimerHook, which is a subclass of FunctionHook.

```python
>>> import chainer, chainer.links as L, chainer.functions as F
... class Model(chainer.Chain):
...     def __call__(self, x):
...         return F.exp(self.l(x))
...     model1 = Model(l=L.Linear(10, 10))
...     model2 = Model(l=L.Linear(10, 10))
...     x = chainer.Variable(numpy.zeros((1, 10), 'f'))
...     with chainer.function_hooks.TimerHook() as m:
...         _ = model1(x)
...         y = model2(x)
...         print(m.total_time())
...     model3 = Model(l=L.Linear(10, 10))
...     z = model3(y)
```
In this example, we measure the elapsed times for each forward propagation of all functions in model1 and model2 (specifically, LinearFunction and Exp of model1 and model2). Note that model3 is not a target of measurement as TimerHook is unregistered before forward propagation of model3.

**Note:** Chainer stores the dictionary of registered function hooks as a thread local object. So, function hooks registered are different depending on threads.

The other one is to register directly to Function object with add_hook() method. Function hooks registered in this way can be removed by delete_hook() method. Contrary to former registration method, function hooks are registered only to the function which add_hook() is called.

**Parameters**

**name (str)** – Name of this function hook.

**backward_postprocess (function, in_data, out_grad)**

Callback function invoked after backward propagation.

**Parameters**

- **function (Function)** – Function object to which the function hook is registered.
- **in_data (tuple of numpy.ndarray or tuple of cupy.ndarray)** – Input of forward propagation.
- **out_grad (tuple of numpy.ndarray or tuple of cupy.ndarray)** – Gradient data of backward propagation.

**backward_preprocess (function, in_data, out_grad)**

Callback function invoked before backward propagation.

**Parameters**

- **function (Function)** – Function object to which the function hook is registered.
- **in_data (tuple of numpy.ndarray or tuple of cupy.ndarray)** – Input data of forward propagation.
- **out_grad (tuple of numpy.ndarray or tuple of cupy.ndarray)** – Gradient data of backward propagation.

**forward_postprocess (function, in_data)**

Callback function invoked after forward propagation.

**Parameters**

- **function (Function)** – Function object to which the function hook is registered.
- **in_data (tuple of numpy.ndarray or tuple of cupy.ndarray)** – Input data of forward propagation.

**forward_preprocess (function, in_data)**

Callback function invoked before forward propagation.

**Parameters**

- **function (Function)** – Function object to which the function hook is registered.
- **in_data (tuple of numpy.ndarray or tuple of cupy.ndarray)** – Input data of forward propagation.
3.8.2 Concrete function hooks

class chainer.function_hooks.PrintHook(sep='', end='n', file=<open file 'stdout'>, mode 'w'), flush=True)

Function hook that prints debug information.

This function hook outputs the debug information of input arguments of forward and backward methods involved in the hooked functions at preprocessing time (that is, just before each method is called).

The basic usage is to use it with with statement.

```python
>>> import chainer
>>> chainer.functions as F
>>> chainer.links as L
... l = L.Linear(10, 10)
... x = chainer.Variable(numpy.zeros((1, 10), 'f'))
... with chainer.function_hooks.PrintHook():
...     y = l(x)
...     z = F.sum(y)
...     z.backward()
```

In this example, PrintHook shows the debug information of forward propagation of LinearFunction (which is implicitly called by l) and Sum (called by F.sum) and backward propagation of z and y.

Unlike simple “debug print” technique, where users insert print functions at every function to be inspected, we can show the information of all functions involved with single with statement.

Further, this hook enables us to show the information of backward methods without inserting print functions into Chainer’s library code.

Variables

- sep – Separator of print function.
- end – Character to be added at the end of print function.
- file – Output file_like object that that redirect to.
- flush – If True, this hook forcibly flushes the text stream at the end of preprocessing.

class chainer.function_hooks.TimerHook

Function hook for measuring elapsed time of functions.

Variables call_history – List of measurement results. It consists of pairs of the function that calls this hook and the elapsed time the function consumes.

total_time()
Returns total elapsed time in seconds.

3.9 Weight Initializers

Weight initializer is an instance of Initializer that destructively edits the contents of numpy.ndarray or cupy.ndarray. Typically, weight initializers are passed to __init__ of Link and initializes its the weights and biases.

3.9.1 Base class

class chainer.initializer.Initializer(dtype=None)

Initializes array.

It initializes the given array.
Variables `dtype` – Data type specifier. It is for type check in `__call__` function.

```python
def __call__(array)
    Initializes given array.
```

This method destructively changes the value of array. The derived class is required to implement this method. The algorithms used to make the new values depend on the concrete derived classes.

Parameters `array` (`numpy.ndarray` or `cupy.ndarray`) – An array to be initialized by this initializer.

### 3.9.2 Concrete initializers

```python
class chainer.initializers.Identity(scale=1.0, dtype=None)
    Initializes array with the identity matrix.
```

It initializes the given array with the constant multiple of the identity matrix. Note that arrays to be passed must be 2D squared matrices.

Variables `scale` (`scalar`) – A constant to be multiplied to identity matrices.

```python
class chainer.initializers.Constant(fill_value, dtype=None)
    Initializes array with constant value.
```

Variables

- `fill_value` (`scalar` or `numpy.ndarray` or `cupy.ndarray`) – A constant to be assigned to the initialized array. Broadcast is allowed on this assignment.

- `dtype` – Data type specifier.

```python
class chainer.initializers.Zero(dtype=None)
    Returns initializer that initializes array with the all-zero array.
```

Parameters `dtype` – Data type specifier.

Returns An initialized array.

Return type `numpy.ndarray` or `cupy.ndarray`

```python
class chainer.initializers.One(dtype=None)
    Returns initializer that initializes array with the all-one array.
```

Parameters `dtype` – Data type specifier.

Returns An initialized array.

Return type `numpy.ndarray` or `cupy.ndarray`

### 3.9.3 Gaussian initializers

```python
class chainer.initializers.Normal(scale=0.05, dtype=None)
    Initializes array with a normal distribution.
```

Each element of the array is initialized by the value drawn independently from Gaussian distribution whose mean is 0, and standard deviation is `scale`.

Parameters

- `scale` (`float`) – Standard deviation of Gaussian distribution.

- `dtype` – Data type specifier.

```python
class chainer.initializers.GlorotNormal(scale=1.0, dtype=None)
    Initializes array with scaled Gaussian distribution.
```

3.9. Weight Initializers
Each element of the array is initialized by the value drawn independently from Gaussian distribution whose mean is 0, and standard deviation is \( \text{scale} \times \sqrt{\frac{2}{\text{fan}_{in} + \text{fan}_{out}}} \), where \( \text{fan}_{in} \) and \( \text{fan}_{out} \) are the number of input and output units, respectively.

Reference: Glorot & Bengio, AISTATS 2010

Parameters

- **scale** *(float)* – A constant that determines the scale of the standard deviation.
- **dtype** – Data type specifier.

**class** chainer.initializers.HeNormal *(scale=1.0, dtype=None)*

Initializes array with scaled Gaussian distribution.

Each element of the array is initialized by the value drawn independently from Gaussian distribution whose mean is 0, and standard deviation is \( \text{scale} \times \sqrt{\frac{2}{\text{fan}_{in}}} \), where \( \text{fan}_{in} \) is the number of input units.


Parameters

- **scale** *(float)* – A constant that determines the scale of the standard deviation.
- **dtype** – Data type specifier.

**class** chainer.initializers.Orthogonal *(scale=1.1, dtype=None)*

Initializes array with an orthogonal system.

This initializer first makes a matrix of the same shape as the array to be initialized whose elements are drawn independently from standard Gaussian distribution. Next, it applies Singular Value Decomposition (SVD) to the matrix. Then, it initializes the array with either side of resultant orthogonal matrices, depending on the shape of the input array. Finally, the array is multiplied by the constant \( \text{scale} \).

If the \( \text{ndim} \) of the input array is more than 2, we consider the array to be a matrix by concatenating all axes except the first one.

The number of vectors consisting of the orthogonal system (i.e. first element of the shape of the array) must be equal to or smaller than the dimension of each vector (i.e. second element of the shape of the array).

Variables

- **scale** *(float)* – A constant to be multiplied by.
- **dtype** – Data type specifier.


**class** chainer.initializers.Uniform *(scale=0.05, dtype=None)*

Initializes array with a scaled uniform distribution.

Each element of the array is initialized by the value drawn independently from uniform distribution \([-\text{scale}, \text{scale}]\).

Variables

- **scale** *(float)* – A constant that determines the scale of the uniform distribution.
- **dtype** – Data type specifier.

**class** chainer.initializers.LeCunUniform *(scale=1.0, dtype=None)*

Initializes array with a scaled uniform distribution.

Each element of the array is initialized by the value drawn independently from uniform distribution \([-s, s]\) where \( s = \text{scale} \times \sqrt{\frac{3}{\text{fan}_{in}}} \). Here \( \text{fan}_{in} \) is the number of input units.
Variables

- **scale** (float) – A constant that determines the scale of the uniform distribution.
- **dtype** – Data type specifier.

```python
class chainer.initializers.GlorotUniform(scale=1.0, dtype=None)
```
Initializes array with a scaled uniform distribution.

Each element of the array is initialized by the value drawn independently from uniform distribution $[-s, s]$ where $s = scale \times \sqrt{\frac{6}{fan_{in} + fan_{out}}}$. Here, $fan_{in}$ and $fan_{out}$ are the number of input and output units, respectively.

Variables

- **scale** (float) – A constant that determines the scale of the uniform distribution.
- **dtype** – Data type specifier.

```python
class chainer.initializers.HeUniform(scale=1.0, dtype=None)
```
Initializes array with scaled uniform distribution.

Each element of the array is initialized by the value drawn independently from uniform distribution $[-s, s]$ where $s = scale \times \sqrt{\frac{6}{fan_{in}}}$. Here, $fan_{in}$ is the number of input units.

Variables

- **scale** (float) – A constant that determines the scale of the uniform distribution.
- **dtype** – Data type specifier.

### 3.9.3 Helper function

```python
chainer.init_weight(weights, initializer, scale=1.0)
```
Helper function for initialization of the weight tensor.

This function accepts several types of initializer, prepares the appropriate `chainer.Initializer` if necessary, and does the initialization.

**Parameters**

- **weights** (numpy.ndarray or cupy.ndarray) – Weight tensor to be initialized.
- **initializer** – The value used to initialize the data. May be `None` (in which case `HeNormal` is used as an initializer), a scalar to set all values to, an `numpy.ndarray` to be assigned, or a callable that takes `numpy.ndarray` or `cupy.ndarray` and edits its value.
- **scale** (scalar) – A constant to multiply initializer by.

### 3.10 Dataset examples

The most basic dataset implementation is an array. Both NumPy and CuPy arrays can be used directly as datasets. In many cases, though, the simple arrays are not enough to write the training procedure. In order to cover most of such cases, Chainer provides many built-in implementations of datasets.
These built-in datasets are divided into two groups. One is a group of general datasets. Most of them are wrapper of other datasets to introduce some structures (e.g., tuple or dict) to each data point. The other one is a group of concrete, popular datasets. These concrete examples use the downloading utilities in the `chainer.dataset` module to cache downloaded and converted datasets.

### 3.10.1 General datasets

General datasets are further divided into three types.

The first one is `DictDataset` and `TupleDataset`, both of which combine other datasets and introduce some structures on them.

The second one is `SubDataset`, which represents a subset of an existing dataset. It can be used to separate a dataset for hold-out validation or cross validation. Convenient functions to make random splits are also provided.

The last one is a group of domain-specific datasets. Currently, `ImageDataset` and `LabeledImageDataset` are provided for datasets of images.

**DictDataset**

```python
class chainer.datasets.DictDataset(**datasets)
Dataset of a dictionary of datasets.

It combines multiple datasets into one dataset. Each example is represented by a dictionary mapping a key to an example of the corresponding dataset.

**Parameters**

- **datasets** – Underlying datasets. The keys are used as the keys of each example. All datasets must have the same length.
```

**TupleDataset**

```python
class chainer.datasets.TupleDataset(*datasets)
Dataset of a tuple of datasets.

It combines multiple datasets into one dataset. Each example is represented by a tuple whose \(i\)-th item corresponds to the \(i\)-th dataset.

**Parameters**

- **datasets** – Underlying datasets. The \(i\)-th one is used for the \(i\)-th item of each example. All datasets must have the length.
```

**SubDataset**

```python
class chainer.datasets.SubDataset(dataset, start, finish, order=None)
Subset of a base dataset.

SubDataset defines a subset of a given base dataset. The subset is defined as an interval of indexes, optionally with a given permutation.

If `order` is given, then the \(i\)-th example of this dataset is the `order[start + i]`-th example of the base dataset, where \(i\) is a non-negative integer. If `order` is not given, then the \(i\)-th example of this dataset is the `start + i`-th example of the base dataset. Negative indexing is also allowed: in this case, the term `start + i` is replaced by `finish + i`.

SubDataset is often used to split a dataset into training and validation subsets. The training set is used for training, while the validation set is used to track the generalization performance, i.e. how the learned model works well on unseen data. We can tune hyperparameters (e.g. number of hidden units, weight initializers,
learning rate, etc.) by comparing the validation performance. Note that we often use another set called test set to measure the quality of the tuned hyperparameter, which can be made by nesting multiple SubDatasets.

There are two ways to make training-validation splits. One is a single split, where the dataset is split just into two subsets. It can be done by `split_dataset()` or `split_dataset_random()`. The other one is a $k$-fold cross validation, in which the dataset is divided into $k$ subsets, and $k$ different splits are generated using each of the $k$ subsets as a validation set and the rest as a training set. It can be done by `get_cross_validation_datasets()`.

### Parameters

- **dataset** – Base dataset.
- **start** *(int)* – The first index in the interval.
- **finish** *(int)* – The next-to-the-last index in the interval.
- **order** *(sequence of ints)* – Permutation of indexes in the base dataset. If this is `None`, then the ascending order of indexes is used.

```python
chainer.datasets.split_dataset(dataset, split_at, order=None)
```

Splits a dataset into two subsets.

This function creates two instances of `SubDataset`. These instances do not share any examples, and they together cover all examples of the original dataset.

### Parameters

- **dataset** – Dataset to split.
- **split_at** *(int)* – Position at which the base dataset is split.
- **order** *(sequence of ints)* – Permutation of indexes in the base dataset. See the document of `SubDataset` for details.

**Returns** Two `SubDataset` objects. The first subset represents the examples of indexes `order[:split_at]` while the second subset represents the examples of indexes `order[split_at:]`.

**Return type** `tuple`

```python
chainer.datasets.split_dataset_random(dataset, first_size, seed=None)
```

Splits a dataset into two subsets randomly.

This function creates two instances of `SubDataset`. These instances do not share any examples, and they together cover all examples of the original dataset. The split is automatically done randomly.

### Parameters

- **dataset** – Dataset to split.
- **first_size** *(int)* – Size of the first subset.
- **seed** *(int)* – Seed the generator used for the permutation of indexes. If an integer being convertible to 32 bit unsigned integers is specified, it is guaranteed that each sample in the given dataset always belongs to a specific subset. If `None`, the permutation is changed randomly.

**Returns** Two `SubDataset` objects. The first subset contains `first_size` examples randomly chosen from the dataset without replacement, and the second subset contains the rest of the dataset.

**Return type** `tuple`
chainer.datasets.get_cross_validation_datasets(dataset, n_fold, order=None)

Creates a set of training/test splits for cross validation.

This function generates \( n \_fold \) splits of the given dataset. The first part of each split corresponds to the training dataset, while the second part to the test dataset. No pairs of test datasets share any examples, and all test datasets together cover the whole base dataset. Each test dataset contains almost same number of examples (the numbers may differ up to 1).

**Parameters**

- **dataset** – Dataset to split.
- **n_fold** (*int*) – Number of splits for cross validation.
- **order** (*sequence of ints*) – Order of indexes with which each split is determined. If it is `None`, then no permutation is used.

**Returns** List of dataset splits.

**Return type** list of tuples

chainer.datasets.get_cross_validation_datasets_random(dataset, n_fold, seed=None)

Creates a set of training/test splits for cross validation randomly.

This function acts almost same as `get_cross_validation_dataset()`, except automatically generating random permutation.

**Parameters**

- **dataset** – Dataset to split.
- **n_fold** (*int*) – Number of splits for cross validation.
- **seed** (*int*) – Seed the generator used for the permutation of indexes. If an integer beginning convertible to 32 bit unsigned integers is specified, it is guaranteed that each sample in the given dataset always belongs to a specific subset. If `None`, the permutation is changed randomly.

**Returns** List of dataset splits.

**Return type** list of tuples

### ImageDataset

**class** chainer.datasets.ImageDataset(paths, root='.', dtype=<type 'numpy.float32'>)

Dataset of images built from a list of paths to image files.

This dataset reads an external image file on every call of the `__getitem__()` operator. The paths to the image to retrieve is given as either a list of strings or a text file that contains paths in distinct lines.

Each image is automatically converted to arrays of shape `channels, height, width`, where `channels` represents the number of channels in each pixel (e.g., 1 for grey-scale images, and 3 for RGB-color images).

**Note:** This dataset requires the Pillow package being installed. In order to use this dataset, install Pillow (e.g. by using the command `pip install Pillow`). Be careful to prepare appropriate libraries for image formats you want to use (e.g. libpng for PNG images, and libjpeg for JPG images).

**Parameters**
• **paths** (*str or list of strs*) – If it is a string, it is a path to a text file that contains paths to images in distinct lines. If it is a list of paths, the *i*-th element represents the path to the *i*-th image. In both cases, each path is a relative one from the root path given by another argument.

• **root** (*str*) – Root directory to retrieve images from.

• **dtype** – Data type of resulting image arrays.

### LabeledImageDataset

```python
class chainer.datasets.LabeledImageDataset(pairs, root='.', dtype=<type 'numpy.float32'>, label_dtype=<type 'numpy.int32'>)
```

Dataset of image and label pairs built from a list of paths and labels.

This dataset reads an external image file like `ImageDataset`. The difference from `ImageDataset` is that this dataset also returns a label integer. The paths and labels are given as either a list of pairs or a text file contains paths/labels pairs in distinct lines. In the latter case, each path and corresponding label are separated by white spaces. This format is same as one used in Caffe.

**Note:** This dataset requires the Pillow package being installed. In order to use this dataset, install Pillow (e.g. by using the command `pip install Pillow`). Be careful to prepare appropriate libraries for image formats you want to use (e.g. libpng for PNG images, and libjpeg for JPG images).

**Parameters**

- **pairs** (*str or list of tuples*) – If it is a string, it is a path to a text file that contains paths to images in distinct lines. If it is a list of pairs, the *i*-th element represents a pair of the path to the *i*-th image and the corresponding label. In both cases, each path is a relative one from the root path given by another argument.

- **root** (*str*) – Root directory to retrieve images from.

- **dtype** – Data type of resulting image arrays.

- **label_dtype** – Data type of the labels.

### 3.10.2 Concrete datasets

#### MNIST

```python
chainer.datasets.get_mnist(withlabel=True, ndim=1, scale=1.0, dtype=<type 'numpy.float32'>, label_dtype=<type 'numpy.int32'>)
```

Gets the MNIST dataset.

**MNIST** is a set of hand-written digits represented by grey-scale 28x28 images. In the original images, each pixel is represented by one-byte unsigned integer. This function scales the pixels to floating point values in the interval [0, scale].

This function returns the training set and the test set of the official MNIST dataset. If `withlabel` is True, each dataset consists of tuples of images and labels, otherwise it only consists of images.

**Parameters**

- **withlabel** (*bool*) – If True, it returns datasets with labels. In this case, each example is a tuple of an image and a label. Otherwise, the datasets only contain images.
• **ndim (int)** – Number of dimensions of each image. The shape of each image is determined depending on ndim as follows:
  - ndim == 1: the shape is (784,)
  - ndim == 2: the shape is (28, 28)
  - ndim == 3: the shape is (1, 28, 28)

• **scale (float)** – Pixel value scale. If it is 1 (default), pixels are scaled to the interval [0, 1].

• **dtype** – Data type of resulting image arrays.

• **label_dtype** – Data type of the labels.

**Returns** A tuple of two datasets. If `withlabel` is True, both datasets are `TupleDataset` instances. Otherwise, both datasets are arrays of images.

### CIFAR10/100

`chainer.datasets.get_cifar10(withlabel=True, ndim=3, scale=1.0)`

Gets the CIFAR-10 dataset.

CIFAR-10 is a set of small natural images. Each example is an RGB color image of size 32x32, classified into 10 groups. In the original images, each component of pixels is represented by one-byte unsigned integer. This function scales the components to floating point values in the interval [0, scale].

This function returns the training set and the test set of the official CIFAR-10 dataset. If `withlabel` is True, each dataset consists of tuples of images and labels, otherwise it only consists of images.

**Parameters**

• **withlabel (bool)** – If True, it returns datasets with labels. In this case, each example is a tuple of an image and a label. Otherwise, the datasets only contain images.

• **ndim (int)** – Number of dimensions of each image. The shape of each image is determined depending on ndim as follows:
  - ndim == 1: the shape is (3072,)
  - ndim == 3: the shape is (3, 32, 32)

• **scale (float)** – Pixel value scale. If it is 1 (default), pixels are scaled to the interval [0, 1].

**Returns** A tuple of two datasets. If `withlabel` is True, both datasets are `TupleDataset` instances. Otherwise, both datasets are arrays of images.

`chainer.datasets.get_cifar100(withlabel=True, ndim=3, scale=1.0)`

Gets the CIFAR-100 dataset.

CIFAR-100 is a set of small natural images. Each example is an RGB color image of size 32x32, classified into 100 groups. In the original images, each component pixels is represented by one-byte unsigned integer. This function scales the components to floating point values in the interval [0, scale].

This function returns the training set and the test set of the official CIFAR-100 dataset. If `withlabel` is True, each dataset consists of tuples of images and labels, otherwise it only consists of images.

**Parameters**

• **withlabel (bool)** – If True, it returns datasets with labels. In this case, each example is a tuple of an image and a label. Otherwise, the datasets only contain images.
• **ndim**(int) – Number of dimensions of each image. The shape of each image is determined depending on ndim as follows:
  - ndim == 1: the shape is (3072,)
  - ndim == 3: the shape is (3, 32, 32)

• **scale**(float) – Pixel value scale. If it is 1 (default), pixels are scaled to the interval \[0, 1\].

**Returns** A tuple of two datasets. If withlabel is True, both are *TupleDataset* instances. Otherwise, both datasets are arrays of images.

---

**Penn Tree Bank**

chainer.datasets.get_ptb_words()

Gets the Penn Tree Bank dataset as long word sequences.

**Penn Tree Bank** is originally a corpus of English sentences with linguistic structure annotations. This function uses a variant distributed at https://github.com/tomsercu/lstm, which omits the annotation and splits the dataset into three parts: training, validation, and test.

This function returns the training, validation, and test sets, each of which is represented as a long array of word IDs. All sentences in the dataset are concatenated by End-of-Sentence mark `<eos>`, which is treated as one of the vocabulary.

**Returns** Int32 vectors of word IDs.

**Return type** tuple of numpy.ndarray

**See also:**

Use *get_ptb_words_vocabulary()* to get the mapping between the words and word IDs.

chainer.datasets.get_ptb_words_vocabulary()

Gets the Penn Tree Bank word vocabulary.

**Returns** Dictionary that maps words to corresponding word IDs. The IDs are used in the Penn Tree Bank long sequence datasets.

**Return type** dict

**See also:**

See *get_ptb_words()* for the actual datasets.

---

### 3.11 Iterator examples

Chainer provides some iterators that implement typical strategies to create mini-batches by iterating over datasets. *SerialIterator* is the simplest one, which extract mini batches in the main thread. *MultiprocessIterator* is a parallelized version of *SerialIterator*. It maintains worker subprocesses to load the next mini-batch in parallel.

#### 3.11.1 SerialIterator

class chainer.iterators.SerialIterator(dataset, batch_size, repeat=True, shuffle=True)

Dataset iterator that serially reads the examples.
This is a simple implementation of `Iterator` that just visits each example in either the order of indexes or a shuffled order.

To avoid unintentional performance degradation, the `shuffle` option is set to `True` by default. For validation, it is better to set it to `False` when the underlying dataset supports fast slicing. If the order of examples has an important meaning and the updater depends on the original order, this option should be set to `False`.

**Parameters**

- `dataset` – Dataset to iterate.
- `batch_size (int)` – Number of examples within each batch.
- `repeat (bool)` – If `True`, it infinitely loops over the dataset. Otherwise, it stops iteration at the end of the first epoch.
- `shuffle (bool)` – If `True`, the order of examples is shuffled at the beginning of each epoch. Otherwise, examples are extracted in the order of indexes.

### 3.11.2 MultiprocessIterator

```python
class chainer.iterators.MultiprocessIterator(dataset, batch_size, repeat=True, shuffle=True, n_processes=None, n_prefetch=1, shared_mem=None)
```

### 3.12 Trainer extensions

#### 3.12.1 dump_graph

```python
chainer.training.extensions.dump_graph(root_name, out_name='cg.dot', variable_style=None, function_style=None)
```

Returns a trainer extension to dump a computational graph.

This extension dumps a computational graph. The graph is output in DOT language.

It only dumps a graph at the first iteration by default.

**Parameters**

- `root_name (str)` – Name of the root of the computational graph. The root variable is retrieved by this name from the observation dictionary of the trainer.
- `out_name (str)` – Output file name.
- `variable_style (dict)` – Dot node style for variables. Each variable is rendered by an octagon by default.
- `function_style (dict)` – Dot node style for functions. Each function is rendered by a rectangular by default.

**See also:**

See `build_computational_graph()` for the `variable_style` and `function_style` arguments.
3.12.2 Evaluator

class chainer.training.extensions.Evaluator(iterator, target, converter=<function concat_examples>, device=None, 
eval_hook=None, eval_func=None)

Trainer extension to evaluate models on a validation set.

This extension evaluates the current models by a given evaluation function. It creates a Reporter object to store values observed in the evaluation function on each iteration. The report for all iterations are aggregated to DictSummary. The collected mean values are further reported to the reporter object of the trainer, where the name of each observation is prefixed by the evaluator name. See Reporter for details in naming rules of the reports.

Evaluator has a structure to customize similar to that of StandardUpdater. The main differences are:

• There are no optimizers in an evaluator. Instead, it holds links to evaluate.
• An evaluation loop function is used instead of an update function.
• Preparation routine can be customized, which is called before each evaluation. It can be used, e.g., to initialize the state of stateful recurrent networks.

There are two ways to modify the evaluation behavior besides setting a custom evaluation function. One is by setting a custom evaluation loop via the eval_func argument. The other is by inheriting this class and overriding the evaluate() method. In latter case, users have to create and handle a reporter object manually. Users also have to copy the iterators before using them, in order to reuse them at the next time of evaluation.

This extension is called at the end of each epoch by default.

Parameters

• iterator – Dataset iterator for the validation dataset. It can also be a dictionary of iterators. If this is just an iterator, the iterator is registered by the name ‘main’.
• target – Link object or a dictionary of links to evaluate. If this is just a link object, the link is registered by the name ‘main’.
• converter – Converter function to build input arrays. concat_examples() is used by default.
• device – Device to which the training data is sent. Negative value indicates the host memory (CPU).
• eval_hook – Function to prepare for each evaluation process. It is called at the beginning of the evaluation. The evaluator extension object is passed at each call.
• eval_func – Evaluation function called at each iteration. The target link to evaluate as a callable is used by default.

Variables

• converter – Converter function.
• device – Device to which the training data is sent.
• eval_hook – Function to prepare for each evaluation process.
• eval_func – Evaluation function called at each iteration.

__call__(trainer=None)

Executes the evaluator extension.

Unlike usual extensions, this extension can be executed without passing a trainer object. This extension reports the performance on validation dataset using the report() function. Thus, users can use this extension independently from any trainer by manually configuring a Reporter object.
Parameters `trainer` (*Trainer*) – Trainer object that invokes this extension. It can be omitted in case of calling this extension manually.

Returns Result dictionary that contains mean statistics of values reported by the evaluation function.

Return type `dict`

`evaluate()` Evaluates the model and returns a result dictionary.

This method runs the evaluation loop over the validation dataset. It accumulates the reported values to `DictSummary` and returns a dictionary whose values are means computed by the summary.

Users can override this method to customize the evaluation routine.

Returns Result dictionary. This dictionary is further reported via `report()` without specifying any observer.

Return type `dict`

`get_all_iterators()` Returns a dictionary of all iterators.

`get_all_targets()` Returns a dictionary of all target links.

`get_iterator(name)` Returns the iterator of the given name.

`get_target(name)` Returns the target link of the given name.

### 3.12.3 ExponentialShift

#### class `chainer.training.extensions.ExponentialShift(attr, rate, init=None, target=None, optimizer=None)`

Trainer extension to exponentially shift an optimizer attribute.

This extension exponentially increases or decreases the specified attribute of the optimizer. The typical use case is an exponential decay of the learning rate.

This extension is also called before the training loop starts by default.

**Parameters**

- `attr (str)` – Name of the attribute to shift.
- `rate (float)` – Rate of the exponential shift. This value is multiplied to the attribute at each call.
- `init (float)` – Initial value of the attribute. If it is `None`, the extension extracts the attribute at the first call and uses it as the initial value.
- `target (float)` – Target value of the attribute. If the attribute reaches this value, the shift stops.
- `optimizer (Optimizer)` – Target optimizer to adjust the attribute. If it is `None`, the main optimizer of the updater is used.
3.12.4 LinearShift

```python
class chainer.training.extensions.LinearShift(attr, value_range, time_range, optimizer=None)
```

Trainer extension to change an optimizer attribute linearly.

This extension changes an optimizer attribute from the first value to the last value linearly within a specified duration. The typical use case is warming up of the momentum coefficient.

For example, suppose that this extension is called at every iteration, and `value_range == (x, y)` and `time_range == (i, j)`. Then, this extension keeps the attribute to be `x` up to the `i`-th iteration, linearly shifts the value to `y` by the `j`-th iteration, and then keeps the value to be `y` after the `j`-th iteration.

This extension is also called before the training loop starts by default.

**Parameters**

- `attr (str)` – Name of the optimizer attribute to adjust.
- `value_range (tuple of float)` – The first and the last values of the attribute.
- `time_range (tuple of ints)` – The first and last counts of calls in which the attribute is adjusted.
- `optimizer (Optimizer)` – Target optimizer object. If it is None, the main optimizer of the trainer is used.

3.12.5 LogReport

```python
class chainer.training.extensions.LogReport(keys=None, trigger=(1, 'epoch'), postprocess=None, log_name='log')
```

Trainer extension to output the accumulated results to a log file.

This extension accumulates the observations of the trainer to `DictSummary` at a regular interval specified by a supplied trigger, and writes them into a log file in JSON format.

There are two triggers to handle this extension. One is the trigger to invoke this extension, which is used to handle the timing of accumulating the results. It is set to `1`, `’epoch’` by default. The other is the trigger to determine when to emit the result. When this trigger returns True, this extension appends the summary of accumulated values to the list of past summaries, and writes the list to the log file. Then, this extension makes a new fresh summary object which is used until the next time that the trigger fires.

It also adds some entries to each result dictionary.

- `’epoch’` and `’iteration’` are the epoch and iteration counts at the output, respectively.
- `’elapsed_time’` is the elapsed time in seconds since the training begins. The value is taken from `Trainer.elapsed_time`.

**Parameters**

- `keys (iterable of strs)` – Keys of values to accumulate. If this is None, all the values are accumulated and output to the log file.
- `trigger` – Trigger that decides when to aggregate the result and output the values. This is distinct from the trigger of this extension itself. If it is a tuple in the form `<int>, ’epoch’` or `<int>, ’iteration’`, it is passed to `IntervalTrigger`.
- `postprocess` – Callback to postprocess the result dictionaries. Each result dictionary is passed to this callback on the output. This callback can modify the result dictionaries, which are used to output to the log file.
• **log_name** *(str)* – Name of the log file under the output directory. It can be a format string: the last result dictionary is passed for the formatting. For example, users can use ‘{iteration}’ to separate the log files for different iterations. If the log name is None, it does not output the log to any file.

**log**

The current list of observation dictionaries.

### 3.12.6 snapshot

chainer.training.extensions.snapshot *(savefun=<function save_npz>, filename='snapshot_iter_{.updater.iteration}', trigger=(1, 'epoch'))*

Returns a trainer extension to take snapshots of the trainer.

This extension serializes the trainer object and saves it to the output directory. It is used to support resuming the training loop from the saved state.

This extension is called once for each epoch by default. The default priority is -100, which is lower than that of most built-in extensions.

**Note:** This extension first writes the serialized object to a temporary file and then rename it to the target file name. Thus, if the program stops right before the renaming, the temporary file might be left in the output directory.

**Parameters**

- **savefun** – Function to save the trainer. It takes two arguments: the output file path and the trainer object.

- **filename** *(str)* – Name of the file into which the trainer is serialized. It can be a format string, where the trainer object is passed to the `str.format()` method.

- **trigger** – Trigger that decides when to take snapshot. It can be either an already built trigger object (i.e., a callable object that accepts a trainer object and returns a bool value), or a tuple in the form `<int>, 'epoch'` or `<int>, 'iteration'`. In latter case, the tuple is passed to `IntervalTrigger`.

### 3.12.7 snapshot_object

chainer.training.extensions.snapshot_object *(target, filename, savefun=<function save_npz>, trigger=(1, 'epoch'))*

Returns a trainer extension to take snapshots of a given object.

This extension serializes the given object and saves it to the output directory.

This extension is called once for each epoch by default. The default priority is -100, which is lower than that of most built-in extensions.

**Parameters**

- **target** – Object to serialize.
• **filename** (*str*) – Name of the file into which the object is serialized. It can be a format string, where the trainer object is passed to the `str.format()` method. For example, ‘`snapshot_{.updater.iteration}`’ is converted to ‘`snapshot_10000`’ at the 10,000th iteration.

• **savefun** – Function to save the object. It takes two arguments: the output file path and the object to serialize.

• **trigger** – Trigger that decides when to take snapshot. It can be either an already built trigger object (i.e., a callable object that accepts a trainer object and returns a bool value), or a tuple in the form `<int>, ‘epoch’` or `<int>, ‘iteration’`. In latter case, the tuple is passed to `IntervalTrigger`.

Returns An extension function.

### 3.12.8 PrintReport

**class** `chainer.training.extensions.PrintReport` *(entries, log_report='LogReport', out=<open file '<stdout>', mode 'w'>)*

Trainer extension to print the accumulated results.

This extension uses the log accumulated by a `LogReport` extension to print specified entries of the log in a human-readable format.

Parameters

• **entries** (*list of str*) – List of keys of observations to print.

• **log_report** (*str or LogReport*) – Log report to accumulate the observations. This is either the name of a `LogReport` extensions registered to the trainer, or a `LogReport` instance to use internally.

• **out** – Stream to print the bar. Standard output is used by default.

### 3.12.9 ProgressBar

**class** `chainer.training.extensions.ProgressBar` *(training_length=None, update_interval=100, bar_length=50, out=<open file '<stdout>', mode 'w'>)*

Trainer extension to print a progress bar and recent training status.

This extension prints a progress bar at every call. It watches the current iteration and epoch to print the bar.

Parameters

• **training_length** (*tuple*) – Length of whole training. It consists of an integer and either ‘epoch’ or ‘iteration’. If this value is omitted and the stop trigger of the trainer is `IntervalTrigger`, this extension uses its attributes to determine the length of the training.

• **update_interval** (*int*) – Number of iterations to skip printing the progress bar.

• **bar_length** (*int*) – Length of the progress bar in characters.

• **out** – Stream to print the bar. Standard output is used by default.
3.13 Trainer triggers

3.13.1 Interval

class chainer.training.triggers.IntervalTrigger(period, unit)

Trigger based on a fixed interval.

This trigger accepts iterations divided by a given interval. There are two ways to specify the interval: per iterations and epochs. *Iteration* means the number of updates, while *epoch* means the number of sweeps over the training dataset. Fractional values are allowed if the interval is a number of epochs; the trigger uses the *iteration* and *epoch_detail* attributes defined by the updater.

For the description of triggers, see `get_trigger()`.

Parameters

- **period** (*int* or *float*) – Length of the interval. Must be an integer if unit is ‘iteration’.
- **unit** (*str*) – Unit of the length specified by period. It must be either ‘iteration’ or ‘epoch’.

__call__(trainer)

Decides whether the extension should be called on this iteration.

Parameters

- **trainer** (*Trainer*) – Trainer object that this trigger is associated with. The updater associated with this trainer is used to determine if the trigger should fire.

Returns

True if the corresponding extension should be invoked in this iteration.

Return type

bool

3.13.2 Minimum and maximum values

class chainer.training.triggers.MaxValueTrigger(key, trigger=(1, ‘epoch’))

Trigger invoked when specific value becomes maximum.

For example you can use this trigger to take snapshot on the epoch the validation accuracy is maximum.

Parameters

- **key** (*str*) – Key of value. The trigger fires when the value associated with this key becomes maximum.
- **trigger** – Trigger that decides the comparison interval between current best value and new value. This must be a tuple in the form of *int*, ‘epoch’ or *int*, ‘iteration’ which is passed to `IntervalTrigger`.

class chainer.training.triggers.MinValueTrigger(key, trigger=(1, ‘epoch’))

Trigger invoked when specific value becomes minimum.

For example you can use this trigger to take snapshot on the epoch the validation loss is minimum.

Parameters

- **key** (*str*) – Key of value. The trigger fires when the value associated with this key becomes minimum.
- **trigger** – Trigger that decides the comparison interval between current best value and new value. This must be a tuple in the form of *int*, ‘epoch’ or *int*, ‘iteration’ which is passed to `IntervalTrigger`. 
3.14 Caffe Reference Model Support

Caffe is a popular framework maintained by BVLC at UC Berkeley. It is widely used by computer vision communities, and aims at fast computation and easy usage without any programming. The BVLC team provides trained reference models in their Model Zoo, one of the reason why this framework gets popular.

Chainer can import the reference models and emulate the network by Link implementations. This functionality is provided by the `chainer.links.caffe.CaffeFunction` class.

```python
class chainer.links.caffe.CaffeFunction(model_path)
```

Caffe emulator based on the model file of Caffe.

Given a protocol buffers file of a Caffe model, this class loads and emulates it on `Variable` objects. It supports the official reference models provided by BVLC.

**Note:** protobuf>=3.0.0 is required if you use Python 3 because protobuf 2 is not supported on Python 3.

**Note:** CaffeFunction ignores the following layers:

- Layers that CaffeFunction does not support (including data layers)
- Layers that have no top blobs
- Layers whose bottom blobs are incomplete (i.e., some or all of them are not given nor computed)

**Warning:** It does not support full compatibility against Caffe. Some layers and configurations are not implemented in Chainer yet, though the reference models provided by the BVLC team are supported except data layers.

**Example**

Consider we want to extract the (unnormalized) log class probability of given images using BVLC reference CaffeNet. The model can be downloaded from:

http://dl.caffe.berkeleyvision.org/bvlc_reference_caffenet.caffemodel

We want to compute the `fc8` blob from the `data` blob. It is simply written as follows:

```python
# Load the model
func = CaffeFunction('path/to/bvlc_reference_caffenet.caffemodel')

# Minibatch of size 10
x_data = numpy.ndarray((10, 3, 227, 227), dtype=numpy.float32)
...  # (Fill the minibatch here)

# Forward the pre-trained net
x = Variable(x_data)
y, = func(inputs={'data': x}, outputs=['fc8'])
```

The result `y` contains the Variable corresponding to the `fc8` blob. The computational graph is memorized as a usual forward computation in Chainer, so we can run backprop through this pre-trained net.

**Parameters**

- `model_path (str)` – Path to the binary-proto model file of Caffe.

**Variables**

- `model_path (str)` – Path to the binary-proto model file of Caffe.
• **fs** (*FunctionSet*) – A set of functions corresponding to parameterized layers of Caffe. The names of its attributes are same as the layer names of the given network.

• **forwards** (*dict*) – A mapping from layer names to corresponding functions.

```python
__call__ (inputs, outputs, disable=(), train=True)
```

Executes a sub-network of the network.

This function acts as an interpreter of the network definition for Caffe. On execution, it interprets each layer one by one, and if the bottom blobs are already computed, then emulates the layer and stores output blobs as *Variable* objects.

**Parameters**

- **inputs** (*dict*) – A dictionary whose key-value pairs indicate initial correspondences between blob names and *Variable* objects.

- **outputs** (*Iterable*) – A list of blob names whose corresponding *Variable* objects are returned.

- **disable** (*Iterable*) – A list of layer names that will be ignored during the forward computation.

- **train** (*bool*) – If True, this function emulates the TRAIN phase of the Caffe layers. Otherwise, it emulates the TEST phase.

**Returns** A tuple of output *Variable* objects corresponding to elements of the *outputs* argument.

**Return type** tuple

### 3.15 Visualization of Computational Graph

As neural networks get larger and complicated, it gets much harder to confirm if their architectures are constructed properly. Chainer supports visualization of computational graphs. Users can generate computational graphs by invoking `build_computational_graph()`. Generated computational graphs are dumped to specified format (Currently Dot Language is supported).

Basic usage is as follows:

```python
import chainer.computational_graph as c
...
g = c.build_computational_graph(vs)
with open('path/to/output/file', 'w') as o:
    o.write(g.dump())
```

where `vs` is list of *Variable* instances and `g` is an instance of *ComputationalGraph*. This code generates the computational graph that are backward-reachable (i.e. reachable by repetition of steps backward) from at least one of `vs`.

Here is an example of (a part of) the generated graph (inception(3a) in GoogLeNet). This example is from `example/imagenet`.

```python
chainer.computational_graph.build_computational_graph (outputs, remove_split=True,
variable_style=None,
function_style=None,
rankdir='TB')
```

Builds a graph of functions and variables backward-reachable from outputs.

**Parameters**
• **outputs** (*list*) – nodes from which the graph is constructed. Each element of outputs must be either Variable object or Function object.

• **remove_split** (*bool*) – It must be True. This argument is left for backward compatibility.

• **variable_style** (*dict*) – Dot node style for variable. Possible keys are ‘shape’, ‘color’, ‘fillcolor’, ‘style’, and etc.

• **function_style** (*dict*) – Dot node style for function.

• **rankdir** (*str*) – Direction of the graph that must be TB (top to bottom), BT (bottom to top), LR (left to right) or RL (right to left).

**Returns**

A graph consisting of nodes and edges that are backward-reachable from at least one of outputs.

If unchain_backward was called in some variable in the computational graph before this function, backward step is stopped at this variable.

For example, suppose that computational graph is as follows:

```
  |--> f ——> y
  x ——+  |--> g ——> z
```

Let outputs = [y, z]. Then the full graph is emitted.

Next, let outputs = [y]. Note that z and g are not backward-reachable from y. The resulting graph would be following:

```
x ——+ f ——> y
```

See TestGraphBuilder for details.

**Return type** *ComputationalGraph*
class chainer.computational_graph.ComputationalGraph(nodes, edges, variable_style=None, function_style=None, rankdir='TB')

Class that represents computational graph.

Note: We assume that the computational graph is directed and acyclic.

dump(format='dot')
Dumps graph as a text.

Parameters
- format (str) – The graph language name of the output.
- it must be 'dot'. (Currently,)

Returns The graph in specified format.

Return type str

3.16 Environment variables

Here are the environment variables Chainer uses.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>CHAINER_CUDNN</td>
<td>Set 0 to disable cuDNN in Chainer. Otherwise cuDNN is enabled automatically.</td>
</tr>
<tr>
<td>CHAINER_SEED</td>
<td>Default seed value of random number generators for CUDA. If it is not set, the seed value is generated from Python random module. Set an integer value in decimal format.</td>
</tr>
<tr>
<td>CHAINER_TYPE_CHECK</td>
<td>Set 0 to disable type checking. Otherwise type checking is enabled automatically. See Function for details.</td>
</tr>
</tbody>
</table>
This is the official documentation of CuPy, a multi-dimensional array on CUDA with a subset of NumPy interface.

## 4.1 CuPy Overview

CuPy is an implementation of NumPy-compatible multi-dimensional array on CUDA. CuPy consists of the core multi-dimensional array class, `cupy.ndarray`, and many functions on it. It supports a subset of `numpy.ndarray` interface that is enough for Chainer.

The following is a brief overview of supported subset of NumPy interface:

- **Basic indexing** (indexing by ints, slices, newaxes, and Ellipsis)
- **Element types (dtypes)**: bool, (u)int{8, 16, 32, 64}, float{16, 32, 64}
- **Most of the array creation routines**
- **Reshaping and transposition**
- **All operators with broadcasting**
- **All Universal functions** (a.k.a. ufuncs) for elementwise operations except those for complex numbers
- **Dot product functions (except einsum)** using cuBLAS
- **Reduction along axes** (sum, max, argmax, etc.)

CuPy also includes following features for performance:

- **Customizable memory allocator, and a simple memory pool as an example**
- **User-defined elementwise kernels**
- **User-defined reduction kernels**
- **cuDNN utilities**

CuPy uses on-the-fly kernel synthesis: when a kernel call is required, it compiles a kernel code optimized for the shapes and dtypes of given arguments, sends it to the GPU device, and executes the kernel. The compiled code is cached to `${HOME}/.cupy/kernel_cache` directory (this cache path can be overwritten by setting the `CUPY_CACHE_DIR` environment variable). It may make things slower at the first kernel call, though this slow down will be resolved at the second execution. CuPy also caches the kernel code sent to GPU device within the process, which reduces the kernel transfer time on further calls.
4.1.1 A list of supported attributes, properties, and methods of ndarray

Memory layout

basectypes itemsize flags nbytes shape size strides

Data type
dtype

Other attributes
T

Array conversion
tolist() tofile() dump() dumps() astype() copy() view() fill()

Shape manipulation
reshape() transpose() swapaxes() ravel() squeeze()

Item selection and manipulation
take() diagonal()

Calculation
max() argmax() min() argmin() clip() trace() sum() mean() var() std() prod() dot()

Arithmetic and comparison operations

__lt__() __le__() __gt__() __ge__() __eq__() __ne__() __nonzero__() __neg__()
__pos__() __abs__() __invert__() __add__() __sub__() __mul__() __div__()
__truediv__() __floordiv__() __mod__() __divmod__() __pow__() __lshift__()
__rshift__() __and__() __or__() __xor__() __iadd__() __isub__() __imul__()
__idiv__() __itruediv__() __ifloordiv__() __imod__() __ipow__() __ilshift__()
__irshift__() __iand__() __ior__() __ixor__()

Special methods

__copy__() __deepcopy__() __reduce__() __array__() __len__() __getitem__()
__setitem__() __int__() __long__() __float__() __oct__() __hex__() __repr__()
__str__()

Memory transfer

get() set()
4.1.2 A list of supported routines of \texttt{cupy} module

Array creation routines

\begin{verbatim}
empty() empty_like() eye() identity() ones() ones_like() zeros() zeros_like()
full() full_like()
array() asarray() ascontiguousarray() copy()
arange() linspace()
diag() diagflat()
\end{verbatim}

Array manipulation routines

\begin{verbatim}
copyto()
reshape() ravel()
rollaxis() swapaxes() transpose()
 atleast_1d() atleast_2d() atleast_3d() broadcast broadcast_arrays()
broadcast_to() expand_dims() squeeze()
column_stack() concatenate() dstack() hstack() vstack()
array_split() dsplit() hsplit() split() vsplit()
roll()
\end{verbatim}

Binary operations

\begin{verbatim}
bitwise_and bitwise_or bitwise_xor invert left_shift right_shift
\end{verbatim}

Indexing routines

\begin{verbatim}
take() diagonal()
\end{verbatim}

Input and output

\begin{verbatim}
load() save() savez() savez_compressed()
array_repr() array_str()
\end{verbatim}

Linear algebra

\begin{verbatim}
dot() vdot() inner() outer() tensordot()
trace()
\end{verbatim}
Logic functions

\texttt{isfinite} \texttt{isinf} \texttt{isnan} \\
\texttt{logical\_and} \texttt{logical\_or} \texttt{logical\_not} \texttt{logical\_xor} \\
\texttt{greater} \texttt{greater\_equal} \texttt{less} \texttt{less\_equal} \texttt{equal} \texttt{not\_equal}

Mathematical functions

\texttt{sin} \texttt{cos} \texttt{tan} \texttt{arcsin} \texttt{arccos} \texttt{arctan} \texttt{hypot} \texttt{arctan2} \texttt{deg2rad} \texttt{rad2deg} \texttt{degrees} \texttt{radians} \\
\texttt{sinh} \texttt{cosh} \texttt{tanh} \texttt{arcsinh} \texttt{arccosh} \texttt{arctanh} \\
\texttt{rint} \texttt{floor} \texttt{ceil} \texttt{trunc} \\
\texttt{sum()} \texttt{prod()} \\
\texttt{exp} \texttt{expm1} \texttt{exp2} \texttt{log} \texttt{log10} \texttt{log2} \texttt{log1p} \texttt{logaddexp} \texttt{logaddexp2} \\
\texttt{signbit} \texttt{copysign} \texttt{ldexp} \texttt{frexp} \texttt{nextafter} \\
\texttt{add} \texttt{reciprocal} \texttt{negative} \texttt{multiply} \texttt{divide} \texttt{power} \texttt{subtract} \texttt{true\_divide} \texttt{floor\_divide} \texttt{fmod} \\
\texttt{mod} \texttt{modf} \texttt{remainder} \\
\texttt{clip()} \texttt{sqrt} \texttt{square} \texttt{absolute} \texttt{sign} \texttt{maximum} \texttt{minimum} \texttt{fmax} \texttt{fmin}

Sorting, searching, and counting

\texttt{argmax()} \texttt{argmin()} \texttt{count\_nonzero()} \texttt{where()}

Statistics

\texttt{amin()} \texttt{amax()} \\
\texttt{mean()} \texttt{var()} \texttt{std()} \\
\texttt{bincount()} 

Other

\texttt{asnumpy()}

4.2 Multi-Dimensional Array (\texttt{ndarray})

class \texttt{cupy.\_ndarray} \\
Multi-dimensional array on a CUDA device.

This class implements a subset of methods of \texttt{numpy.\_ndarray}. The difference is that this class allocates the array content on the current GPU device.

Parameters

- \texttt{shape} (tuple of ints) – Length of axes.
- \texttt{dtype} – Data type. It must be an argument of \texttt{numpy.dtype}. 

• `memptr (cupy.cuda.MemoryPointer)` – Pointer to the array content head.
• `strides (tuple of ints)` – The strides for axes.

Variables
• `base (None or cupy.ndarray)` – Base array from which this array is created as a view.
• `data (cupy.cuda.MemoryPointer)` – Pointer to the array content head.
• `dtype (numpy.dtype)` – Dtype object of element type.

See also:
Data type objects (dtype)
• `size (int)` – Number of elements this array holds.
This is equivalent to product over the shape tuple.
See also:
`numpy.ndarray.size`

T
Shape-reversed view of the array.
If ndim < 2, then this is just a reference to the array itself.

  __abs__
  __add__
    x.__add__(y) <=> x+y
  __and__
    x.__and__(y) <=> x&y
  __delitem__
    x.__delitem__(y) <=> del x[y]
  __div__
    x.__div__(y) <=> x/y
  __divmod__
  __eq__
    x.__eq__(y) <=> x==y
  __float__
  __floordiv__
    x.__floordiv__(y) <=> x//y
  __ge__
    x.__ge__(y) <=> x>=y
  __getitem__
    x.__getitem__(y) <=> x[y]
  __gt__
    x.__gt__(y) <=> x>y
  __hex__
  __iadd__
    x.__iadd__(y) <=> x+=y
__iand__
x.__iand__(y) <==> x&=y

__idiv__
x.__idiv__(y) <==> x/=y

__ifloordiv__
x.__ifloordiv__(y) <==> x//=y

__ilshift__
x.__ilshift__(y) <==> x<<=y

__imod__
x.__imod__(y) <==> x%=y

__imul__
x.__imul__(y) <==> x*=y

__int__
x.__invert__() <==> ~x

__ior__
x.__ior__(y) <==> x|=y

__ipow__
x.__ipow__(y) <==> x**=y

__irshift__
x.__irshift__(y) <==> x>>=y

__isub__
x.__isub__(y) <==> x-=y

__itruediv__
x.__itruediv__(y) <==> x/y

__ixor__
x.__ixor__(y) <==> x^=y

__le__
x.__le__(y) <==> x<=y

__len__
x.__len__() <==> x<=
y

__lshift__
x.__lshift__(y) <==> x<<y

__lt__
x.__lt__(y) <==> x<y

__mod__
x.__mod__(y) <==> x%y

__mul__
x.__mul__(y) <==> x*y

__ne__
x.__ne__(y) <==> x!=y

__neg__
x.__neg__() <==> -x
__nonzero__
    x.__nonzero__() <==> x != 0
__oct__
__or__
    x.__or__(y) <==> x|y
__pos__
    x.__pos__() <==> +x
__pow__
__radd__
    x.__radd__(y) <==> y+x
__rand__
    x.__rand__(y) <==> y&x
__rdiv__
    x.__rdiv__(y) <==> y/x
__rdivmod__
__repr__
__rfloordiv__
    x.__rfloordiv__(y) <==> y//x
__rlshift__
    x.__rlshift__(y) <==> y<<x
__rmod__
    x.__rmod__(y) <==> y%x
__rmul__
    x.__rmul__(y) <==> y*x
__ror__
    x.__ror__(y) <==> y|x
__rrpow__
__rrshift__
    x.__rrshift__(y) <==> y>>x
__rshift__
    x.__rshift__(y) <==> x>>y
__rsub__
    x.__rsub__(y) <==> y-x
__rtruediv__
    x.__rtruediv__(y) <==> y/x
__rxor__
    x.__rxor__(y) <==> y^x
__setitem__
    x.__setitem__(i, y) <==> x[i]=y
__str__
__sub__
    x.__sub__(y) <==> x-y
__truediv__
    x.__truediv__(y) <=> x/y
__xor__
    x.__xor__(y) <=> x^y
argmax()
    Returns the indices of the maximum along a given axis.
    See also:
    cupy.argmax() for full documentation, numpy.ndarray.argmax()
argmin()
    Returns the indices of the minimum along a given axis.
    See also:
    cupy.argmin() for full documentation, numpy.ndarray.argmin()
astype()
    Casts the array to given data type.
    Parameters
        • dtype – Type specifier.
        • copy (bool) – If it is False and no cast happens, then this method returns the array itself. Otherwise, a copy is returned.
    Returns  If copy is False and no cast is required, then the array itself is returned. Otherwise, it returns a (possibly casted) copy of the array.

    Note: This method currently does not support order, casting, and subok arguments.
    See also:
    numpy.ndarray.astype()
clip()
    Returns an array with values limited to [a_min, a_max].
    See also:
    cupy.clip() for full documentation, numpy.ndarray.clip()
copy()
    Returns a copy of the array.
    See also:
    cupy.copy() for full documentation, numpy.ndarray.copy()
cstruct
    C representation of the array.
    This property is used for sending an array to CUDA kernels. The type of returned C structure is different for different dtypes and ndims. The definition of C type is written in cupy/carray.cuh.
device
    CUDA device on which this array resides.
diagonal()
Returns a view of the specified diagonals.

See also:
cupy.diagonal() for full documentation, numpy.ndarray.diagonal()

dot()
Returns the dot product with given array.

See also:
cupy.dot() for full documentation, numpy.ndarray.dot()

dump()
Dumps a pickle of the array to a file.
Dumped file can be read back to cupy.ndarray by cupy.load().
dumps()
Dumps a pickle of the array to a string.
fill()
Fills the array with a scalar value.

Parameters value – A scalar value to fill the array content.

See also:
numpy.ndarray.fill()
flags
Object containing memory-layout information.
It only contains c_contiguous, f_contiguous, and owndata attributes. All of these are read-only.
Accessing by indexes is also supported.

See also:
numpy.ndarray.flags
flatten()
Returns a copy of the array flatten into one dimension.
It currently supports C-order only.

Returns A copy of the array with one dimension.

Return type cupy.ndarray

See also:
numpy.ndarray.flatten()
get()
Returns a copy of the array on host memory.

Parameters stream (cupy.cuda.Stream) – CUDA stream object. If it is given, the copy
runs asynchronously. Otherwise, the copy is synchronous.

Returns Copy of the array on host memory.

Return type numpy.ndarray

itemsize
Size of each element in bytes.

See also:
numpy.ndarray.itemsize

max()
Returns the maximum along a given axis.

See also:
cupy.amax() for full documentation, numpy.ndarray.max()

mean()
Returns the mean along a given axis.

See also:
cupy.mean() for full documentation, numpy.ndarray.mean()

min()
Returns the minimum along a given axis.

See also:
cupy.amin() for full documentation, numpy.ndarray.min()

nbytes
Size of whole elements in bytes.
It does not count skips between elements.

See also:
numpy.ndarray.nbytes

ndim
Number of dimensions.
a.ndim is equivalent to len(a.shape).

See also:
numpy.ndarray.ndim

nonzero()
Return the indices of the elements that are non-zero.
Returned Array is containing the indices of the non-zero elements in that dimension.

Returns  Indices of elements that are non-zero.

Return type  tuple of arrays

See also:
numpy.nonzero()

prod()
Returns the product along a given axis.

See also:
cupy.prod() for full documentation, numpy.ndarray.prod()

ravel()
Returns an array flattened into one dimension.

See also:
cupy.ravel() for full documentation, numpy.ndarray.ravel()
reduced_view()
Returns a view of the array with minimum number of dimensions.

Parameters
dtype – Data type specifier. If it is given, then the memory sequence is reinterpreted as the new type.

Returns A view of the array with reduced dimensions.

Return type cupy.ndarray

repeat()
Returns an array with repeated arrays along an axis.

See also:
cupy.repeat() for full documentation, numpy.ndarray.repeat()

reshape()
Returns an array of a different shape and the same content.

See also:
cupy.reshape() for full documentation, numpy.ndarray.reshape()

set()
Copies an array on the host memory to cupy.ndarray.

Parameters
• arr (numpy.ndarray) – The source array on the host memory.
• stream (cupy.cuda.Stream) – CUDA stream object. If it is given, the copy runs asynchronously. Otherwise, the copy is synchronous.

shape
Lengths of axes.
Setter of this property involves reshaping without copy. If the array cannot be reshaped without copy, it raises an exception.

squeeze()
Returns a view with size-one axes removed.

See also:
cupy.squeeze() for full documentation, numpy.ndarray.squeeze()

std()
Returns the standard deviation along a given axis.

See also:
cupy.std() for full documentation, numpy.ndarray.std()

strides
Strides of axes in bytes.
See also:
numpy.ndarray.strides

sum()
Returns the sum along a given axis.

See also:
cupy.sum() for full documentation, numpy.ndarray.sum()
**swapaxes()**

Returns a view of the array with two axes swapped.

See also:

```
cupy.swapaxes() for full documentation, numpy.ndarray.swapaxes()
```

**take()**

Returns an array of elements at given indices along the axis.

See also:

```
cupy.take() for full documentation, numpy.ndarray.take()
```

**tolist()**

Converts the array to a (possibly nested) Python list.

- **Returns** The possibly nested Python list of array elements.
- **Return type** list

See also:

```
numpy.ndarray.tolist()
```

**trace()**

Returns the sum along diagonals of the array.

See also:

```
cupy.trace() for full documentation, numpy.ndarray.trace()
```

**transpose()**

Returns a view of the array with axes permuted.

See also:

```
cupy.transpose() for full documentation, numpy.ndarray.reshape()
```

**var()**

Returns the variance along a given axis.

See also:

```
cupy.var() for full documentation, numpy.ndarray.var()
```

**view()**

Returns a view of the array.

- **Parameters** `dtype` – If this is different from the data type of the array, the returned view reinterpret the memory sequence as an array of this type.

- **Returns** A view of the array. A reference to the original array is stored at the `base` attribute.

- **Return type** `cupy.ndarray`

See also:

```
numpy.ndarray.view()
```
cupy.\texttt{asnumpy} \((a, \texttt{stream}=None)\)

Returns an array on the host memory from an arbitrary source array.

**Parameters**

- \textit{a} – Arbitrary object that can be converted to \texttt{numpy.ndarray}.
- \textit{stream} (\texttt{cupy.cuda.Stream}) – CUDA stream object. If it is specified, then the device-to-host copy runs asynchronously. Otherwise, the copy is synchronous. Note that if \textit{a} is not a \texttt{cupy.ndarray} object, then this argument has no effect.

**Returns** Converted array on the host memory.

**Return type** \texttt{numpy.ndarray}

### 4.3 Universal Functions (ufunc)

CuPy provides universal functions (a.k.a. ufuncs) to support various elementwise operations. CuPy’s ufunc supports following features of NumPy’s one:

- Broadcasting
- Output type determination
- Casting rules

CuPy's ufunc currently does not provide methods such as \texttt{reduce}, \texttt{accumulate}, \texttt{reduceat}, \texttt{outer}, and \texttt{at}.

#### 4.3.1 Ufunc class

\texttt{class cupy.ufunc}

Universal function.

**Variables**

- \texttt{name (str)} – The name of the universal function.
- \texttt{nin (int)} – Number of input arguments.
- \texttt{nout (int)} – Number of output arguments.
- \texttt{nargs (int)} – Number of all arguments.

\texttt{__call__}()

Applies the universal function to arguments elementwise.

**Parameters**

- \texttt{args} – Input arguments. Each of them can be a \texttt{cupy.ndarray} object or a scalar. The output arguments can be omitted or be specified by the \texttt{out} argument.
- \texttt{out (cupy.ndarray)} – Output array. It outputs to new arrays default.
- \texttt{dtype} – Data type specifier.

**Returns** Output array or a tuple of output arrays.

**types**

A list of type signatures.

Each type signature is represented by type character codes of inputs and outputs separated by ‘->’.
4.3.2 Available ufuncs

Math operations

```
add subtract multiply divide logaddexp logaddexp2 true_divide floor_divide negative
power remainder mod fmod absolute rint sign exp exp2 log log2 log10 expm1 log1p sqrt
square reciprocal
```

Trigonometric functions

```
sin cos tan arcsin arccos arctan arctan2 hypot sinh cosh tanh arccosh arctanh
deg2rad rad2deg
```

Bit-twiddling functions

```
bitwise_and bitwise_or bitwise_xor invert left_shift right_shift
```

Comparison functions

```
greater greater_equal less less_equal not_equal equal logical_and logical_or
logical_xor logical_not maximum minimum fmax fmin
```

Floating point values

```
isfinite isinf isnan signbit copysign nextafter modf ldexp frexp fmod floor ceil trunc
```

4.4 Routines

The following pages describe NumPy-compatible routines. These functions cover a subset of NumPy routines.

4.4.1 Array Creation Routines

Basic creation routines

```
cupy.empty(shape, dtype=<type 'float'>)
```

Returns an array without initializing the elements.

This function currently does not support `order` option.

Parameters

- `shape` *(tuple of ints)* – Dimensionalities of the array.
- `dtype` – Data type specifier.

Returns

A new array with elements not initialized.

Return type

cupy.ndarray

See also:

```
numpy.empty()
```
cupy.empty_like(a, dtype=None)
Returns a new array with same shape and dtype of a given array.
This function currently does not support order and subok options.

Parameters
- `a` (cupy.ndarray) – Base array.
- `dtype` – Data type specifier. The data type of `a` is used by default.

Returns
A new array with same shape and dtype of `a` with elements not initialized.

Return type
cupy.ndarray

See also:
numpy.empty_like()

cupy.eye(N, M=None, k=0, dtype=<type 'float'>)
Returns a 2-D array with ones on the diagonals and zeros elsewhere.

Parameters
- `N` (int) – Number of rows.
- `M` (int) – Number of columns. `M == N` by default.
- `k` (int) – Index of the diagonal. Zero indicates the main diagonal, a positive index an upper diagonal, and a negative index a lower diagonal.
- `dtype` – Data type specifier.

Returns
A 2-D array with given diagonals filled with ones and zeros elsewhere.

Return type
cupy.ndarray

See also:
numpy.eye()

cupy.identity(n, dtype=<type 'float'>)
Returns a 2-D identity array.
It is equivalent to `eye(n, n, dtype)`.

Parameters
- `n` (int) – Number of rows and columns.
- `dtype` – Data type specifier.

Returns
A 2-D identity array.

Return type
cupy.ndarray

See also:
numpy.identity()

cupy.ones(shape, dtype=<type 'float'>)
Returns a new array of given shape and dtype, filled with ones.
This function currently does not support order option.

Parameters
- `shape` (tuple of ints) – Dimensionalities of the array.
- `dtype` – Data type specifier.
Returns An array filled with ones.

Return type cupy.ndarray

See also:
numpy.ones()

cupy.ones_like(a, dtype=None)
Returns an array of ones with same shape and dtype as a given array.
This function currently does not support order and subok options.

Parameters

• a (cupy.ndarray) – Base array.
• dtype – Data type specifier. The dtype of a is used by default.

Returns An array filled with ones.

Return type cupy.ndarray

See also:
numpy.ones_like()

cupy.zeros(shape, dtype=<type 'float'>)
Returns a new array of given shape and dtype, filled with zeros.
This function currently does not support order option.

Parameters

• shape (tuple of ints) – Dimensionalities of the array.
• dtype – Data type specifier.

Returns An array filled with ones.

Return type cupy.ndarray

See also:
numpy.zeros()

cupy.zeros_like(a, dtype=None)
Returns an array of zeros with same shape and dtype as a given array.
This function currently does not support order and subok options.

Parameters

• a (cupy.ndarray) – Base array.
• dtype – Data type specifier. The dtype of a is used by default.

Returns An array filled with ones.

Return type cupy.ndarray

See also:
numpy.zeros_like()

cupy.full(shape, fill_value, dtype=None)
Returns a new array of given shape and dtype, filled with a given value.
This function currently does not support order option.
Parameters

• **shape** (tuple of ints) – Dimensionalities of the array.
• **fill_value** – A scalar value to fill a new array.
• **dtype** – Data type specifier.

Returns An array filled with fill_value.

Return type cupy.ndarray

See also:

numpy.full()

cupy.full_like(a, fill_value, dtype=None)
Returns a full array with same shape and dtype as a given array.
This function currently does not support order and subok options.

Parameters

• **a** (cupy.ndarray) – Base array.
• **fill_value** – A scalar value to fill a new array.
• **dtype** – Data type specifier. The dtype of a is used by default.

Returns An array filled with fill_value.

Return type cupy.ndarray

See also:

numpy.full_like()

Creation from other data

cupy.array(obj, dtype=None, copy=True, ndmin=0)
Creates an array on the current device.
This function currently does not support the order and subok options.

Parameters

• **obj** – cupy.ndarray object or any other object that can be passed to numpy.array().
• **dtype** – Data type specifier.
• **copy** (bool) – If False, this function returns obj if possible. Otherwise this function always returns a new array.
• **ndmin** (int) – Minimum number of dimensions. Ones are inserted to the head of the shape if needed.

Returns An array on the current device.

Return type cupy.ndarray

See also:

numpy.array()
cupy.asarray \((a, dtypenone)\)
Converts an object to array.

This is equivalent to array(a, dtype, copy=False). This function currently does not support the order option.

**Parameters**
- **a** – The source object.
- **dtype** – Data type specifier. It is inferred from the input by default.

**Returns** An array on the current device. If a is already on the device, no copy is performed.

**Return type** cupy.ndarray

See also:
numpy.asarray()

cupy.asanyarray \((a, dtypenone)\)
Converts an object to array.

This is currently equivalent to asarray(), since there is no subclass of ndarray in CuPy. Note that the original numpy.asanyarray() returns the input array as is if it is an instance of a subtype of numpy.ndarray.

See also:
cupy.asarray(), numpy.asanyarray()

cupy.ascontiguousarray \((a, dtypenone)\)
Returns a C-contiguous array.

**Parameters**
- **a** (cupy.ndarray) – Source array.
- **dtype** – Data type specifier.

**Returns** If no copy is required, it returns a. Otherwise, it returns a copy of a.

**Return type** cupy.ndarray

See also:
numpy.ascontiguousarray()

cupy.copy \((a)\)
Creates a copy of a given array on the current device.

This function allocates the new array on the current device. If the given array is allocated on the different device, then this function tries to copy the contents over the devices.

**Parameters** **a** (cupy.ndarray) – The source array.

**Returns** The copy of a on the current device.

**Return type** cupy.ndarray

See: numpy.copy(), cupy.ndarray.copy()

**Numerical ranges**

cupy.arange \((start, stopnoney, step1, dtypenone)\)
Returns an array with evenly spaced values within a given interval.
Values are generated within the half-open interval [start, stop). The first three arguments are mapped like the \texttt{range} built-in function, i.e. start and step are optional.

**Parameters**

- \texttt{start} – Start of the interval.
- \texttt{stop} – End of the interval.
- \texttt{step} – Step width between each pair of consecutive values.
- \texttt{dtype} – Data type specifier. It is inferred from other arguments by default.

**Returns**  The 1-D array of range values.

**Return type**  \texttt{cupy.ndarray}

**See also:**  \texttt{numpy.arange()}

\texttt{cupy.linspace(start, stop, num=50, endpoint=True, retstep=False, dtype=None)}

Returns an array with evenly-spaced values within a given interval.

Instead of specifying the step width like \texttt{cupy.arange()}, this function requires the total number of elements specified.

**Parameters**

- \texttt{start} – Start of the interval.
- \texttt{stop} – End of the interval.
- \texttt{num} – Number of elements.
- \texttt{endpoint (bool)} – If \texttt{True}, the stop value is included as the last element. Otherwise, the stop value is omitted.
- \texttt{retstep (bool)} – If \texttt{True}, this function returns (array, step). Otherwise, it returns only the array.
- \texttt{dtype} – Data type specifier. It is inferred from the start and stop arguments by default.

**Returns**  The 1-D array of ranged values.

**Return type**  \texttt{cupy.ndarray}

**Matrix creation**

\texttt{cupy.diag(v, k=0)}

Returns a diagonal or a diagonal array.

**Parameters**

- \texttt{v (array-like)} – Array or array-like object.
- \texttt{k (int)} – Index of diagonals. Zero indicates the main diagonal, a positive value an upper diagonal, and a negative value a lower diagonal.

**Returns**  If \texttt{v} indicates a 1-D array, then it returns a 2-D array with the specified diagonal filled by \texttt{v}. If \texttt{v} indicates a 2-D array, then it returns the specified diagonal of \texttt{v}. In latter case, if \texttt{v} is a \texttt{cupy.ndarray} object, then its view is returned.

**Return type**  \texttt{cupy.ndarray}
See also:

numpy.diag()

`cupy.diagflat(v, k=0)`

Creates a diagonal array from the flattened input.

Parameters

- `v (array-like)` – Array or array-like object.
- `k (int)` – Index of diagonals. See `cupy.diag()` for detail.

Returns

A 2-D diagonal array with the diagonal copied from `v`.

Return type `cupy.ndarray`

### 4.4.2 Array Manipulation Routines

#### Basic manipulations

`cupy.copyto(dst, src, casting='same_kind', where=None)`

Copies values from one array to another with broadcasting.

This function can be called for arrays on different devices. In this case, casting, `where`, and broadcasting is not supported, and an exception is raised if these are used.

Parameters

- `dst (cupy.ndarray)` – Target array.
- `src (cupy.ndarray)` – Source array.
- `casting (str)` – Casting rule. See `numpy.can_cast()` for detail.
- `where (cupy.ndarray of bool)` – If specified, this array acts as a mask, and an element is copied only if the corresponding element of `where` is True.

See also:

numpy.copyto()

#### Shape manipulation

`cupy.reshape(a, newshape)`

Returns an array with new shape and same elements.

It tries to return a view if possible, otherwise returns a copy.

This function currently does not support `order` option.

Parameters

- `a (cupy.ndarray)` – Array to be reshaped.
- `newshape (int or tuple of ints)` – The new shape of the array to return. If it is an integer, then it is treated as a tuple of length one. It should be compatible with `a.size`. One of the elements can be -1, which is automatically replaced with the appropriate value to make the shape compatible with `a.size`.

Returns

A reshaped view of `a` if possible, otherwise a copy.

Return type `cupy.ndarray`
See also:

numpy.reshape()
cupy.ravel(a)
Returns a flattened array.
It tries to return a view if possible, otherwise returns a copy.
This function currently does not support order option.
Parameters a (cupy.ndarray) – Array to be flattened.
Returns A flattened view of a if possible, otherwise a copy.
Return type cupy.ndarray
See also:
numpy.ravel()

Transposition
cupy.rollaxis(a, axis, start=0)
Moves the specified axis backwards to the given place.
Parameters
• a (cupy.ndarray) – Array to move the axis.
• axis (int) – The axis to move.
• start (int) – The place to which the axis is moved.
Returns A view of a that the axis is moved to start.
Return type cupy.ndarray
See also:
numpy.rollaxis()
cupy.swapaxes(a, axis1, axis2)
Swaps the two axes.
Parameters
• a (cupy.ndarray) – Array to swap the axes.
• axis1 (int) – The first axis to swap.
• axis2 (int) – The second axis to swap.
Returns A view of a that the two axes are swapped.
Return type cupy.ndarray
See also:
numpy.swapaxes()
cupy.transpose(a, axes=None)
Permutes the dimensions of an array.
Parameters
• a (cupy.ndarray) – Array to permute the dimensions.
• **axes** *(tuple of ints)* – Permutation of the dimensions. This function reverses the shape by default.

**Returns** A view of a that the dimensions are permuted.

**Return type** `cupy.ndarray`

See also: `numpy.transpose()`

### Edit dimensionalities

**cupy.atleast_1d** *(arys)*

Converts arrays to arrays with dimensions >= 1.

**Parameters**

*arys* *(tuple of arrays)* – Arrays to be converted. All arguments must be `cupy.ndarray` objects. Only zero-dimensional array is affected.

**Returns** If there are only one input, then it returns its converted version. Otherwise, it returns a list of converted arrays.

See also: `numpy.atleast_1d()`

**cupy.atleast_2d** *(arys)*

Converts arrays to arrays with dimensions >= 2.

If an input array has dimensions less than two, then this function inserts new axes at the head of dimensions to make it have two dimensions.

**Parameters**

*arys* *(tuple of arrays)* – Arrays to be converted. All arguments must be `cupy.ndarray` objects.

**Returns** If there are only one input, then it returns its converted version. Otherwise, it returns a list of converted arrays.

See also: `numpy.atleast_2d()`

**cupy.atleast_3d** *(arys)*

Converts arrays to arrays with dimensions >= 3.

If an input array has dimensions less than three, then this function inserts new axes to make it have three dimensions. The place of the new axes are following:

- If its shape is (), then the shape of output is (1, 1, 1).
- If its shape is (N,), then the shape of output is (1, N, 1).
- If its shape is (M, N), then the shape of output is (M, N, 1).
- Otherwise, the output is the input array itself.

**Parameters**

*arys* *(tuple of arrays)* – Arrays to be converted. All arguments must be `cupy.ndarray` objects.

**Returns** If there are only one input, then it returns its converted version. Otherwise, it returns a list of converted arrays.
class `cupy.broadcast`
Object that performs broadcasting.

CuPy actually uses this class to support broadcasting in various operations. Note that this class does not provide an iterator.

**Parameters**
- `arrays` *(tuple of arrays)* – Arrays to be broadcasted.

**Variables**
- `shape` *(tuple of ints)* – The broadcasted shape.
- `nd` *(int)* – Number of dimensions of the broadcasted shape.
- `size` *(int)* – Total size of the broadcasted shape.
- `values` *(list of arrays)* – The broadcasted arrays.

See also:
```
numpy.atleast_3d()
```

`cupy.broadcast_arrays(*args)`
Broadcasts given arrays.

**Parameters**
- `args` *(tuple of arrays)* – Arrays to broadcast for each other.

**Returns**
A list of broadcasted arrays.

**Return type** `list`

See also:
```
numpy.broadcast_arrays()
```

`cupy.broadcast_to(array, shape)`
Broadcast an array to a given shape.

**Parameters**
- `array` *(cupy.ndarray)* – Array to broadcast.
- `shape` *(tuple of int)* – The shape of the desired array.

**Returns**
Broadcasted view.

**Return type** `cupy.ndarray`

See also:
```
numpy.broadcast_to()
```

`cupy.expand_dims(a, axis)`
Expands given arrays.

**Parameters**
- `a` *(cupy.ndarray)* – Array to be expanded.
- `axis` *(int)* – Position where new axis is to be inserted.

**Returns**
The number of dimensions is one greater than that of the input array.

**Return type** `cupy.ndarray`
See also:

numpy.expand_dims()

cupy.squeeze (a, axis=None)
Removes size-one axes from the shape of an array.

Parameters

• a (cupy.ndarray) – Array to be reshaped.
• axis (int or tuple of ints) – Axes to be removed. This function removes all size-one axes by default. If one of the specified axes is not of size one, an exception is raised.

Returns An array without (specified) size-one axes.

Return type cupy.ndarray

See also: cupy.squeeze()

Changing kind of array

cupy.asfortranarray (a, dtype=None)
Return an array laid out in Fortran order in memory.

Parameters

• a (ndarray) – The input array.
• dtype (str or dtype object, optional) – By default, the data-type is inferred from the input data.

Returns The input a in Fortran, or column-major, order.

Return type ndarray

See also: numpy.asfortranarray()

Joining arrays along axis

cupy.column_stack (tup)
Stacks 1-D and 2-D arrays as columns into a 2-D array.

A 1-D array is first converted to a 2-D column array. Then, the 2-D arrays are concatenated along the second axis.

Parameters tup (sequence of arrays) – 1-D or 2-D arrays to be stacked.

Returns A new 2-D array of stacked columns.

Return type cupy.ndarray

See also:

numpy.column_stack()

cupy.concatenate (tup, axis=0)
Joins arrays along an axis.

Parameters
• **tup** *(sequence of arrays)* – Arrays to be joined. All of these should have same dimensionalities except the specified axis.

• **axis** *(int)* – The axis to join arrays along.

**Returns** Joined array.

**Return type** `cupy.ndarray`

**See also:**

- `numpy.concatenate()`
- `cupy.vstack(tup)`
  Stacks arrays vertically.
  If an input array has one dimension, then the array is treated as a horizontal vector and stacked along the additional axis at the head. Otherwise, the array is stacked along the first axis.

  **Parameters**
  - **tup** *(sequence of arrays)* – Arrays to be stacked. Each array is converted by `cupy.atleast_2d()` before stacking.

  **Returns** Stacked array.

  **Return type** `cupy.ndarray`

  **See also:**

  - `numpy.dstack()`
- `cupy.hstack(tup)`
  Stacks arrays horizontally.
  If an input array has one dimension, then the array is treated as a horizontal vector and stacked along the first axis. Otherwise, the array is stacked along the second axis.

  **Parameters**
  - **tup** *(sequence of arrays)* – Arrays to be stacked.

  **Returns** Stacked array.

  **Return type** `cupy.ndarray`

  **See also:**

  - `numpy.hstack()`
- `cupy.dstack(tup)`
  Stacks arrays along the third axis.

  **Parameters**
  - **tup** *(sequence of arrays)* – Arrays to be stacked. Each array is converted by `cupy.atleast_3d()` before stacking.

  **Returns** Stacked array.

  **Return type** `cupy.ndarray`

  **See also:**

  - `numpy.dstack()`
- `cupy.stack(tup, axis=0)`
  Stacks arrays along a new axis.

  **Parameters**
  - **tup** *(sequence of arrays)* – Arrays to be stacked.
  - **axis** *(int)* – Axis along which the arrays are stacked.
Returns Stackd array.

Return type cupy.ndarray

See also:
numpy.stack()

Splitting arrays along axis

cupy.array_split(ary, indices_or_sections, axis=0)
Splits an array into multiple sub arrays along a given axis.
This function is almost equivalent to cupy.split(). The only difference is that this function allows an integer sections that does not evenly divide the axis.

See also:
cupy.split() for more detail, numpy.array_split()

cupy.split(ary, indices_or_sections, axis=0)
Splits an array into multiple sub arrays along a given axis.

Parameters
• ary (cupy.ndarray) – Array to split.

• indices_or_sections (int or sequence of ints) – A value indicating how to divide the axis. If it is an integer, then is treated as the number of sections, and the axis is evenly divided. Otherwise, the integers indicate indices to split at. Note that the sequence on the device memory is not allowed.

• axis (int) – Axis along which the array is split.

Returns A list of sub arrays. Each array is a view of the corresponding input array.

See also:
numpy.split()

cupy.vsplit(ary, indices_or_sections)
Splits an array into multiple sub arrays along the first axis.
This is equivalent to split with axis=0.

See also:
cupy.split() for more detail, numpy.dsplit()

cupy.hsplit(ary, indices_or_sections)
Splits an array into multiple sub arrays horizontally.
This is equivalent to split with axis=0 if ary has one dimension, and otherwise that with axis=1.

See also:
cupy.split() for more detail, numpy.hsplit()

cupy.dsplit(ary, indices_or_sections)
Splits an array into multiple sub arrays along the third axis.
This is equivalent to split with axis=2.

See also:
cupy.split() for more detail, numpy.dsplit()
4.4.3 Repeating part of arrays along axis

cupy.tile(A, reps)

Construct an array by repeating A the number of times given by reps.

Parameters

• A (cupy.ndarray) – Array to transform.
• reps (int or tuple) – The number of repeats.

Returns

Transformed array with repeats.

Return type

cupy.ndarray

See also:

numpy.tile()

cupy.repeat(a, repeats, axis=None)

Repeat arrays along an axis.

Parameters

• a (cupy.ndarray) – Array to transform.
• repeats (int, list or tuple) – The number of repeats.
• axis (int) – The axis to repeat.

Returns

Transformed array with repeats.

Return type

cupy.ndarray

See also:

numpy.repeat()

4.4.4 Rearranging elements

cupy.roll(a, shift, axis=None)

Roll array elements along a given axis.

Parameters

• a (ndarray) – Array to be rolled.
• shift (int) – The number of places by which elements are shifted.
• axis (int or None) – The axis along which elements are shifted. If axis is None, the array is flattened before shifting, and after that it is reshaped to the original shape.

Returns

Output array.

Return type

ndarray

See also:

numpy.roll()
4.4.5 Binary Operations

Elementwise bit operations

cupy.bitwise_and = <ufunc ‘cupy_bitwise_and’>
Computes the bitwise AND of two arrays elementwise.

   Only integer and boolean arrays are handled.
   See also:
   numpy.bitwise_and
cupy.bitwise_or = <ufunc ‘cupy_bitwise_or’>
Computes the bitwise OR of two arrays elementwise.

   Only integer and boolean arrays are handled.
   See also:
   numpy.bitwise_or
cupy.bitwise_xor = <ufunc ‘cupy_bitwise_xor’>
Computes the bitwise XOR of two arrays elementwise.

   Only integer and boolean arrays are handled.
   See also:
   numpy.bitwise_xor
cupy.invert = <ufunc ‘cupy_invert’>
Computes the bitwise NOT of an array elementwise.

   Only integer and boolean arrays are handled.
   See also:
   numpy.invert
cupy.left_shift = <ufunc ‘cupy_left_shift’>
Shifts the bits of each integer element to the left.

   Only integer arrays are handled.
   See also:
   numpy.left_shift
cupy.right_shift = <ufunc ‘cupy_right_shift’>
Shifts the bits of each integer element to the right.

   Only integer arrays are handled.
   See also:
   numpy.right_shift

4.4.6 Indexing Routines

cupy.take(a, indices, axis=None, out=None)
Takes elements of an array at specified indices along an axis.
   This is an implementation of “fancy indexing” at single axis.
This function does not support mode option.

**Parameters**

- `a (cupy.ndarray)` – Array to extract elements.
- `indices (int or array-like)` – Indices of elements that this function takes.
- `axis (int)` – The axis along which to select indices. The flattened input is used by default.
- `out (cupy.ndarray)` – Output array. If provided, it should be of appropriate shape and dtype.

**Returns** The result of fancy indexing.

**Return type** `cupy.ndarray`

See also:

- `numpy.take()`
- `cupy.diagonal(a, offset=0, axis1=0, axis2=1)`
  Returns specified diagonals.
  This function extracts the diagonals along two specified axes. The other axes are not changed. This function returns a writable view of this array as NumPy 1.10 will do.

**Parameters**

- `a (cupy.ndarray)` – Array from which the diagonals are taken.
- `offset (int)` – Index of the diagonals. Zero indicates the main diagonals, a positive value upper diagonals, and a negative value lower diagonals.
- `axis1 (int)` – The first axis to take diagonals from.
- `axis2 (int)` – The second axis to take diagonals from.

**Returns** A view of the diagonals of `a`.

**Return type** `cupy.ndarray`

See also:

- `numpy.diagonal()`
- `cupy.ix_(*args)`
  Construct an open mesh from multiple sequences.
  This function takes N 1-D sequences and returns N outputs with N dimensions each, such that the shape is 1 in all but one dimension and the dimension with the non-unit shape value cycles through all N dimensions.
  Using `ix_` one can quickly construct index arrays that will index the cross product. `a[cupy.ix_([1,3],[2,5])]` returns the array `[[a[1,2] a[1,5]], [a[3,2] a[3,5]]]`.

**Parameters** `*args` – 1-D sequences

**Returns** N arrays with N dimensions each, with N the number of input sequences. Together these arrays form an open mesh.

**Return type** tuple of ndarrays

**Examples**
>>> a = cupy.arange(10).reshape(2, 5)
>>> a
array([[0, 1, 2, 3, 4],
       [5, 6, 7, 8, 9]])
>>> ixgrid = cupy.ix_([0,1], [2,4])
>>> ixgrid
(array([[0],
        [1]]), array([[2, 4]]))

See also:

numpy.ix_()

cupy.fill_diagonal(a, val, wrap=False)
Fill the main diagonal of the given array of any dimensionality.

For an array a with a.ndim > 2, the diagonal is the list of locations with indices a[i, i, ..., i] all identical. This function modifies the input array in-place, it does not return a value.

Parameters
- **a** (cupy.ndarray) – The array, at least 2-D.
- **val** (scalar) – The value to be written on the diagonal. Its type must be compatible with that of the array a.
- **wrap** (bool) – If specified, the diagonal is “wrapped” after N columns. This affects only tall matrices.

Examples

```python
>>> a = cupy.zeros((3, 3), int)
>>> cupy.fill_diagonal(a, 5)
>>> a
array([[5, 0, 0],
       [0, 5, 0],
       [0, 0, 5]])
```

See also:

numpy.fill_diagonal()

---

### 4.4.7 Input and Output

#### NPZ files

cupy.load(file, mmap_mode=None)

Loads arrays or pickled objects from .npy, .npz or pickled file.

This function just calls numpy.load and then sends the arrays to the current device. NPZ file is converted to NpzFile object, which defers the transfer to the time of accessing the items.

Parameters
- **file** (file-like object or string) – The file to read.
• **mmap_mode** *(None, 'r+', 'r', 'w+', 'c')* – If not None, memory-map the file to construct an intermediate `numpy.ndarray` object and transfer it to the current device.

**Returns** CuPy array or NpzFile object depending on the type of the file. NpzFile object is a dictionary-like object with the context manager protocol (which enables us to use `with` statement on it).

**See also:**

`numpy.load()`

```python
cupy.save(file, arr)
```
Saves an array to a binary file in `.npy` format.

**Parameters**

- `file (file or str)` – File or filename to save.
- `arr (array_like)` – Array to save. It should be able to feed to `cupy.asnumpy()`.

**See also:**

`numpy.save()`

```python
cupy.savez(file, *args, **kwds)
```
Saves one or more arrays into a file in uncompressed `.npz` format.

Arguments without keys are treated as arguments with automatic keys named `arr_0`, `arr_1`, etc. corresponding to the positions in the argument list. The keys of arguments are used as keys in the `.npz` file, which are used for accessing NpzFile object when the file is read by `cupy.load()` function.

**Parameters**

- `file (file or str)` – File or filename to save.
- `*args` – Arrays with implicit keys.
- `**kwds` – Arrays with explicit keys.

**See also:**

`numpy.savez()`

```python
cupy.savez_compressed(file, *args, **kwds)
```
Saves one or more arrays into a file in compressed `.npz` format.

It is equivalent to `cupy.savez()` function except the output file is compressed.

**See also:**

`cupy.savez()` for more detail, `numpy.savez_compressed()`

**String formatting**

```python
cupy.array_repr(arr, max_line_width=None, precision=None, suppress_small=None)
```
Returns the string representation of an array.

**Parameters**

- `arr (array_like)` – Input array. It should be able to feed to `cupy.asnumpy()`.
- `max_line_width (int)` – The maximum number of line lengths.
- `precision (int)` – Floating point precision. It uses the current printing precision of NumPy.
• `suppress_small (bool)` – If True, very small numbers are printed as zeros

Returns The string representation of `arr`.

Return type `str`

See also:

`numpy.array_repr()`

`cupy.array_str (arr, max_line_width=None, precision=None, suppress_small=None)`

Returns the string representation of the content of an array.

Parameters

• `arr (array_like)` – Input array. It should be able to feed to `cupy.asnumpy()`.
• `max_line_width (int)` – The maximum number of line lengths.
• `precision (int)` – Floating point precision. It uses the current printing precision of NumPy.
• `suppress_small (bool)` – If True, very small number are printed as zeros.

See also:

`numpy.array_str()`

### 4.4.8 Linear Algebra

#### Matrix and vector products

`cupy.dot (a, b, out=None)`

Returns a dot product of two arrays.

For arrays with more than one axis, it computes the dot product along the last axis of `a` and the second-to-last axis of `b`. This is just a matrix product if the both arrays are 2-D. For 1-D arrays, it uses their unique axis as an axis to take dot product over.

Parameters

• `a (cupy.ndarray)` – The left argument.
• `b (cupy.ndarray)` – The right argument.
• `out (cupy.ndarray)` – Output array.

Returns The dot product of `a` and `b`.

Return type `cupy.ndarray`

See also:

`numpy.dot()`

`cupy.vdot (a, b)`

Returns the dot product of two vectors.

The input arrays are flattened into 1-D vectors and then it performs inner product of these vectors.

Parameters

• `a (cupy.ndarray)` – The first argument.
• `b (cupy.ndarray)` – The second argument.
**Returns** Zero-dimensional array of the dot product result.

**Return type** `cupy.ndarray`

See also:

`numpy.vdot()`

cupy.**inner**(a, b)

Returns the inner product of two arrays.

It uses the last axis of each argument to take sum product.

**Parameters**

- a (cupy.ndarray) – The first argument.
- b (cupy.ndarray) – The second argument.

**Returns** The inner product of a and b.

**Return type** `cupy.ndarray`

See also:

`numpy.inner()`

cupy.**outer**(a, b, out=None)

Returns the outer product of two vectors.

The input arrays are flattened into 1-D vectors and then it performs outer product of these vectors.

**Parameters**

- a (cupy.ndarray) – The first argument.
- b (cupy.ndarray) – The second argument.
- out (cupy.ndarray) – Output array.

**Returns** 2-D array of the outer product of a and b.

**Return type** `cupy.ndarray`

See also:

`numpy.outer()`

cupy.**tensordot**(a, b, axes=2)

Returns the tensor dot product of two arrays along specified axes.

This is equivalent to compute dot product along the specified axes which are treated as one axis by reshaping.

**Parameters**

- a (cupy.ndarray) – The first argument.
- b (cupy.ndarray) – The second argument.
- axes –
  - If it is an integer, then axes axes at the last of a and the first of b are used.
  - If it is a pair of sequences of integers, then these two sequences specify the list of axes for a and b. The corresponding axes are paired for sum-product.
- out (cupy.ndarray) – Output array.

**Returns** The tensor dot product of a and b along the axes specified by axes.
Return type  \texttt{cupy.ndarray}

See also:
\texttt{numpy.tensordot()}

\textbf{Norms etc.}

\texttt{cupy.trace} \( (a, \text{offset}=0, \text{axis1}=0, \text{axis2}=1, \text{dtype}=\text{None}, \text{out}=None) \)

Returns the sum along the diagonals of an array.

It computes the sum along the diagonals at \texttt{axis1} and \texttt{axis2}.

Parameters

\begin{itemize}
\item \texttt{a} (\texttt{cupy.ndarray}) – Array to take trace.
\item \texttt{offset} (\texttt{int}) – Index of diagonals. Zero indicates the main diagonal, a positive value an upper diagonal, and a negative value a lower diagonal.
\item \texttt{axis1} (\texttt{int}) – The first axis along which the trace is taken.
\item \texttt{axis2} (\texttt{int}) – The second axis along which the trace is taken.
\item \texttt{dtype} – Data type specifier of the output.
\item \texttt{out} (\texttt{cupy.ndarray}) – Output array.
\end{itemize}

Returns The trace of \texttt{a} along axes \texttt{(axis1, axis2)}.

Return type  \texttt{cupy.ndarray}

See also:  \texttt{numpy.trace()}

\section*{4.4.9 Logic Functions}

\textbf{Infinities and NaNs}

\texttt{cupy.isfinite = <ufunc `cupy_isfinite`>}

Tests finiteness elementwise.

Each element of returned array is \texttt{True} only if the corresponding element of the input is finite (i.e. not an infinity nor NaN).

See also:  \texttt{numpy.isfinite}

\texttt{cupy.isinf = <ufunc `cupy_isinf`>}

Tests if each element is the positive or negative infinity.

See also:  \texttt{numpy.isinf}

\texttt{cupy.isnan = <ufunc `cupy_isnan`>}

Tests if each element is a NaN.

See also:  \texttt{numpy.isnan}
Logic operations

cupy.logical_and = <ufunc ‘cupy_logical_and’>
Computes the logical AND of two arrays.

See also:
numpy.logical_and

cupy.logical_or = <ufunc ‘cupy_logical_or’>
Computes the logical OR of two arrays.

See also:
numpy.logical_or

cupy.logical_not = <ufunc ‘cupy_logical_not’>
Computes the logical NOT of an array.

See also:
numpy.logical_not

cupy.logical_xor = <ufunc ‘cupy_logical_xor’>
Computes the logical XOR of two arrays.

See also:
numpy.logical_xor

Comparison operations

cupy.greater = <ufunc ‘cupy_greater’>
Tests elementwise if \( x_1 > x_2 \).

See also:
numpy.greater

cupy.greater_equal = <ufunc ‘cupy_greater_equal’>
Tests elementwise if \( x_1 \geq x_2 \).

See also:
numpy.greater_equal

cupy.less = <ufunc ‘cupy_less’>
Tests elementwise if \( x_1 < x_2 \).

See also:
numpy.less

cupy.less_equal = <ufunc ‘cupy_less_equal’>
Tests elementwise if \( x_1 \leq x_2 \).

See also:
numpy.less_equal

cupy.equal = <ufunc ‘cupy_equal’>
Tests elementwise if \( x_1 = x_2 \).

See also:
numpy.equal
cupy.not_equal = <ufunc ‘cupy_not_equal’>
Tests elementwise if $x_1 \neq x_2$.

See also:

numpy.equal

4.4.10 Mathematical Functions

Trigonometric functions

cupy.sin = <ufunc ‘cupy_sin’>
Elementwise sine function.

See also:

numpy.sin

cupy.cos = <ufunc ‘cupy_cos’>
Elementwise cosine function.

See also:

numpy.cos

cupy.tan = <ufunc ‘cupy_tan’>
Elementwise tangent function.

See also:

numpy.tan

cupy.arcsin = <ufunc ‘cupy_arcsin’>
Elementwise inverse-sine function (a.k.a. arcsine function).

See also:

numpy.arcsin

cupy.arccos = <ufunc ‘cupy_arccos’>
Elementwise inverse-cosine function (a.k.a. arccosine function).

See also:

numpy.arccos

cupy.arctan = <ufunc ‘cupy_arctan’>
Elementwise inverse-tangent function (a.k.a. arctangent function).

See also:

numpy.arctan

cupy.hypot = <ufunc ‘cupy_hypot’>
Computes the hypoteneous of orthogonal vectors of given length.

This is equivalent to $\sqrt{x_1 \times 2 + x_2 \times 2}$, while this function is more efficient.

See also:

numpy.hypot
cupy.arctan2 = <ufunc ‘cupy_arctan2’>
Elementwise inverse-tangent of the ratio of two arrays.

See also:
numpy.arctan2

cupy.deg2rad = <ufunc ‘cupy_deg2rad’>
Converts angles from degrees to radians elementwise.

See also:
numpy.deg2rad, numpy.radians

cupy.rad2deg = <ufunc ‘cupy_rad2deg’>
Converts angles from radians to degrees elementwise.

See also:
numpy.rad2deg, numpy.degrees

cupy.degrees = <ufunc ‘cupy_rad2deg’>
Converts angles from radians to degrees elementwise.

See also:
numpy.rad2deg, numpy.degrees

cupy.radians = <ufunc ‘cupy_deg2rad’>
Converts angles from degrees to radians elementwise.

See also:
numpy.deg2rad, numpy.radians

Hyperbolic functions

cupy.sinh = <ufunc ‘cupy_sinh’>
Elementwise hyperbolic sine function.

See also:
numpy.sinh

cupy.cosh = <ufunc ‘cupy_cosh’>
Elementwise hyperbolic cosine function.

See also:
numpy.cosh

cupy.tanh = <ufunc ‘cupy_tanh’>
Elementwise hyperbolic tangent function.

See also:
numpy.tanh

cupy.arcsinh = <ufunc ‘cupy_arcsinh’>
Elementwise inverse of hyperbolic sine function.

See also:
numpy.arcsinh
cupy.arccosh = <ufunc ‘cupy_arccosh’>
  Elementwise inverse of hyperbolic cosine function.
  
  See also:
  
  numpy.arccosh

cupy.arctanh = <ufunc ‘cupy_arctanh’>
  Elementwise inverse of hyperbolic tangent function.
  
  See also:
  
  numpy.arctanh

## Rounding

cupy.rint = <ufunc ‘cupy_rint’>
  Rounds each element of an array to the nearest integer.
  
  See also:
  
  numpy.rint

cupy.floor = <ufunc ‘cupy_floor’>
  Rounds each element of an array to its floor integer.
  
  See also:
  
  numpy.floor

cupy.ceil = <ufunc ‘cupy ceil’>
  Rounds each element of an array to its ceiling integer.
  
  See also:
  
  numpy.ceil

cupy.trunc = <ufunc ‘cupy trunc’>
  Rounds each element of an array towards zero.
  
  See also:
  
  numpy.trunc

## Sums and products

cupy.sum(a, axis=None, dtype=None, out=None, keepdims=False)
  Returns the sum of an array along given axes.

  Parameters
  
  * a (cupy.ndarray) – Array to take sum.
  * axis (int or sequence of ints) – Axes along which the sum is taken.
  * dtype – Data type specifier.
  * out (cupy.ndarray) – Output array.
  * keepdims (bool) – If True, the specified axes are remained as axes of length one.

  Returns
  The result array.

  Return type
  cupy.ndarray
See also:

numpy.sum()

cupy.prod(a, axis=None, dtype=None, out=None, keepdims=False)
Returns the product of an array along given axes.

Parameters

- a (cupy.ndarray) – Array to take product.
- axis (int or sequence of ints) – Axes along which the product is taken.
- dtype – Data type specifier.
- out (cupy.ndarray) – Output array.
- keepdims (bool) – If True, the specified axes are remained as axes of length one.

Returns

The result array.

Return type

cupy.ndarray

See also:

numpy.prod()

Exponential and logarithm functions

cupy.exp = <ufunc ‘cupy_exp’>
Elementwise exponential function.

See also:

numpy.exp

cupy.expm1 = <ufunc ‘cupy_expm1’>
Computes \( \exp(x) - 1 \) elementwise.

See also:

numpy.expm1

cupy.exp2 = <ufunc ‘cupy_exp2’>
Elementwise exponentiation with base 2.

See also:

numpy.exp2

cupy.log = <ufunc ‘cupy_log’>
Elementwise natural logarithm function.

See also:

numpy.log

cupy.log10 = <ufunc ‘cupy_log10’>
Elementwise common logarithm function.

See also:

numpy.log10
cupy.

**log2 = <ufunc ‘cupy_log2’>**
Elementwise binary logarithm function.

See also:

numpy.log2

**log1p = <ufunc ‘cupy_log1p’>**
Computes \( \log(1 + x) \) elementwise.

See also:

numpy.log1p

**logaddexp = <ufunc ‘cupy_logaddexp’>**
Computes \( \log(\exp(x_1) + \exp(x_2)) \) elementwise.

See also:

numpy.logaddexp

**logaddexp2 = <ufunc ‘cupy_logaddexp2’>**
Computes \( \log2(\exp2(x_1) + \exp2(x_2)) \) elementwise.

See also:

numpy.logaddexp2

Floating point manipulations

**signbit = <ufunc ‘cupy_signbit’>**
Tests elementwise if the sign bit is set (i.e. less than zero).

See also:

numpy.signbit

**copysign = <ufunc ‘cupy_copysign’>**
Returns the first argument with the sign bit of the second elementwise.

See also:

numpy.copysign

**ldexp = <ufunc ‘cupy_ldexp’>**
Computes \( x_1 \times 2^{x_2} \) elementwise.

See also:

numpy.ldexp

**frexp = <ufunc ‘cupy_frexp’>**
Decomposes each element to mantissa and two’s exponent.

This ufunc outputs two arrays of the input dtype and the int dtype.

See also:

numpy.frexp

**nextafter = <ufunc ‘cupy_nextafter’>**
Computes the nearest neighbor float values towards the second argument.

See also:

numpy.nextafter
Arithmetic operations

CuPy does not provide overloads for these operations:

- `cupy.add`
- `cupy.subtract`
- `cupy.multiply`
- `cupy.divide`
- `cupy.true_divide`
- `cupy.fmod`

CuPy provides the following analogous operations:

- `cupy.negative`
- `cupy.add`
- `cupy.subtract`
- `cupy.multiply`
- `cupy.true_divide`
- `cupy.floor_divide`
- `cupy.power`

CuPy arithmetic functions:

- `cupy.negative`
  - Takes numerical negative elementwise.
  - See also: `numpy.negative`

- `cupy.add`
  - Adds two arrays elementwise.
  - See also: `numpy.add`

- `cupy.subtract`
  - Subtracts arguments elementwise.
  - See also: `numpy.subtract`

- `cupy.multiply`
  - Multiplies two arrays elementwise.
  - See also: `numpy.multiply`

- `cupy.true_divide`
  - Elementwise true division (i.e. division as floating values).
  - See also: `numpy.true_divide`

- `cupy.floor_divide`
  - Elementwise floor division (i.e. integer quotient).
  - See also: `numpy.floor_divide`

- `cupy.power`
  - Computes \( x1 \times x2 \) elementwise.
  - See also: `numpy.power`

- `cupy.fmod`
  - Computes the remainder of \( C \) division elementwise.
  - See also: `numpy.fmod`


cupy.mod = <ufunc ‘cupy_remainder’>
Computes the remainder of Python division elementwise.

See also:
numpy.remainder

cupy.remainder = <ufunc ‘cupy_remainder’>
Computes the remainder of Python division elementwise.

See also:
numpy.remainder

cupy.modf = <ufunc ‘cupy_modf’>
Extracts the fractional and integral parts of an array elementwise.
This ufunc returns two arrays.

See also:
numpy.modf

cupy.reciprocal = <ufunc ‘cupy_reciprocal’>
Computes 1 / x elementwise.

See also:
numpy.reciprocal

Miscellaneous

cupy.clip(a, a_min, a_max, out=None)
Clips the values of an array to a given interval.
This is equivalent to maximum(minimum(a, a_max), a_min), while this function is more efficient.

Parameters

- a (cupy.ndarray) – The source array.
- a_min (scalar or cupy.ndarray) – The left side of the interval.
- a_max (scalar or cupy.ndarray) – The right side of the interval.
- out (cupy.ndarray) – Output array.

Returns Clipped array.

Return type cupy.ndarray

See also:
numpy.clip()

cupy.sqrt = <ufunc ‘cupy_sqrt’>
cupy.square = <ufunc ‘cupy_square’>
Elementwise square function.

See also:
numpy.square
cupy.\texttt{absolute} = \texttt{ufunc 'cupy\_absolute'}
Elementwise absolute value function.

See also:
\texttt{numpy.absolute}

cupy.\texttt{sign} = \texttt{ufunc 'cupy\_sign'}
Elementwise sign function.
It returns -1, 0, or 1 depending on the sign of the input.

See also:
\texttt{numpy.sign}

cupy.\texttt{maximum} = \texttt{ufunc 'cupy\_maximum'}
Takes the maximum of two arrays elementwise.
If NaN appears, it returns the NaN.

See also:
\texttt{numpy.maximum}

cupy.\texttt{minimum} = \texttt{ufunc 'cupy\_minimum'}
Takes the minimum of two arrays elementwise.
If NaN appears, it returns the NaN.

See also:
\texttt{numpy.minimum}

cupy.\texttt{fmax} = \texttt{ufunc 'cupy\_fmax'}
Takes the maximum of two arrays elementwise.
If NaN appears, it returns the other operand.

See also:
\texttt{numpy.fmax}

cupy.\texttt{fmin} = \texttt{ufunc 'cupy\_fmin'}
Takes the minimum of two arrays elementwise.
If NaN appears, it returns the other operand.

See also:
\texttt{numpy.fmin}

### 4.4.11 Random Sampling (\texttt{cupy.random})

CuPy's random number generation routines are based on cuRAND. They cover a small fraction of \texttt{numpy.random}.
The big difference of \texttt{cupy.random} from \texttt{numpy.random} is that \texttt{cupy.random} supports \texttt{dtype} option for most functions. This option enables us to generate float32 values directly without any space overhead.

**Sample random data**

cupy.random.\texttt{rand}(\ast size, \ast kwarg)
Returns an array of uniform random values over the interval \([0, 1)\).
Each element of the array is uniformly distributed on the half-open interval \([0, 1)\). All elements are identically and independently distributed (i.i.d.).

Parameters

- **size** *(tuple of ints)* – The shape of the array.
- **dtype** – Data type specifier. Only `numpy.float32` and `numpy.float64` types are allowed. The default is `numpy.float64`.

Returns A random array.

Return type `cupy.ndarray`

See also: `numpy.random.rand()`

`cupy.random.randn(*size, **kwarg)`

Returns an array of standard normal random values.

Each element of the array is normally distributed with zero mean and unit variance. All elements are identically and independently distributed (i.i.d.).

Parameters

- **size** *(tuple of ints)* – The shape of the array.
- **dtype** – Data type specifier. Only `numpy.float32` and `numpy.float64` types are allowed. The default is `numpy.float64`.

Returns An array of standard normal random values.

Return type `cupy.ndarray`

See also: `numpy.random.randn()`

`cupy.random.randint(low, high=None, size=None)`

Returns a scalar or an array of integer values over \([low, high)\).

Each element of returned values are independently sampled from uniform distribution over left-close and right-open interval \([low, high)\).

Parameters

- **low** *(int)* – If `high` is not `None`, it is the lower bound of the interval. Otherwise, it is the upper bound of the interval and lower bound of the interval is set to 0.
- **high** *(int)* – Upper bound of the interval.
- **size** *(None or int or tuple of ints)* – The shape of returned value.

Returns If `size` is `None`, it is single integer sampled. If `size` is integer, it is the 1D-array of length `size` element. Otherwise, it is the array whose shape specified by `size`.

Return type `int` or `cupy.ndarray` of ints

`cupy.random.random_integers(low, high=None, size=None)`

Return a scalar or an array of integer values over \([low, high]\).

Each element of returned values are independently sampled from uniform distribution over closed interval \([low, high]\).

Parameters
• **low**(*int*) – If high is not None, it is the lower bound of the interval. Otherwise, it is the upper bound of the interval and the lower bound is set to 1.

• **high**(*int*) – Upper bound of the interval.

• **size**(*None or int or tuple of ints*) – The shape of returned value.

**Returns** If size is None, it is single integer sampled. If size is integer, it is the 1D-array of length size element. Otherwise, it is the array whose shape specified by size.

**Return type** int or cupy.ndarray of ints

cupy.random.random_sample(size=None, dtype=<type ‘float’>)

Returns an array of random values over the interval \([0, 1)\).

This is a variant of cupy.random.rand().

**Parameters**

• **size**(*int or tuple of ints*) – The shape of the array.

• **dtype** – Data type specifier. Only numpy.float32 and numpy.float64 types are allowed.

**Returns** An array of uniformly distributed random values.

**Return type** cupy.ndarray

See also: numpy.random.random_sample()

cupy.random.random(size=None, dtype=<type ‘float’>)

Returns an array of random values over the interval \([0, 1)\).

This is a variant of cupy.random.rand().

**Parameters**

• **size**(*int or tuple of ints*) – The shape of the array.

• **dtype** – Data type specifier. Only numpy.float32 and numpy.float64 types are allowed.

**Returns** An array of uniformly distributed random values.

**Return type** cupy.ndarray

See also: numpy.random.random_sample()

cupy.random.ranf(size=None, dtype=<type ‘float’>)

Returns an array of random values over the interval \([0, 1)\).

This is a variant of cupy.random.rand().

**Parameters**

• **size**(*int or tuple of ints*) – The shape of the array.

• **dtype** – Data type specifier. Only numpy.float32 and numpy.float64 types are allowed.

**Returns** An array of uniformly distributed random values.

**Return type** cupy.ndarray
See also:

numpy.random.random_sample()

cupy.random.sample(size=None, dtype=<type 'float'>)

Returns an array of random values over the interval [0, 1).

This is a variant of cupy.random.rand().

Parameters

• size (int or tuple of ints) – The shape of the array.

• dtype – Data type specifier. Only numpy.float32 and numpy.float64 types are allowed.

Returns An array of uniformly distributed random values.

Return type cupy.ndarray

See also: cupy.ndarray

Distributions

cupy.random.gumbel(loc=0.0, scale=1.0, size=None, dtype=<type 'float'>)

Returns an array of samples drawn from a Gumbel distribution.

The samples are drawn from a Gumbel distribution with location \( \mu \) and scale \( \eta \). Its probability density function is defined as

\[
f(x) = \frac{1}{\eta} \exp\left(-\frac{x - \mu}{\eta}\right) \exp\left[- \exp\left(-\frac{x - \mu}{\eta}\right)\right],
\]

where \( \mu \) is \( \text{loc} \) and \( \eta \) is \( \text{scale} \).

Parameters

• loc (float) – The location of the mode \( \mu \).

• scale (float) – The scale parameter \( \eta \).

• size (int or tuple of ints) – The shape of the array. If None, a zero-dimensional array is generated.

• dtype – Data type specifier. Only numpy.float32 and numpy.float64 types are allowed.

Returns Samples drawn from the Gumbel distribution.

Return type cupy.ndarray

See also:

numpy.random.gumbel()

cupy.random.lognormal(mean=0.0, sigma=1.0, size=None, dtype=<type 'float'>)

Returns an array of samples drawn from a log normal distribution.

The samples are natural log of samples drawn from a normal distribution with mean \( \text{mean} \) and deviation \( \text{sigma} \).

Parameters

• mean (float) – Mean of the normal distribution.
• \texttt{sigma(float)} – Standard deviation of the normal distribution.

• \texttt{size (int or tuple of ints)} – The shape of the array. If None, a zero-dimensional array is generated.

• \texttt{dtype} – Data type specifier. Only \texttt{numpy.float32} and \texttt{numpy.float64} types are allowed.

\textbf{Returns} Samples drawn from the log normal distribution.

\textbf{Return type} \texttt{cupy.ndarray}

\textbf{See also:} \texttt{numpy.random.lognormal()}

\texttt{cupy.random.normal(loc=0.0, scale=1.0, size=None, dtype=<type 'float'>)}

Returns an array of normally distributed samples.

\textbf{Parameters}

• \texttt{loc(float)} – Mean of the normal distribution.

• \texttt{scale(float)} – Standard deviation of the normal distribution.

• \texttt{size (int or tuple of ints)} – The shape of the array. If None, a zero-dimensional array is generated.

• \texttt{dtype} – Data type specifier. Only \texttt{numpy.float32} and \texttt{numpy.float64} types are allowed.

\textbf{Returns} Normally distributed samples.

\textbf{Return type} \texttt{cupy.ndarray}

\textbf{See also:} \texttt{numpy.random.normal()}

\texttt{cupy.random.standard_normal(size=None, dtype=<type 'float'>)}

Returns an array of samples drawn from the standard normal distribution.

This is a variant of \texttt{cupy.random.randn()}.

\textbf{Parameters}

• \texttt{size (int or tuple of ints)} – The shape of the array. If None, a zero-dimensional array is generated.

• \texttt{dtype} – Data type specifier.

\textbf{Returns} Samples drawn from the standard normal distribution.

\textbf{Return type} \texttt{cupy.ndarray}

\textbf{See also:} \texttt{numpy.random.standard_normal()}

\texttt{cupy.random.uniform(low=0.0, high=1.0, size=None, dtype=<type 'float'>)}

Returns an array of uniformly-distributed samples over an interval.

Samples are drawn from a uniform distribution over the half-open interval \([\text{low}, \text{high})\).

\textbf{Parameters}

• \texttt{low(float)} – Lower end of the interval.

• \texttt{high(float)} – Upper end of the interval.
• **size** (*int or tuple of ints*) – The shape of the array. If None, a zero-dimensional array is generated.

• **dtype** – Data type specifier.

**Returns** Samples drawn from the uniform distribution.

**Return type** `cupy.ndarray`

**See also:**

`numpy.random.uniform()`

### Random number generator

`cupy.random.seed(seed=None)`

Resets the state of the random number generator with a seed.

This function resets the state of the global random number generator for the current device. Be careful that generators for other devices are not affected.

**Parameters**

- **seed** (*None or int*) – Seed for the random number generator. If None, it uses `os.urandom()` if available or `time.clock()` otherwise. Note that this function does not support seeding by an integer array.

`cupy.random.get_random_state()`

Gets the state of the random number generator for the current device.

If the state for the current device is not created yet, this function creates a new one, initializes it, and stores it as the state for the current device.

**Returns** The state of the random number generator for the device.

**Return type** `RandomState`

**class** `cupy.random.RandomState (seed=None, method=100)`

Portable container of a pseudo-random number generator.

An instance of this class holds the state of a random number generator. The state is available only on the device which has been current at the initialization of the instance.

Functions of `cupy.random` use global instances of this class. Different instances are used for different devices. The global state for the current device can be obtained by the `cupy.random.get_random_state()` function.

**Parameters**

- **seed** (*None or int*) – Seed of the random number generator. See the `seed()` method for detail.

- **method** (*int*) – Method of the random number generator. Following values are available:

  `cupy.cuda.curand.CURAND_RNG_PSEUDO_DEFAULT`
  `cupy.cuda.curand.CURAND_RNG_XORWOW`
  `cupy.cuda.curand.CURAND_RNG_MRG32K3A`
  `cupy.cuda.curand.CURAND_RNG_MTGP32`
  `cupy.cuda.curand.CURAND_RNG_MTI9937`
  `cupy.cuda.curand.CURAND_RNG_PHILOX4_32_10`

**interval** (*mx, size*)

Generate multiple integers independently sampled uniformly from `[0, mx]`.

**Parameters**
mx (int) – Upper bound of the interval

size (None or int or tuple) – Shape of the array or the scalar returned.

Returns

If None, an cupy.ndarray with shape () is returned. If int, 1-D array of length
size is returned. If tuple, multi-dimensional array with shape size is returned. Currently,
each element of the array is numpy.int32.

Return type

int or cupy.ndarray

lognormal (mean=0.0, sigma=1.0, size=None, dtype=<type ‘float’>)

Returns an array of samples drawn from a log normal distribution.

See also:

cupy.random.lognormal() for full documentation, numpy.random.RandomState.lognormal()

normal (loc=0.0, scale=1.0, size=None, dtype=<type ‘float’>)

Returns an array of normally distributed samples.

See also:

cupy.random.normal() for full documentation, numpy.random.RandomState.normal()

rand (*size, **kwarg)

Returns uniform random values over the interval [0, 1).

See also:

cupy.random.rand() for full documentation, numpy.random.RandomState.rand()

.randn (*size, **kwarg)

Returns an array of standard normal random values.

See also:

cupy.random.randn() for full documentation, numpy.random.RandomState.randn()

random_sample (size=None, dtype=<type ‘float’>)

Returns an array of random values over the interval [0, 1).

See also:

cupy.random.random_sample() for full documentation, numpy.random.RandomState.random_sample()

seed (seed=None)

Resets the state of the random number generator with a seed.

See also:

cupy.random.seed() for full documentation, numpy.random.RandomState.seed()

standard_normal (size=None, dtype=<type ‘float’>)

Returns samples drawn from the standard normal distribution.

See also:

cupy.random.standard_normal() for full documentation, numpy.random.RandomState.standard_normal()

uniform (low=0.0, high=1.0, size=None, dtype=<type ‘float’>)

Returns an array of uniformly-distributed samples over an interval.

See also:

cupy.random.uniform() for full documentation, numpy.random.RandomState.uniform()
4.4.12 Sorting, Searching, and Counting

cupy.argmax(a, axis=None, dtype=None, out=None, keepdims=False)

Returns the indices of the maximum along an axis.

Parameters

- **a** (cupy.ndarray) – Array to take argmax.
- **axis** (int) – Along which axis to find the maximum. a is flattened by default.
- **dtype** – Data type specifier.
- **out** (cupy.ndarray) – Output array.
- **keepdims** (bool) – If True, the axis axis is preserved as an axis of length one.

Returns The indices of the maximum of a along an axis.

Return type cupy.ndarray

See also:

numpy.argmax()

cupy.argmin(a, axis=None, dtype=None, out=None, keepdims=False)

Returns the indices of the minimum along an axis.

Parameters

- **a** (cupy.ndarray) – Array to take argmin.
- **axis** (int) – Along which axis to find the minimum. a is flattened by default.
- **dtype** – Data type specifier.
- **out** (cupy.ndarray) – Output array.
- **keepdims** (bool) – If True, the axis axis is preserved as an axis of length one.

Returns The indices of the minimum of a along an axis.

Return type cupy.ndarray

See also:

numpy.argmin()

cupy.count_nonzero(x)

Counts the number of non-zero values in the array.

Parameters **x** (cupy.ndarray) – The array for which to count non-zeros.

Returns Number of non-zero values in the array.

Return type int

cupy.nonzero(a)

Return the indices of the elements that are non-zero.

Returns a tuple of arrays, one for each dimension of a, containing the indices of the non-zero elements in that dimension.

Parameters **a** (cupy.ndarray) – array

Returns Indices of elements that are non-zero.

Return type tuple of arrays
See also:

numpy.nonzero()

cupy.flatnonzero(a)
Return indices that are non-zero in the flattened version of a.
This is equivalent to a.ravel().nonzero()[0].

Parameters  
• a (cupy.ndarray) – input array

Returns  
Output array, containing the indices of the elements of a.ravel() that are non-zero.

Return type  
cupy.ndarray

See also:

numpy.flatnonzero()

cupy.where(condition, x=None, y=None)
Return elements, either from x or y, depending on condition.

Note: Currently CuPy doesn’t support where(condition), that NumPy supports.

Parameters  
• condition (cupy.ndarray) – When True, take x, otherwise take y.
• x (cupy.ndarray) – Values from which to choose on True.
• y (cupy.ndarray) – Values from which to choose on False.

Returns  
Each element of output contains elements of x when condition is True, otherwise elements of y.

Return type  
cupy.ndarray

4.4.13 Statistics

Order statistics

cupy.amin(a, axis=None, out=None, keepdims=False, dtype=None)
Returns the minimum of an array or the minimum along an axis.

Note: When at least one element is NaN, the corresponding min value will be NaN.

Parameters  
• a (cupy.ndarray) – Array to take the minimum.
• axis (int) – Along which axis to take the minimum. The flattened array is used by default.
• out (cupy.ndarray) – Output array.
• keepdims (bool) – If True, the axis is remained as an axis of size one.
• dtype – Data type specifier.

Returns  
The minimum of a, along the axis if specified.
Return type  *cupy.ndarray*

See also:

numpy.amin()

cupy.amax(a, axis=None, out=None, keepdims=False, dtype=None)

Returns the maximum of an array or the maximum along an axis.

**Note:** When at least one element is NaN, the corresponding min value will be NaN.

### Parameters

- **a (cupy.ndarray)** – Array to take the maximum.
- **axis (int)** – Along which axis to take the maximum. The flattened array is used by default.
- **out (cupy.ndarray)** – Output array.
- **keepdims (bool)** – If True, the axis is remained as an axis of size one.
- **dtype** – Data type specifier.

### Returns

The maximum of *a*, along the axis if specified.

Return type  *cupy.ndarray*

See also:

numpy.amax()

cupy.nanmin(a, axis=None, out=None, keepdims=False)

Returns the minimum of an array along an axis ignoring NaN.

When there is a slice whose elements are all NaN, a **RuntimeWarning** is raised and NaN is returned.

### Parameters

- **a (cupy.ndarray)** – Array to take the minimum.
- **axis (int)** – Along which axis to take the minimum. The flattened array is used by default.
- **out (cupy.ndarray)** – Output array.
- **keepdims (bool)** – If True, the axis is remained as an axis of size one.

### Returns

The minimum of *a*, along the axis if specified.

Return type  *cupy.ndarray*

See also:

numpy.nanmin()

cupy.nanmax(a, axis=None, out=None, keepdims=False)

Returns the maximum of an array along an axis ignoring NaN.

When there is a slice whose elements are all NaN, a **RuntimeWarning** is raised and NaN is returned.

### Parameters

- **a (cupy.ndarray)** – Array to take the maximum.
• **axis** (*int*) –Along which axis to take the maximum. The flattened array is used by default.

• **out** (*cupy.ndarray*) –Output array.

• **keepdims** (*bool*) –If True, the axis is remained as an axis of size one.

Returns The maximum of a, along the axis if specified.

Return type *cupy.ndarray*

See also: *numpy.nanmax()*

### Means and variances

*cupy.mean*(a, axis=None, dtype=None, out=None, keepdims=False)  
Returns the arithmetic mean along an axis.

Parameters

• **a** (*cupy.ndarray*) –Array to compute mean.

• **axis** (*int*) –Along which axis to compute mean. The flattened array is used by default.

• **dtype** –Data type specifier.

• **out** (*cupy.ndarray*) –Output array.

• **keepdims** (*bool*) –If True, the axis is remained as an axis of size one.

Returns The mean of the input array along the axis.

Return type *cupy.ndarray*

See also: *numpy.mean()*

*cupy.var*(a, axis=None, dtype=None, out=None, ddof=0, keepdims=False)  
Returns the variance along an axis.

Parameters

• **a** (*cupy.ndarray*) –Array to compute variance.

• **axis** (*int*) –Along which axis to compute variance. The flattened array is used by default.

• **dtype** –Data type specifier.

• **out** (*cupy.ndarray*) –Output array.

• **keepdims** (*bool*) –If True, the axis is remained as an axis of size one.

Returns The variance of the input array along the axis.

Return type *cupy.ndarray*

See also: *numpy.var()*

*cupy.std*(a, axis=None, dtype=None, out=None, ddof=0, keepdims=False)  
Returns the standard deviation along an axis.

Parameters
• **a** ([cupy.ndarray]) – Array to compute standard deviation.

• **axis** (int) – Along which axis to compute standard deviation. The flattened array is used by default.

• **dtype** – Data type specifier.

• **out** ([cupy.ndarray]) – Output array.

• **keepdims** (bool) – If True, the axis is remained as an axis of size one.

**Returns** The standard deviation of the input array along the axis.

**Return type** [cupy.ndarray]

**See also:**

cupy.std()
4.6 Low-Level CUDA Support

4.6.1 Device management

class cupy.cuda.Device
    Object that represents a CUDA device.

This class provides some basic manipulations on CUDA devices.
It supports the context protocol. For example, the following code is an example of temporarily switching the current device:

    with Device(0):
        do_something_on_device_0()

After the with statement gets done, the current device is reset to the original one.

**Parameters**

device (**int** or **cupy.cuda.Device**) – Index of the device to manipulate. Be careful that the device ID (a.k.a. GPU ID) is zero origin. If it is a Device object, then its ID is used. The current device is selected by default.

**Variables**

id (**int**) – ID of this device.

__eq__

x.__eq__(y) <=> x==y

__ge__

x.__ge__(y) <=> x>=y

__gt__

x.__gt__(y) <=> x>y

__int__

__le__

x.__le__(y) <=> x<=y

__long__

__lt__

x.__lt__(y) <=> x<y

__ne__

x.__ne__(y) <=> x!=y

__repr__

**compute_capability**

Compute capability of this device.

The capability is represented by a string containing the major index and the minor index. For example, compute capability 3.5 is represented by the string ‘35’.

**cublas_handle**

The cuBLAS handle for this device.

The same handle is used for the same device even if the Device instance itself is different.

**synchronize**()

Synchronizes the current thread to the device.
use()
   Makes this device current.

   If you want to switch a device temporarily, use the with statement.

4.6.2 Memory management

class cupy.cuda.Memory
   Memory allocation on a CUDA device.

   This class provides an RAII interface of the CUDA memory allocation.

   Parameters
   • device (cupy.cuda.Device) – Device whose memory the pointer refers to.
   • size (int) – Size of the memory allocation in bytes.

   __int__
       Returns the pointer value to the head of the allocation.

   __long__

class cupy.cuda.MemoryPointer
   Pointer to a point on a device memory.

   An instance of this class holds a reference to the original memory buffer and a pointer to a place within this buffer.

   Parameters
   • mem (Memory) – The device memory buffer.
   • offset (int) – An offset from the head of the buffer to the place this pointer refers.

   Variables
   • device (cupy.cuda.Device) – Device whose memory the pointer refers to.
   • mem (Memory) – The device memory buffer.
   • ptr (int) – Pointer to the place within the buffer.

   __add__
       Adds an offset to the pointer.

   __iadd__
       Adds an offset to the pointer in place.

   __int__
       Returns the pointer value.

   __isub__
       Subtracts an offset from the pointer in place.

   __long__
   __radd__
       x.__radd__(y) <=> y+x

   __rsub__
       x.__rsub__(y) <=> y-x

   __sub__
       Subtracts an offset from the pointer.
copy_from()
Copies a memory sequence from a (possibly different) device or host.

This function is a useful interface that selects appropriate one from `copy_from_device()` and `copy_from_host()`.

Parameters
- `mem (ctypes.c_void_p or cupy.cuda.MemoryPointer)` – Source memory pointer.
- `size (int)` – Size of the sequence in bytes.

copy_from_async()
Copies a memory sequence from an arbitrary place asynchronously.

This function is a useful interface that selects appropriate one from `copy_from_device_async()` and `copy_from_host_async()`.

Parameters
- `mem (ctypes.c_void_p or cupy.cuda.MemoryPointer)` – Source memory pointer.
- `size (int)` – Size of the sequence in bytes.
- `stream (cupy.cuda.Stream)` – CUDA stream.

copy_from_device()
Copies a memory sequence from a (possibly different) device.

Parameters
- `src (cupy.cuda.MemoryPointer)` – Source memory pointer.
- `size (int)` – Size of the sequence in bytes.

copy_from_device_async()
Copies a memory from a (possibly different) device asynchronously.

Parameters
- `src (cupy.cuda.MemoryPointer)` – Source memory pointer.
- `size (int)` – Size of the sequence in bytes.
- `stream (cupy.cuda.Stream)` – CUDA stream.

copy_from_host()
Copies a memory sequence from the host memory.

Parameters
- `mem (ctypes.c_void_p)` – Source memory pointer.
- `size (int)` – Size of the sequence in bytes.

copy_from_host_async()
Copies a memory sequence from the host memory asynchronously.

Parameters
- `src (ctypes.c_void_p)` – Source memory pointer. It must be a pinned memory.
- `size (int)` – Size of the sequence in bytes.

copy_to_host()
Copies a memory sequence to the host memory.
Parameters

- **mem** (*ctypes.c_void_p*) – Target memory pointer.
- **size** (*int*) – Size of the sequence in bytes.

**copy_to_host_async()**
Copies a memory sequence to the host memory asynchronously.

Parameters

- **mem** (*ctypes.c_void_p*) – Target memory pointer. It must be a pinned memory.
- **size** (*int*) – Size of the sequence in bytes.
- **stream** (*cupy.cuda.Stream*) – CUDA stream.

**memset()**
Fills a memory sequence by constant byte value.

Parameters

- **value** (*int*) – Value to fill.
- **size** (*int*) – Size of the sequence in bytes.

**memset_async()**
Fills a memory sequence by constant byte value asynchronously.

Parameters

- **value** (*int*) – Value to fill.
- **size** (*int*) – Size of the sequence in bytes.
- **stream** (*cupy.cuda.Stream*) – CUDA stream.

**cupy.cuda.alloc()**
Calls the current allocator.

Parameters

- **size** (*int*) – Size of the memory allocation.

Returns
Pointer to the allocated buffer.

Return type **MemoryPointer**

**cupy.cuda.set_allocator()**
Sets the current allocator.

Parameters

- **allocator** (*function*) – CuPy memory allocator. It must have the same interface as the **cupy.cuda.alloc()** function, which takes the buffer size as an argument and returns the device buffer of that size.

**class cupy.cuda.MemoryPool**
Memory pool for all devices on the machine.

A memory pool preserves any allocations even if they are freed by the user. Freed memory buffers are held by the memory pool as free blocks, and they are reused for further memory allocations of the same sizes. The allocated blocks are managed for each device, so one instance of this class can be used for multiple devices.

**Note:** When the allocation is skipped by reusing the pre-allocated block, it does not call cudaMalloc and therefore CPU-GPU synchronization does not occur. It makes interleaves of memory allocations and kernel invocations very fast.
Note: The memory pool holds allocated blocks without freeing as much as possible. It makes the program hold most of the device memory, which may make other CUDA programs running in parallel out-of-memory situation.

Parameters `allocator(function)` – The base CuPy memory allocator. It is used for allocating new blocks when the blocks of the required size are all in use.

`free_all_free()`
Release free blocks.

`malloc()`
Allocates the memory, from the pool if possible.
This method can be used as a CuPy memory allocator. The simplest way to use a memory pool as the default allocator is the following code:

```python
set_allocator(MemoryPool().malloc)
```

Parameters `size(int)` – Size of the memory buffer to allocate in bytes.

Returns Pointer to the allocated buffer.

Return type `MemoryPointer`

`n_free_blocks()`
Count the total number of free blocks.

Returns The total number of free blocks.

Return type `int`

### 4.6.3 Streams and events

#### class `cupy.cuda.Stream(null=False, non_blocking=False)`
CUDA stream.

This class handles the CUDA stream handle in RAII way, i.e., when an Stream instance is destroyed by the GC, its handle is also destroyed.

Parameters

- `null (bool)` – If True, the stream is a null stream (i.e. the default stream that synchronizes with all streams). Otherwise, a plain new stream is created.
- `non_blocking (bool)` – If True, the stream does not synchronize with the NULL stream.

Variables `ptr (cupy.cuda.runtime.Stream)` – Raw stream handle. It can be passed to the CUDA Runtime API via ctypes.

`add_callback (callback, arg)`
Adds a callback that is called when all queued work is done.

Parameters

- `callback (function)` – Callback function. It must take three arguments (Stream object, int error status, and user data object), and returns nothing.
- `arg (object)` – Argument to the callback.
done
True if all work on this stream has been done.

record\(\text{event=\text{None}}\)
Records an event on the stream.

\textbf{Parameters} \text{event} (\text{None or cupy.cuda.Event}) – CUDA event. If None, then a new plain event is created and used.

\textbf{Returns} The recorded event.

\textbf{Return type} cupy.cuda.Event

\textbf{See also:} cupy.cuda.Event.record()

synchronize()
Waits for the stream completing all queued work.

wait\_event\(\text{event}\)
Makes the stream wait for an event.

The future work on this stream will be done after the event.

\textbf{Parameters} \text{event} (cupy.cuda.Event) – CUDA event.

class cupy.cuda.Event (\text{block=False, disable\_timing=False, interprocess=False})
CUDA event, a synchronization point of CUDA streams.

This class handles the CUDA event handle in RAII way, i.e., when an Event instance is destroyed by the GC, its handle is also destroyed.

\textbf{Parameters}
- \textbf{block} (\text{bool}) – If True, the event blocks on the synchronize() method.
- \textbf{disable\_timing} (\text{bool}) – If True, the event does not prepare the timing data.
- \textbf{interprocess} (\text{bool}) – If True, the event can be passed to other processes.

\textbf{Variables} \text{ptr} (cupy.cuda.runtime.Stream) – Raw stream handle. It can be passed to the CUDA Runtime API via ctypes.

done
True if the event is done.

record\(\text{stream=\text{None}}\)
Records the event to a stream.

\textbf{Parameters} \text{stream} (cupy.cuda.Stream) – CUDA stream to record event. The null stream is used by default.

\textbf{See also:} cupy.cuda.Stream.record()

synchronize()
Synchronizes all device work to the event.

If the event is created as a blocking event, it also blocks the CPU thread until the event is done.

cupy.cuda.get\_elapsed\_time\(\text{start\_event, end\_event}\)
Gets the elapsed time between two events.

\textbf{Parameters}
• `start_event` (*Event*) – Earlier event.
• `end_event` (*Event*) – Later event.

Returns Elapsed time in milliseconds.

Return type float

### 4.6.4 Profiler

`cupy.cuda.profile` (*args, **kwds*)

Enable CUDA profiling during with statement.

This function enables profiling on entering a with statement, and disables profiling on leaving the statement.

```python
>>> with cupy.cuda.profile():
...    # do something you want to measure
...    pass
```

`cupy.cuda.profiler.initialize()`

Initialize the CUDA profiler.

This function initialize the CUDA profiler. See the CUDA document for detail.

Parameters

- `config_file` (*str*) – Name of the configuration file.
- `output_file` (*str*) – Name of the output file.
- `output_mode` (*int*) – `cupy.cuda.profiler.cudaKeyValuePair` or `cupy.cuda.profiler.cudaCSV`.

`cupy.cuda.profiler.start()`

Enable profiling.

A user can enable CUDA profiling. When an error occurs, it raises an exception.

See the CUDA document for detail.

`cupy.cuda.profiler.stop()`

Disable profiling.

A user can disable CUDA profiling. When an error occurs, it raises an exception.

See the CUDA document for detail.

### 4.7 Kernel binary memoization

`cupy.memoize()`

Makes a function memoizing the result for each argument and device.

This decorator provides automatic memoization of the function result.

Parameters `for_each_device` (*bool*) – If True, it memoizes the results for each device. Otherwise, it memoizes the results only based on the arguments.

`cupy.clear_memo()`

Clears the memoized results for all functions decorated by memoize.
4.8 User-Defined Kernels

CuPy provides easy ways to define two types of CUDA kernels: elementwise kernels and reduction kernels. We first describe how to define and call elementwise kernels, and then describe how to define and call reduction kernels.

### 4.8.1 Basics of elementwise kernels

An elementwise kernel can be defined by the `ElementwiseKernel` class. The instance of this class defines a CUDA kernel which can be invoked by the `__call__` method of this instance.

A definition of an elementwise kernel consists of four parts: an input argument list, an output argument list, a loop body code, and the kernel name. For example, a kernel that computes a squared difference $f(x, y) = (x - y)^2$ is defined as follows:

```python
>>> squared_diff = cupy.ElementwiseKernel(
    ... 'float32 x, float32 y',
    ... 'float32 z',
    ... 'z = (x - y) * (x - y)',
    ... 'squared_diff')
```

The argument lists consist of comma-separated argument definitions. Each argument definition consists of a type specifier and an argument name. Names of NumPy data types can be used as type specifiers.

**Note:** `n`, `i`, and names starting with an underscore `_` are reserved for the internal use.

The above kernel can be called on either scalars or arrays with broadcasting:

```python
>>> x = cupy.arange(10, dtype=np.float32).reshape(2, 5)
>>> y = cupy.arange(5, dtype=np.float32)
>>> squared_diff(x, y)
array([[ 0., 0., 0., 0., 0.],
>>> squared_diff(x, 5)
array([[ 25., 16., 9., 4., 1.],
       [ 0., 1., 4., 9., 16.]], dtype=float32)
```

Output arguments can be explicitly specified (next to the input arguments):

```python
>>> z = cupy.empty((2, 5), dtype=np.float32)
>>> squared_diff(x, y, z)
array([[ 0., 0., 0., 0., 0.],
```

### 4.8.2 Type-generic kernels

If a type specifier is one character, then it is treated as a type placeholder. It can be used to define a type-generic kernels. For example, the above `squared_diff` kernel can be made type-generic as follows:

```python
>>> squared_diff_generic = cupy.ElementwiseKernel(
    ... 'T x, T y',
    ... 'T z',
    ... 'z = (x - y) * (x - y)',
    ... 'squared_diff_generic')
```
Type placeholders of a same character in the kernel definition indicate the same type. The actual type of these placeholders is determined by the actual argument type. The ElementwiseKernel class first checks the output arguments and then the input arguments to determine the actual type. If no output arguments are given on the kernel invocation, then only the input arguments are used to determine the type.

The type placeholder can be used in the loop body code:

```python
generated = cupy.ElementwiseKernel('T x, T y', 'T z', '
    T diff = x - y;
    z = diff * diff;
    ', 'generated')
```

More than one type placeholder can be used in a kernel definition. For example, the above kernel can be further made generic over multiple arguments:

```python
generated = cupy.ElementwiseKernel('X x, Y y', 'Z z', 'z = (x - y) * (x - y)', 'generated')
```

Note that this kernel requires the output argument explicitly specified, because the type `Z` cannot be automatically determined from the input arguments.

### 4.8.3 Raw argument specifiers

The ElementwiseKernel class does the indexing with broadcasting automatically, which is useful to define most elementwise computations. On the other hand, we sometimes want to write a kernel with manual indexing for some arguments. We can tell the ElementwiseKernel class to use manual indexing by adding the `raw` keyword preceding the type specifier.

We can use the special variable `i` and method `_ind.size()` for the manual indexing. `i` indicates the index within the loop. `_ind.size()` indicates total number of elements to apply the elementwise operation. Note that it represents the size after broadcast operation.

For example, a kernel that adds two vectors with reversing one of them can be written as follows:

```python
generated = cupy.ElementwiseKernel('T x, raw T y', 'T z', 'z = x + y[_ind.size() - i - 1]', 'generated')
```

(Note that this is an artificial example and you can write such operation just by `z = x + y[::-1]` without defining a new kernel). A raw argument can be used like an array. The indexing operator `y[_ind.size() - i - 1]` involves an indexing computation on `y`, so `y` can be arbitrarily shaped and strode.

Note that raw arguments are not involved in the broadcasting. If you want to mark all arguments as `raw`, you must specify the `size` argument on invocation, which defines the value of `_ind.size()`.

### 4.8.4 Reduction kernels

Reduction kernels can be defined by the `ReductionKernel` class. We can use it by defining four parts of the kernel code:
1. Identity value: This value is used for the initial value of reduction.

2. Mapping expression: It is used for the pre-processing of each element to be reduced.

3. Reduction expression: It is an operator to reduce the multiple mapped values. The special variables a and b are used for its operands.

4. Post mapping expression: It is used to transform the resulting reduced values. The special variable a is used as its input. Output should be written to the output parameter.

ReductionKernel class automatically inserts other code fragments that are required for an efficient and flexible reduction implementation.

For example, L2 norm along specified axes can be written as follows:

```python
>>> l2norm_kernel = cupy.ReductionKernel(
    ... 'T x',       # input params
    ... 'T y',      # output params
    ... 'x * x',    # map
    ... 'a + b',    # reduce
    ... 'y = sqrt(a)', # post-reduction map
    ... '0',       # identity value
    ... 'l2norm'   # kernel name
    ...
)
>>> x = cupy.arange(10, dtype='f').reshape(2, 5)
>>> l2norm_kernel(x, axis=1)
array([5.47722578, 15.96871948], dtype=float32)
```

Note: raw specifier is restricted for usages that the axes to be reduced are put at the head of the shape. It means, if you want to use raw specifier for at least one argument, the axis argument must be 0 or a contiguous increasing sequence of integers starting from 0, like (0, 1), (0, 1, 2), etc.

### 4.8.5 Reference

class `cupy.ElementwiseKernel`

User-defined elementwise kernel.

This class can be used to define an elementwise kernel with or without broadcasting.

The kernel is compiled at an invocation of the `__call__()` method, which is cached for each device. The compiled binary is also cached into a file under the `$HOME/.cupy/kernel_cache/` directory with a hashed file name. The cached binary is reused by other processes.

**Parameters**

- `in_params (str)` – Input argument list.
- `out_params (str)` – Output argument list.
- `operation (str)` – The body in the loop written in CUDA-C/C++.
- `name (str)` – Name of the kernel function. It should be set for readability of the performance profiling.
- `reduce_dims (bool)` – If False, the shapes of array arguments are kept within the kernel invocation. The shapes are reduced (i.e., the arrays are reshaped without copy to the minimum dimension) by default. It may make the kernel fast by reducing the index calculations.
- `options (list)` – Options passed to the nvcc command.
• **preamble** (`str`) – Fragment of the CUDA-C/C++ code that is inserted at the top of the cu file.

• **loop_prep** (`str`) – Fragment of the CUDA-C/C++ code that is inserted at the top of the kernel function definition and above the `for` loop.

• **after_loop** (`str`) – Fragment of the CUDA-C/C++ code that is inserted at the bottom of the kernel function definition.

___call___
Compiles and invokes the elementwise kernel.

The compilation runs only if the kernel is not cached. Note that the kernels with different argument dtypes or dimensions are not compatible. It means that single ElementwiseKernel object may be compiled into multiple kernel binaries.

**Parameters**
- **args** – Arguments of the kernel.
- **size** (`int`) – Range size of the indices. If specified, the variable `n` is set to this value. Otherwise, the result of broadcasting is used to determine the value of `n`.

**Returns** Arrays are returned according to the `out_params` argument of the `__init__` method.

```python
class cupy.ReductionKernel
    User-defined reduction kernel.
```

This class can be used to define a reduction kernel with or without broadcasting.

The kernel is compiled at an invocation of the `__call__()` method, which is cached for each device. The compiled binary is also cached into a file under the `$HOME/.cupy/kernel_cache/` directory with a hashed file name. The cached binary is reused by other processes.

**Parameters**
- **in_params** (`str`) – Input argument list.
- **out_params** (`str`) – Output argument list.
- **map_expr** (`str`) – Mapping expression for input values.
- **reduce_expr** (`str`) – Reduction expression.
- **post_map_expr** (`str`) – Mapping expression for reduced values.
- **identity** (`str`) – Identity value for starting the reduction.
- **name** (`str`) – Name of the kernel function. It should be set for readability of the performance profiling.
- **reduce_type** (`str`) – Type of values to be used for reduction. This type is used to store the special variables `a`.
- **reduce_dims** (`bool`) – If True, input arrays are reshaped without copy to smaller dimensions for efficiency.
- **preamble** (`str`) – Fragment of the CUDA-C/C++ code that is inserted at the top of the cu file.
- **options** (`tuple of str`) – Additional compilation options.

___call___()
Compiles and invokes the reduction kernel.
The compilation runs only if the kernel is not cached. Note that the kernels with different argument dtypes, ndims, or axis are not compatible. It means that single ReductionKernel object may be compiled into multiple kernel binaries.

Parameters

- **args** – Arguments of the kernel.

Returns

Arrays are returned according to the out_params argument of the __init__ method.

4.9 Testing Modules

CuPy offers testing utilities to support unit testing. They are under namespace `cupy.testing`.

4.9.1 Standard Assertions

The assertions have same names as NumPy’s ones. The difference from NumPy is that they can accept both `numpy.ndarray` and `cupy.ndarray`.

`cupy.testing.assert_allclose(actual, desired, rtol=1e-07, atol=0, err_msg='', verbose=True)`

Raises an AssertionError if objects are not equal up to desired tolerance.

Parameters

- **actual** (`numpy.ndarray or cupy.ndarray`) – The actual object to check.
- **desired** (`numpy.ndarray or cupy.ndarray`) – The desired, expected object.
- **rtol** (`float`) – Relative tolerance.
- **atol** (`float`) – Absolute tolerance.
- **err_msg** (`str`) – The error message to be printed in case of failure.
- **verbose** (`bool`) – If True, the conflicting values are appended to the error message.

See also:

`numpy.testing.assert_allclose()`

`cupy.testing.assert_array_almost_equal(x, y, decimal=6, err_msg='', verbose=True)`

Raises an AssertionError if objects are not equal up to desired precision.

Parameters

- **x** (`numpy.ndarray or cupy.ndarray`) – The actual object to check.
- **y** (`numpy.ndarray or cupy.ndarray`) – The desired, expected object.
- **decimal** (`int`) – Desired precision.
- **err_msg** (`str`) – The error message to be printed in case of failure.
- **verbose** (`bool`) – If True, the conflicting values are appended to the error message.

See also:

`numpy.testing.assert_array_almost_equal()`

`cupy.testing.assert_array_almost_equal_nulp(x, y, nulp=1)`

Compare two arrays relatively to their spacing.

Parameters
• `x` (*numpy.ndarray* or *cupy.ndarray*) – The actual object to check.
• `y` (*numpy.ndarray* or *cupy.ndarray*) – The desired, expected object.
• `nulp` (*int*) – The maximum number of unit in the last place for tolerance.

See also:

`numpy.testing.assert_array_almost_equal_nulp()`

`cupy.testing.assert_array_max_ulp(a, b, maxulp=1, dtype=None)`

Check that all items of arrays differ in at most N Units in the Last Place.

Parameters

• `a` (*numpy.ndarray* or *cupy.ndarray*) – The actual object to check.
• `b` (*numpy.ndarray* or *cupy.ndarray*) – The desired, expected object.
• `maxulp` (*int*) – The maximum number of units in the last place that elements of `a` and `b` can differ.
• `dtype` (*numpy.dtype*) – Data-type to convert `a` and `b` to if given.

See also:

`numpy.testing.assert_array_max_ulp()`

`cupy.testing.assert_array_equal(x, y, err_msg='', verbose=True)`

Raises an AssertionError if two array_like objects are not equal.

Parameters

• `x` (*numpy.ndarray* or *cupy.ndarray*) – The actual object to check.
• `y` (*numpy.ndarray* or *cupy.ndarray*) – The desired, expected object.
• `err_msg` (*str*) – The error message to be printed in case of failure.
• `verbose` (*bool*) – If True, the conflicting values are appended to the error message.

See also:

`numpy.testing.assert_array_equal()`

`cupy.testing.assert_array_list_equal(xlist, ylist, err_msg='', verbose=True)`

Compares lists of arrays pairwise with `assert_array_equal()`.

Parameters

• `x` (*array_like*) – Array of the actual objects.
• `y` (*array_like*) – Array of the desired, expected objects.
• `err_msg` (*str*) – The error message to be printed in case of failure.
• `verbose` (*bool*) – If True, the conflicting values are appended to the error message.

Each element of `x` and `y` must be either `numpy.ndarray` or `cupy.ndarray`. `x` and `y` must have same length. Otherwise, this function raises AssertionError. It compares elements of `x` and `y` pairwise with `assert_array_equal()` and raises error if at least one pair is not equal.

See also:

`numpy.testing.assert_array_equal()`

`cupy.testing.assert_array_less(x, y, err_msg='', verbose=True)`

Raises an AssertionError if array_like objects are not ordered by less than.
Parameters

- \(x\) (numpy.ndarray or cupy.ndarray) – The smaller object to check.
- \(y\) (numpy.ndarray or cupy.ndarray) – The larger object to compare.
- err_msg (str) – The error message to be printed in case of failure.
- verbose (bool) – If True, the conflicting values are appended to the error message.

See also:

numpy.testing.assert_array_less()

4.9.2 NumPy-CuPy Consistency Check

The following decorators are for testing consistency between CuPy’s functions and corresponding NumPy’s ones.

\[
\text{cupy.testing.numpypy_cupy_allclose}(\text{rtol}=1e-07, \text{atol}=0, \text{err_msg}=\text{''}, \text{verbose}=\text{True}, \text{name}=\text{'xp'}, \text{type_check}=\text{True}, \text{accept_error}=\text{False})
\]

Decorator that checks NumPy results and CuPy ones are close.

Parameters

- rtol (float) – Relative tolerance.
- atol (float) – Absolute tolerance.
- err_msg (str) – The error message to be printed in case of failure.
- verbose (bool) – If True, the conflicting values are appended to the error message.
- name (str) – Argument name whose value is either numpy or cupy module.
- type_check (bool) – If True, consistency of dtype is also checked.
- accept_error (bool, Exception or tuple of Exception) – Specify acceptable errors. When both NumPy test and CuPy test raises the same type of errors, and the type of the errors is specified with this argument, the errors are ignored and not raised. If it is True all error types are acceptable. If it is False no error is acceptable.

Decorated test fixture is required to return the arrays whose values are close between numpy case and cupy case. For example, this test case checks numpy.zeros and cupy.zeros should return same value.

```python
>>> import unittest
>>> from cupy import testing,
... @testing.gpu
... class TestFoo(unittest.TestCase):
...     ...
...     @testing.numpypy_cupy_allclose()
...     def test_foo(self, xp):
...         ...
...         # Prepare data with xp
...         ...
...         xp_result = xp.zeros(10)
...         return xp_result
```

See also:

cupy.testing.assert_allclose()
Decorator that checks NumPy results and CuPy ones are almost equal.

Parameters

- `decimal (int)` – Desired precision.
- `err_msg (str)` – The error message to be printed in case of failure.
- `verbose (bool)` – If True, the conflicting values are appended to the error message.
- `name (str)` – Argument name whose value is either `numpy` or `cupy` module.
- `type_check (bool)` – If True, consistency of dtype is also checked.
- `accept_error (bool, Exception or tuple of Exception)` – Specify acceptable errors. When both NumPy test and CuPy test raises the same type of errors, and the type of the errors is specified with this argument, the errors are ignored and not raised. If it is True all error types are acceptable. If it is False no error is acceptable.

Decorated test fixture is required to return the same arrays in the sense of `cupy.testing.assert_array_almost_equal()` (except the type of array module) even if `xp` is `numpy` or `cupy`.

See also:

- `cupy.testing.assert_array_almost_equal()`

Decorator that checks results of NumPy and CuPy are equal w.r.t. spacing.

Parameters

- `nulp (int)` – The maximum number of unit in the last place for tolerance.
- `name (str)` – Argument name whose value is either `numpy` or `cupy` module.
- `type_check (bool)` – If True, consistency of dtype is also checked.
- `accept_error (bool, Exception or tuple of Exception)` – Specify acceptable errors. When both NumPy test and CuPy test raises the same type of errors, and the type of the errors is specified with this argument, the errors are ignored and not raised. If it is True all error types are acceptable. If it is False no error is acceptable.

Decorated test fixture is required to return the same arrays in the sense of `cupy.testing.assert_array_almost_equal_nulp()` (except the type of array module) even if `xp` is `numpy` or `cupy`.

See also:

- `cupy.testing.assert_array_almost_equal_nulp()`

Decorator that checks results of NumPy and CuPy ones are equal w.r.t. ulp.

Parameters

- `maxulp (int)` – The maximum number of units in the last place that elements of resulting two arrays can differ.
- `dtype (numpy.dtype)` – Data-type to convert the resulting two array to if given.
• **name** (*str*) – Argument name whose value is either `numpy` or `cupy` module.

• **type_check** (*bool*) – If True, consistency of dtype is also checked.

• **accept_error** (*bool, Exception or tuple of Exception*) – Specify acceptable errors. When both NumPy test and CuPy test raises the same type of errors, and the type of the errors is specified with this argument, the errors are ignored and not raised. If it is True all error types are acceptable. If it is False no error is acceptable.

Decorated test fixture is required to return the same arrays in the sense of `assert_array_max_ulp()` (except the type of array module) even if `xp` is `numpy` or `cupy`.

See also:

```
cupy.testing.assert_array_max_ulp()
cupy.testing.numpy_cupy_array_equal(err_msg='', verbose=True, name='xp',
                                      type_check=True, accept_error=False)
```

Decorator that checks NumPy results and CuPy ones are equal.

**Parameters**

• **err_msg** (*str*) – The error message to be printed in case of failure.

• **verbose** (*bool*) – If True, the conflicting values are appended to the error message.

• **name** (*str*) – Argument name whose value is either `numpy` or `cupy` module.

• **type_check** (*bool*) – If True, consistency of dtype is also checked.

• **accept_error** (*bool, Exception or tuple of Exception*) – Specify acceptable errors. When both NumPy test and CuPy test raises the same type of errors, and the type of the errors is specified with this argument, the errors are ignored and not raised. If it is True all error types are acceptable. If it is False no error is acceptable.

Decorated test fixture is required to return the same arrays in the sense of `numpy_cupy_array_equal()` (except the type of array module) even if `xp` is `numpy` or `cupy`.

See also:

```
cupy.testing.assert_array_equal()
cupy.testing.numpy_cupy_array_list_equal(err_msg='', verbose=True, name='xp')
```

Decorator that checks the resulting lists of NumPy and CuPy’s one are equal.

**Parameters**

• **err_msg** (*str*) – The error message to be printed in case of failure.

• **verbose** (*bool*) – If True, the conflicting values are appended to the error message.

• **name** (*str*) – Argument name whose value is either `numpy` or `cupy` module.

Decorated test fixture is required to return the same list of arrays (except the type of array module) even if `xp` is `numpy` or `cupy`.

See also:

```
cupy.testing.assert_array_list_equal()
cupy.testing.numpy_cupy_array_less(err_msg='', verbose=True, name='xp',
                                   type_check=True, accept_error=False)
```

Decorator that checks the CuPy result is less than NumPy result.

**Parameters**

• **err_msg** (*str*) – The error message to be printed in case of failure.
• **verbose** (*bool*) — If True, the conflicting values are appended to the error message.
• **name** (*str*) — Argument name whose value is either numpy or cupy module.
• **type_check** (*bool*) — If True, consistency of dtype is also checked.
• **accept_error** (*bool, Exception or tuple of Exception*) — Specify acceptable errors. When both NumPy test and CuPy test raises the same type of errors, and the type of the errors is specified with this argument, the errors are ignored and not raised. If it is True all error types are acceptable. If it is False no error is acceptable.

Decorated test fixture is required to return the smaller array when xp is cupy than the one when xp is numpy.

See also:

cupy.testing.assert_array_less()
cupy.testing.numpy_cupy_raises (*name='xp*)
Decorator that checks the NumPy and CuPy throw same errors.

Parameters
• **name** (*str*) — Argument name whose value is either
• **or** cupy module (*numpy*) —

Decorated test fixture is required throw same errors even if xp is numpy or cupy.

See also:

cupy.testing.assert_array_less()

### 4.9.3 Parameterized dtype Test

The following decorators offers the standard way for parameterized test with respect to single or the combination of dtype(s).

cupy.testing.for_dtypes (*dtypes, name='dtype*)
Decorator for parameterized dtype test.

Parameters
• **dtypes** (*list of dtypes*) — dtypes to be tested.
• **name** (*str*) — Argument name to which specified dtypes are passed.

This decorator adds a keyword argument specified by name to the test fixture. Then, it runs the fixtures in parallel by passing the each element of dtypes to the named argument.

cupy.testing.for_all_dtypes (*name='dtype', no_float16=False, no_bool=False*)
Decorator that checks the fixture with all dtypes.

Parameters
• **name** (*str*) — Argument name to which specified dtypes are passed.
• **no_float16** (*bool*) — If, True, numpy.float16 is omitted from candidate dtypes.
• **no_bool** (*bool*) — If, True, numpy.bool_ is omitted from candidate dtypes.

dtypes to be tested: numpy.float16 (optional), numpy.float32, numpy.float64, numpy.dtype(‘b’), numpy.dtype(‘h’), numpy.dtype(‘i’), numpy.dtype(‘l’), numpy.dtype(‘q’), numpy.dtype(‘B’), numpy.dtype(‘H’), numpy.dtype(‘I’), numpy.dtype(‘L’), numpy.dtype(‘Q’), and numpy.bool_ (optional).
The usage is as follows. This test fixture checks if `cPickle` successfully reconstructs `cupy.ndarray` for various dtypes. `dtype` is an argument inserted by the decorator.

```python
>>> import unittest
>>> from cupy import testing
>>> @testing.gpu
... class TestNpz(unittest.TestCase):
...     @testing.for_all_dtypes()
...     def test_pickle(self, dtype):
...         a = testing.shaped_arange((2, 3, 4), dtype=dtype)
...         s = six.moves.cPickle.dumps(a)
...         b = six.moves.cPickle.loads(s)
...         testing.assert_array_equal(a, b)
```

Typically, we use this decorator in combination with decorators that check consistency between NumPy and CuPy like `cupy.testing.numpy_cupy_allclose()`. The following is such an example.

```python
>>> import unittest
>>> from cupy import testing
>>> @testing.gpu
... class TestMean(unittest.TestCase):
...     @testing.for_all_dtypes()
...     @testing.numpy_cupy_allclose()
...     def test_mean_all(self, xp, dtype):
...         a = testing.shaped_arange((2, 3), xp, dtype)
...         return a.mean()
```

See also:

`cupy.testing.for_dtypes()`

`cupy.testing.for_float_dtypes(name='dtype', no_float16=False)`

Decorator that checks the fixture with all float dtypes.

Parameters

- `name (str)` – Argument name to which specified dtypes are passed.
- `no_float16 (bool)` – If True, `numpy.float16` is omitted from candidate dtypes.

dtypes to be tested are `numpy.float16` (optional), `numpy.float32`, and `numpy.float64`.

See also:

`cupy.testing.for_dtypes()`, `cupy.testing.for_all_dtypes()`

`cupy.testing.for_signed_dtypes(name='dtype')`

Decorator that checks the fixture with signed dtypes.

Parameters `name (str)` – Argument name to which specified dtypes are passed.

dtypes to be tested are `numpy.dtype('b')`, `numpy.dtype('h')`, `numpy.dtype('i')`, `numpy.dtype('l')`, and `numpy.dtype('q')`.

See also:

`cupy.testing.for_dtypes()`, `cupy.testing.for_all_dtypes()`

`cupy.testing.for_unsigned_dtypes(name='dtype')`

Decorator that checks the fixture with all dtypes.

Parameters `name (str)` – Argument name to which specified dtypes are passed.
dtypes to be tested are numpy.dtype('B'), numpy.dtype('H'),
numpy.dtype('I'), numpy.dtype('L'), and numpy.dtype('Q').

See also:
cupy.testing.for_dtypes(), cupy.testing.for_all_dtypes()
cupy.testing.for_int_dtypes(name='dtype', no_bool=False)
Decorator that checks the fixture with integer and optionally bool dtypes.

Parameters
- name (str) – Argument name to which specified dtypes are passed.
- no_bool (bool) – If True, numpy.bool_ is omitted from candidate dtypes.

dtotypes to be tested are numpy.dtype('b'), numpy.dtype('h'), numpy.dtype('i'),
numpy.dtype('l'), numpy.dtype('q'), numpy.dtype('B'), numpy.dtype('H'),
numpy.dtype('I'), numpy.dtype('L'), numpy.dtype('Q'), and numpy.bool_(optional).

See also:
cupy.testing.for_dtypes(), cupy.testing.for_all_dtypes()
cupy.testing.for_dtypes_combination(names=('dtype',), full=None)
Decorator that checks the fixture with a product set of dtypes.

Parameters
- types (list of dtypes) – dtypes to be tested.
- names (list of str) – Argument names to which dtypes are passed.
- full (bool) – If True, then all combinations of dtypes will be tested. Otherwise, the
  subset of combinations will be tested (see the description below).

Decorator adds the keyword arguments specified by names to the test fixture. Then, it runs the fixtures in
parallel with passing (possibly a subset of) the product set of dtypes. The range of dtypes is specified by
types.

The combination of dtypes to be tested changes depending on the option full. If full is True, all combinations
of types are tested. Sometimes, such an exhaustive test can be costly. So, if full is False, only
the subset of possible combinations is tested. Specifically, at first, the shuffled lists of types are made for
each argument name in names. Let the lists be D1, D2, ..., Dn where n is the number of arguments. Then, the
combinations to be tested will be zip(D1, D2, ..., Dn). If full is None, the behavior is switched by setting
the environment variable CUPY_TEST_FULL_COMBINATION=1.

For example, let types be [float16, float32, float64] and names be ['a_type',
'b_type']. If full is True, then the decorated test fixture is executed with all 2^3 patterns. On the other
hand, if full is False, shuffled lists are made for a_type and b_type. Suppose the lists are (16, 64,
32) for a_type and (32, 64, 16) for b_type (prefixes are removed for short). Then the combinations
of (a_type, b_type) to be tested are (16, 32), (64, 64) and (32, 16).

cupy.testing.for_all_dtypes_combination(names=('dtype',), no_float16=False,
no_bool=False, full=None)
Decorator that checks the fixture with a product set of all dtypes.

Parameters
- names (list of str) – Argument names to which dtypes are passed.
- no_float16 (bool) – If True, numpy.float16 is omitted from candidate dtypes.
- no_bool (bool) – If True, numpy.bool_ is omitted from candidate dtypes.
• **full (bool)** – If True, then all combinations of dtypes will be tested. Otherwise, the subset of combinations will be tested (see description in `cupy.testing.for_dtypes_combination()`).

See also:

  
  `cupy.testing.for_dtypes_combination()`

`cupy.testing.for_signed_dtypes_combination(names=('dtype',), full=None)`

Decorator for parameterized test w.r.t. the product set of signed dtypes.

Parameters

- **names (list of str)** – Argument names to which dtypes are passed.
- **full (bool)** – If True, then all combinations of dtypes will be tested. Otherwise, the subset of combinations will be tested (see description in `cupy.testing.for_dtypes_combination()`).

See also:

  
  `cupy.testing.for_dtypes_combination()`

`cupy.testing.for_unsigned_dtypes_combination(names=('dtype',), full=None)`

Decorator for parameterized test w.r.t. the product set of unsigned dtypes.

Parameters

- **names (list of str)** – Argument names to which dtypes are passed.
- **full (bool)** – If True, then all combinations of dtypes will be tested. Otherwise, the subset of combinations will be tested (see description in `cupy.testing.for_dtypes_combination()`).

See also:

  
  `cupy.testing.for_dtypes_combination()`

`cupy.testing.for_int_dtypes_combination(names=('dtype',), no_bool=False, full=None)`

Decorator for parameterized test w.r.t. the product set of int and boolean.

Parameters

- **names (list of str)** – Argument names to which dtypes are passed.
- **no_bool (bool)** – If True, `numpy.bool_` is omitted from candidate dtypes.
- **full (bool)** – If True, then all combinations of dtypes will be tested. Otherwise, the subset of combinations will be tested (see description in `cupy.testing.for_dtypes_combination()`).

See also:

  
  `cupy.testing.for_dtypes_combination()`

### 4.10 Environment variables

Here are the environment variables Chainer uses.

<table>
<thead>
<tr>
<th>Environment Variable</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>CUPY_CACHE_DIR</td>
<td>Path to the directory to store kernel cache. <code>$(HOME)/.cupy.kernel_cache</code> is used by default. See <strong>CuPy Overview</strong> for detail.</td>
</tr>
</tbody>
</table>
4.10.1 For install

These environment variables are only used during installation.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>CUDA_PATH</td>
<td>Path to the directory containing CUDA. The parent of the directory containing nvcc is used as default. When nvcc is not found, /usr/local/cuda is used. See Install Chainer with CUDA for details.</td>
</tr>
</tbody>
</table>

4.11 Difference between CuPy and NumPy

The interface of CuPy is designed to obey that of NumPy. However, there are some differences.

4.11.1 Cast behavior from float to integer

Some casting behaviors from float to integer are not defined in C++ specification. The casting from a negative float to unsigned integer and infinity to integer is one of such examples. The behavior of NumPy depends on your CPU architecture. This is Intel CPU result:

```python
>>> numpy.array([-1], dtype='f').astype('i')
array([4294967295], dtype=uint32)

>>> cupy.array([-1], dtype='f').astype('i')
array([0], dtype=uint32)

>>> numpy.array([float('inf')], dtype='f').astype('i')
array([-2147483648], dtype=int32)

>>> cupy.array([float('inf')], dtype='f').astype('i')
array([2147483647], dtype=int32)
```

4.11.2 Boolean values squared

In NumPy implementation, x ** 2 is calculated using multiplication operator as x * x. Because the result of the multiplication of boolean values is boolean, True ** 2 return boolean value. However, when you use power operator with other arguments, it returns int values. If we aligned the behavior of the squared boolean values of CuPy to that of NumPy, we would have to check their values in advance of the calculation. But it would be slow because it would force CPUs to wait until the calculation on GPUs end. So we decided not to check its value:

```python
>>> numpy.array([True]) ** 2
array([ True], dtype=bool)

>>> cupy.array([True]) ** 2
array([1])
```

4.11.3 Random methods support dtype argument

NumPy's random value generator does not support dtype option and it always returns a float32 value. We support the option in CuPy because cuRAND, which is used in CuPy, supports any types of float values:

```python
>>> numpy.random.randn(dtype='f')
Traceback (most recent call last):
  File "<stdin>", line 1, in <module>
TypeError: randn() got an unexpected keyword argument 'dtype'

>>> cupy.random.randn(dtype='f')
array(0.10689262300729752, dtype=float32)
```
This is a guide for all contributions to Chainer. The development of Chainer is running on the official repository at GitHub. Anyone that wants to register an issue or to send a pull request should read through this document.

5.1 Classification of Contributions

There are several ways to contribute to Chainer community:

1. Registering an issue
2. Sending a pull request (PR)
3. Sending a question to Chainer User Group
4. Open-sourcing an external example
5. Writing a post about Chainer

This document mainly focuses on 1 and 2, though other contributions are also appreciated.

5.2 Release and Milestone

We are using GitHub Flow as our basic working process. In particular, we are using the master branch for our development, and releases are made as tags.

Releases are classified into three groups: major, minor, and revision. This classification is based on following criteria:

- **Major update** contains disruptive changes that break the backward compatibility.
- **Minor update** contains additions and extensions to the APIs keeping the supported backward compatibility.
- **Revision update** contains improvements on the API implementations without changing any API specification.

The release classification is reflected into the version number x.y.z, where x, y, and z corresponds to major, minor, and revision updates, respectively.

We set a milestone for an upcoming release. The milestone is of name ‘vX.Y.Z’, where the version number represents a revision release at the outset. If at least one feature PR is merged in the period, we rename the milestone to represent a minor release (see the next section for the PR types).

See also API Compatibility Policy.
5.3 Issues and PRs

Issues and PRs are classified into following categories:

- **Bug**: bug reports (issues) and bug fixes (PRs)
- **Enhancement**: implementation improvements without breaking the interface
- **Feature**: feature requests (issues) and their implementations (PRs)
- **NoCompat**: disrupts backward compatibility
- **Test**: test fixes and updates
- **Document**: document fixes and improvements
- **Example**: fixes and improvements on the examples
- **Install**: fixes installation script
- **Contribution-Welcome**: issues that we request for contribution (only issues are categorized to this)
- **Other**: other issues and PRs

Issues and PRs are labeled by these categories. This classification is often reflected into its corresponding release category: Feature issues/PRs are contained into minor/major releases and NoCompat issues/PRs are contained into major releases, while other issues/PRs can be contained into any releases including revision ones.

On registering an issue, write precise explanations on what you want Chainer to be. Bug reports must include necessary and sufficient conditions to reproduce the bugs. Feature requests must include what you want to do (and why you want to do, if needed). You can contain your thoughts on how to realize it into the feature requests, though what part is most important for discussions.

**Warning:** If you have a question on usages of Chainer, it is highly recommended to send a post to Chainer User Group instead of the issue tracker. The issue tracker is not a place to share knowledge on practices. We may redirect question issues to Chainer User Group.

If you can write code to fix an issue, send a PR to the master branch. Before writing your code for PRs, read through the **Coding Guidelines**. The description of any PR must contain a precise explanation of what and how you want to do; it is the first documentation of your code for developers, a very important part of your PR.

Once you send a PR, it is automatically tested on Travis CI for Linux and Mac OS X, and on AppVeyor for Windows. Your PR need to pass at least the test for Linux on Travis CI. After the automatic test passes, some of the core developers will start reviewing your code. Note that this automatic PR test only includes CPU tests.

**Note:** We are also running continuous integration with GPU tests for the master branch. Since this service is running on our internal server, we do not use it for automatic PR tests to keep the server secure.

Even if your code is not complete, you can send a pull request as a work-in-progress PR by putting the [WIP] prefix to the PR title. If you write a precise explanation about the PR, core developers and other contributors can join the discussion about how to proceed the PR.

5.4 Coding Guidelines

We use PEP8 and a part of OpenStack Style Guidelines related to general coding style as our basic style guidelines. To check your code, use `autopep8` and `flake8` command installed by `hacking` package:
To check Cython code, use `.flake8.cython` configuration file:

```
$ flake8 --config=.flake8.cython path/to/your/cython/code.pyx
```

The `autopep8` supports automatically correct Python code to conform to the PEP 8 style guide:

```
$ autopep8 --in-place --global-config .pep8 path/to/your/code.py
```

The `flake8` command lets you know the part of your code not obeying our style guidelines. Before sending a pull request, be sure to check that your code passes the `flake8` checking.

Note that `flake8` command is not perfect. It does not check some of the style guidelines. Here is a (not-complete) list of the rules that `flake8` cannot check.

- Relative imports are prohibited. [H304]
- Importing non-module symbols is prohibited.
- Import statements must be organized into three parts: standard libraries, third-party libraries, and internal imports. [H306]

In addition, we restrict the usage of *shortcut symbols* in our code base. They are symbols imported by packages and sub-packages of `chainer`. For example, `chainer.Variable` is a shortcut of `chainer.variable.Variable`. It is not allowed to use such shortcuts in the "chainer" library implementation. Note that you can still use them in tests and examples directories. Also note that you should use shortcut names of CuPy APIs in Chainer implementation.

Once you send a pull request, your coding style is automatically checked by Travis-CI. The reviewing process starts after the check passes.

## 5.5 Testing Guidelines

Testing is one of the most important part of your code. You must test your code by unit tests following our testing guidelines. Note that we are using the nose package and the mock package for testing, so install nose and mock before writing your code:

```
$ pip install nose mock
```

In order to run unit tests at the repository root, you first have to build Cython files in place by running the following command:

```
$ python setup.py develop
```

Once the Cython modules are built, you can run unit tests simply by running `nosetests` command at the repository root:

```
$ nosetests
```

It requires CUDA by default. In order to run unit tests that do not require CUDA, pass `--attr='!gpu'` option to the `nosetests` command:

```
$ nosetests path/to/your/test.py --attr='!gpu'
```
Some GPU tests involve multiple GPUs. If you want to run GPU tests with insufficient number of GPUs, specify the number of available GPUs by `--eval-attr='gpu<N'` where N is a concrete integer. For example, if you have only one GPU, launch `nose tests` by the following command to skip multi-GPU tests:

```bash
$ nosetests path/to/gpu/test.py --eval-attr='gpu<2'
```

Some tests spend too much time. If you want to skip such tests, pass `--attr='!slow'` option to the `nose tests` command:

```bash
$ nosetests path/to/your/test.py --attr='!slow'
```

Tests are put into the `tests/chainer_tests`, `tests/cupy_tests` and `tests/install_tests` directories. These have the same structure as that of `chainer`, `cupy` and `install` directories, respectively. In order to enable test runner to find test scripts correctly, we are using special naming convention for the test subdirectories and the test scripts.

- The name of each subdirectory of `tests` must end with the `_tests` suffix.
- The name of each test script must start with the `test_` prefix.

Following this naming convention, you can run all the tests by just typing `nose tests` at the repository root:

```bash
$ nosetests
```

Or you can also specify a root directory to search test scripts from:

```bash
$ nosetests tests/chainer_tests  # to just run tests of Chainer
$ nosetests tests/cupy_tests   # to just run tests of CuPy
$ nosetests tests/install_tests # to just run tests of installation modules
```

If you modify the code related to existing unit tests, you must run appropriate commands.

**Note:** CuPy tests include type-exhaustive test functions which take long time to execute. If you are running tests on a multi-core machine, you can parallelize the tests by following options:

```bash
$ nosetests --processes=12 --process-timeout=1000 tests/cupy_tests
```

The magic numbers can be modified for your usage. Note that some tests require many CUDA compilations, which require a bit long time. Without the `process-timeout` option, the timeout is set shorter, causing timeout failures for many test cases.

There are many examples of unit tests under the `tests` directory. They simply use the `unittest` package of the standard library.

Even if your patch includes GPU-related code, your tests should not fail without GPU capability. Test functions that require CUDA must be tagged by the `chainer.testing.attr.gpu` decorator (or `cupy.testing.attr.gpu` for testing CuPy APIs):

```python
import unittest
from chainer.testing import attr

class TestMyFunc(unittest.TestCase):
    ...

    @attr.gpu
    def test_my_gpu_func(self):
        ...
```

The functions tagged by the `gpu` decorator are skipped if `--attr='!gpu'` is given. We also have the `chainer.testing.attr.cudnn` decorator to let `nose tests` know that the test depends on cuDNN.
The test functions decorated by `gpu` must not depend on multiple GPUs. In order to write tests for multiple GPUs, use `chainer.testing.attr.multi_gpu()` or `cupy.testing.attr.multi_gpu()` decorators instead:

```python
import unittest
from chainer.testing import attr
class TestMyFunc(unittest.TestCase):
    ...
    @attr.multi_gpu(2)  # specify the number of required GPUs here
    def test_my_two_gpu_func(self):
        ...
```

If your test requires too much time, add `chainer.testing.attr.slow` decorator. The test functions decorated by `slow` are skipped if `--attr='!slow'` is given:

```python
import unittest
from chainer.testing import attr
class TestMyFunc(unittest.TestCase):
    ...
    @attr.slow
    def test_my_slow_func(self):
        ...
```

**Note:** If you want to specify more than two attributes, separate them with a comma such as `--attr='!gpu,!slow'`. See detail in the document of nose.

Once you send a pull request, your code is automatically tested by Travis-CI with `--attr='!gpu,!slow'` option. Since Travis-CI does not support CUDA, we cannot check your CUDA-related code automatically. The reviewing process starts after the test passes. Note that reviewers will test your code without the option to check CUDA-related code.

**Note:** Some of numerically unstable tests might cause errors irrelevant to your changes. In such a case, we ignore the failures and go on to the review process, so do not worry about it.
CHAPTER 6

API Compatibility Policy

This document expresses the design policy on compatibilities of Chainer APIs. Development team should obey this policy on deciding to add, extend, and change APIs and their behaviors.

This document is written for both users and developers. Users can decide the level of dependencies on Chainer’s implementations in their codes based on this document. Developers should read through this document before creating pull requests that contain changes on the interface. Note that this document may contain ambiguities on the level of supported compatibilities.

6.1 Targeted Versions

This policy is applied to Chainer of versions v1.5.1 and higher. Note that this policy is not applied to Chainer of lower versions.

6.2 Versioning and Backward Compatibilities

The updates of Chainer are classified into three levels: major, minor, and revision. These types have distinct levels of backward compatibilities.

- **Major update** contains disruptive changes that break the backward compatibility.
- **Minor update** contains addition and extension to the APIs keeping the supported backward compatibility.
- **Revision update** contains improvements on the API implementations without changing any API specifications.

Note that we do not support full backward compatibility, which is almost infeasible for Python-based APIs, since there is no way to completely hide the implementation details.

6.3 Processes to Break Backward Compatibilities

6.3.1 Deprecation, Dropping, and Its Preparation

Any APIs may be *deprecated* at some minor updates. In such a case, the deprecation note is added to the API documentation, and the API implementation is changed to fire deprecation warning (if possible). There should be another way to reimplement the same things previously written with the deprecated APIs.
Any APIs may be marked as to be dropped in the future. In such a case, the dropping is stated in the documentation with the major version number on which the API is planned to be dropped, and the API implementation is changed to fire the future warning (if possible).

The actual dropping should be done through the following steps:

- Make the API deprecated. At this point, users should not need the deprecated API in their new application codes.
- After that, mark the API as to be dropped in the future. It must be done in the minor update different from that of the deprecation.
- At the major version announced in the above update, drop the API.

Consequently, it takes at least two minor versions to drop any APIs after the first deprecation.

### 6.3.2 API Changes and Its Preparation

Any APIs may be marked as to be changed in the future for changes without backward compatibility. In such a case, the change is stated in the documentation with the version number on which the API is planned to be changed, and the API implementation is changed to fire the future warning on the certain usages.

The actual change should be done in the following steps:

- Announce that the API will be changed in the future. At this point, the actual version of change need not be accurate.
- After the announcement, mark the API as to be changed in the future with version number of planned changes. At this point, users should not use the marked API in their new application codes.
- At the major update announced in the above update, change the API.

### 6.4 Supported Backward Compatibility

This section defines backward compatibilities that minor updates must maintain.

#### 6.4.1 Documented Interface

Chainer has the official API documentation. Many applications can be written based on the documented features. We support backward compatibilities of documented features. In other words, codes only based on the documented features run correctly with minor/revision-updated versions.

Developers are encouraged to use apparent names for objects of implementation details. For example, attributes outside of the documented APIs should have one or more underscores at the prefix of their names.

#### 6.4.2 Undocumented behaviors

Behaviors of Chainer implementation not stated in the documentation are undefined. Undocumented behaviors are not guaranteed to be stable between different minor/revision versions.

Minor update may contain changes to undocumented behaviors. For example, suppose an API X is added at the minor update. In the previous version, attempts to use X cause AttributeError. This behavior is not stated in the documentation, so this is undefined. Thus, adding the API X in minor version is permissible.

Revision update may also contain changes to undefined behaviors. Typical example is a bug fix. Another example is an improvement on implementation, which may change the internal object structures not shown in the documentation. As
a consequence, even revision updates do not support compatibility of pickling, unless the full layout of pickled objects is clearly documented.

### 6.4.3 Documentation Error

Compatibility is basically determined based on the documentation, though it sometimes contains errors. It may make the APIs confusing to assume the documentation always stronger than the implementations. We therefore may fix the documentation errors in any updates that may break the compatibility in regard to the documentation.

**Note:** Developers MUST NOT fix the documentation and implementation of the same functionality at the same time in revision updates as "bug fix". Such a change completely breaks the backward compatibility. If you want to fix the bugs in both sides, first fix the documentation to fit it into the implementation, and start the API changing procedure described above.

### 6.4.4 Object Attributes and Properties

Object attributes and properties are sometimes replaced by each other at minor updates. It does not break the user codes, except the codes depend on how the attributes and properties are implemented.

### 6.4.5 Functions and Methods

Methods may be replaced by callable attributes keeping the compatibility of parameters and return values in minor updates. It does not break the user codes, except the codes depend on how the methods and callable attributes are implemented.

### 6.4.6 Exceptions and Warnings

The specifications of raising exceptions are considered as a part of standard backward compatibilities. No exception is raised in the future versions with correct usages that the documentation allows, unless the API changing process is completed.

On the other hand, warnings may be added at any minor updates for any APIs. It means minor updates do not keep backward compatibility of warnings.

### 6.5 Model Format Compatibility

Objects serialized by official serializers that Chainer provides are correctly loaded with the higher (future) versions. They might not be correctly loaded with Chainer of the lower versions.

**Note:** Current serialization APIs do not support versioning (at least in v1.6.1). It prevents us from introducing changes in the layout of objects that support serialization. We are discussing about introducing versioning in serialization APIs.
6.6 Installation Compatibility

The installation process is another concern of compatibilities. We support environmental compatibilities in the following ways.

- Any changes of dependent libraries that force modifications on the existing environments must be done in major updates. Such changes include following cases:
  - dropping supported versions of dependent libraries (e.g. dropping cuDNN v2)
  - adding new mandatory dependencies (e.g. adding h5py to setup_requires)
- Supporting optional packages/libraries may be done in minor updates (e.g. supporting h5py in optional features).

Note: The installation compatibility does not guarantee that all the features of Chainer correctly run on supported environments. It may contain bugs that only occurs in certain environments. Such bugs should be fixed in some updates.
7.1 It takes too long time to compile a computational graph. Can I skip it?

Chainer does not compile computational graphs, so you cannot skip it, or, I mean, you have already skipped it :).

It seems you have actually seen on-the-fly compilations of CUDA kernels. CuPy compiles kernels on demand to make kernels optimized to the number of dimensions and element types of input arguments. Pre-compilation is not available, because we have to compile an exponential number of kernels to support all CuPy functionalities. This restriction is unavoidable because Python cannot call CUDA/C++ template functions in generic way. Note that every framework using CUDA require compilation at some point; the difference between other statically-compiled frameworks (such as cutorch) and Chainer is whether a kernel is compiled at installation or at the first use.

These compilations should run only at the first use of the kernels. The compiled binaries are cached to the $(HOME)/.cupy/kernel_cache directory by default. If you see that compilations run every time you run the same script, then the caching is failed. Please check that the directory is kept as is between multiple executions of the script. If your home directory is not suited to caching the kernels (e.g. in case that it uses NFS), change the kernel caching directory by setting the CUPY_CACHE_DIR environment variable to an appropriate path. See CuPy Overview for more details.

7.2 mnist example does not converge in CPU mode on Mac OS X

Many users reported that mnist example does not work correctly on Mac OS X. We are suspecting it is caused by vecLib, that is a default BLAS library installed on Mac OS X.

**Note:** Mac OS X is not officially supported. I mean it is not tested continuously on our test server.

We recommend to use other BLAS libraries such as OpenBLAS. We empirically found that it fixes this problem. It is necessary to reinstall NumPy to use replaced BLAS library. Here is an instruction to install NumPy with OpenBLAS using Homebrew.

```
$ brew tap homebrew/science
$ brew install openblas
$ brew install numpy --with-openblas
```

If you want to install NumPy with pip, use site.cfg file.

You can check if NumPy uses OpenBLAS with numpy.show_config method. Check if blas_opt_info refers to openblas.
>>> import numpy
>>> numpy.show_config()

lapack_opt_info:
    libraries = ['openblas', 'openblas']
    library_dirs = ['/usr/local/opt/openblas/lib']
    define_macros = [('HAVE_CBLAS', None)]
    language = c

blas_opt_info:
    libraries = ['openblas', 'openblas']
    library_dirs = ['/usr/local/opt/openblas/lib']
    define_macros = [('HAVE_CBLAS', None)]
    language = c

openblas_info:
    libraries = ['openblas', 'openblas']
    library_dirs = ['/usr/local/opt/openblas/lib']
    define_macros = [('HAVE_CBLAS', None)]
    language = c

openblas_lapack_info:
    libraries = ['openblas', 'openblas']
    library_dirs = ['/usr/local/opt/openblas/lib']
    define_macros = [('HAVE_CBLAS', None)]
    language = c

blas_mkl_info:
    NOT AVAILABLE

See detail about this problem in issue #704.
Comparison with Other Frameworks

8.1 A table for quick comparison

This table compares Chainer with other popular deep learning frameworks. We hope it helps you to choose an appropriate framework for the demand.

**Note:** This chart may be out-dated, since the developers of Chainer do not perfectly follow the latest development status of each framework. Please report us if you find an out-dated cell. Requests for new comparison axes are also welcome.

<table>
<thead>
<tr>
<th>Specs</th>
<th>Chainer</th>
<th>Theano-based</th>
<th>Torch7</th>
<th>Caffe</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scripting</td>
<td>Python</td>
<td>Python</td>
<td>LuaJIT</td>
<td>Python</td>
</tr>
<tr>
<td>Net definition language</td>
<td>Python</td>
<td>Python</td>
<td>LuaJIT</td>
<td>Protocol Buffers</td>
</tr>
<tr>
<td>Define-by-Run scheme</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
</tr>
<tr>
<td>CPU Array backend</td>
<td>NumPy</td>
<td>NumPy</td>
<td>Tensor</td>
<td>Protocol Buffers</td>
</tr>
<tr>
<td>GPU Array backend</td>
<td>CuPy</td>
<td>CudaNdarray</td>
<td>CudaTensor</td>
<td></td>
</tr>
<tr>
<td>NNs</td>
<td>Reverse-mode AD</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
</tr>
<tr>
<td></td>
<td>Basic RNN support</td>
<td>Y</td>
<td>Y</td>
<td>Y(nnx) #2033</td>
</tr>
<tr>
<td></td>
<td>Variable-length loops</td>
<td>Y</td>
<td>Y(scan)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Stateful RNNs ²</td>
<td>Y</td>
<td>Y</td>
<td>Y ²</td>
</tr>
<tr>
<td></td>
<td>Per-batch architectures</td>
<td>Y</td>
<td>Y</td>
<td></td>
</tr>
<tr>
<td>Perf</td>
<td>CUDA support</td>
<td>Y</td>
<td>Y</td>
<td>Y (cudnn.torch)</td>
</tr>
<tr>
<td></td>
<td>cuDNN support</td>
<td>Y</td>
<td>Y</td>
<td>Y (cudnn.torch)</td>
</tr>
<tr>
<td></td>
<td>FFT-based convolution</td>
<td>Y</td>
<td>Y (fbcunn)</td>
<td>#544</td>
</tr>
<tr>
<td></td>
<td>CPU/GPU generic coding ³</td>
<td>Y</td>
<td>Y ⁴</td>
<td>Y</td>
</tr>
<tr>
<td></td>
<td>Multi GPU (data parallel)</td>
<td>Y</td>
<td>Y ⁵</td>
<td>Y (fbcunn)</td>
</tr>
<tr>
<td></td>
<td>Multi GPU (model parallel)</td>
<td>Y</td>
<td>Y ⁶</td>
<td>Y (fbcunn)</td>
</tr>
<tr>
<td>Misc</td>
<td>Type checking</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
</tr>
<tr>
<td></td>
<td>Model serialization</td>
<td>Y</td>
<td>Y (pickle)</td>
<td>Y</td>
</tr>
<tr>
<td></td>
<td>Caffe reference model</td>
<td>Y</td>
<td>Y (loadcaffe)</td>
<td>Y</td>
</tr>
</tbody>
</table>

¹They are also developing libgparray
²Stateful RNN is a type of RNN implementation that maintains states in the loops. It should enable us to use the states arbitrarily to update them.
³Also available in the Torch RNN package
⁴This row shows whether each array API supports unified codes for CPU and GPU.
⁵The array backend of Theano does not have compatible interface with NumPy, though most users write code on Theano variables, which is generic for CPU and GPU.
⁶Via Platoon
⁷Experimental as May 2016
⁸Depending on the frameworks.
8.2 Benchmarks

We are preparing for the benchmarks.
• genindex
• modindex
• search
[Graves2006] Alex Graves, Santiago Fernandez, Faustino Gomez, Jurgen Schmidhuber, Connectionist Temporal Classification: Labelling Unsegmented Sequence Data with Recurrent Neural Networks

[Graves2012] Alex Graves, Supervised Sequence Labelling with Recurrent Neural Networks
C
chainer, 159
chainer.computational_graph, 174
chainer.cuda, 72
chainer.dataset, 61
chainer.datasets, 159
chainer.function, 154
chainer.function_hooks, 155
chainer.functions, 84
chainer.gradient_check, 80
chainer.initializer, 156
chainer.initializers, 157
chainer.iterators, 165
chainer.links, 129
chainer.links.caffe, 173
chainer.serializers, 152
chainer.testing, 82
chainer.training, 64
chainer.training.extensions, 166
chainer.training.triggers, 171
chainer.utils, 75
chainer.utils.type_check, 79
cupy, 190
cupy.random, 219
cupy.testing, 242
Symbols

__abs__ (cupy.ndarray attribute), 181
__abs__() (chainer.Variable method), 41
__add__ (cupy.cuda.MemoryPointer attribute), 232
__add__ (cupy.ndarray attribute), 181
__add__() (chainer.Variable method), 42
__and__ (cupy.cuda.MemoryPointer attribute), 231
__call__ (cupy.ElementwiseKernel attribute), 241
__call__() (chainer.AbstractSerializer method), 60
__call__() (chainer.Function method), 46
__call__() (chainer.initializer.Initializer method), 157
__call__() (chainer.links.BatchNormalization method), 146
__call__() (chainer.links.Bias method), 129
__call__() (chainer.links.Bilinear method), 130
__call__() (chainer.links.BinaryHierarchicalSoftmax method), 147
__call__() (chainer.links.Classifier method), 151
__call__() (chainer.links.Convolution2D method), 131
__call__() (chainer.links.ConvolutionND method), 132
__call__() (chainer.links.DilatedConvolution2D method), 135
__call__() (chainer.links.EmbedID method), 136
__call__() (chainer.links.Highway method), 137
__call__() (chainer.links.Inception method), 138
__call__() (chainer.links.LSTM method), 140
__call__() (chainer.links.Linear method), 139
__call__() (chainer.links.MLPConvolution2D method), 141
__call__() (chainer.links.Maxout method), 149
__call__() (chainer.links.NegativeSampling method), 150
__call__() (chainer.links.PReLU method), 148
__call__() (chainer.links.Parameter method), 151
__call__() (chainer.links.Scale method), 142
__call__() (chainer.links.StatefulPeepholeLSTM method), 144
__call__() (chainer.links StatelessLSTM method), 145
__call__() (chainer.links.caffe.CaffeFunction method), 174
__call__() (chainer.training.Extension method), 69
__call__() (chainer.training.extensions.Evaluator method), 167
__call__() (chainer.training.triggers.IntervalTrigger method), 172
__call__() (cupy.ReductionKernel method), 241
__call__() (cupy.ufunc method), 189
__delitem__ (cupy.ndarray attribute), 181
__div__ (cupy.ndarray attribute), 181
__div__() (chainer.Variable method), 42
__divmod__ (cupy.ndarray attribute), 181
__enter__() (chainer.Reporter method), 76
__eq__ (cupy.cuda.Device attribute), 231
__eq__ (cupy.ndarray attribute), 181
__exit__() (chainer.Reporter method), 76
__float__ (cupy.ndarray attribute), 181
__floordiv__ (cupy.ndarray attribute), 181
__ge__ (cupy.cuda.Device attribute), 231
__ge__ (cupy.ndarray attribute), 181
__getitem__ (cupy.ndarray attribute), 181
__gt__ (cupy.cuda.Device attribute), 231
__gt__ (cupy.ndarray attribute), 181
__hex__ (cupy.ndarray attribute), 182
__iadd__ (cupy.cuda.MemoryPointer attribute), 232
__iadd__ (cupy.ndarray attribute), 181
__iand__ (cupy.ndarray attribute), 181
__idiv__ (cupy.ndarray attribute), 182
__ifloordiv__ (cupy.ndarray attribute), 182
__ilshift__ (cupy.ndarray attribute), 182
__imod__ (cupy.ndarray attribute), 182
__imul__ (cupy.ndarray attribute), 182
__int__ (cupy.cuda.Device attribute), 231
__int__ (cupy.cuda.Memory attribute), 232
__int__ (cupy.cuda.MemoryPointer attribute), 232
__int__ (cupy.ndarray attribute), 182
__invert__ (cupy.ndarray attribute), 182
__invert__ (cupy.ndarray attribute), 182

273
arctanh (in module cupy), 214
argmax() (chainer.links.CRF1d method), 148
argmax() (cupy.ndarray method), 184
argmax() (module chainer.functions), 113
argmax() (in module cupy), 226
argmax_crf1d() (module chainer.functions), 108
argmin() (chainer.functions), 114
argmin() (module cupy), 226
array() (in module cupy), 193
array_repr() (in module cupy), 207
array_split() (in module cupy), 202
array_str() (in module cupy), 208
asanyarray() (in module cupy), 194
asarray() (in module cupy), 194
ascontiguousarray() (in module cupy), 200
asnumpy() (in module cupy), 188
assert_allclose() (module chainer.testing), 82
assert_allclose() (module cupy.testing), 242
assert_array_almost_equal() (module cupy.testing), 242
assert_array_almost_equal_nulp() (module cupy.testing), 242
assert_array_equal() (module cupy.testing), 242
assert_array_less() (module cupy.testing), 243
assert_array_list_equal() (module cupy.testing), 243
assert_array_max_ulp() (module cupy.testing), 243
astype() (cupy.ndarray method), 184
atleast_1d() (module cupy), 198
atleast_2d() (module cupy), 198
atleast_3d() (module cupy), 198
AUTO (module chainer), 45
average_pooling_2d() (module chainer.functions), 125

B
backward() (chainer.Function method), 47
backward() (chainer.Variable method), 44
backward_cpu() (chainer.Function method), 47
backward_gpu() (chainer.Function method), 47
backward_postprocess() (chainer.function.FunctionHook method), 155
backward_preprocess() (chainer.function.FunctionHook method), 155
batch_inv() (module chainer.functions), 114
batch_l2_norm_squared() (module chainer.functions), 114
batch_matmul() (module chainer.functions), 114
batch_normalization() (module chainer.functions), 123
BatchNormalization (class in chainer.links), 145
beroulli_nll() (module chainer.functions), 104
Bias (class in chainer.links), 129
bias() (module chainer.functions), 115
Bilinear (class in chainer.links), 130
bilinear() (module chainer.functions), 97
BinaryHierarchicalSoftmax (class in chainer.links), 146
bincoun() (module cupy), 230
bitwise_and() (module cupy), 204
bitwise_or() (module cupy), 204
bitwise_xor() (module cupy), 204
black_out() (module chainer.functions), 105
BlackOut (class in chainer.links), 147
broadcast (class in cupy), 199
broadcast() (module chainer.functions), 91
broadcast_arrays() (module cupy), 199
broadcast_to() (module chainer.functions), 91
broadcast_to() (module cupy), 199
build_computational_graph() (module chainer.computational_graph), 174

C
cache_or_load_file() (module chainer.dataset), 64
cached_download() (module chainer.dataset), 63
CaffeFunction (class in chainer.links.caffe), 173
call_hooks() (chainer.Optimizer method), 56
cast() (module chainer.functions), 91
cell (module cupy), 214
cell() (module chainer.functions), 115
Chain (class in chainer), 53
chainer (module), 41, 159
chainer.computational_graph (module), 174
chainer.cuda (module), 72
chainer.dataset (module), 61
chainer.datasets (module), 159
chainer.function (module), 154
chainer.function_hooks (module), 155
chainer.functions (module), 84
chainer.gradient_check (module), 80
chainer.initializer (module), 156
chainer.initializers (module), 157
chainer.iterators (module), 165
chainer.links (module), 129
chainer.links.caffe (module), 173
chainer.serializers (module), 152
chainer.training (module), 64
chainer.training.extensions (module), 166
chainer.utils (module), 75
chainer.utils.type_check (module), 79
ChainList (class in chainer), 54
clear_memo() (module chainer.cuda), 74
clear_memo() (module cupy), 237
ceregrad() (chainer.Variable method), 44
cleargrads() (chainer.Link method), 52
clip() (cupy.ndarray method), 184
clip() (in module chainer.functions), 115
clip() (in module cupy), 218
clip_grads() (chainer.Optimizer method), 56
clipped_relu() (in module chainer.functions), 84
collect_parameters() (chainer.FunctionSet method), 71
column_stack() (in module cupy), 200
ComputationalGraph (class in chainer.computational_graph), 175
compute_capability (cupy.cuda.Device attribute), 231
compute_grads_norm() (chainer.Optimizer method), 56
compute_mean() (chainer.DictSummary method), 78
copy() (chainer.Link method), 52
copy() (cupy.ndarray method), 184
copy() (in module chainer.cudnn), 73
copy() (in module chainer.functions), 92
copy_from() (cupy.cudnn.MemoryPointer method), 232
copy_from_async() (cupy.cudnn.MemoryPointer method), 233
copy_from_device() (cupy.cudnn.MemoryPointer method), 233
copy_from_device_async() (cupy.cudnn.MemoryPointer method), 233
copy_from_host() (cupy.cudnn.MemoryPointer method), 233
copy_from_host_async() (cupy.cudnn.MemoryPointer method), 233
copy_parameters_from() (chainer.FunctionSet method), 71
copy_to_host() (cupy.cudnn.MemoryPointer method), 233
copy_to_host_async() (cupy.cudnn.MemoryPointer method), 234
copydata() (chainer.Variable method), 44
copyparams() (chainer.Link method), 52
copiesign (in module cupy), 216
copyto() (in module cupy), 196
cos (in module cupy), 212
cosh (in module cupy), 213
cosh() (in module chainer.functions), 116
count_nonzero() (in module cupy), 226
create_huffman_tree() (chainer.links.BinaryHierarchicalSoftmax
static method), 147
crelu() (in module chainer.functions), 84
CRF1d (class in chainer.links), 148
crf1d() (in module chainer.functions), 106
cross_covariance() (in module chainer.functions), 108
cstruct (cupy.ndarray attribute), 184
cublas_handle (cupy.cudnn.Device attribute), 231
cupy (module), 177, 190, 240
cupy.random (module), 219
cupy.testing (module), 242
D
DatasetMixin (class in chainer.dataset), 61
deg2rad (in module cupy), 213
degrees (in module cupy), 213
delete_hook() (chainer.Function method), 48
deserialization (class in chainer), 60
device (in module cupy), 231
diag() (in module cupy), 195
diagflat() (in module cupy), 196
diagonal() (cupy.ndarray method), 184
diagonal() (in module cupy), 205
dict_dataset (class in chainer.datasets), 160
dictionary_serializer (class in chainer.serializers), 152
dict_summary (class in chainer), 78
dilated_convolution_2d() (in module chainer.functions), 102
DilatedConvolution2D (class in chainer.links), 134
divide (in module cupy), 217
done (cupy.cuda.Event attribute), 236
done (cupy.cuda.Stream attribute), 236
dot() (cupy.ndarray method), 185
dot() (in module cupy), 208
dropout() (in module chainer.functions), 122
dsplit() (in module cupy), 202
dstack() (in module chainer.functions), 92
dstack() (in module cupy), 201
dump() (chainer.computational_graph.ComputationalGraph
method), 176
dump() (cupy.ndarray method), 185
dump_graph() (in module chainer.training.extensions), 166
dumps() (cupy.ndarray method), 185

e
elapsed_time (chainer.training.Trainer attribute), 66
elementwise() (in module chainer.cuda), 74
ElementwiseKernel (class in cupy), 240
elu() (in module chainer.functions), 85
embed_id() (in module chainer.functions), 103
EmbedID (class in chainer.links), 135
empty() (in module cupy), 190
empty_like() (in module cupy), 190
equal (in module cupy), 211
eval() (chainer.utils.type_check.Expr method), 79
evaluate() (chainer.training.extensions&Evaluator method), 168
Evaluator (class in chainer.training.extensions), 167
Event (class in cupy.cuda), 236
exp (in module cupy), 215
exp() (in module chainer.functions), 116
exp2 (in module cupy), 215
expand_dims() (in module chainer.functions), 92
expand_dims() (in module cupy), 199
expect() (in module chainer.utils.type_check), 79
expm1 (in module cupy), 215
ExponentialShift (class in chainer.training.extensions), 168
Expr (class in chainer.utils.type_check), 79
extend() (chainer.training.Trainer method), 66
Extension (class in chainer.training), 69
eye() (in module cupy), 191

F

fill() (cupy.ndarray method), 185
fill_diagonal() (in module cupy), 206
finalize() (chainer.dataset.Iterator method), 62
finalize() (chainer.training.Extension method), 69
finalize() (chainer.trainingUpdater method), 67
fixed_batch_normalization() (in module chainer.functions), 124
Flag (class in chainer), 45
flags (cupy.ndarray attribute), 185
flatnonzero() (in module cupy), 227
flatten() (cupy.ndarray method), 185
flatten() (in module chainer.functions), 92
floor() (in module cupy), 214
floor() (in module chainer.functions), 116
floor_divide (in module cupy), 217
fmax (in module cupy), 219
fmin (in module cupy), 219
fmod (in module cupy), 217
for_all_dtypes() (in module cupy.testing), 247
for_all_dtypes_combination() (in module cupy.testing), 247
for_dtypes() (in module cupy.testing), 247
for_dtypes_combination() (in module cupy.testing), 249
for_floating_dtypes() (in module cupy.testing), 248
for_int_dtypes() (in module cupy.testing), 249
for_int_dtypes_combination() (in module cupy.testing), 250
for_signed_dtypes() (in module cupy.testing), 248
for_signed_dtypes_combination() (in module cupy.testing), 250
for_unsigned_dtypes() (in module cupy.testing), 248
for_unsigned_dtypes_combination() (in module cupy.testing), 250
force_backprop_mode() (in module chainer), 49
forget() (in module chainer.functions), 128
forward() (chainer.Function method), 48
forward_cup() (chainer.Function method), 48
forward_cupu() (chainer.Function method), 48
forward_postprocess() (chainer.function.FunctionHook method), 155
forward_preprocess() (chainer.function.FunctionHook method), 155
free_all_free() (cupy.cudamemoryPool method), 235
frexp (in module cupy), 216
full() (in module cupy), 192
full_like() (in module cupy), 193
Function (class in chainer), 45
FunctionHook (class in chainer.function), 154
FunctionSet (class in chainer), 71

G

gaussian() (in module chainer.functions), 122
gaussian_kl_divergence() (in module chainer.functions), 108
gaussian_nll() (in module chainer.functions), 109
get() (cupy.ndarray method), 185
get_all_iterators() (chainer.training.extensions.Evaluator method), 168
get_all_optimizers() (chainer.training.Updater method), 67
get_all_targets() (chainer.training.extensions.Evaluator method), 168
get_array_module() (in module chainer.cuda), 74
get_array_module() (in module cupy), 230
get_cifar10() (in module chainer.datasets), 164
get_cifar100() (in module chainer.datasets), 164
get_cross_validation_datasets() (in module chainer.datasets), 161
get_cross_validation_datasets_random() (in module chainer.datasets), 162
get_current_reporter() (in module chainer), 77
get_dataset_root() (in module chainer.datasets), 63
get_device() (in module chainer.cuda), 72
get_elapsed_time() (in module cupy.cuda), 236
get_example() (chainer.dataset.DatasetMixin method), 61
get_extension() (chainer.training.Trainer method), 66

Index 277
Index

lognormal() (cupy.random.RandomState method), 225
lognormal() (in module cupy.random), 222
LogReport (class in chainer.training.extensions), 169
logsumexp() (in module chainer.functions), 118
LSTM (class in chainer.links), 140
lstm() (in module chainer.functions), 86

make_extension() (in module chainer.training), 69
make_statistics() (chainer.DictSummary method), 78
make_statistics() (chainer.Summary method), 78
malloc() (cupy.cuda.MemoryPool method), 235
matmul() (in module chainer.functions), 118
max() (cupy.ndarray method), 186
max() (in module chainer.functions), 119
max_pooling_2d() (in module chainer.functions), 126
maximum (in module cupy), 219
maxout() (in module chainer.functions), 87
MaxValueTrigger (class in chainer.training.triggers), 172
mean() (cupy.ndarray method), 186
mean() (in module cupy), 229
mean_squared_error() (in module chainer.functions), 110
memozize() (in module chainer.cupy), 74
memozize() (in module cupy), 237
Memory (class in cupy.cupy), 232
MemoryPointer (class in cupy.cupy), 232
MemoryPool (class in cupy.cupy), 234
memset() (cupy.cupy.MemoryPool method), 234
memset_async() (cupy.cupy.MemoryPointer method), 234
min() (cupy.ndarray method), 186
min() (in module chainer.functions), 119
minimum (in module cupy), 219
minimum() (in module chainer.functions), 119
MinValueTrigger (class in chainer.training.triggers), 172
MLPConvolution2D (class in chainer.links), 141
mod (in module cupy), 217
modf (in module cupy), 188
MomentumSGD (class in chainer.optimizers), 151
multiply (in module cupy), 218
MultiprocessIterator (class in chainer.iterators), 166

n_free_blocks() (cupy.cupy.MemoryPool method), 235
namedlinks() (chainer.Link method), 52
namedparams() (chainer.Link method), 52
nanmax() (in module cupy), 228
nanmin() (in module cupy), 228
nbytes (cupy.ndarray attribute), 186
ndarray (class in cupy), 180
ndim (cupy.ndarray attribute), 186
negative (in module cupy), 217
negative_sampling() (in module chainer.functions), 110
NegativeSampling (class in chainer.links), 150
NesterovAG (class in chainer.optimizers), 152
new_epoch() (chainer.Optimizer method), 57
next() (chainer.dataset.Iterator method), 62
nextafter (in module cupy), 216
no_backprop_mode() (in module chainer), 49
nonzero() (cupy.ndarray method), 186
nonzero() (in module cupy), 226
Normal (class in chainer.initializers), 157
normal() (cupy.random.RandomState method), 225
normal() (in module cupy.random), 223
normalize() (in module chainer.functions), 125
not_equal (in module cupy), 211
NpzDeserializer (class in chainer.serializers), 152
numerical_grad() (in module chainer.gradient_check), 81
numpy_cupy_allclose() (in module cupy.testing), 244
numpy_cupy_array_almost_equal() (in module cupy.testing), 244
numpy_cupy_array_almost_equal_nulp() (in module cupy.testing), 245
numpy_cupy_array_equal() (in module cupy.testing), 246
numpy_cupy_array_less() (in module cupy.testing), 246
numpy_cupy_array_list_equal() (in module cupy.testing), 246
numpy_cupy_array_max_ulp() (in module cupy.testing), 247
numpy_cupy_raises() (in module cupy.testing), 247

OFF (in module chainer), 45
ON (in module chainer), 45
One() (in module chainer.initializers), 157
ones() (in module cupy), 191
ones_like() (in module cupy), 192
Optimizer (class in chainer), 55
Orthogonal (class in chainer.initializers), 158
outer() (in module cupy), 209

P
ParallelUpdater (class in chainer.training), 68
Parameter (class in chainer.links), 151
parameters (chainer.FunctionSet attribute), 71
params() (chainer.Link method), 52
permurate() (in module chainer.functions), 93
power (in module cupy), 217
PReLU (class in chainer.links), 148
prelu() (in module chainer.functions), 88
prepare() (chainer.Optimizer method), 57
PrintHook (class in chainer.function_hooks), 156
PrintReport (class in chainer.training.extensions), 171
prod() (cupy.ndarray method), 186
prod() (in module cupy), 215
profile() (in module cupy.cupy), 237
split_dataset() (in module chainer.datasets), 161
split_dataset_random() (in module chainer.datasets), 161
sqrt() (in module chainer.functions), 121
square() (in module cupy), 218
square() (in module cupy.functions), 121
square_difference() (in module chainer.functions), 121
squeeze() (cupy.ndarray method), 187
squeeze() (in module chainer.functions), 95
squeeze() (in module cupy), 200
stack() (in module chainer.functions), 95
stack() (in module cupy), 201
standard_normal() (cupy.random.RandomState method), 225
standard_normal() (in module cupy.random), 223
StandardUpdater (class in chainer.training), 67
start() (in module cupy.cudenarray.profiler), 237
start_finetuning() (chainer.links.BatchNormalization method), 146
StatefulGRU (class in chainer.links), 142
StatefulPeepholeLSTM (class in chainer.links), 143
 StatelessLSTM (class in chainer.links), 144
std() (cupy.ndarray method), 187
std() (in module cupy), 229
stop() (in module cupy.cudenarray.profiler), 237
Stream (in module cupy.cudenarray), 235
strides (cupy.ndarray attribute), 187
SubDataset (class in chainer.datasets), 160
subtract (in module cupy.multiproc), 217
sum() (cupy.ndarray method), 187
sum() (in module chainer.functions), 122
Summary (class in chainer), 78
swapaxes() (cupy.ndarray method), 187
swapaxes() (in module chainer.functions), 96
swapaxes() (in module cupy), 197
synchronize() (cupy.cudenarray.Device method), 231
synchronize() (cupy.cudenarray.Event method), 236
synchronize() (cupy.cudenarray.Stream method), 236
T
T (cupy.ndarray attribute), 181
take() (cupy.ndarray method), 188
take() (in module cupy), 204
tan() (in module cupy), 212
tan() (in module chainer.functions), 122
tanh() (in module cupy), 213
tanh() (in module chainer.functions), 90
tensordot() (in module cupy), 209
tile() (in module chainer.functions), 96
tile() (in module cupy), 203
TimerHook (class in chainer.function_hooks), 156
to_cpu() (chainer.function_hooks.TimerHook method), 156
to_cpu() (in module chainer.cudenarray), 73
to_gpu() (chainer.Link method), 53
to_gpu() (chainer.utils.WalkerAlias method), 75
to_gpu() (chainer.Variable method), 44
to_gpu() (in module chainer.cudenarray), 73
tofile() (cupy.ndarray method), 188
tolist() (cupy.ndarray method), 188
total_time() (chainer.function_hooks.TimerHook method), 156
trace() (cupy.ndarray method), 188
trace() (in module cupy), 210
Trainer (class in chainer.training), 64
transpose() (cupy.ndarray method), 188
transpose() (in module chainer.functions), 96
transpose() (in module cupy), 197
transpose_sequence() (in module chainer.functions), 97
triplet() (in module chainer.functions), 112
true_divide() (in module cupy), 217
trunc() (in module cupy), 214
TupleDataset (class in chainer.datasets), 160
TypeInfo (class in chainer.utils.type_check), 80
TypeInfoTuple (class in chainer.utils.type_check), 80
types (cupy.ufunc attribute), 189
U
ufunc (class in cupy), 189
unary_math_function_unittest() (in module chainer.testing), 82
unchain() (chainer.Function method), 49
unchain_backward() (chainer.Variable method), 44
Uniform (class in chainer.initializers), 158
uniform() (cupy.random.RandomState method), 225
uniform() (in module cupy.random), 223
unpooling_2d() (in module chainer.functions), 127
update() (chainer.GradientMethod method), 58
update() (chainer.Optimizer method), 57
update() (chainer.training.Update method), 67
update_one() (chainer.GradientMethod method), 58
update_one() (chainer.GradientMethod method), 58
update_one_cpu() (chainer.GradientMethod method), 58
update_one_gpu() (chainer.GradientMethod method), 59
Updater (class in chainer.training), 67
use() (cupy.cudenarray.Device method), 232
use_cleargrads() (chainer.GradientMethod method), 59
V
var() (cupy.ndarray method), 188
var() (in module cupy), 229
Variable (class in chainer), 41
vdot() (in module cupy), 208
view() (cupy.ndarray method), 188
vsplit() (in module cupy), 202
vstack() (in module chainer.functions), 97
vstack() (in module cupy), 201
W
wait_event() (cupy.cuda.Stream method), 236
WalkerAlias (class in chainer.utils), 75
weight_decay() (chainer.Optimizer method), 58
WeightDecay (class in chainer.optimizer), 59
where() (in module chainer.functions), 97
where() (in module cupy), 227

X
xp (chainer.Link attribute), 53

Z
Zero() (in module chainer.initializers), 157
zero_grads() (chainer.Optimizer method), 58
zerograd() (chainer.Variable method), 45
zerograds() (chainer.Link method), 53
zeros() (in module cupy), 192
zeros_like() (in module cupy), 192