Caffe

Caffe V1 Introduction

- Convolutional Architecture for Fast Feature Embedding -

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- Deep learning hierarchy
- Deep learning frameworks
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- What is Caffe
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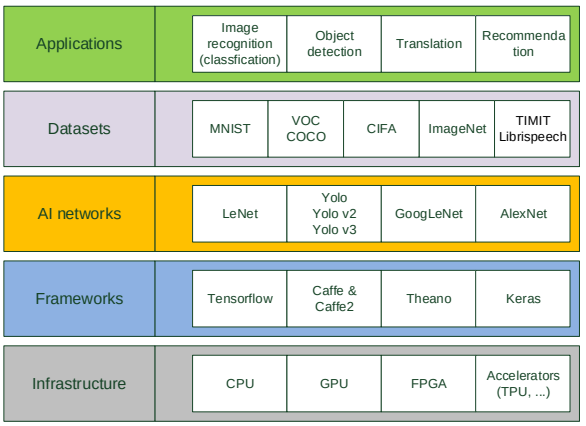
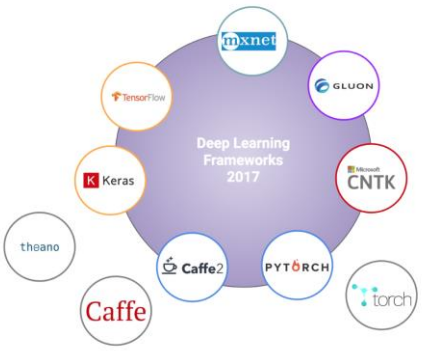
Deep Learning Hierarchy



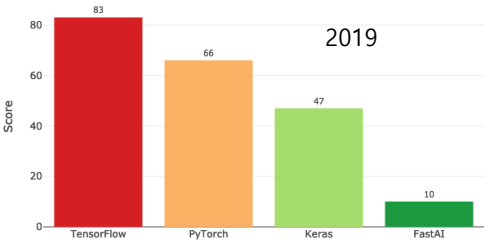
- Data set
  - A collection of data to be used for AI training, validation, and testing.
- AI networks
  - Artificial neural network
- Frameworks and libraries
- Infrastructure

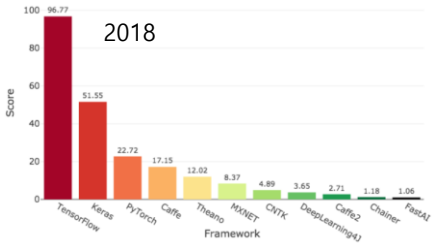
Deep learning frameworks



- Caffe V1
  - Berkeley / BVLC (Berkeley Vision and Learning Center) BAIR (Artificial Intelligence Research)
  - C++, Python, Matlab
- TensorFlow
  - Google Brain
  - C++, Python
- Caffe V2 → PyTorch
  - Facebook
- theano
  - U. Montreal
  - Python
- torch
  - Facebook / NUU
  - C, C++, Lua
- CNTK
  - Microsoft
- MXNet
  - Carnegie Mellon University / DMLC (Distributed Machine Learning Community)

Deep learning frameworks





Related topics

- Protocol buffer (protobuf)
  - Protobuf is a data structure format in short.
  - Caffe uses protobuf to describe network (i.e., layer, net, solver)
- Lightning memory-mapped database (LMDB)
  - database in the form of a key-value store.
  - Caffe uses LMDB to store training data, which is huge.
- HDF
  - Hierarchical Data Format (HDF) is an open source file format for storing huge amounts of numerical data.
  - HDF5 data requires two files.
    - .h5 file containing data and label
    - .txt file specifing path to the .h5 file(s)

Protocol buffer (Protobuf)

- There are many ways to capture structured data to serialize.
  - XML (eXtensible Markup Language)
  - JSON (JavaScript Object Notation)
  - Protobuf (Protocol Buffer)

```
<!-- XML example -->
<person>
  <name>Kil-Dong Hong</name>
  <age>30</age>
  <contacts>
     <email>kdhong@email.com</email>
     <phone>111-222-333</phone>
  </contacts>
</person>
```

```
// JSON example
person {
   name: "Kil-Dong Hong"
   age: 30
    contacts: {
          email: kdhong@email.com
          phone: "111-222-333"
    }
}
```

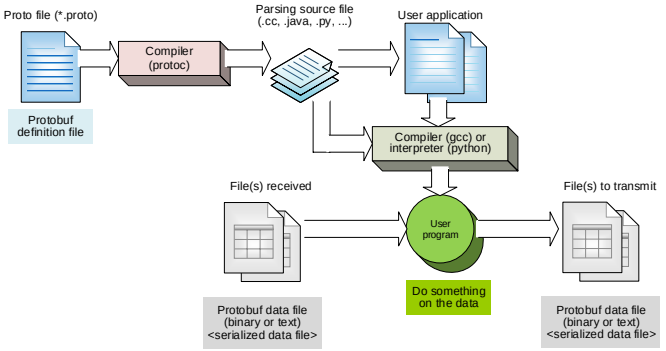

Protocol buffer (Protobuf)

- Protobuf
  - A message is just an aggregate containing a set of typed fields. (bool, int32, float, double, and string) and structures.
  - Each element has its unique identifier, i.e., 'tag'. ('=1', '=2', ...)
  - Field modifiers (required, optional, repeated)
  - Accessor methods (for each field)
    - foo(), set_foo(), get_foo(), has_foo(), clear_foo(), ...
  - comment: '//'

```
// ptotobuf example (person.proto)
message Person {
     required string name = 1;
     optional string email = 2;

     enum PhoneType {
          MOBILE = 0;
          HOME = 1;
          WORK = 2;
     }

     message PhoneNumber {
          required string number = 1;
          optional PhoneType type = 2 [default = HOME];
     }

     repeated PhoneNumber phone = 3;
}
```

Protobuf

- Protocol buffers are a language-neutral, platform-neutral extensible mechanism for serializing structured data.



- The **.proto** file is used to describe the structure (the 'protocol') of the data to be serialized. The protobuf compiler can turn this file into python/or C++/or Java code to serialize and deserialize data with that structure. (use '//' for comments.)
- The **.prototxt** file is serialized file in text instead of binary. (use '#' for comments.)
- The **.binaryproto** or **.protobin** file is serialized file in binary format.

Protobuf

```
adki@AndoUbuntu: ~/work/seminars/20180110_DeepLe
[adki@AndoUbuntu] ls
main.cpp  Makefile  person.proto*
[adki@AndoUbuntu] make
protoc --cpp_out=out person.proto
g++ -o test main.cpp out/person.pb.cc\
        -Iout `pkg-config --cflags --libs protobuf`
[adki@AndoUbuntu] ls
main.cpp  Makefile  out/  person.proto*  test*
[adki@AndoUbuntu] ls out
person.pb.cc  person.pb.h
[adki@AndoUbuntu] make run
./test
Name: Kil-Dong Hong
E-mail: kdhong@email.com
[adki@AndoUbuntu]
```

- refer to following program and files
  - protoc
    - Google protocol buffer compiler
  - out/person.pb.{h,cc}
    - parsing program
  - myfile
    - serialized data file

It handles binary form of protobuf file.

```
#include <fstream>
#include <iostream>
#include "person.pb.h"

using namespace std;

int main(int argc, char *argv[])
{
    Person personA;
    personA.set_name("Kil-Dong Hong");
    personA.set_email("kdhong@email.com");

    //write binary
    fstream output("myfile.protobin", ios::out | ios::binary);
    personA.SerializeToOstream(&output);
    output.close();

    Person personB;
    //read binary
    fstream input("myfile.protobin", ios::in | ios::binary);
    personB.ParseFromIstream(&input);
    cout << "Name: " << personB.name() << endl;
    cout << "E-mail: " << personB.email() << endl;
    input.close();

    return 0;
}
```

To install protocol buffer compiler (**protoc**).
$ sudo apt-get install libprotobuf-dev libleveldb-dev libsnappy-dev libopencv-dev libhdf5-serial-dev protobuf-compiler

Running protobuf example

- This example shows how to use compile Tiny-Dnn program
  - Step 1: go to your project directory
    - [user@host] cd $(PROJECT)/codes/caffe_v1-projects/protobuf_person
  - Step 2: see the codes
  - Step 3: compile
    - [user@host] make
  - Step 4: run
    - [user@host] make run

```
[user@host] cd $(PROJECT)/codes/caffe_v1-projects/protobuf_person
[user@host] make
[user@host] make run
```


Protobuf: handling .prototxt

It handles textual form of protobuf file.

```
#include <fstream>
#include <iostream>
#include <fcntl.h>
#include <unistd.h>
#include <google/protobuf/io/coded_stream.h>
#include <google/protobuf/io/zero_copy_stream_impl.h>
#include <google/protobuf/text_format.h>
#include "person.pb.h"

using namespace std;
using google::protobuf::io::FileInputStream;
using google::protobuf::io::FileOutputStream;
using google::protobuf::io::ZeroCopyInputStream;
using google::protobuf::io::CodedInputStream;
using google::protobuf::io::ZeroCopyOutputStream;
using google::protobuf::io::CodedOutputStream;

int main(int argc, char *argv[])
{
    GOOGLE_PROTOBUF_VERIFY_VERSION;

    Person personA;
    personA.set_name("Kil-Dong Hong");
    personA.set_email("kdhong@email.com");
    //write textual file
    int fd = open("myfile.prototxt",
O_WRONLY|O_CREAT|O_TRUNC, 0644);
    FileOutputStream *output = new FileOutputStream(fd);
    google::protobuf::TextFormat::Print(personA, output);
    delete output;
    close(fd);

    Person personB;
    //read textual file
    fd = open("myfile.prototxt", O_RDONLY);
    FileInputStream *input = new FileInputStream(fd);
    google::protosun::TextFormat::Parse(input, &personB);
    delete input;
    close(fd);
    cout << "Name: " << personB.name() << endl;
    cout << "E-mail: " << personB.email() << endl;

    return 0;
}
```

Running protobuf example

- This example shows how to use compile Tiny-Dnn program
  - Step 1: go to your project directory
    - [user@host] cd $(PROJECT)/codes/caffe_v1-projects/protobuf_person_text
  - Step 2: see the codes
  - Step 3: compile
    - [user@host] make
  - Step 4: run
    - [user@host] make run

```
[user@host] cd $(PROJECT)/codes/caffe_v1-projects/protobuf_person_text
[user@host] make
[user@host] make run
```


LMDB

- LMDB
  - Lightning memory-mapped database
  - database in the form of a key-value store.
  - A tiny database with fast search and cheap read transactions with concurrent reads
  - Memory mapped, allowing for zero copy lookup and iteration
- Recall that
  - Training involves huge number of iterations for the same data.
  - So read-efficient database is required
- LMDB creates two files
  - *lock*.mdb
    - to synchronize data between different readers
  - *data*.mdb
- Caffe also uses Google **LevelDB**.
  - LevelDB is an open-source on-disk key-value store.
- Caffe also uses **HDF5** file format.
  - Hierarchical Data Format (HDF) is an open source file format for storing huge amounts of numerical data.
  - HDF5 data requires two files.
    - .h5 file containing data and label
    - .txt file specifing path to the .h5 file(s)

Contents

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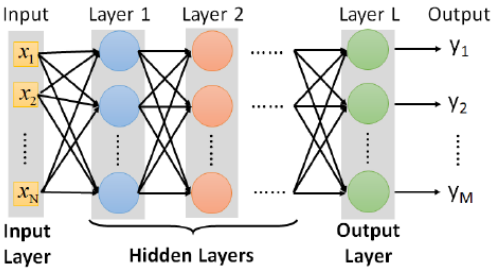
- Caffe: blob, layer, net, solver

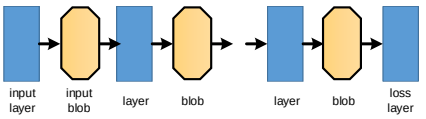
What is Caffe

- Caffe is a deep learning framework.
  - Convolutional Architecture for Fast Feature Embedding
  - It is written in C++, with a Python interface.
  - models and optimizations are defined as plaintext schema instead of code. (i.e., prototext)
- Yangqing Jia created the project during his PhD at Berkeley AI Research (BAIR).
- BSD 2-Clause license

- Main classes
  - **Blob** is the standard array and unified memory interface for the framework.
  - **Layer** is the foundation of both model and computation.
  - **Net** is the collection and connection of layers.
  - **Solver** is the model optimization.
- Caffe develop steps
  - *Step 1*: Data preparation
  - *Step 2*: Model definition - parameters in a configuration file with extension **.prototxt**.
  - *Step 3*: Solver definition: - solver parameters in a configuration file with extension **.prototxt**.
  - *Step 4*: Model training - trained model in a file with extension **.caffemodel**.
  - *Step 5*: Prediction (inference, deploy) – use trained model (.caffemodel) to make predictions of new data.

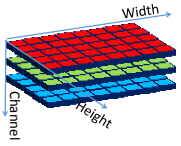
Caffe

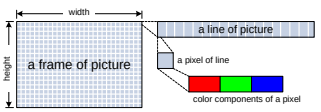


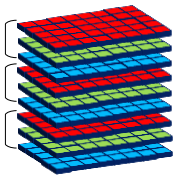


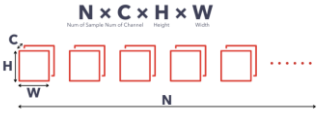
Caffe: blob

- Store data in memory
  - C-contiguous fashion (row-major)
  - CxHxW convention
    - C: channel (e.g., R, G, B)
    - H: height (e.g., height of image)
    - W: width (e.g., width of image)

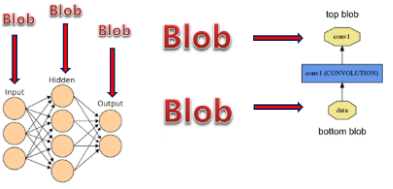






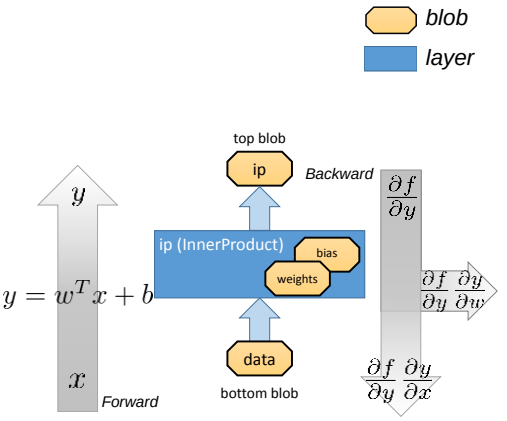


- **Blob** is the standard array and unified memory interface for the framework.
  - Caffe stores and communicates data using blobs.
    - Caffe 내에서 데이터 저장과 레이어 간의 통신을 위한 구조체
  - N-Dimensional arrays for stored in a C-contiguous fashion (row-major) and communicating data
  - Blobs provide a unified memory interface holding data
  - Blob size: N x C x H x W

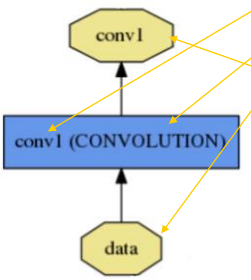


Caffe: layer

- **Layer** is the foundation of both model and computation.
  - Caffe's fundamental unit of computation
  - Transforms bottom blobs to top blobs
  - 네트웍 구성에 필요한 각종 요소들이 미리 준비되어 있음
    - Data access, convolution, pooling, activation functions, loss functions, drop out, and so on
  - Each layer type defines three computations: setup, forward, and backward.
  - Blob should be used between layers.



Caffe: layer




```
layer {
  name: "conv1"
  type: CONVOLUTION
  bottom: "data"
  top: "conv1"
  convolution_param {
    num_output: 20
    kernel_size: 5
    stride: 1
    weight_filler {
      type: "uniform"
    }
  }
}
```

name and type;
connection structure: input blobs and output blobs

layer-specific parameters

for convolution type:
- num_output: number of filters
- kernel_size (or kernel_h and kernel_w): height and width of each filter
- weight_filler: weight initializer

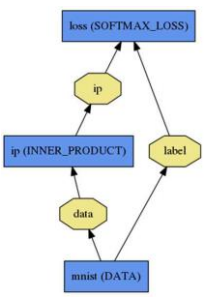
Caffe: layers

- Data Layers
  - Data can come from efficient databases (LevelDB or LMDB), directly from memory, or, when efficiency is not critical, from files on disk in HDF5 or common image formats.
  - Has common input preprocessing (mean subtraction, scaling, random cropping, and mirroring)
- Common Layers
  - Various commonly used layers, such as: Inner Product, Reshape, Concatenation, Softmax, …
- Neuron Layers
  - Neuron layers are element-wise operators, taking one bottom blob and producing one top blob of the same size.
  - ReLU, Sigmoid, tanh, Dropout, ...
- Vision Layers
  - Vision layers usually take images as input and produce other images as output.
  - convolutional layer & deconvolutional (convolution transpose) layer
  - Pooling layer
- Loss Layers
  - Loss drives learning by comparing an output to a target and assigning cost to minimize. The loss is computed by the forward pass.
  - SoftmaxWithLoss layer, EuclideanLoss layer

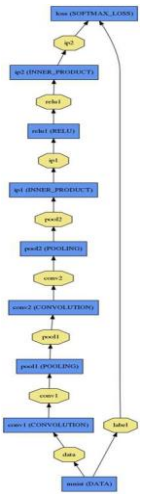
Caffe: net

- **Net** is the collection and connection of layers.
  - 레이어로 구성된 네트웍 (Directed Acyclic Graph)
  - Many layers
  - computes gradients via Forward / Backward

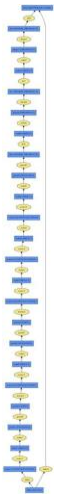
```
name: “mynetwork"
layers { name: "data" …}
layers { name: "conv" …}
layers { name: "pool" …}
… more layers …
layers { name: "loss" …}
```



Logistic Regression

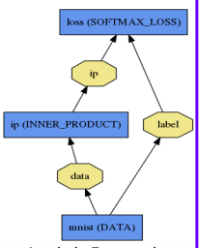


LeNet



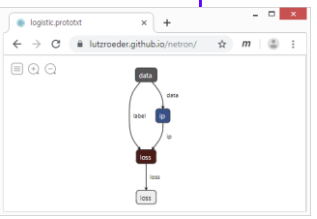
ImageNet

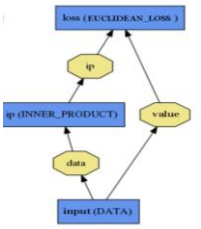
Caffe: net



Logistic Regression

```
name: "simple logistic regression classifier"
layer {
  name: "data"
  type: "Data"
  top: "data"
  top: "label"
  include { phase: TRAIN }
}
layer {
  name: " ip"
  type: "InnerProduct"
  bottom: "data"
  top: "ip"
  inner_product_param { num_output: 2 }
}
layer {
  name: "loss"
  type: "SoftmaxWithLoss"
  bottom: "ip"
  bottom: "label"
  top: "loss"
}
```





Linear Regression

```
name: "LinearReg"
layer {
  name: "input"
  type: "Data"
  top: "data"
  top: "value"
  data_param {
    source: "input_leveldb"
    batch_size: 64
  }
}
layer {
  name: "ip"
  type: "InnerProduct"
  bottom: "data"
  top: "ip"
  inner_product_param { num_output: 1 }
}
layer {
  name: "loss"
  type: "EuclideanLoss"
  bottom: "ip"
  bottom: "value"
  top: "loss"
}
```

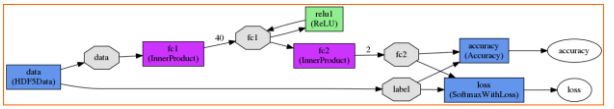

Visualizing Caffe network

- Visualize Caffe network prototxt file as DAGs
- Install dependencies
  - $ sudo pip install pydot
  - $ sudo apt-get install graphviz
- Add following to your bash startup (.bashrc) at the home

```
if [ -n "${PATH}" ]; then
export PATH=${HOME}/caffe_v1/caffe/build/tools:${HOME}/caffe_v1/caffe/python:${PATH}
else
export PATH=${HOME}/caffe_v1/caffe/build:${HOME}/caffe_v1/caffe/python
fi
```

- Run as follows

```
$ draw_net.py xor_net.prototxt xor_net.png
$ display xor_net.png
```



Caffe: solver

- **Solver** is the model optimization
  - Orchestrated model optimization by coordinating the network's forward interface and backward gradients
  - Uses gradients to update weights
    - Calls forward/backward and updates net parameters
  - Calls forward/backward and updates net parameters
  - Periodically evaluates model on the test netowrk(s)
  - Snapshots model and solver state
  - Solvers available
    - SGD, AdaDelta, AdaGrad, Adam, Nesterov, RMSprp

Solver specifies the net to apply optimization for train.

```
# solver prototxt file example
train_net: "lenet_train.prototxt"
base_lr: 0.01 # begin training at a learning rate of 0.01
lr_policy: "step"
gamma: 0.1 # drop the learning rate
stepsize: 100000 # drop the learning rate every 100K
iterations
max_iter: 350000
momentum: 0.9
snapshot_prefix: "lenet_snapshot"
solver_mode: CPU
```

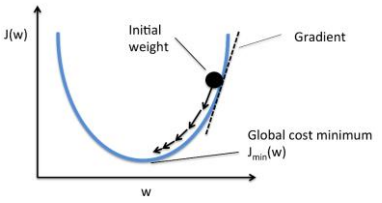

Caffe: solver

- net: Proto filename for the train net, possibly combined with test net
- display: the number of iterations between displaying info
- max_iter : The maximum number of iterations
- solver_mode: the mode solver will use: CPU or GPU
- test_iter: The number of iterations for each test net
- test_interval: The number of iterations between two testing phases
- base_lr: initial learning rate
- lr_policy: "fixed" = always 'base_lr'
- lr_policy: "step" = start at 'base_lr' and after each 'stepsize' iterations reduce learning rate by 'gamma'
- lr_policy: "inv" = start at 'base_lr' and after each iteration reducd learning rate some equation
- momentum: weight of the previous update
- weight_decay
- snapshot:
- snapshot_prefix:

Solver methods

- The solver orchestrates model optimization by coordinating the network's forward inference and backward gradients to form parameter updates that attempt to improve the loss.
  - Stochastic Gradient Descent (type: "SGD"),
  - AdaDelta (type: "AdaDelta"),
  - Adaptive Gradient (type: "AdaGrad"),
  - Adam (type: "Adam"),
  - Nesterov's Accelerated Gradient (type: "Nesterov") and
  - RMSprop (type: "RMSProp")

- SGD: Stochastic Gradient Descent
  - 확율적 경사하강법



$$V_{t+1}=\mu V_t-\eta \nabla L(W_t)$$

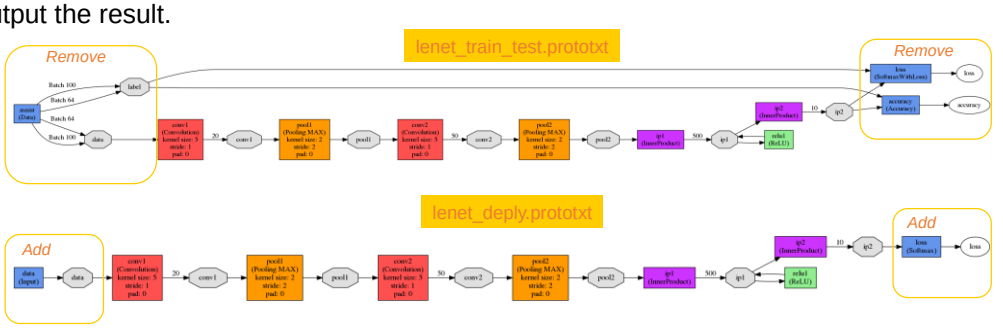
$$W_{t+1}=W_t+V_{t+1}$$

W_t: Weight at time t (i.e., at iteration t)
V_t: Weight updated at time t

$\nabla L(W_t)$: negative gradient of Weight at time t
η: Learning rate (weight of negative gradient)
μ: Momentum (weight of previous update)

Deploy prototxt

- Remove input data layer and replace with a description of input data dimension
  - Remove the data layer that was used for training, as for in the case of classification we are no longer providing labels for our data.
  - Remove any layer that is dependent upon data labels.
  - Set the network up to accept data.
- Remove "loss" and "accuracy" layers and replace with an appropriate layer to have the network output the result.



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