Parallelizing the Interpolation between Latent Space of Autoencoder Networks

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Overview

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- Convolutional Neural Network
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- Parallelism
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- Introduction to Numba
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Related Work

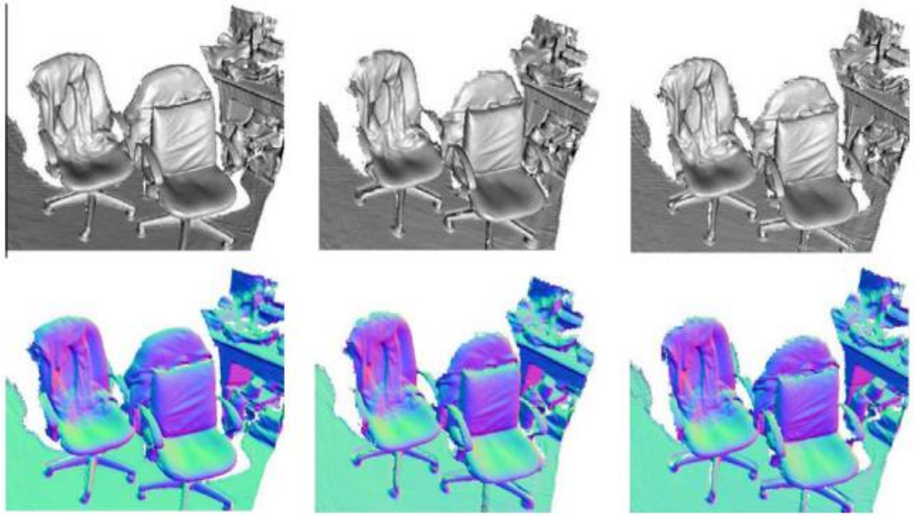
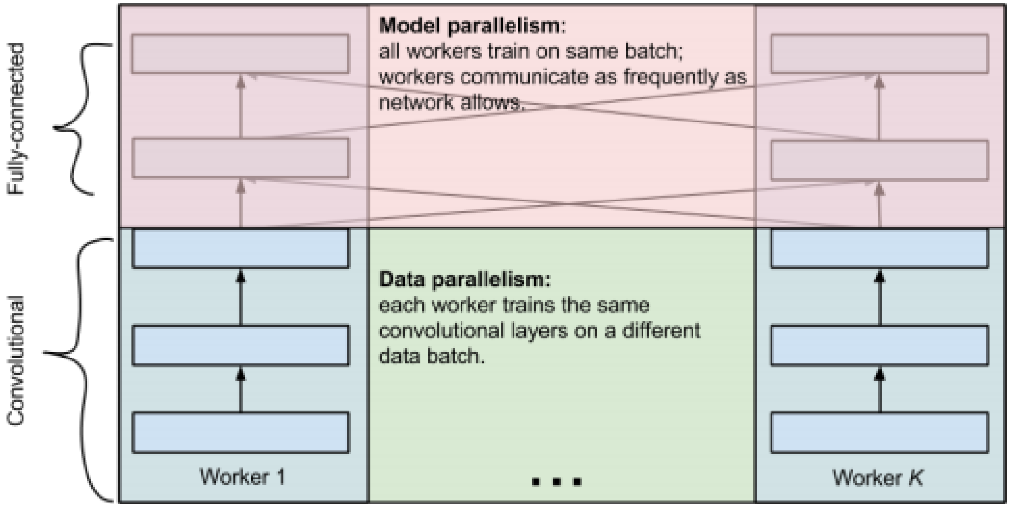


Fig. 6. Reconstruction of the "chairs" scene. Top row are the Phong shading results and bottom are normal maps. The first column are KF_{512}, the middle column are OF_9 and the third column are OF_{10}.

Octree-based fusion for realtime 3D reconstruction (2012)
[Ming Zeng, Fukai Zhao, Jiaxiang Zheng, Xinguo Liu]

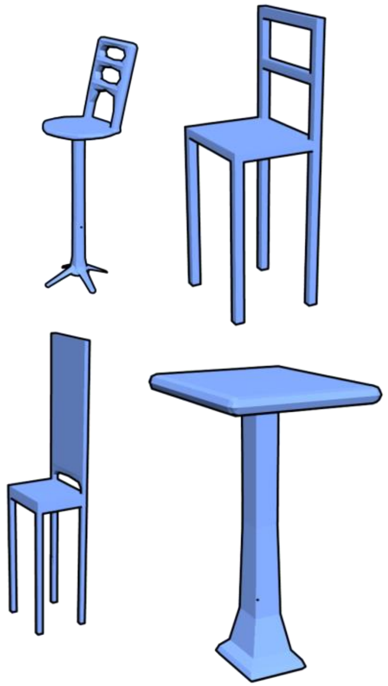
(a) Images of objects we wish to reconstruct (b) Overview of the network

3D-R2N2: A Unified Approach for Single and Multi-view 3D Object Reconstruction (2016)
[Christopher B. Choy, Danfei Xu, JunYoung Gwak, Kevin Chen, Silvio Savarese]

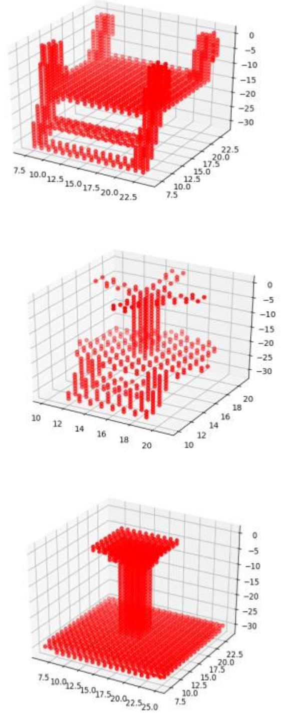


One weird trick for parallelizing convolutional neural networks (2014)
[Alex Krizhevsky]

Project Overview



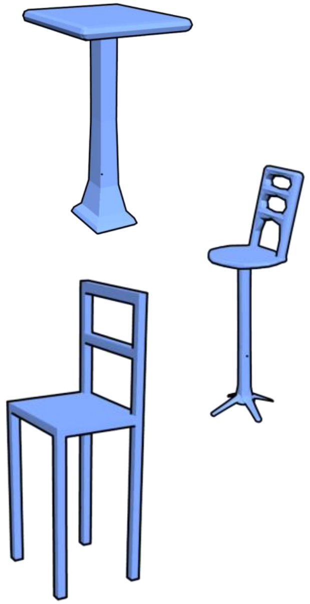
Actual chair models



Converted 3D voxelized shape

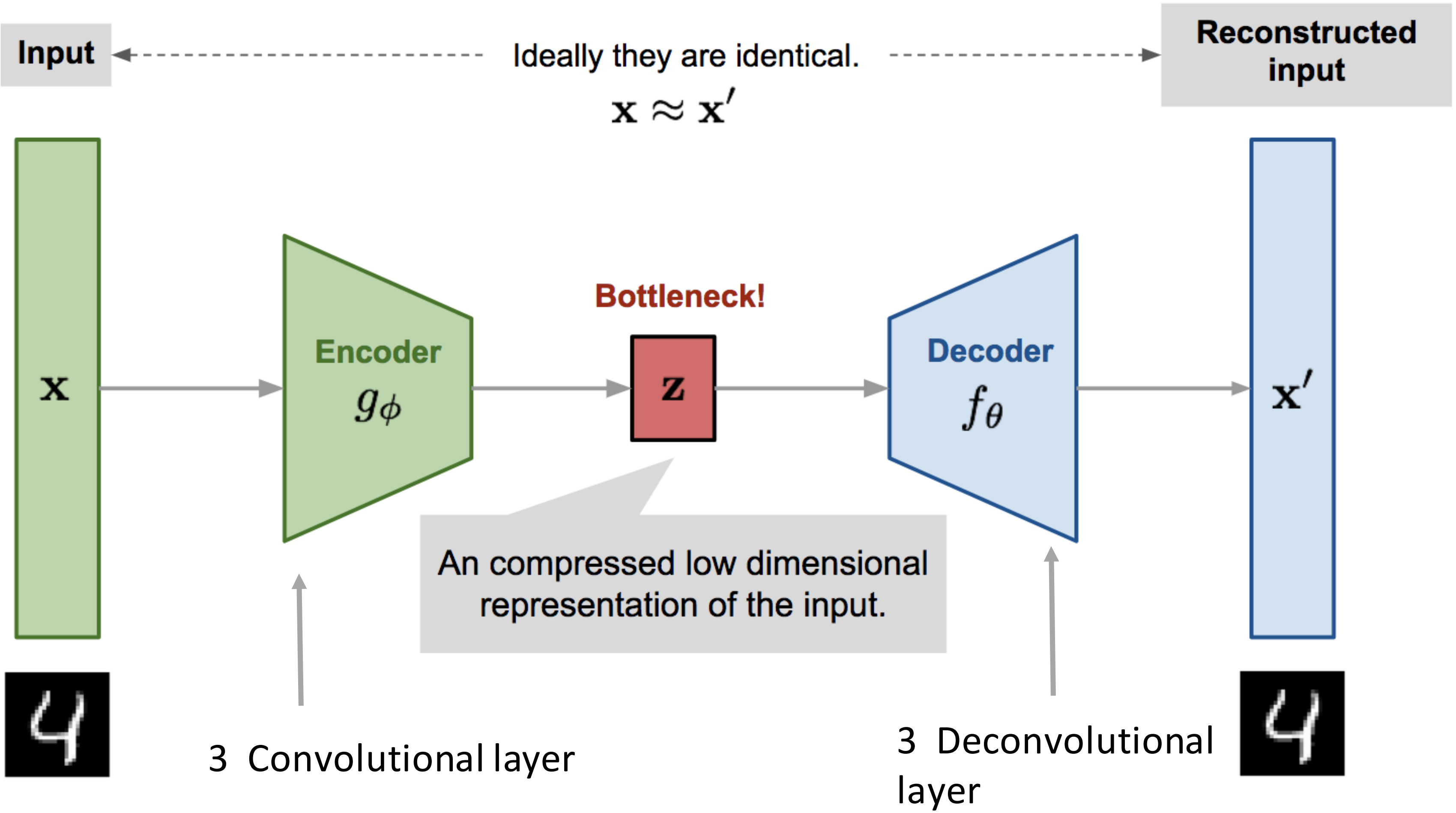
Autoencoder

Deep Network



Reconstructed output

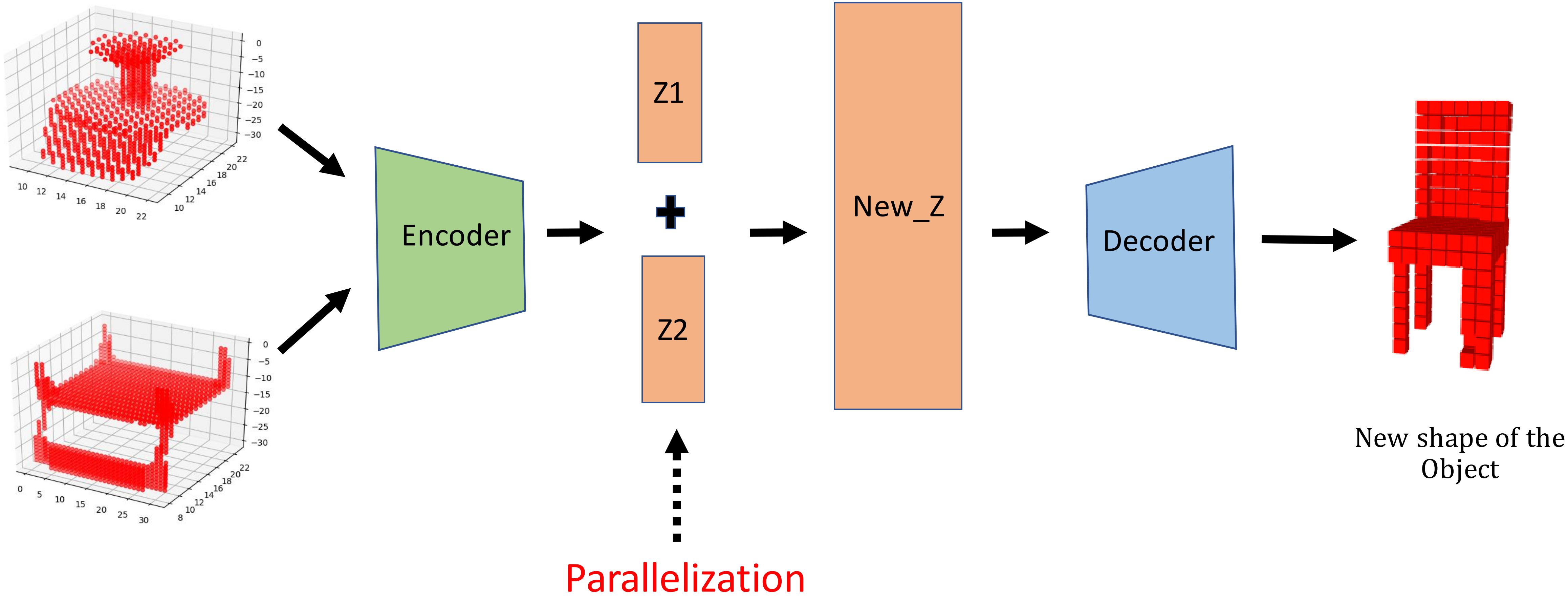
Autoencoder



Autoencoder

```
def autoencoder(inputs):
    # encoder
    # 32 x 32 x 32 x 1   -> 16 x 16 x 16 x 32
    # 16 x 16 x 16 x 32  ->  8 x 8 x 8 x 16
    # 8 x 8 x 8 x 16    ->  2 x 2 x 2 x 8
    net = lays.conv3d(inputs, 32, [5, 5, 5], stride=2, padding='SAME')
    net = lays.conv3d(net, 16, [5, 5, 5], stride=2, padding='SAME')
    net = lays.conv3d(net, 8, [5, 5, 5], stride=4, padding='SAME')

    latent_space = net


    # decoder
    # 2 x 2 x 2 x 8   ->  8 x 8 x 8 x 16
    # 8 x 8 x 8 x 16  ->  16 x 16 x 16 x 32
    # 16 x 16 x 16 x 32  ->  32 x 32 x 32 x 1
    net = lays.conv3d_transpose(net, 16, [5, 5, 5], stride=4, padding='SAME')
    net = lays.conv3d_transpose(net, 32, [5, 5, 5], stride=2, padding='SAME')
    net = lays.conv3d_transpose(net, 1, [5, 5, 5], stride=2,
padding='SAME', activation_fn=tf.nn.tanh)


    return latent_space, net
```

Interpolation in latent space



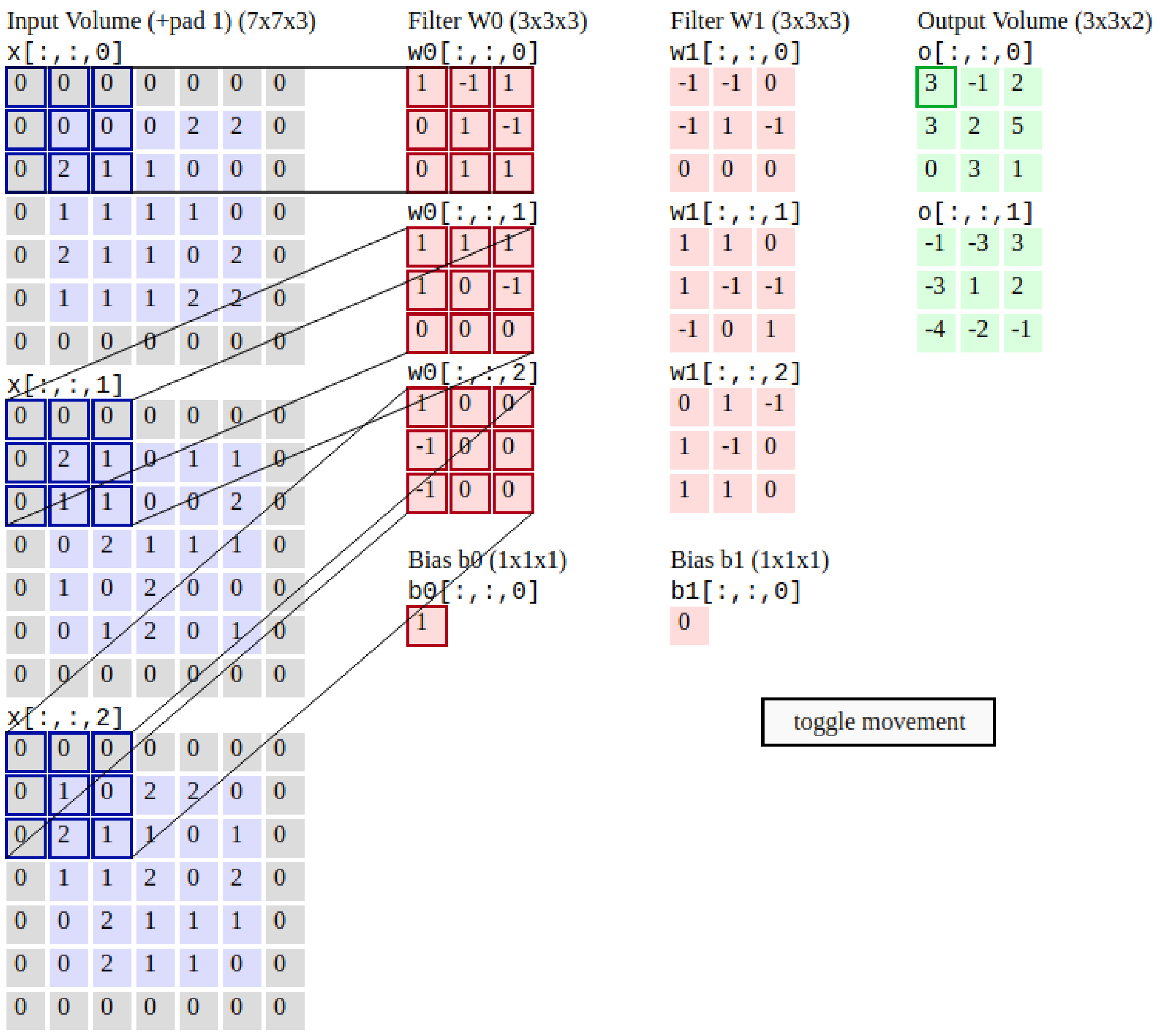
Convolutional Neural Network

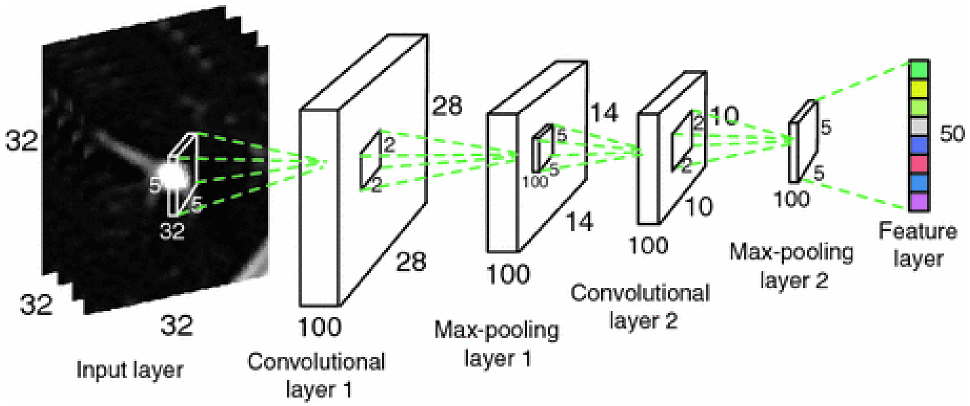
A simple Convolutional Network is a sequence of layers: **Convolutional Layer**, **Pooling Layer, Fully-Connected Layer**
for example -

[INPUT - CONV - RELU - POOL - FC]

Convolution Layer -

- Takes input with dimension [wxhxd]
- Requires number of filters, F (e.g. [3x3x3])
- Define stride, S and other hyperparameters
- Produce output volume [wxhxd] using F, S and other hyperparame





Algorithm

```
for i = first input volume
    for j = second input volume
        Z1 = z vector for i
        Z2 = z vector for j
        for t = 0 to 1
            new_z = (1-t) x Z1 + t x Z2
            run decoder network
            t = t + 0.1
```

i= all 50 rows from the input file

j= all 50 rows from the input file except i

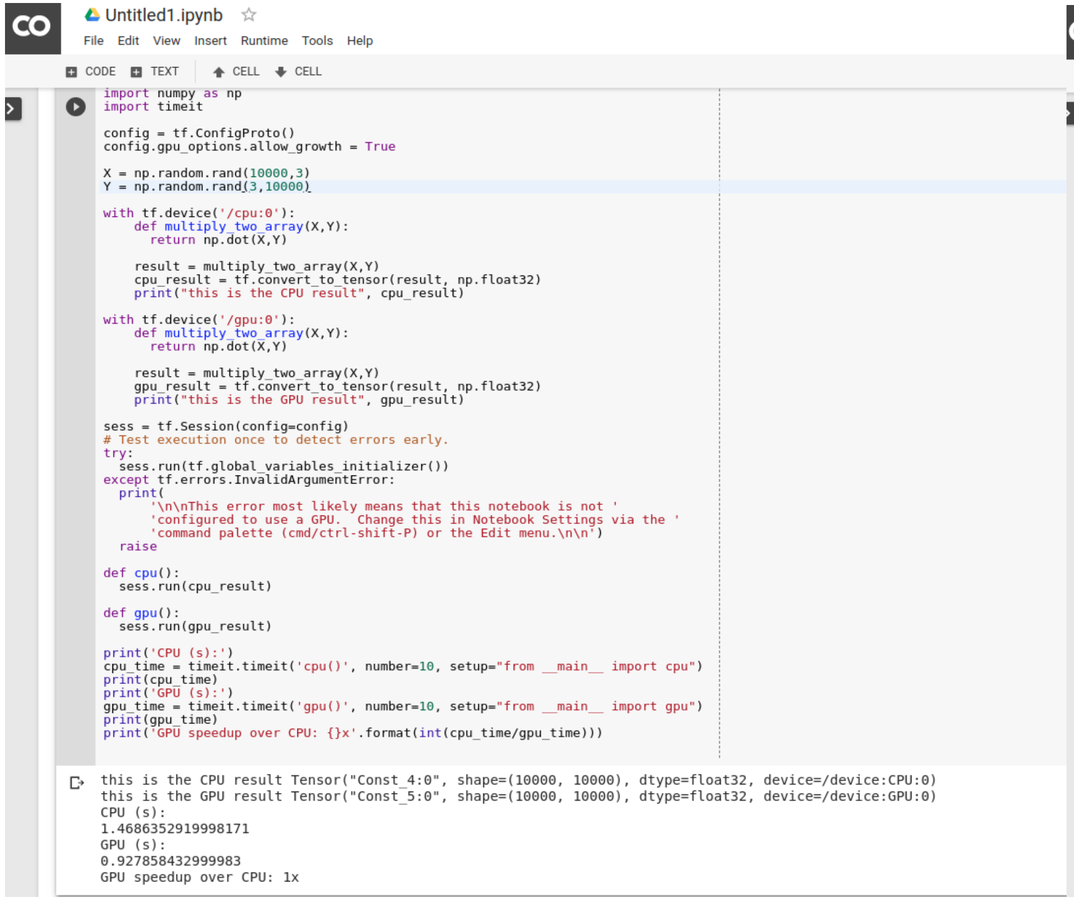
Z1 = [2 x 2 x 2 x 8] = 64
Z2 = [2 x 2 x 2 x 8] = 64

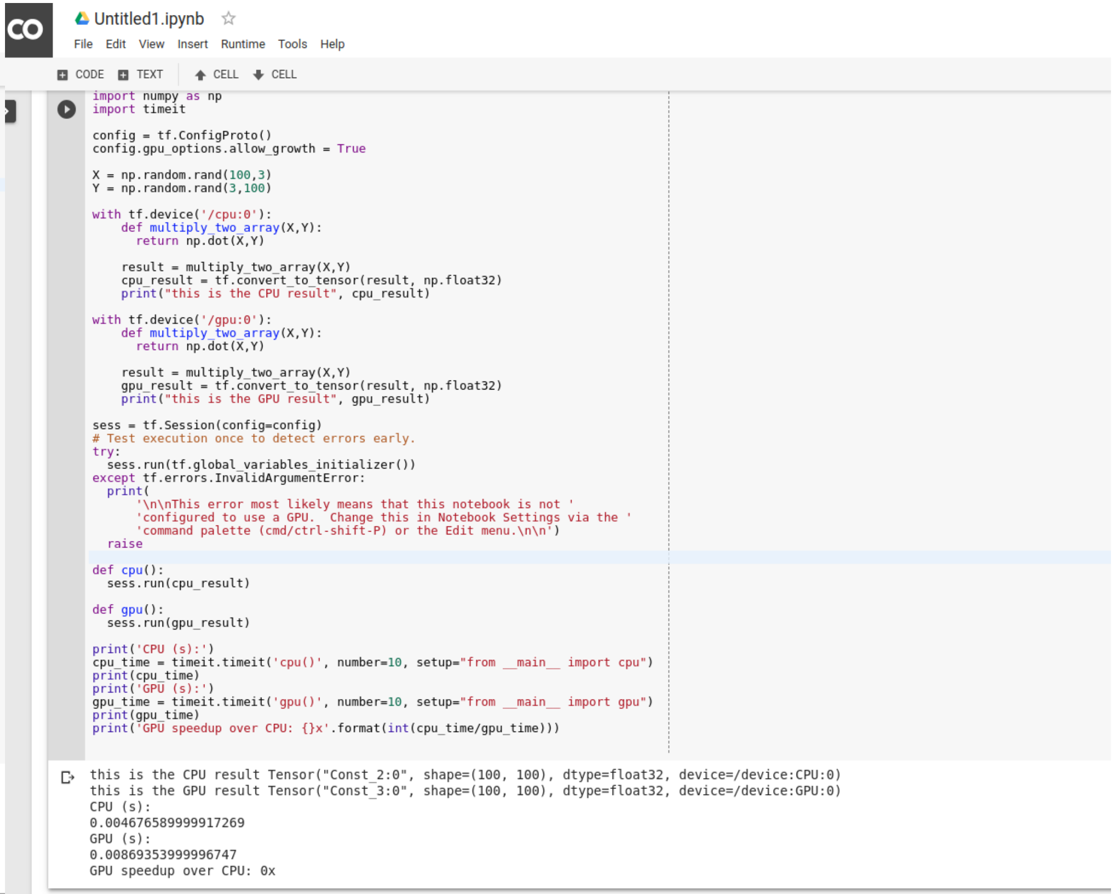
Why parallelism

- GPU utilization for heavy computation of data
- Increase performance (linear speedup)

Parallel Languages

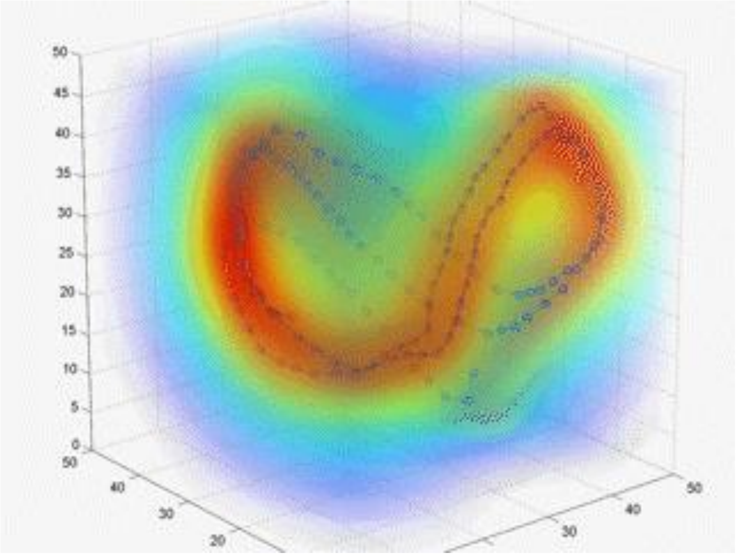
Cilk
OpenCl
MPI
CUDA





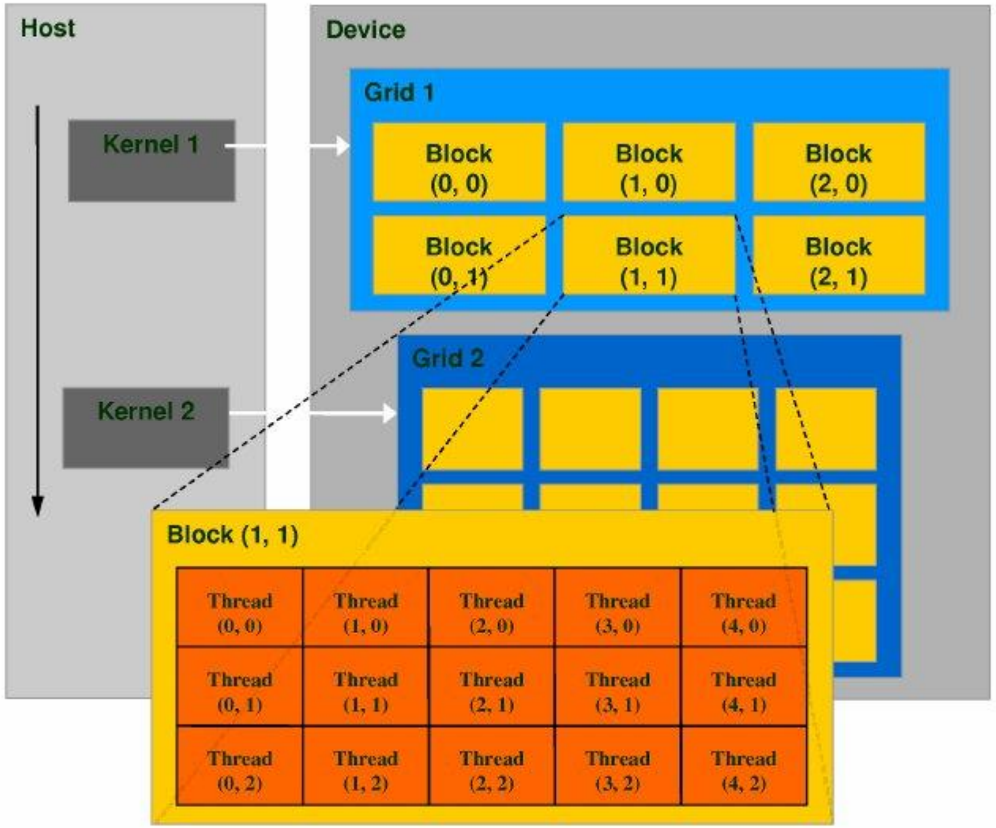
Why Parallelization inside **Z** vector

- Lower dimension but maximum features
- Can be reshape easily
- Linearly grows with input data
- Involve significant amount of time while comparing with different combination of dataset



CUDA Parallel Programming Framework

- Host
- Device
- Kernel
- Threads
- Block
- Grid



CUDA supported languages

- C
- C++
- fortran
- Python

CUDA programming
(Introduction to Numba)

- Numba supports CUDA GPU programming
- Compiles Python code into CUDA kernels and device functions following the CUDA execution model.
- Numba makes it appear that the kernel has direct access to NumPy arrays

Python decorators

```
import numpy as np
from timeit import default_timer as timer
from numba import vectorize

@vectorize(["float32(float32,float32)"], target='cuda')
def vectorAdd(a,b):
     return a + b

def main():
 N =  3200000

 A = np.ones(N, dtype = np.float32)
 B = np.ones(N, dtype = np.float32)
 C = np.zeros(N, dtype = np.float32)

 start = timer()
 C = vectorAdd(A,B)
 vectoradd_time = timer() - start

 print("C[:5] = " + str(C[:5]))
 print("C[-5:] = " + str(C[-5:]))

 print("Vector Add took %f seconds:" , vectoradd_time)


if __name__ == "__main__":
   main()
```

Numba Kernels

Kernel Declaration

```
from numba import cuda

@cuda.jit
def my_kernel(io_array):
    """
    Code for kernel.
    """
    # code here
```

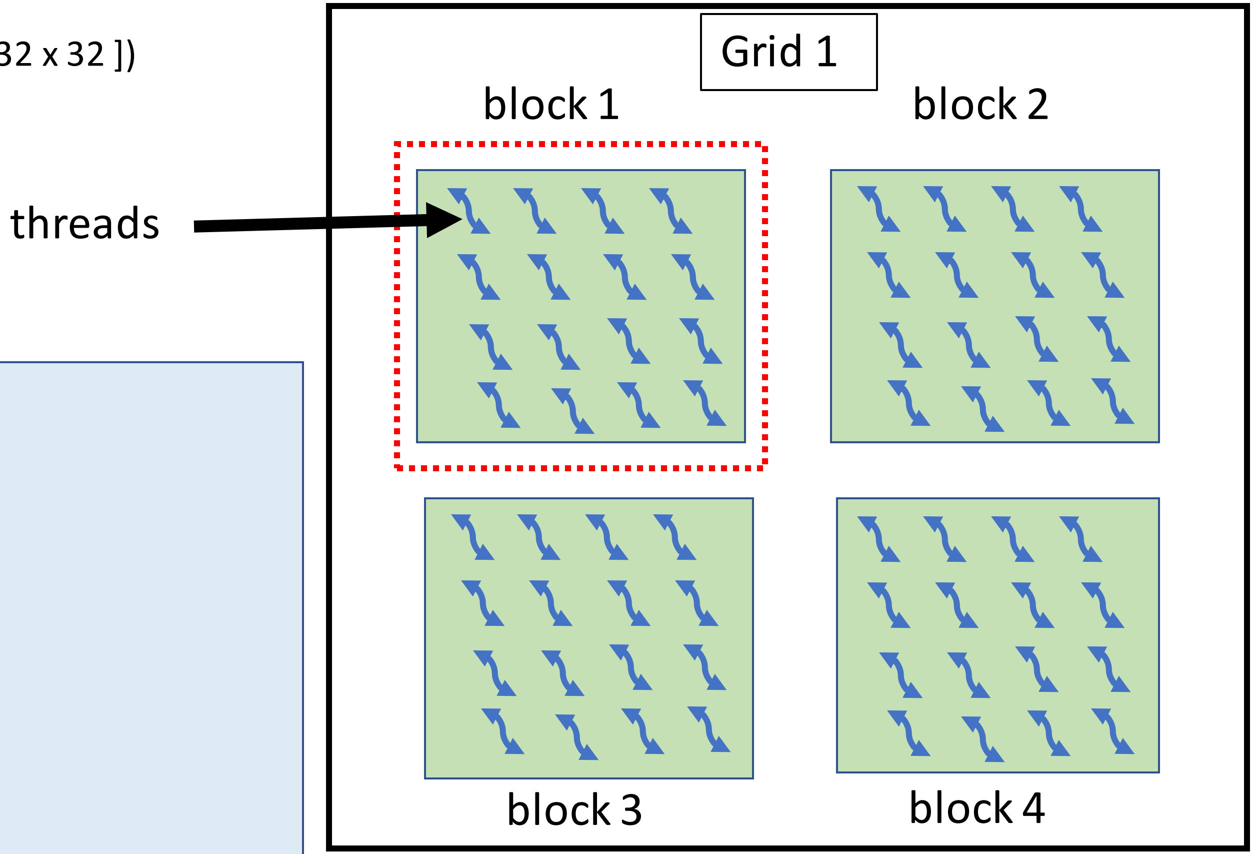
Kernel Invocation

```
import numpy

# Create the data array - usually initialized some other way
data = numpy.ones(256)

# Set the number of threads in a block
threadsperblock = 32

# Calculate the number of thread blocks in the grid
blockspergrid = (data.size + (threadsperblock - 1)) // threadsperblock

# Now start the kernel
my_kernel[blockspergrid, threadsperblock](data)

# Print the result
print(data)
```

Project Implementation

- Dataset -- > 50 shapes of chair (each with dimension [32 x 32 x 32])
- Epoch = 5
- Z vector = [2x2x2x8] -> reshape into [8, 8]
- Thread = [4 , 4]
- Blocks = [2, 2]

```
    TPB = 4
    l_space1 = np.reshape(l_space1,(8,8))
    l_space2 = np.reshape(l_space2,(8,8))
    print("lspace 1", l_space1)
    print("lspace 2", l_space2)
    dA = cuda.to_device(l_space1)
    dB = cuda.to_device(l_space2)
    c = np.empty_like(l_space2)
    dC = cuda.to_device(c)

    start = timer()
    threadsperblock = (TPB, TPB)

    blockspergrid_x = int(math.ceil(l_space1.shape[0] / threadsperblock[0]))
    blockspergrid_y = int(math.ceil(l_space2.shape[1] / threadsperblock[1]))
    blockspergrid = (blockspergrid_x, blockspergrid_y)
    for t in range(0, 100):
        interpolationBetnLatentSpace[blockspergrid, threadsperblock](dA, dB,
dC, t)
```



Implemented CUDA architecture for the project

Threads Index Calculation

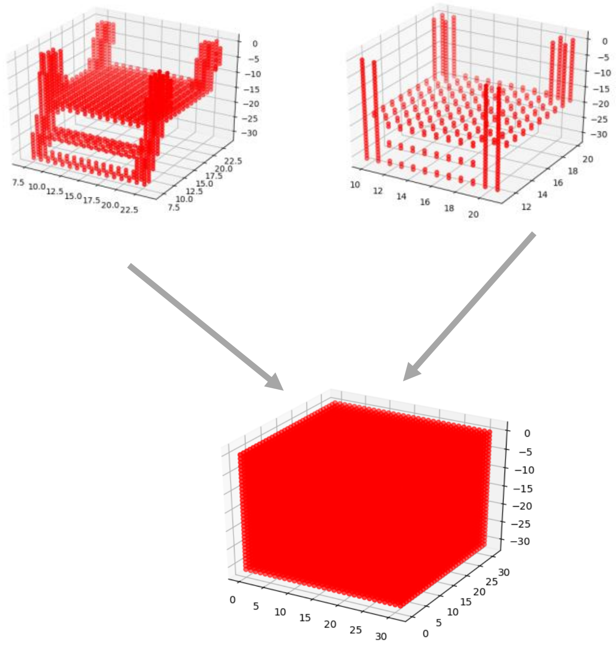
```
@numba.cuda.jit
def interpolationBetnLatentSpace(A,B,C,t):
    tx = cuda.threadIdx.x
    ty = cuda.threadIdx.y
    bx = cuda.blockIdx.x
    by = cuda.blockIdx.y
    bw = cuda.blockDim.x
    bh = cuda.blockDim.y
    row = tx + bx * bw
    col = ty + by * bh

    if row < C.shape[0] and col < C.shape[1]:
        for k in range(A.shape[1]):
            tmp = (1-t) * A[row, k] + t * 
B[row, k]
            C[row, k] = tmp
```

Global memory

```
@numba.cuda.jit
def interpolationBetnLatentSpace(A,B,C,t):
    sA = cuda.shared.array(shape=(8, 8), 
dtype=float32)
    sB = cuda.shared.array(shape=(8, 8), 
dtype=float32)
    x, y = cuda.grid(2)
    tx = cuda.threadIdx.x
    ty = cuda.threadIdx.y
    if x < C.shape[0] and y < C.shape[1]:
        tmp = 0
        for i in range(int(A.shape[1] / TPB)):
            # Preload data into shared memory
            sA[tx, ty] = A[x, ty + i * TPB]
            sB[tx, ty] = B[tx + i * TPB, y]
            cuda.syncthreads()
            for k in range(8):
                tmp = (1-t) * A[tx, k] + t * B[tx, k]
                cuda.syncthreads()
                C[tx, k] = tmp
```

Shared memory

Results



Output volume after interpolation

CPU vs GPU analysis

For 5 epochs :

Total time CPU = 37.15s

Vector Add time CPU = 0.0017s

Time taken by CNN layers = 11s

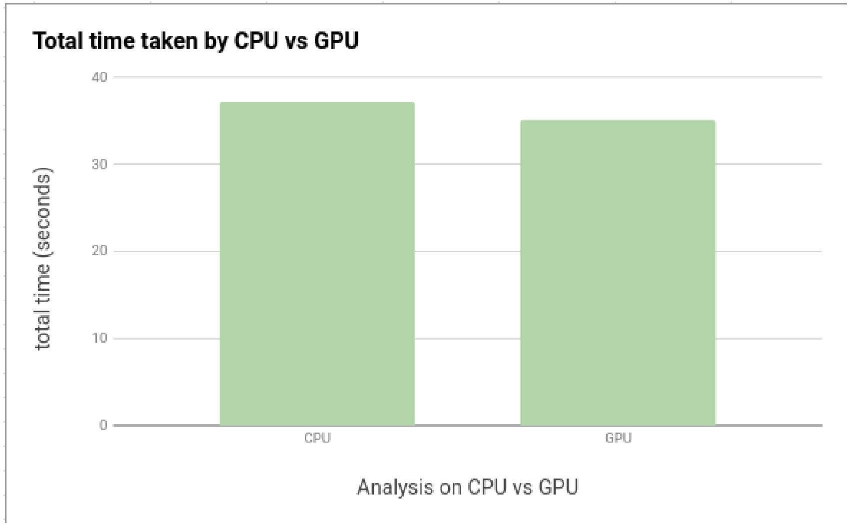
Total time GPU = 35.04s

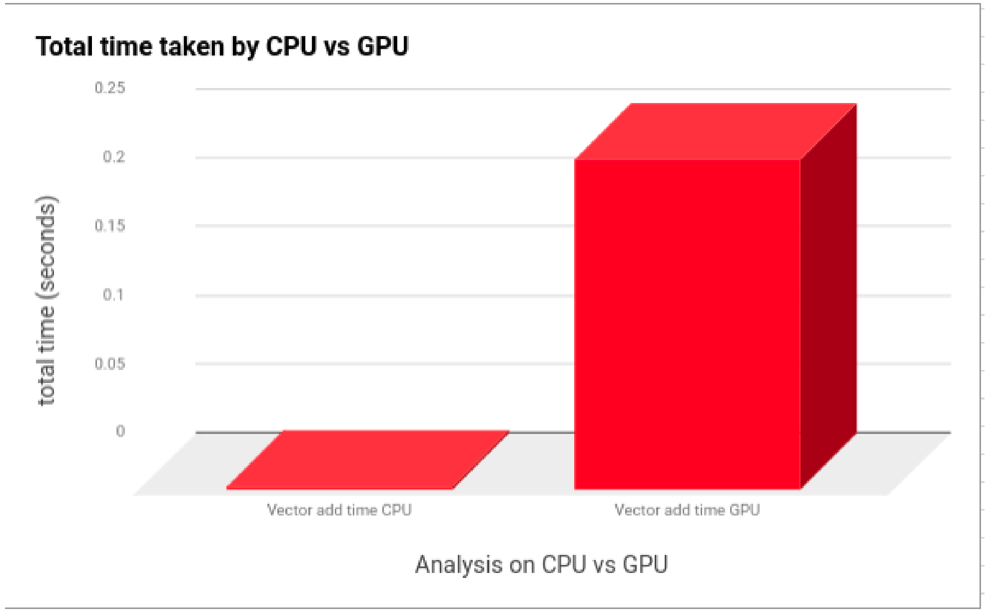
Vector Add time GPU (global memory) = 0.24s

Vector Add time GPU (shared memory) = 0.37s

Time taken by CNN layers = 11s

GPU speedup over CPU = 37.15 / 35.04 seconds = 1.06 seconds





Limitation

1. For one pair comparison of volumes, CPU performs better than GPU
2. Very low dimension of Z could effect GPU performance
3. Running threads in shared memory of GPU is taking 1.5x more than global memory

Challenges

1. As a dynamic type system, explicit memory allocation in Python is not possible
2. Less example and documentation of Python-CUDA compared to CUDA-C or CUDA-C++
3. Inside Kernel function, debugging is not available

Questions

1. What is Linear Interpolation ?

2. How does Numba work ?

3. Considering the results, does increasing the dimension of Z vectors or volumes of input shape would increase the GPU performance ?