Deep Learning Topics: Special Connections, Encoder-Decoders, Transformers

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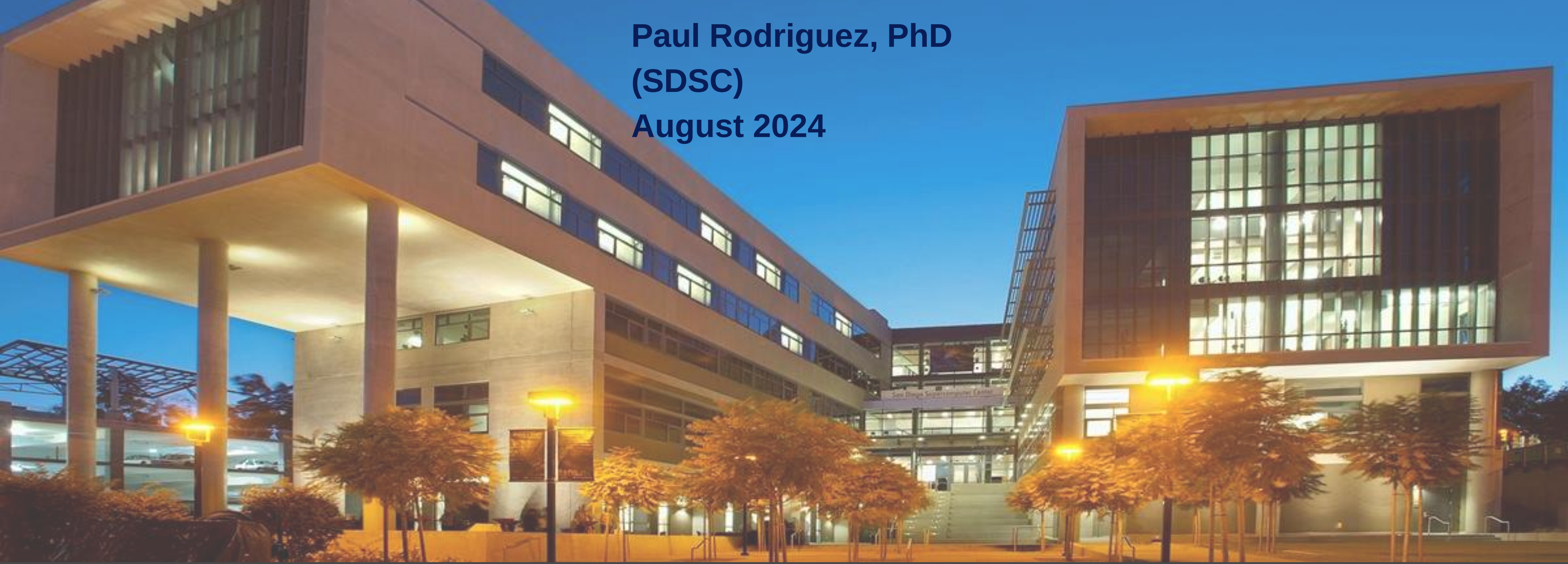


Outline

- Part I

Gate connection idea

Skip and Residual connections

Programing connections and Keras Model API

Encoder-Decoder (Autoencoder)

Exercise MNIST Autoencoder

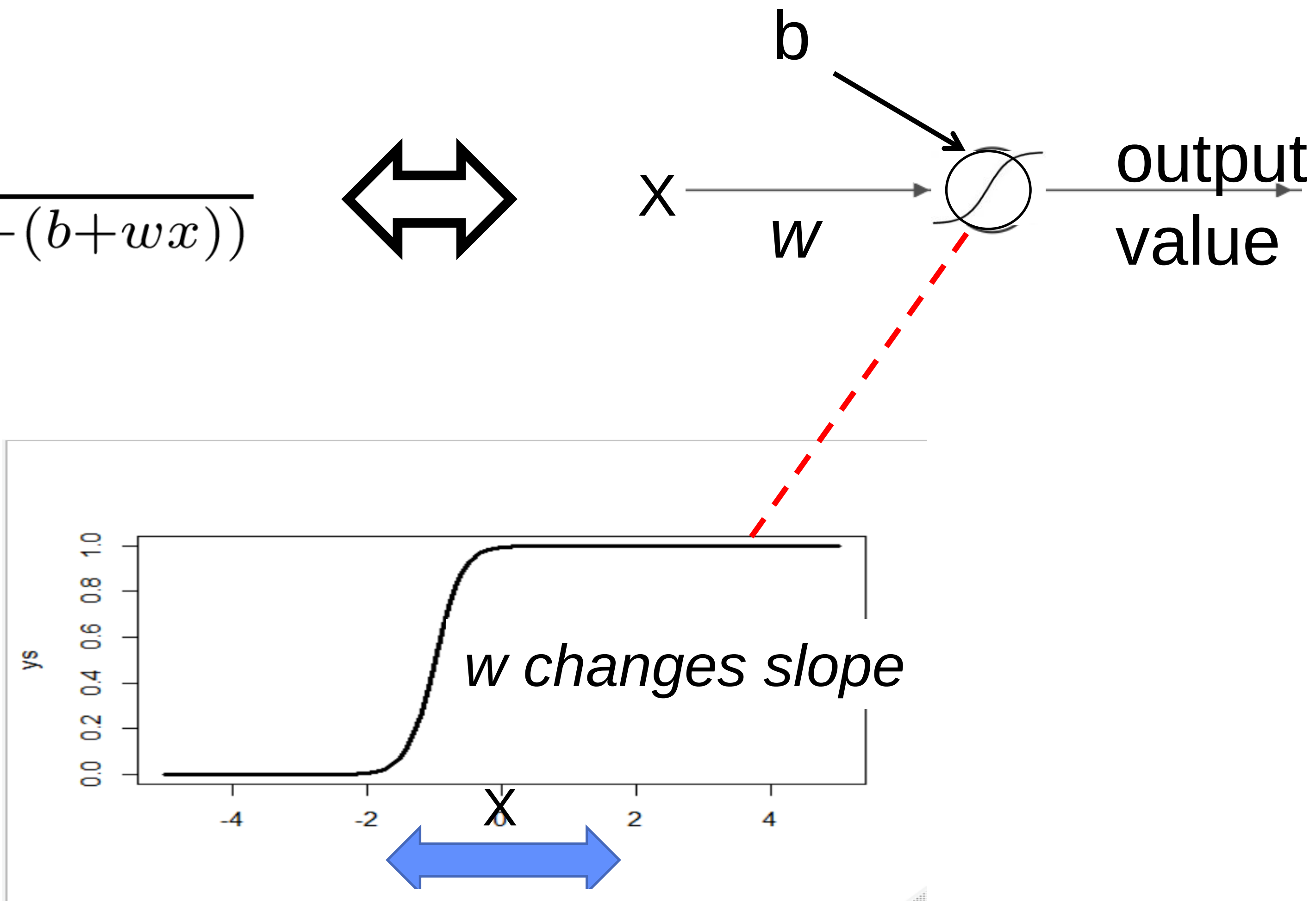
Autoencoder with Stable Diffusion

- Part II

Attention Head and Transformers

Recall: the logistic unit

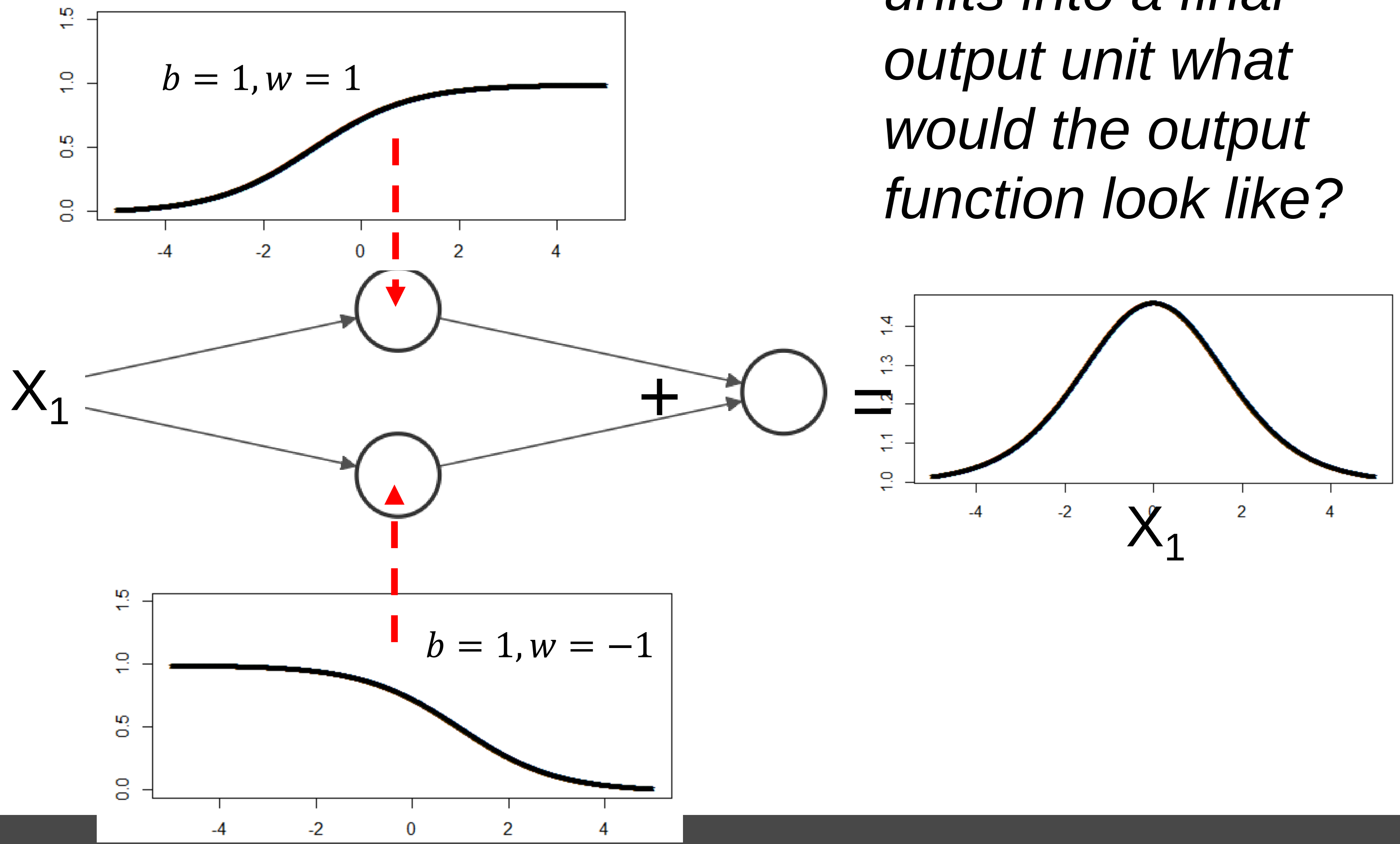
$$f(x) = \frac{1}{1 + exp^{(-(b+wx))}}$$



b shifts function

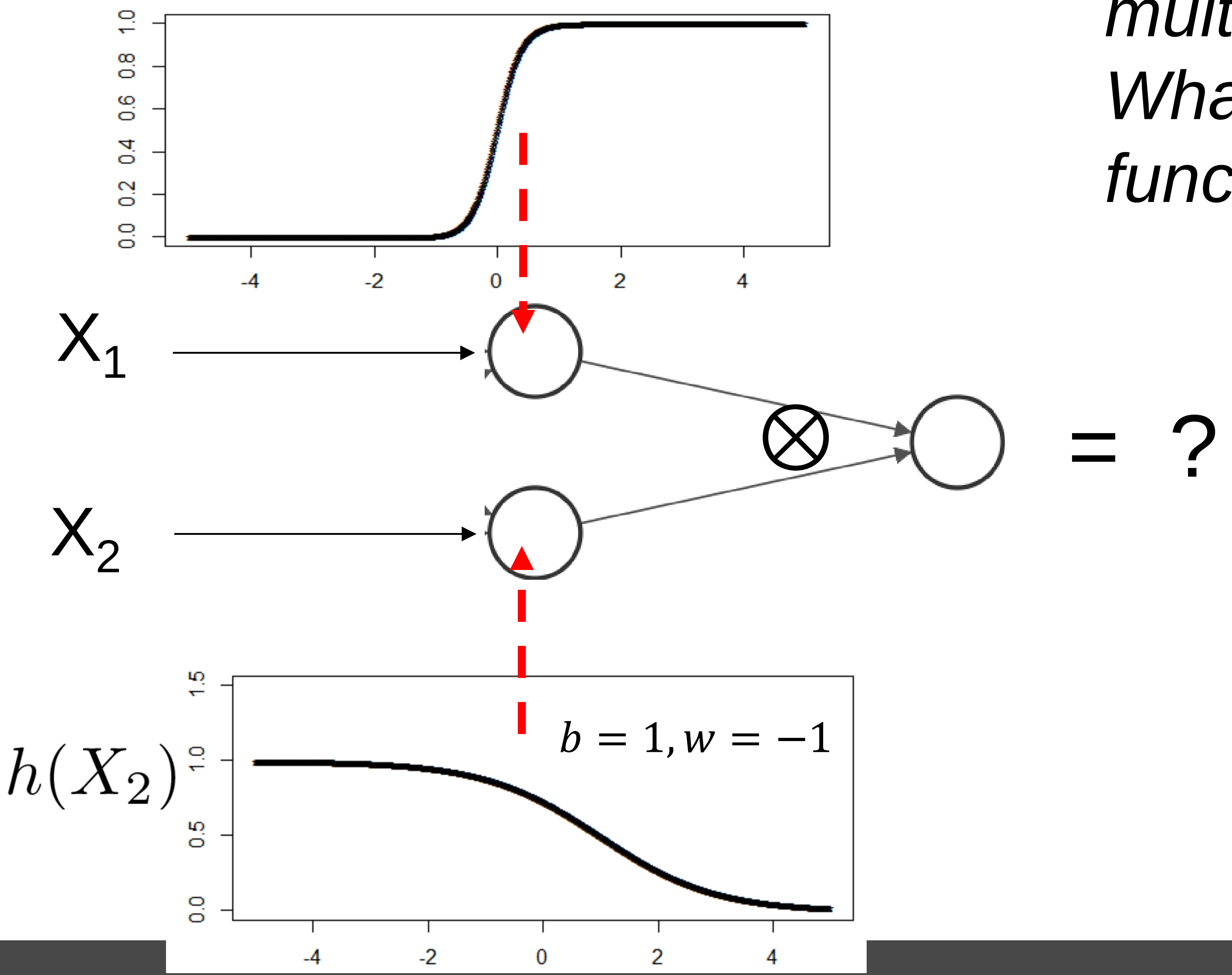
Example: 1 input into 2 logistic units with these activations

If you add these 2 units into a final output unit what would the output function look like?



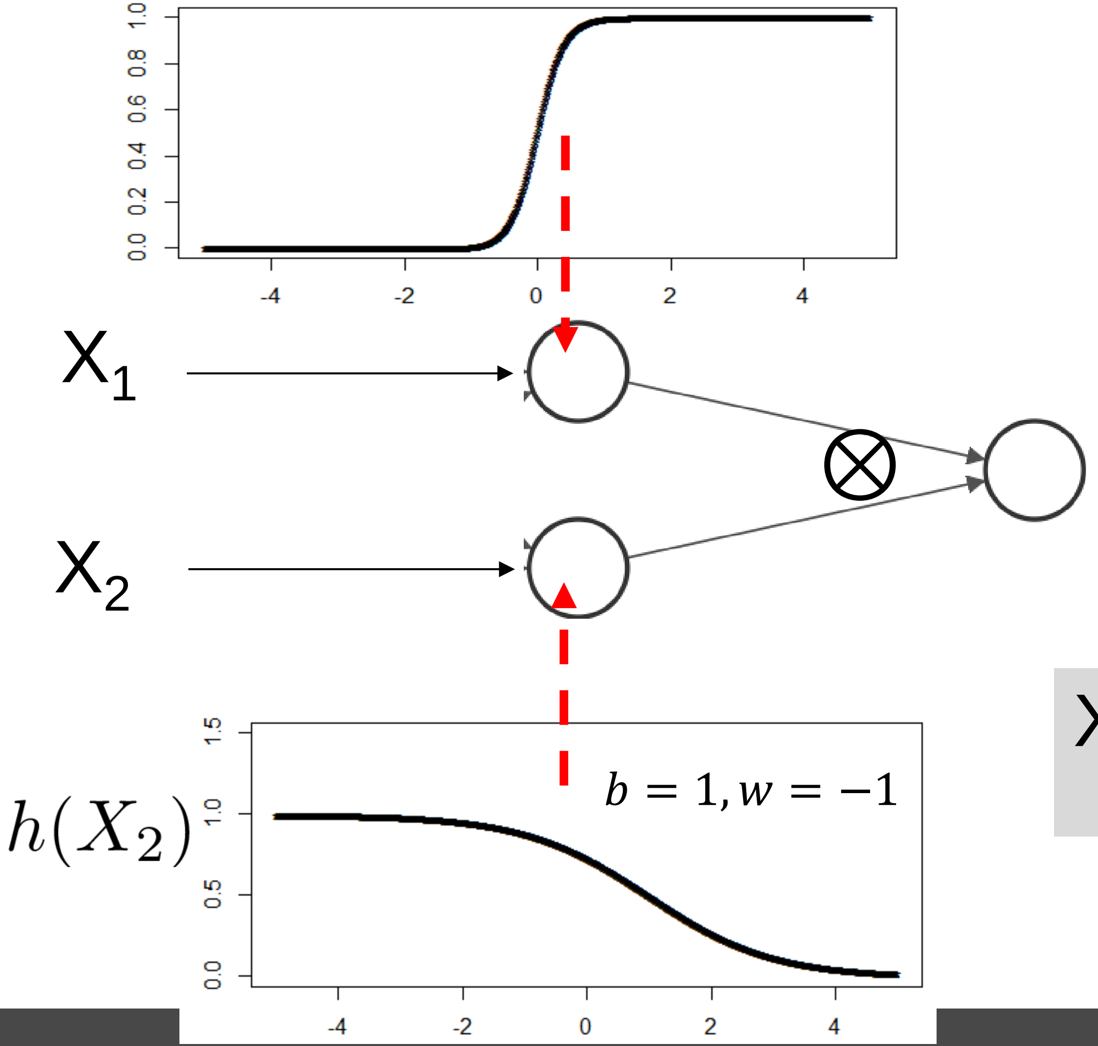
Example: 2 input into 2 logistic units with these activations

What if you multiply these? What is the output function doing?



Example: 2 input into 2 logistic units with these activations

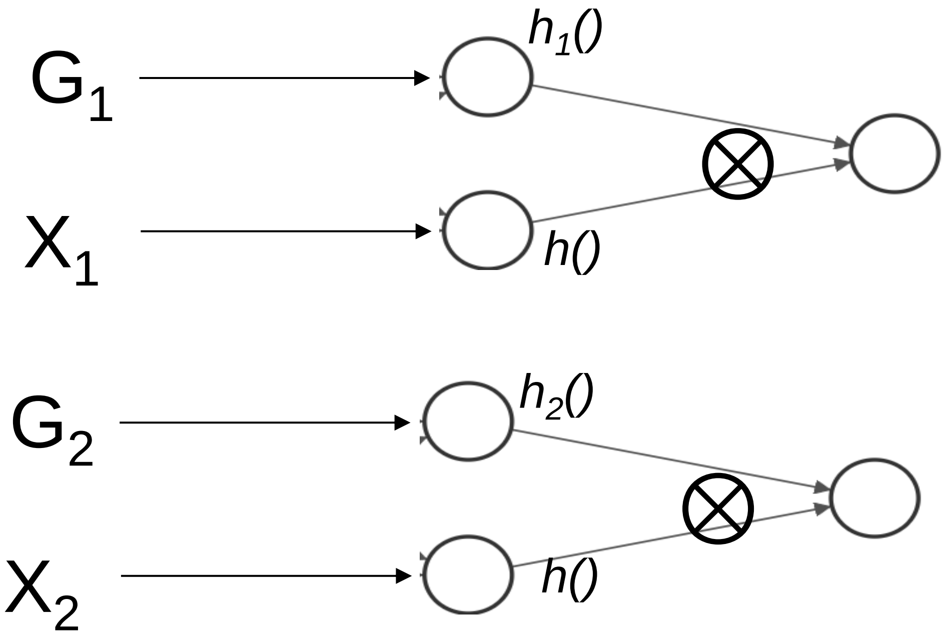
What if you multiply these?
For linear activation, what is the output function doing ?



$$= \begin{cases} 0 & \text{if } X_1 < 0 \\ h(X_2) & \text{if } X_1 > 0 \end{cases}$$

X_1 "gates" X_2 activation

Example: 2 pairs of gates together

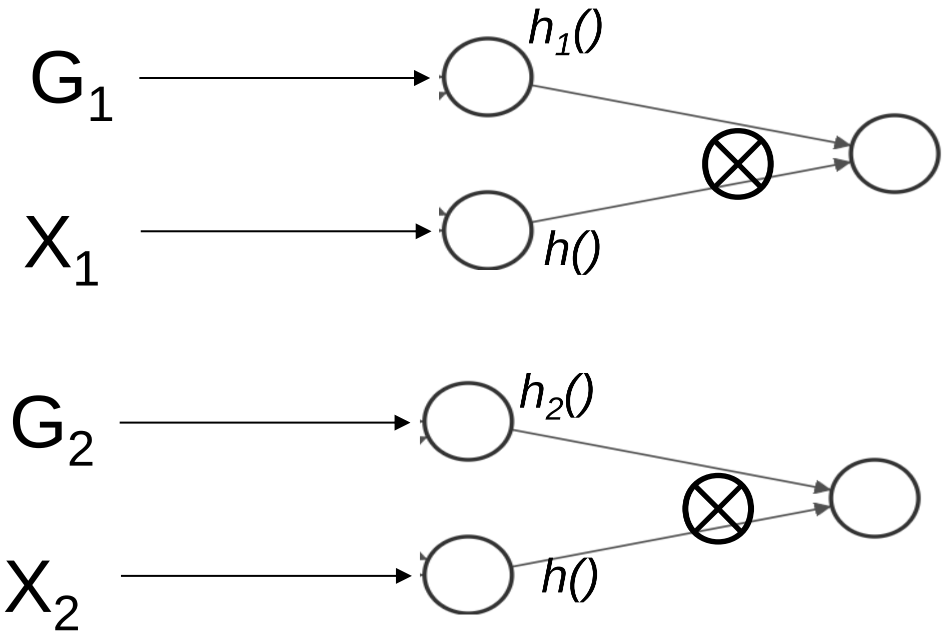


$$= h_1(G_1) * h(X_1)$$

$$= h_2(G_2) * h(X_2)$$

Let $h_1()$ *be* logistic function to be learned.

Example: 2 pairs of gates together



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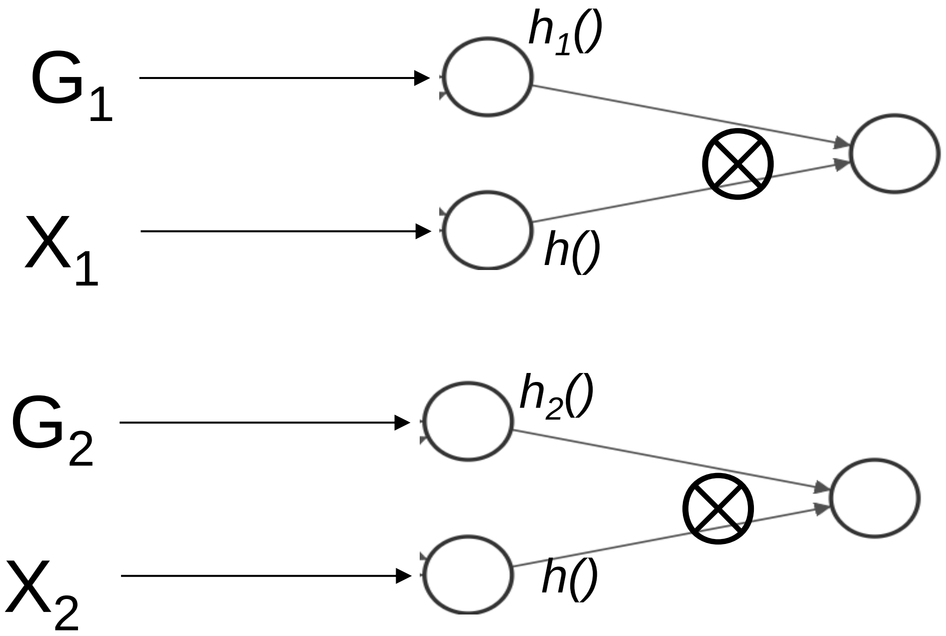
If we set $h_2(G_2) = (1 - h_1(G_1))$

then output is probabilistically weighted.

Example: 2 pairs of gates together



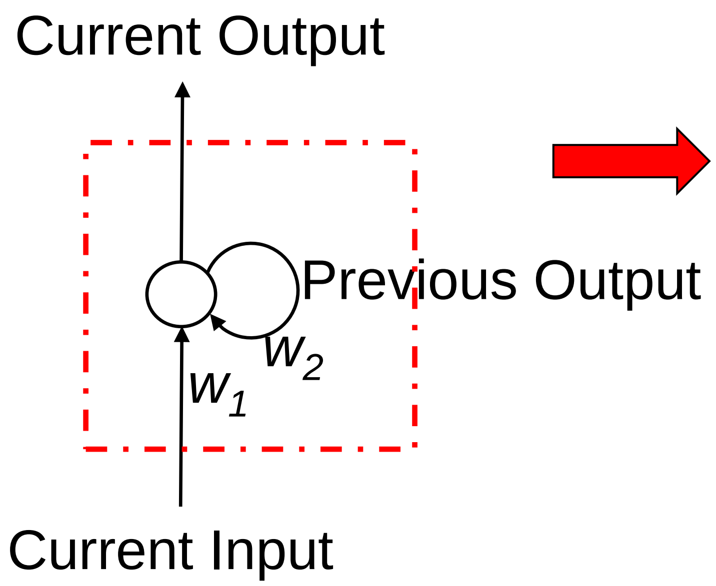
$= h_1(G_1) * h(X_1)$

$= h_2(G_2) * h(X_2)$

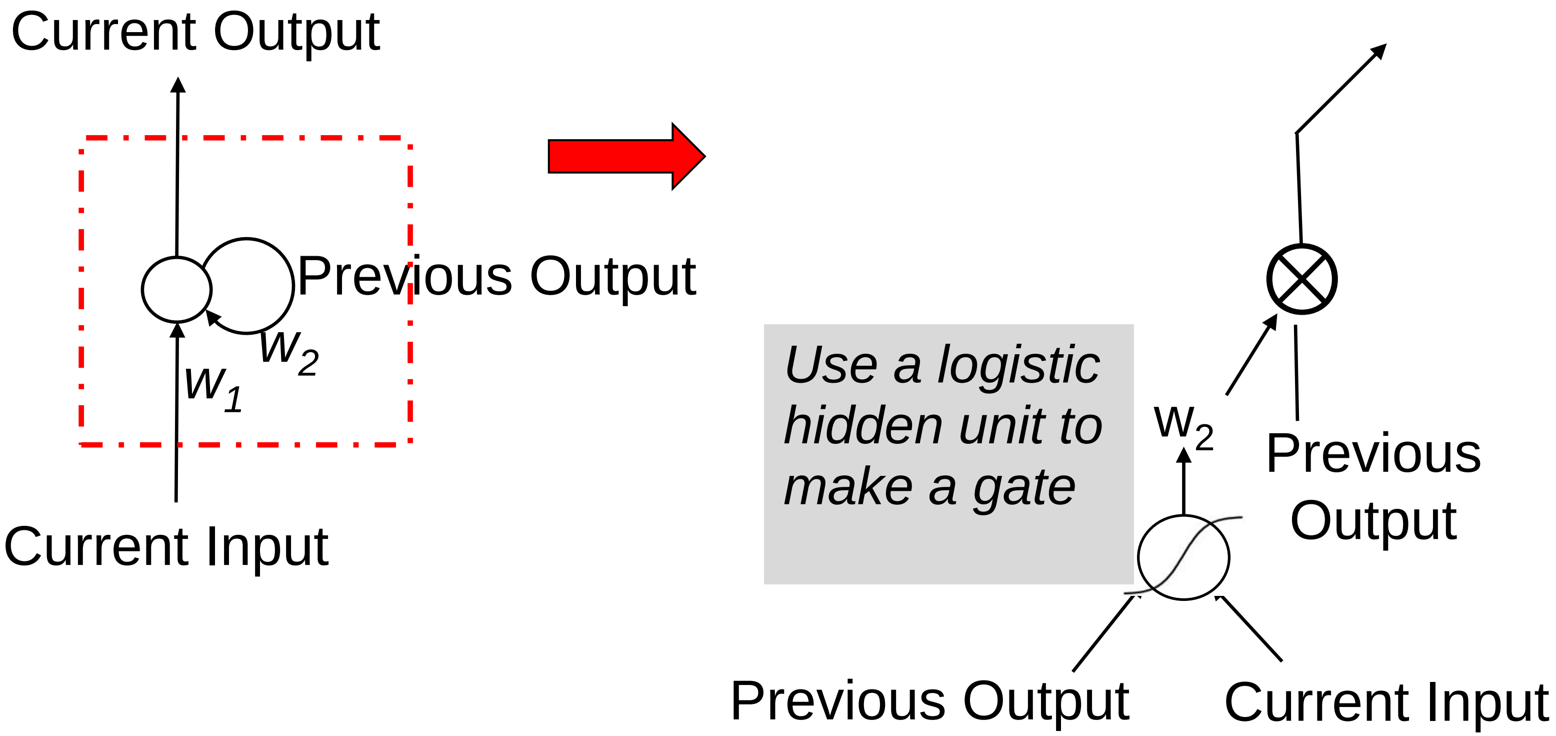
Let $h_1()$ *be* logistic function to be learned.
If we set $h_2(G_2)=(1 - h_1(G_1))$
then output is probabilistically weighted.

Q: Where should the G_1 value come from?

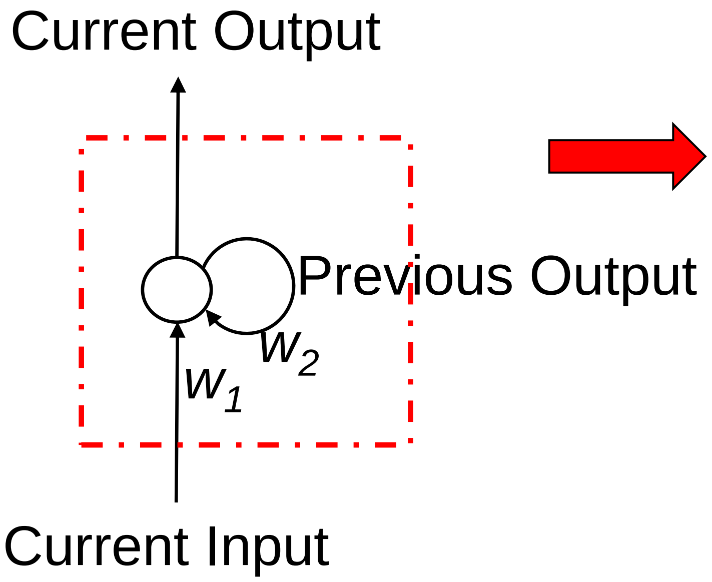
A recurrent unit for sequence learning can be replaced by a gated unit

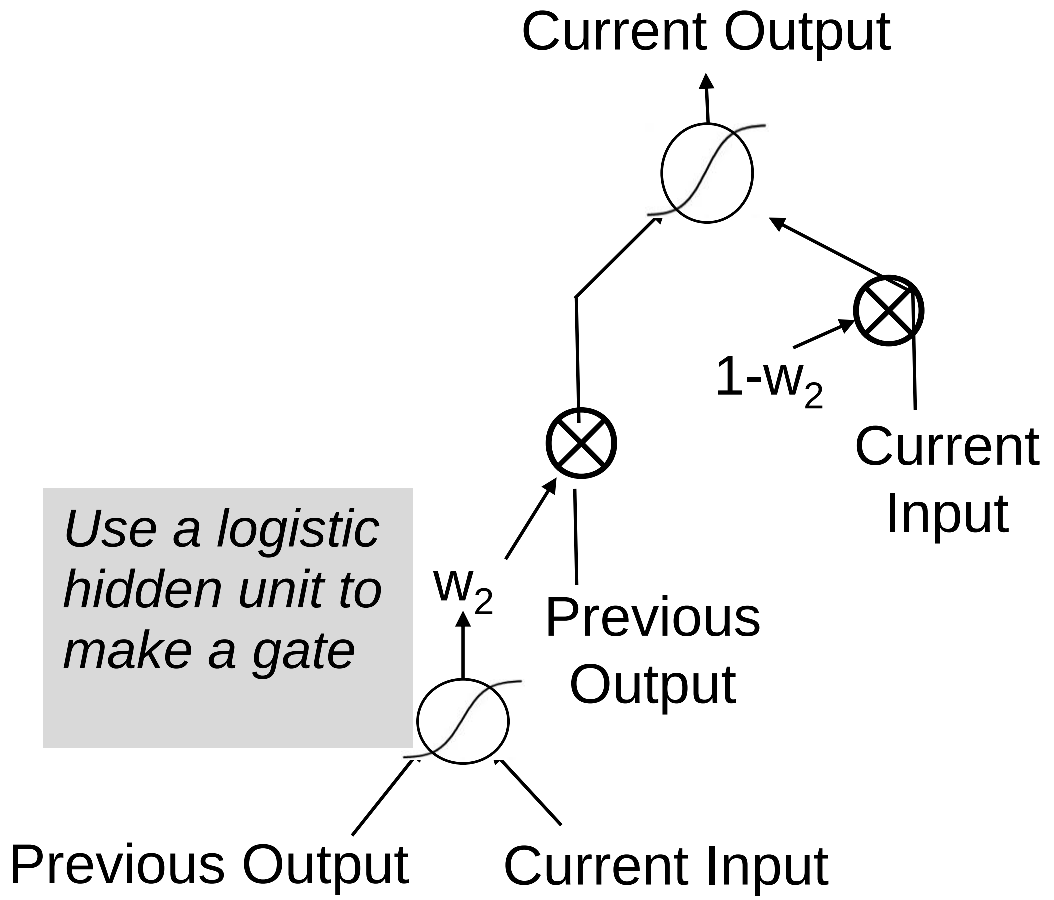


A recurrent unit for sequence learning can be replaced by a gated unit



A recurrent unit for sequence learning can be replaced by a gated unit



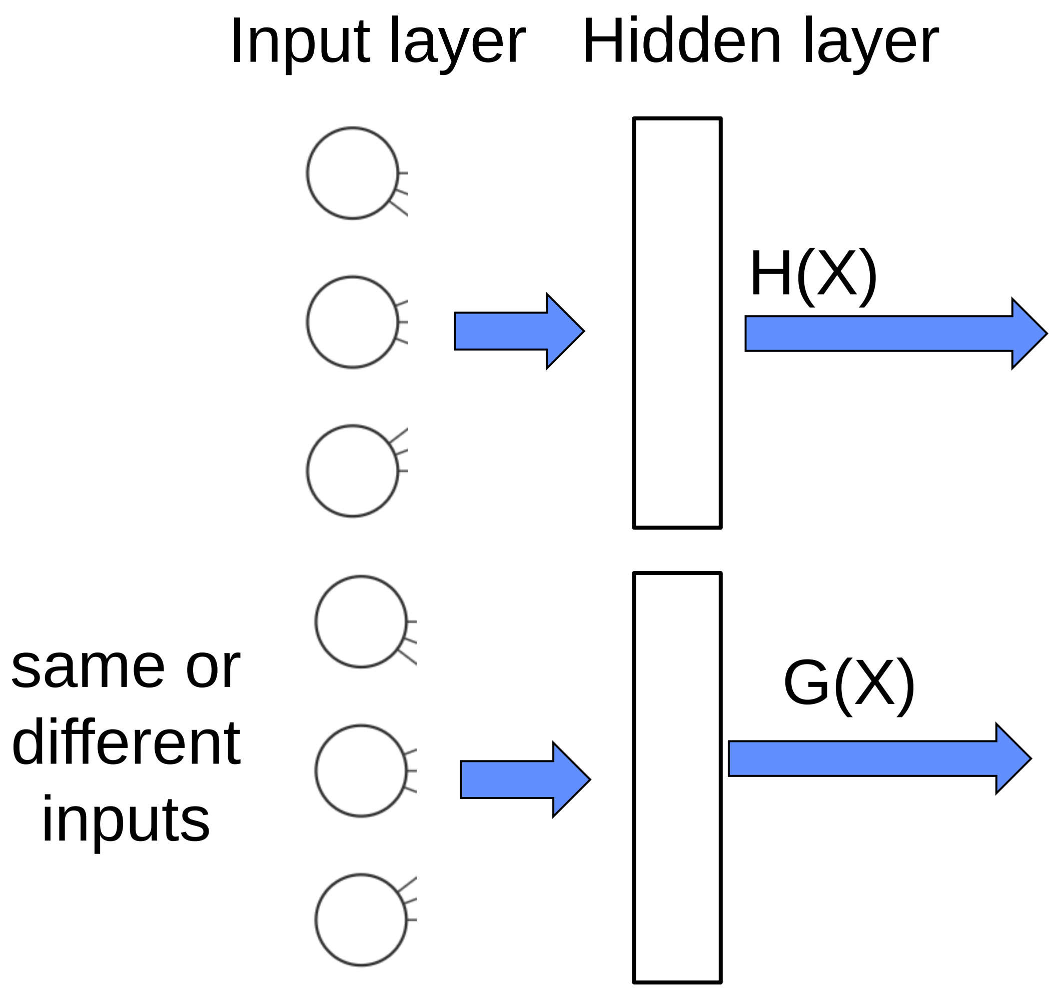


Use the gate to either keep previous output or update it with current input

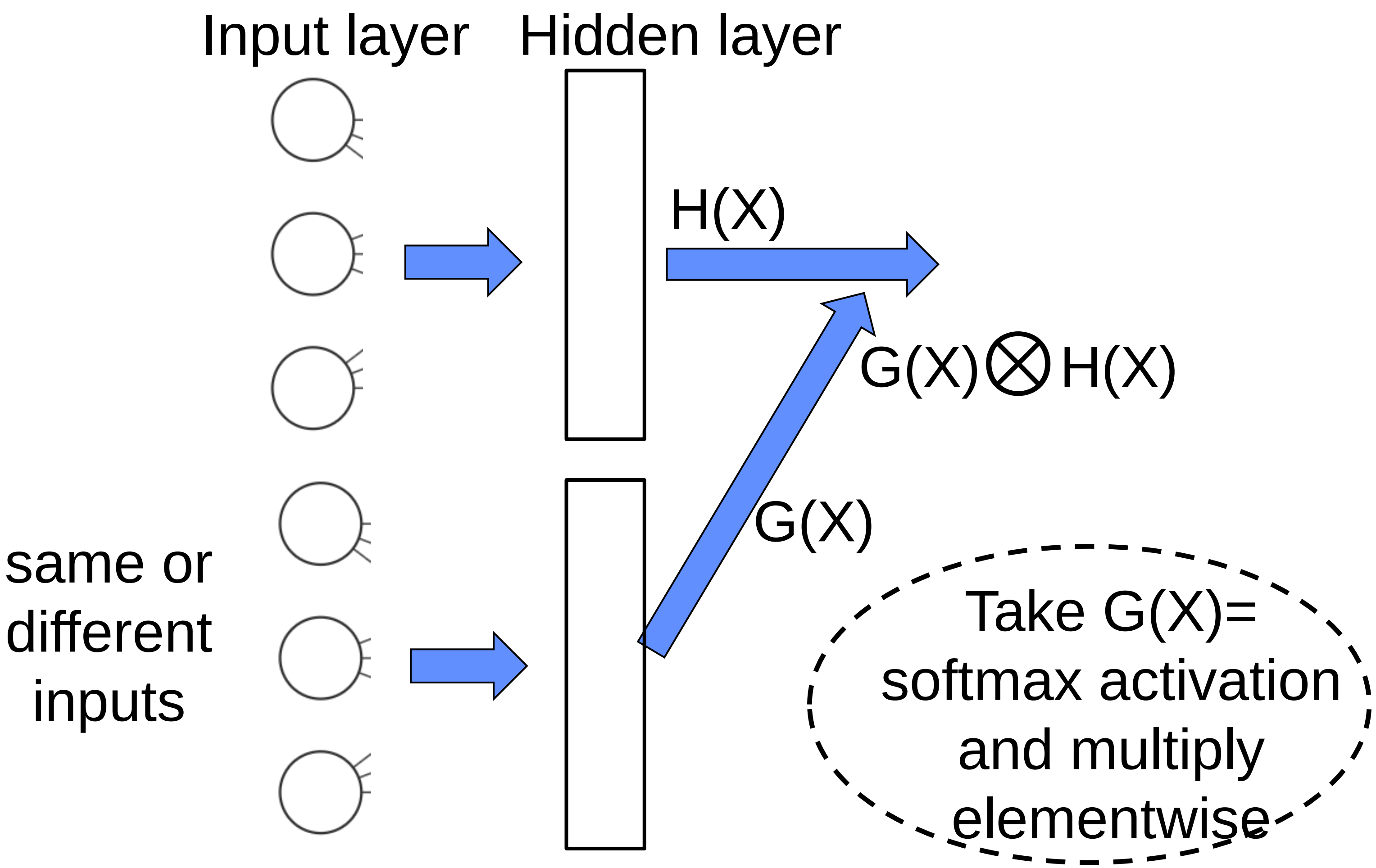
Use a logistic hidden unit to make a gate

'Gated Recurrent Unit'
Cho, Bengio 2015

Redrawing the gate for sets of hidden units



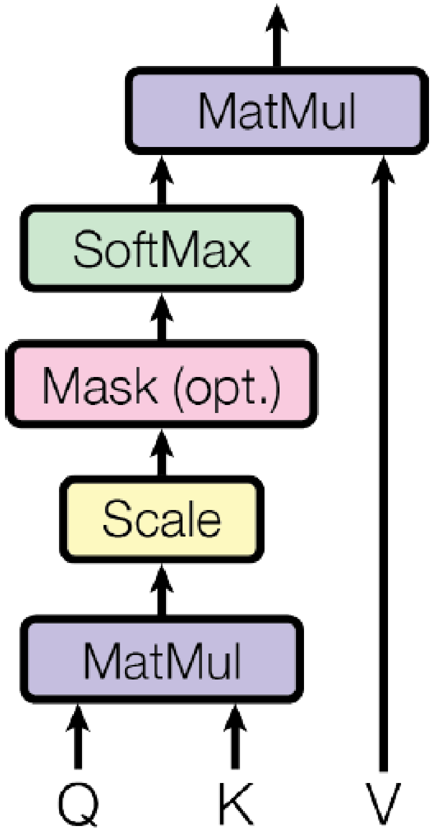
Use softmax for G(X) to get gating weights



Recall: softmax normalizes outputs into probability weights

Scaled Dot-Product Attention
(very rough summary)

"Attention" mechanism in language transformers use a softmax gate

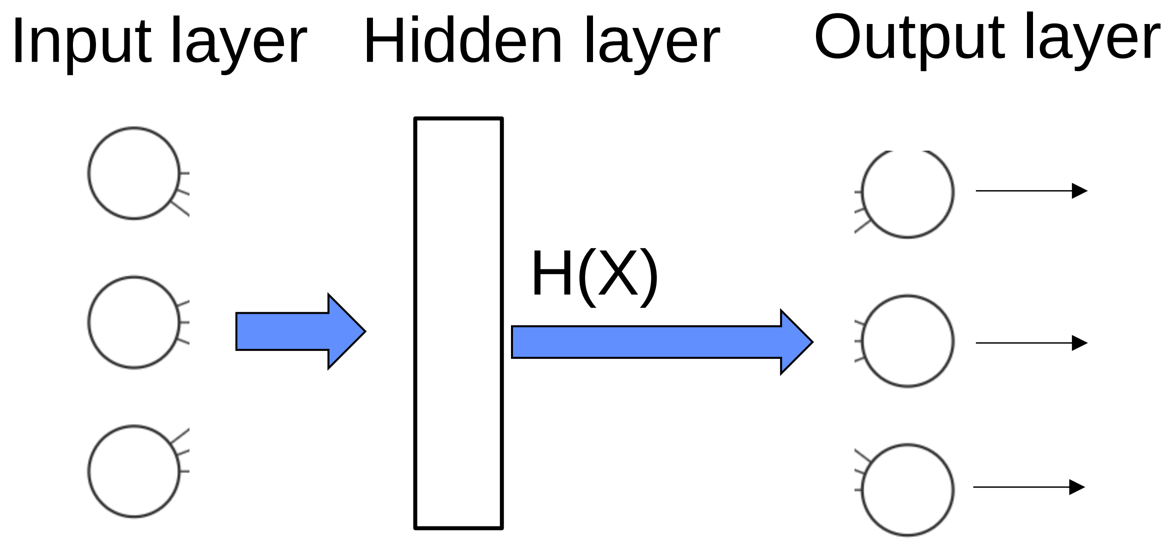


input

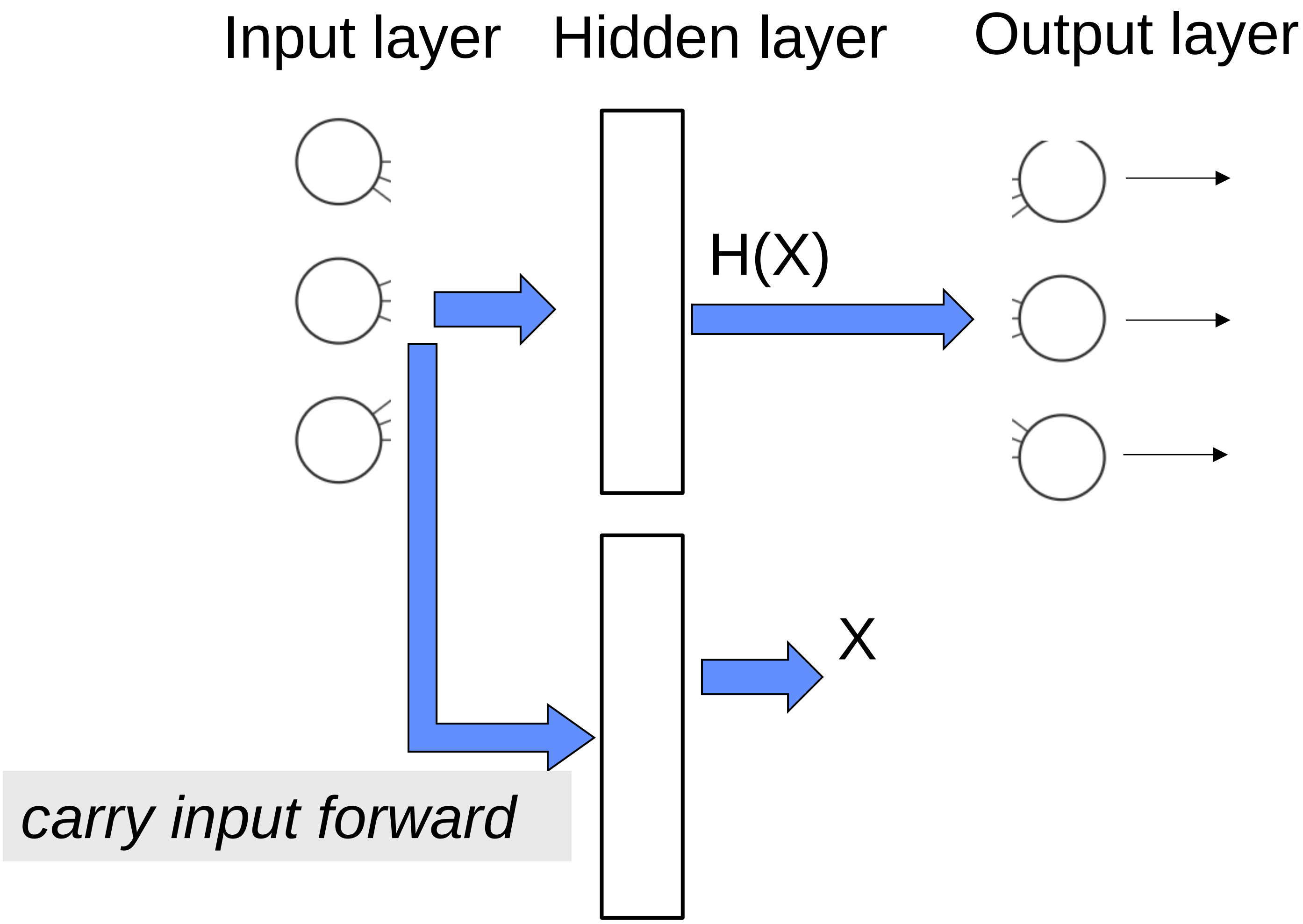
The gate is applied to possible Values (V) for decoding

Vaswani, et al. 2017
Attention Is All You Need (for Transformers)

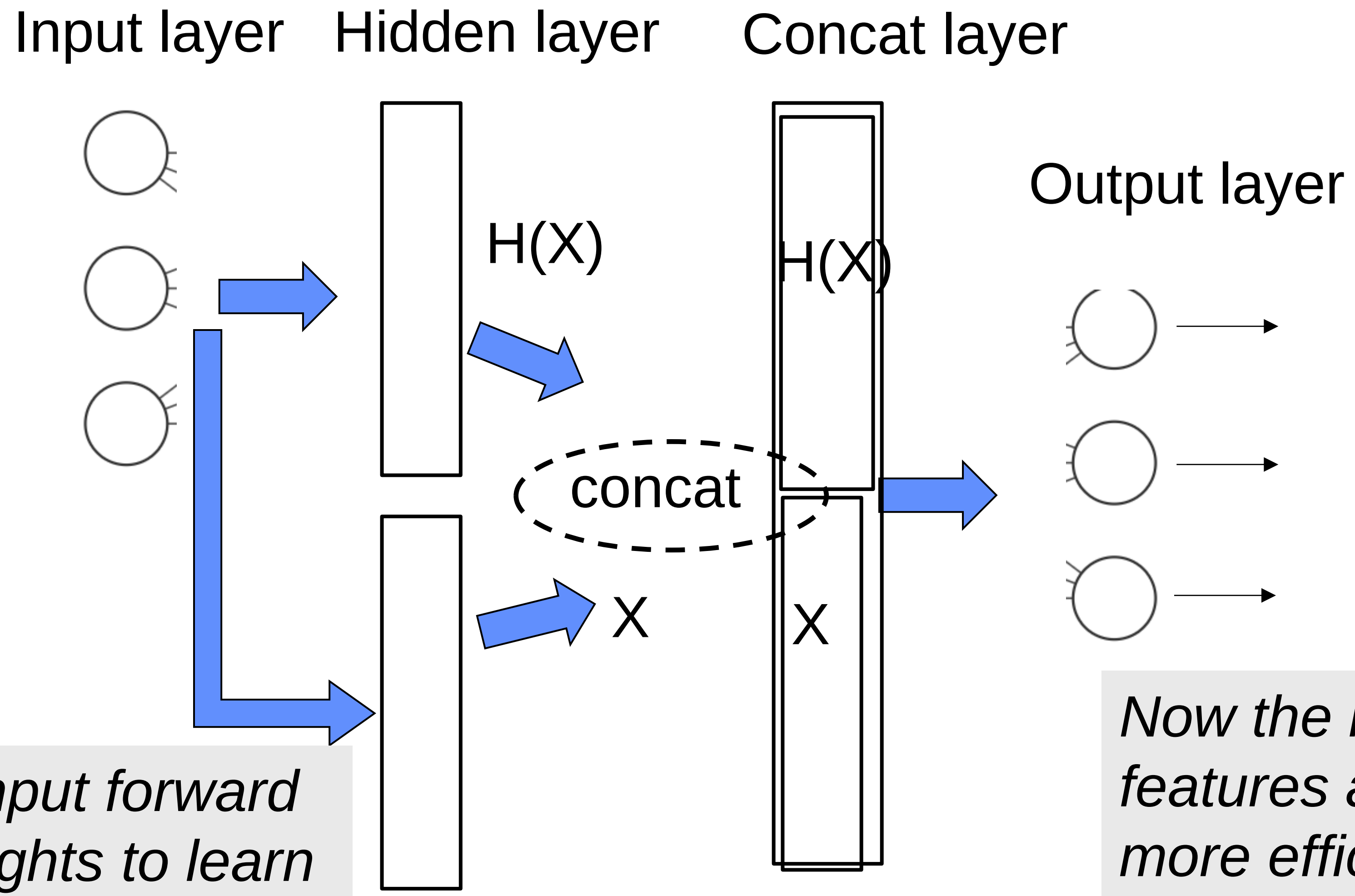
Skip Connections:
Recall the Multilayer Perceptron (MLP)



To help the MLP learn directly from input carry input forward



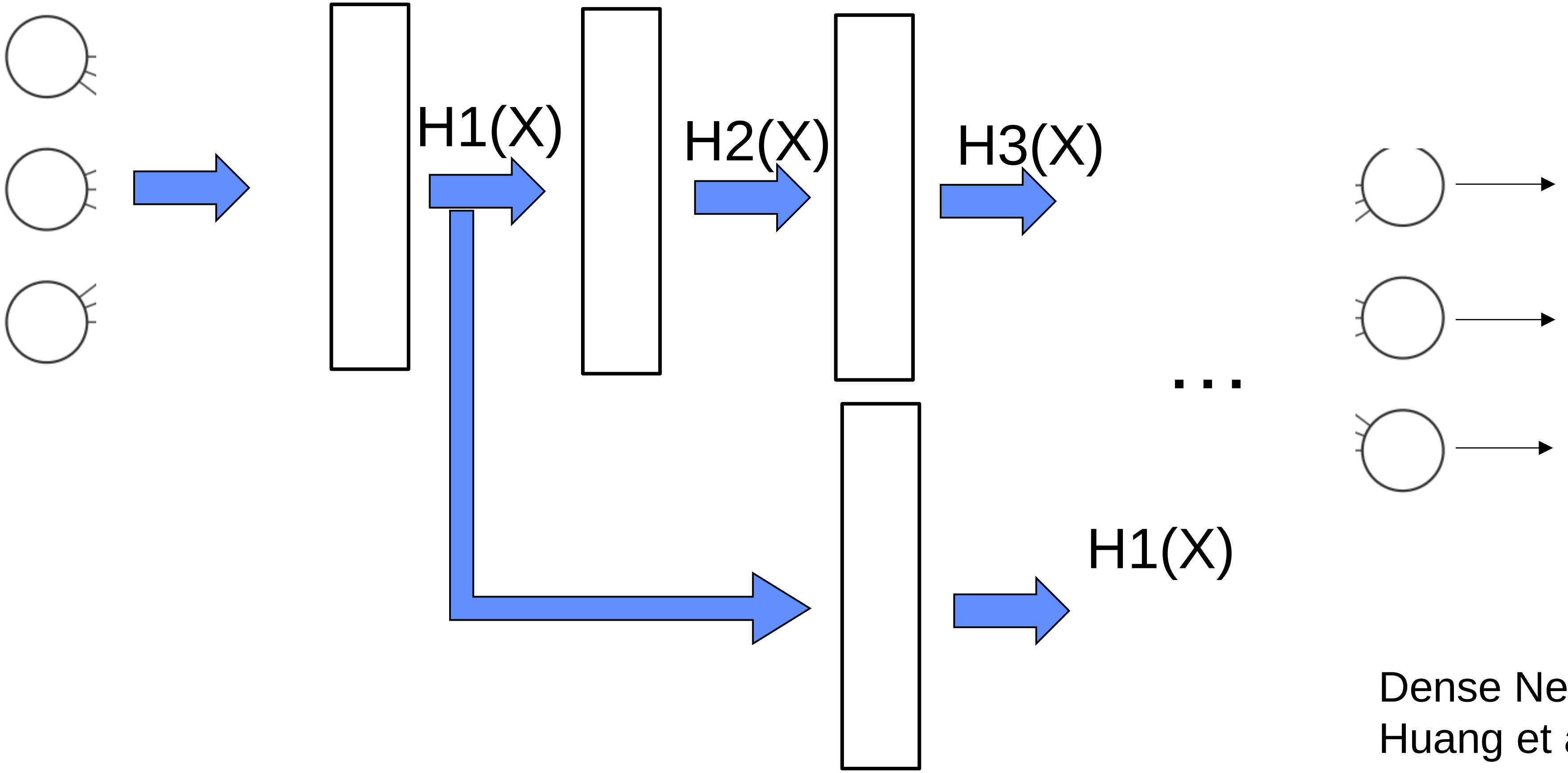
Concatenate input with hidden units into new layer



carry input forward
No weights to learn

Now the input features are used more efficiently

Can be done for any (or all) previous layer and *skip* any number of layers

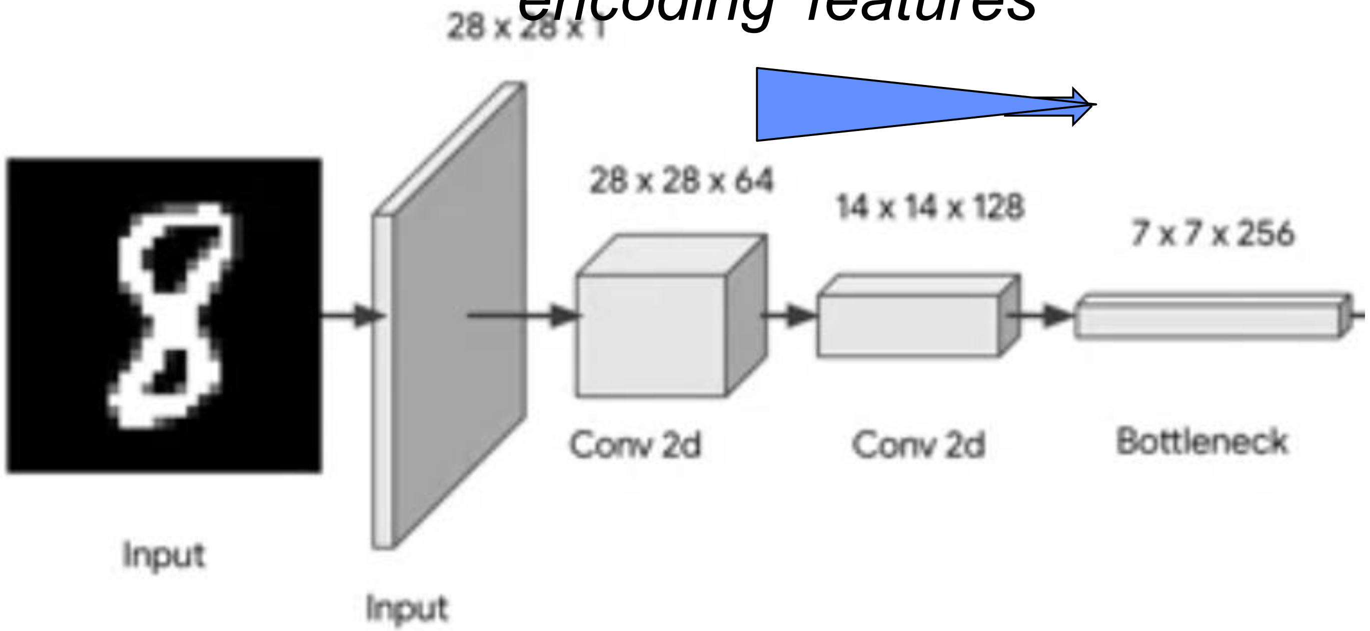


Dense Nets
Huang et al

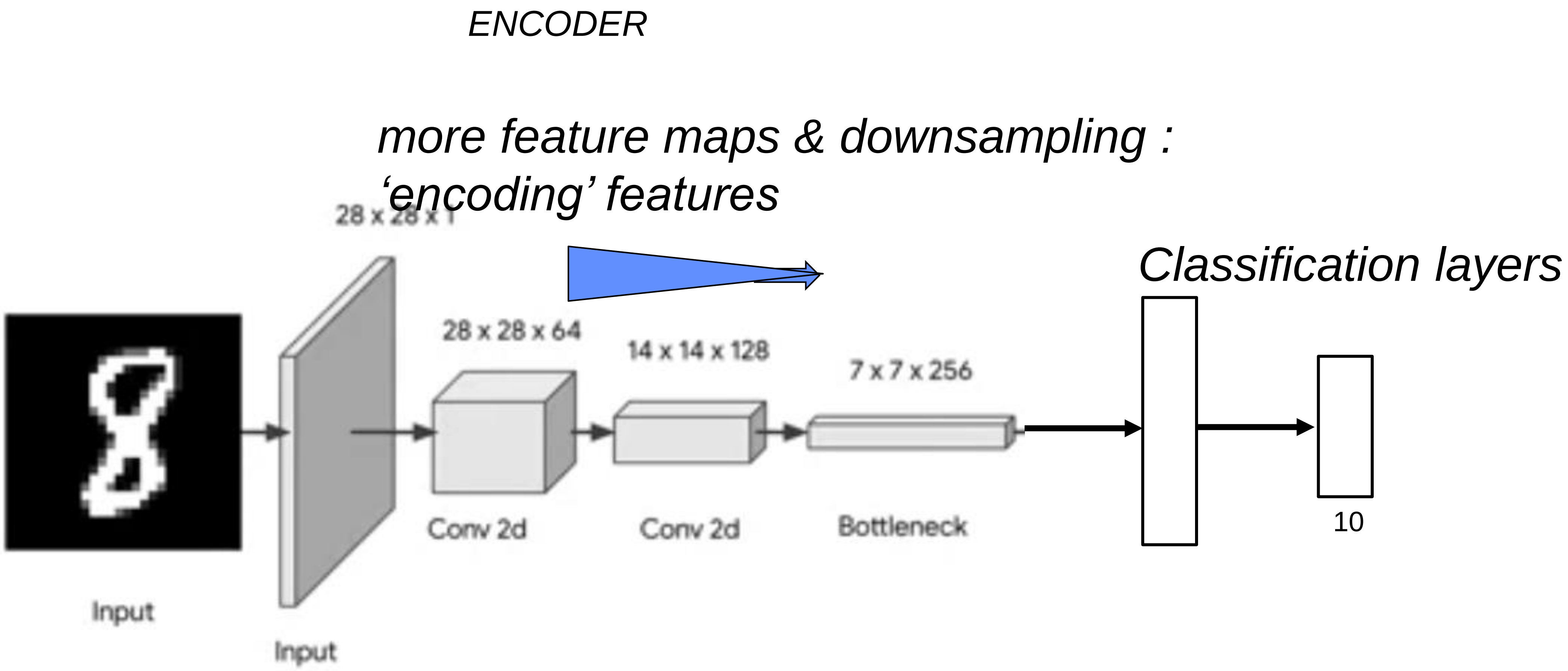
Recall: CNN architecture for MNIST classification

ENCODER

more feature maps & downsampling :
‘encoding’ features



Consider: CNN architecture for MNIST classification

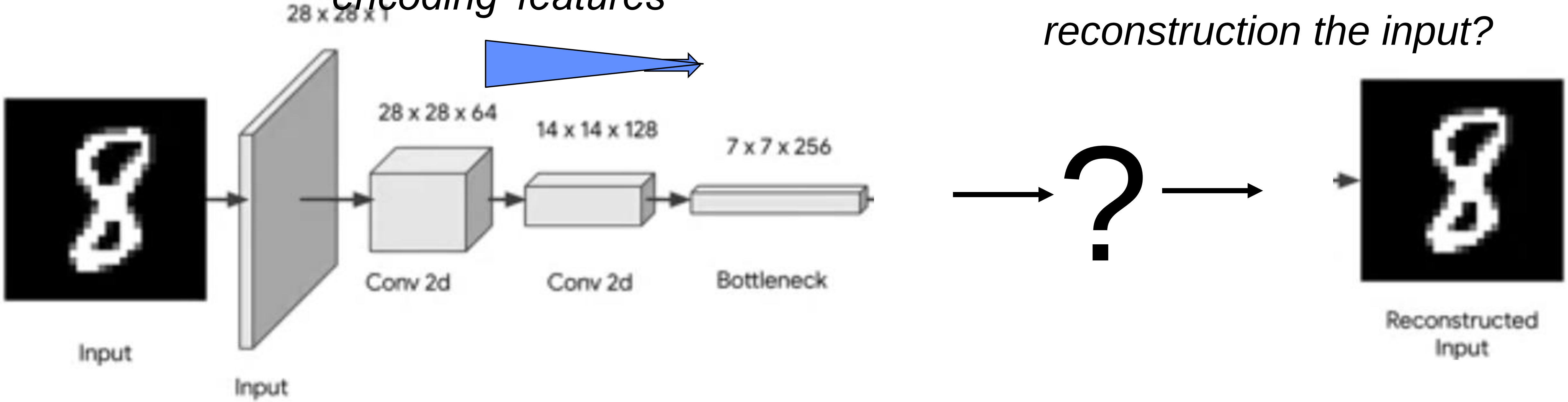


A CNN architecture for MNIST autoencoding

ENCODER

more feature maps & downsampling : ‘encoding’ features

What if we want to reconstruction the input?



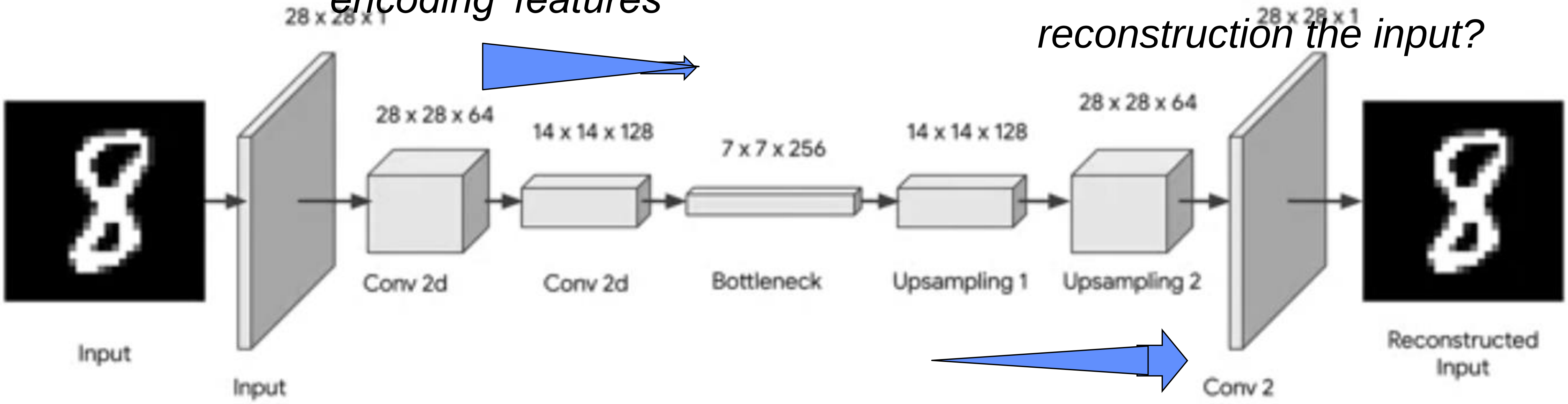
A CNN architecture for MNIST autoencoding

ENCODER

DECODER

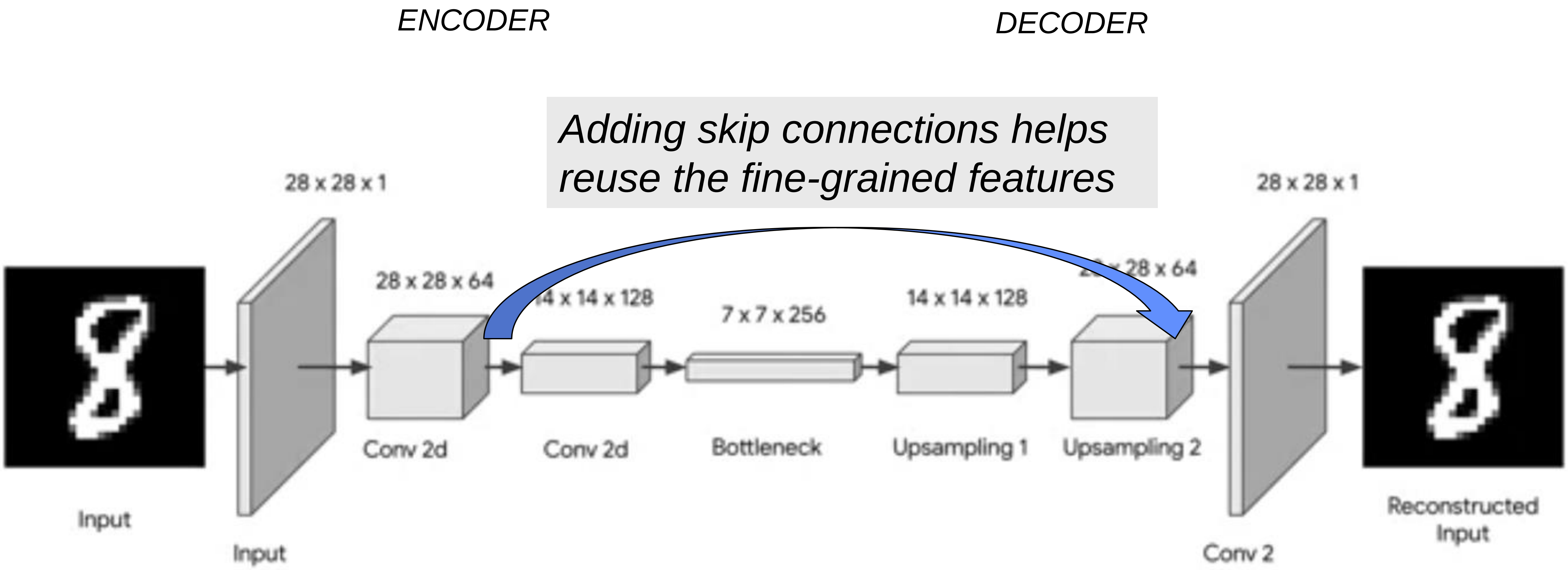
more feature maps & downsampling : ‘encoding’ features

What if we want to reconstruction the input?



Use ‘upsampling’ to reverse the encoding – ie. decoding

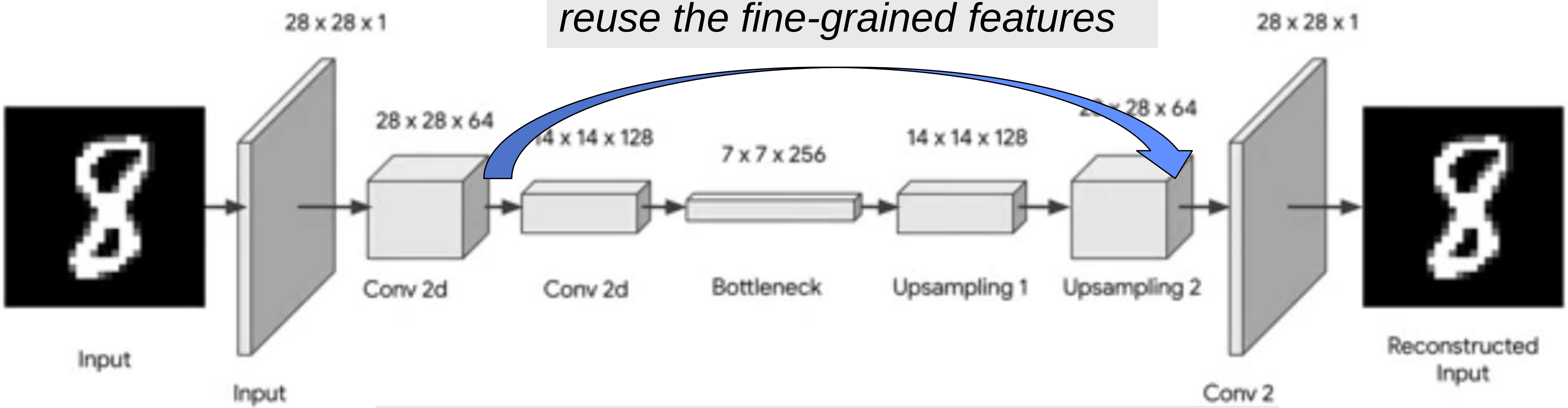
A CNN architecture for MNIST autoencoding



A CNN architecture for MNIST autoencoding

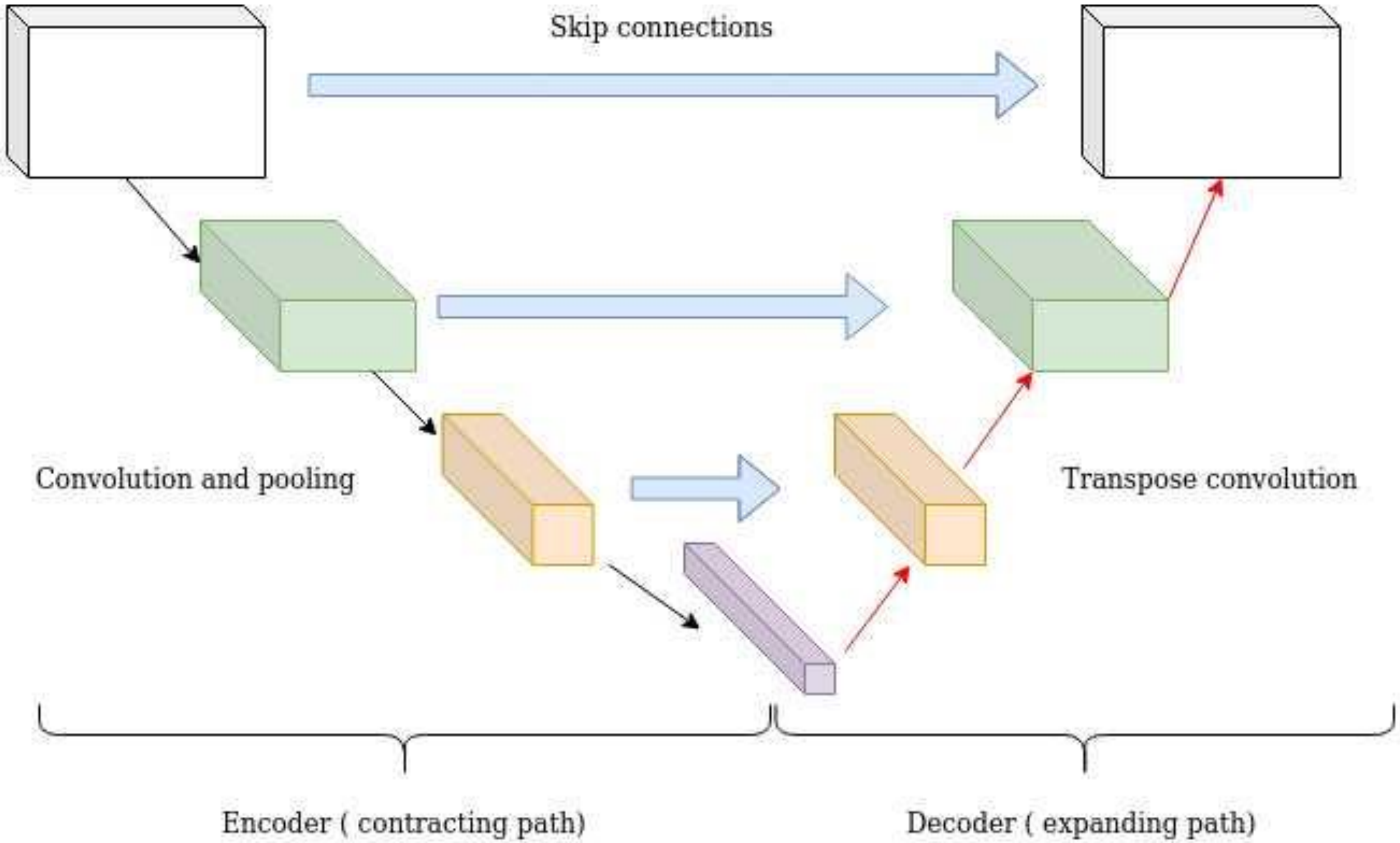
ENCODER *DECODER*

Adding skip connections helps reuse the fine-grained features



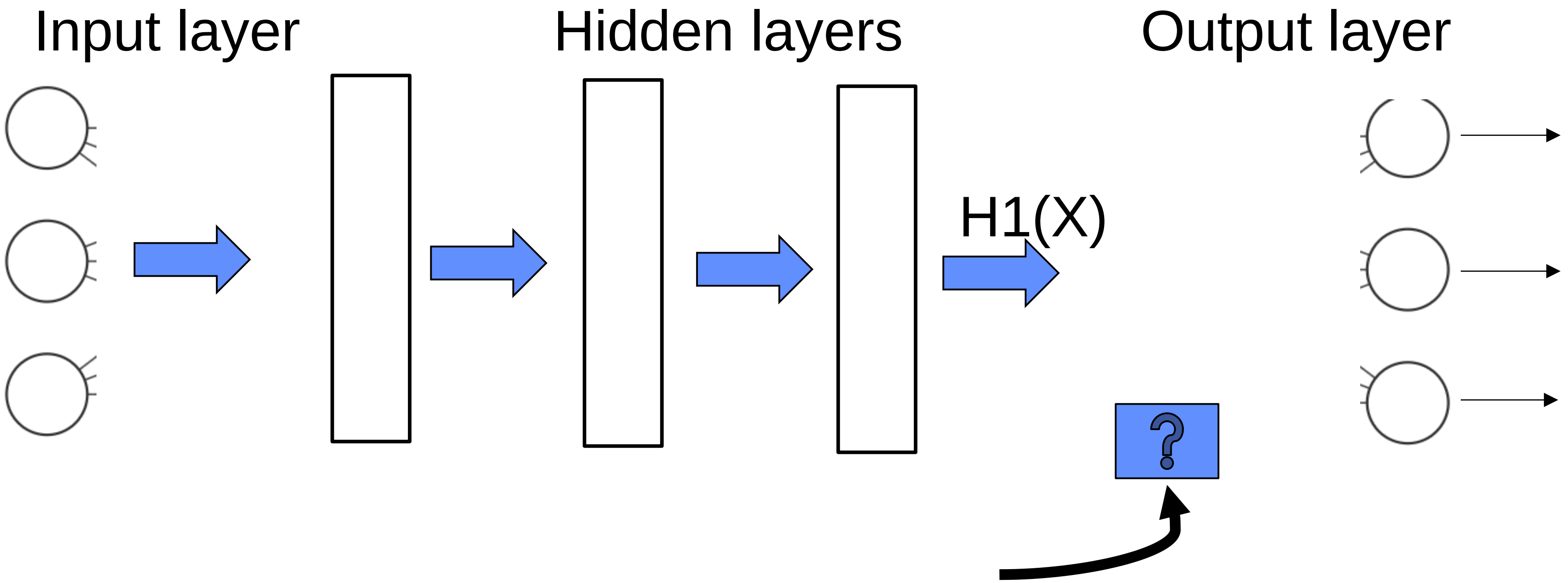
NOTE the 28x28x64 encoded maps have to be skipped ahead to where the 28x28x64 decoding maps are – which axis is concatenated?

Image Encoder-Decoder is a “UNET” architecture



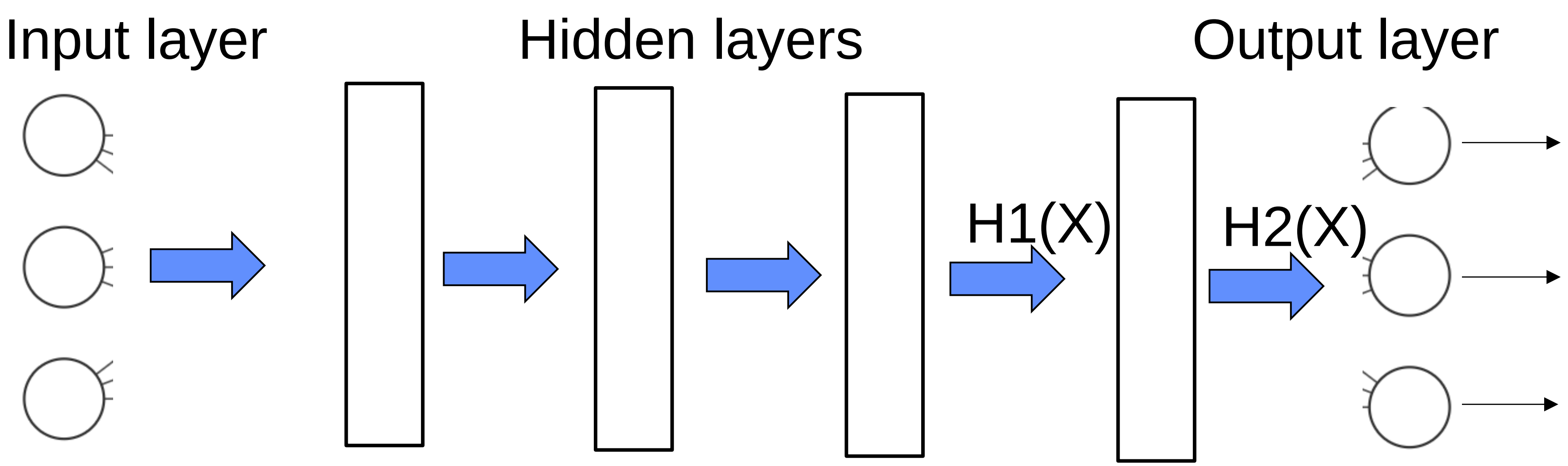
- **pause**

Consider: Can we keep adding deep layers?



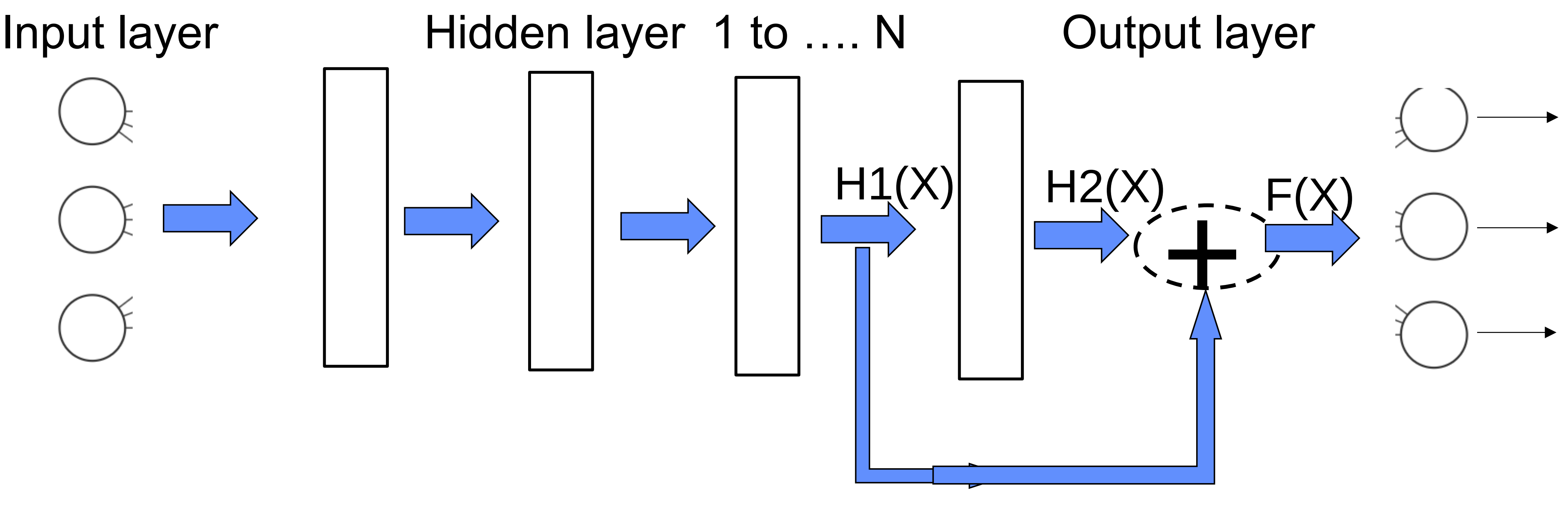
Given some deep network,
should I add another layer?
What should a new layer learn?

Consider: Can we keep adding deep layers?



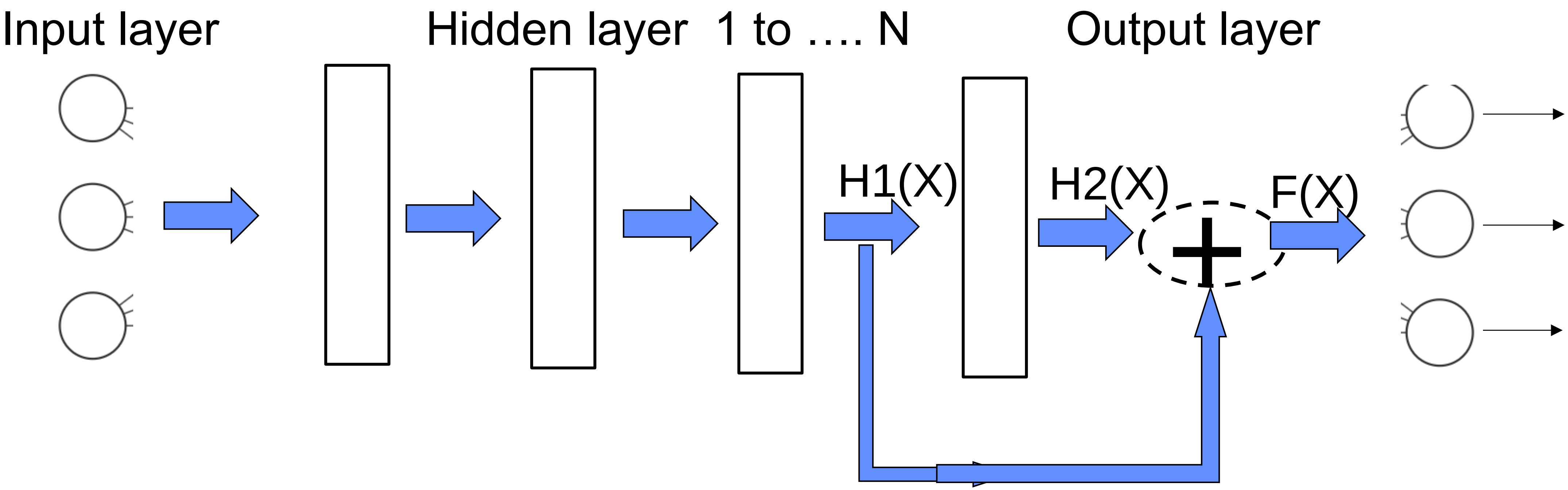
If H1(X) is good then this new layer could be unnecessary,
Eg H2(X) should be just H1(X)

Skip with addition makes a ‘residual’ connection



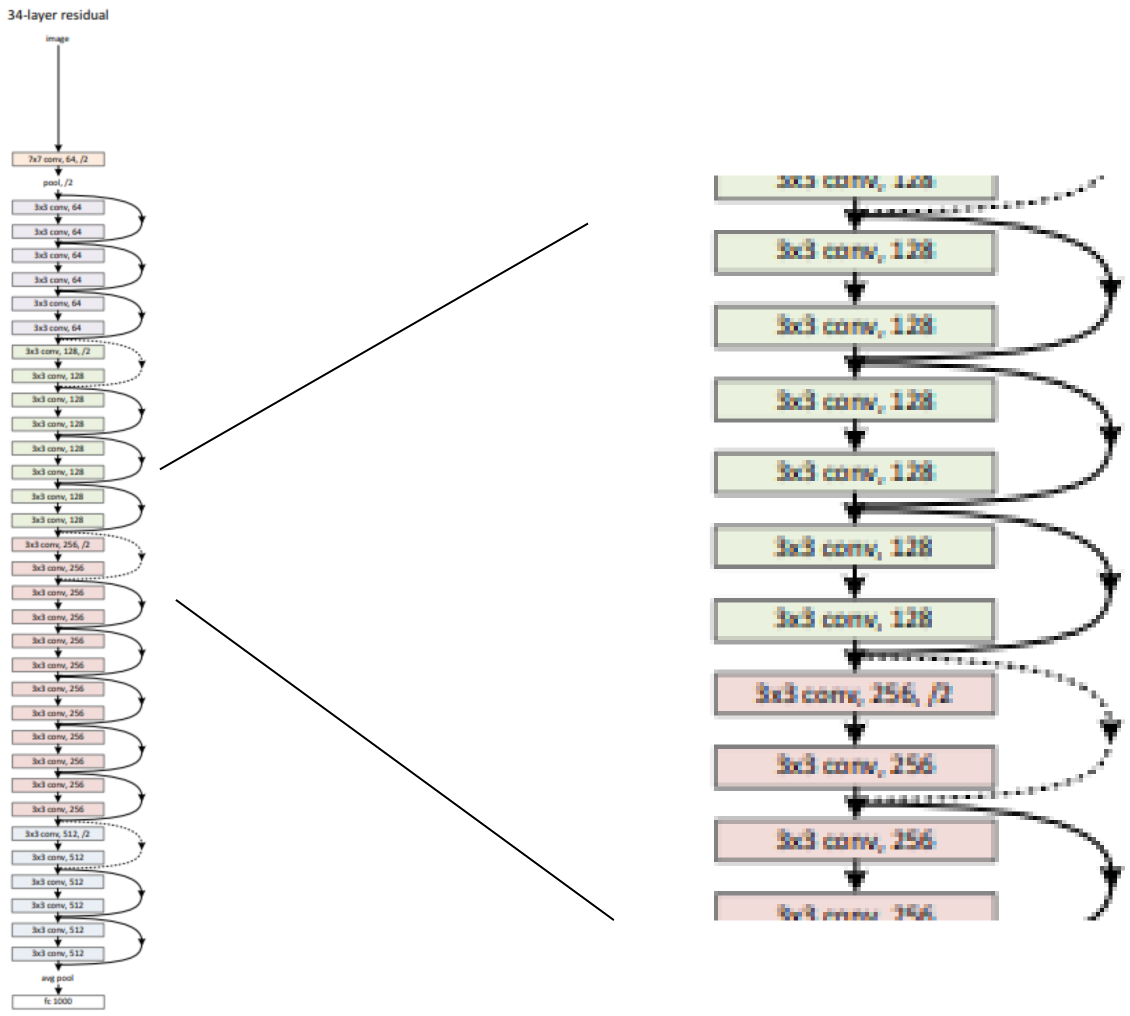
Make it easy for next layer to learn nothing –

Skip with addition makes a 'residual' connection



Make it easy for next layer to learn nothing –
e.g. use F(X)=H2(X)+H1(X) so that H2(X)=F(X)-H1(X) .
The H2() function learned is a residual function

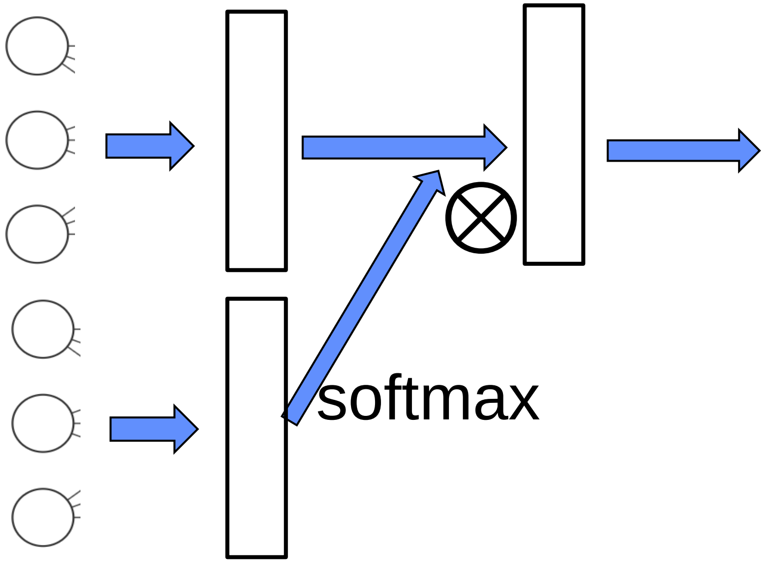
“Resnet” residual connections help deeper learning



Deep Residual Learning,
He et.al, 2015

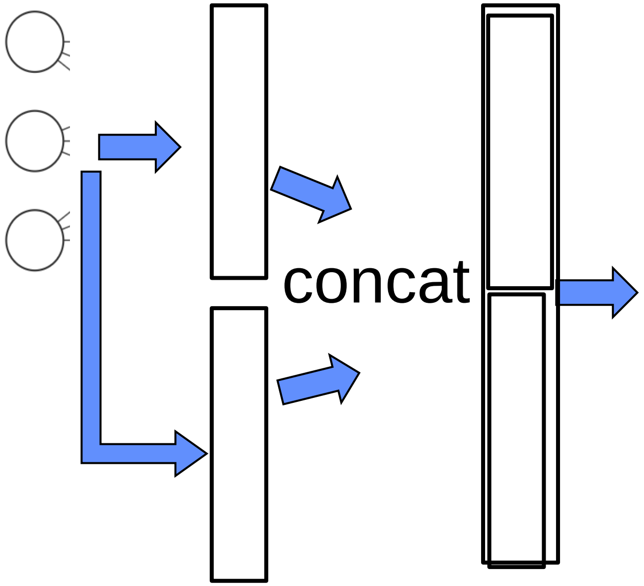
Summary: useful connections for architectures, and the intuitions

Softmax for gating



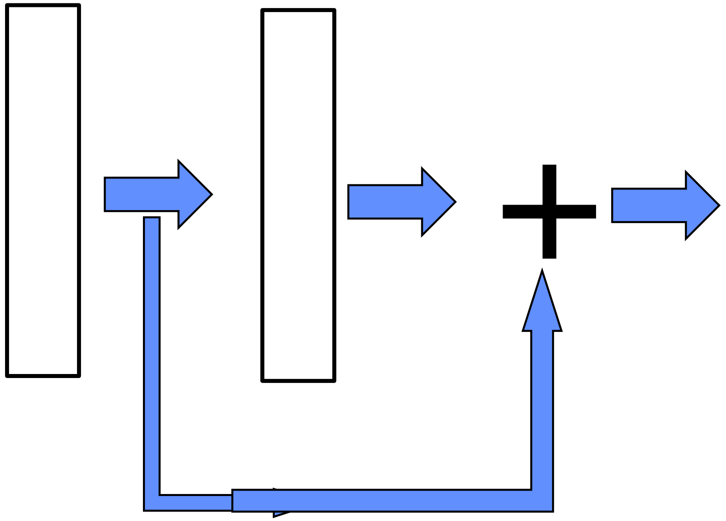
Recurrent nets,
attention network

Skip connections for feature reuse



UNET, also
feedforward nets..

Residual connections help deeper learning



Resnet, large image
classification

- **Programing connections and Keras Model API**

Keras: Sequential API VS Functional API

```
#specify the neural network model and learning parameters
my_model  = tf.keras.models.Sequential([
                  tf.keras.layers.Flatten(input_shape=(28, 28)),
                  tf.keras.layers.Dense(32,activation='relu'),
                  tf.keras.layers.Dense(10,activation='softmax')])
my_model.summary()
```

A sequence of layers: the inputs are assumed to be in order

Keras: Sequential API VS Functional API

A sequence of layers: the inputs are assumed to be in order

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A sequence of functions: Input layer(s) are specified

```
#specify the neural network model and learning parameters
inputs              = tf.keras.layers.Input(shape=(28, 28, 1,))
inputs_flattened   = tf.keras.layers.Flatten()(inputs)
hidden_layer        = tf.keras.layers.Dense(32,activation='relu')(inputs_flattened)
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Keras: Sequential API VS Functional API

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output_layer          = tf.keras.layers.Dense(10,activation='softmax')(hidden_layer)

my_model = tf.keras.Model(inputs,output_layer)
my_model.summary()
```

A sequence of functions: Input layer(s) are specified

The Model() function figures out the full path(s) to connect the input(s) to output(s)

Keras: Functional API

A sequence of functions: Input layer(s) are specified

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output_layer            = tf.keras.layers.Dense(10,activation='softmax')(hidden_layer)
```

```
my_model = tf.keras.Model(inputs =inputs, outputs=[output_layer, hidden_layer])


my_model.compile(optimizer=tf.keras.optimizers.Adam(),
                 loss={'output_layer':'binary_crossentropy',
                       'hidden_layer':'mae'},
                 ...
```

The Model() function can also have multiple outputs with corresponding loss functions.

Keras: Functional API

A sequence of functions: Input layer(s) are specified

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```

The Model() function can also have multiple outputs with corresponding loss functions.

This could 'inform' the network to learn some property or constraint

Exercise

- MNIST autoencoder, reconstruct digits from noisy inputs

- Add skip connections with concatenation

Note: make sure outputs from encoding layers are matched up to inputs for decoding layers!

i.e. 14x14 encoding feature maps should be concatenated with 14x14 decoding maps

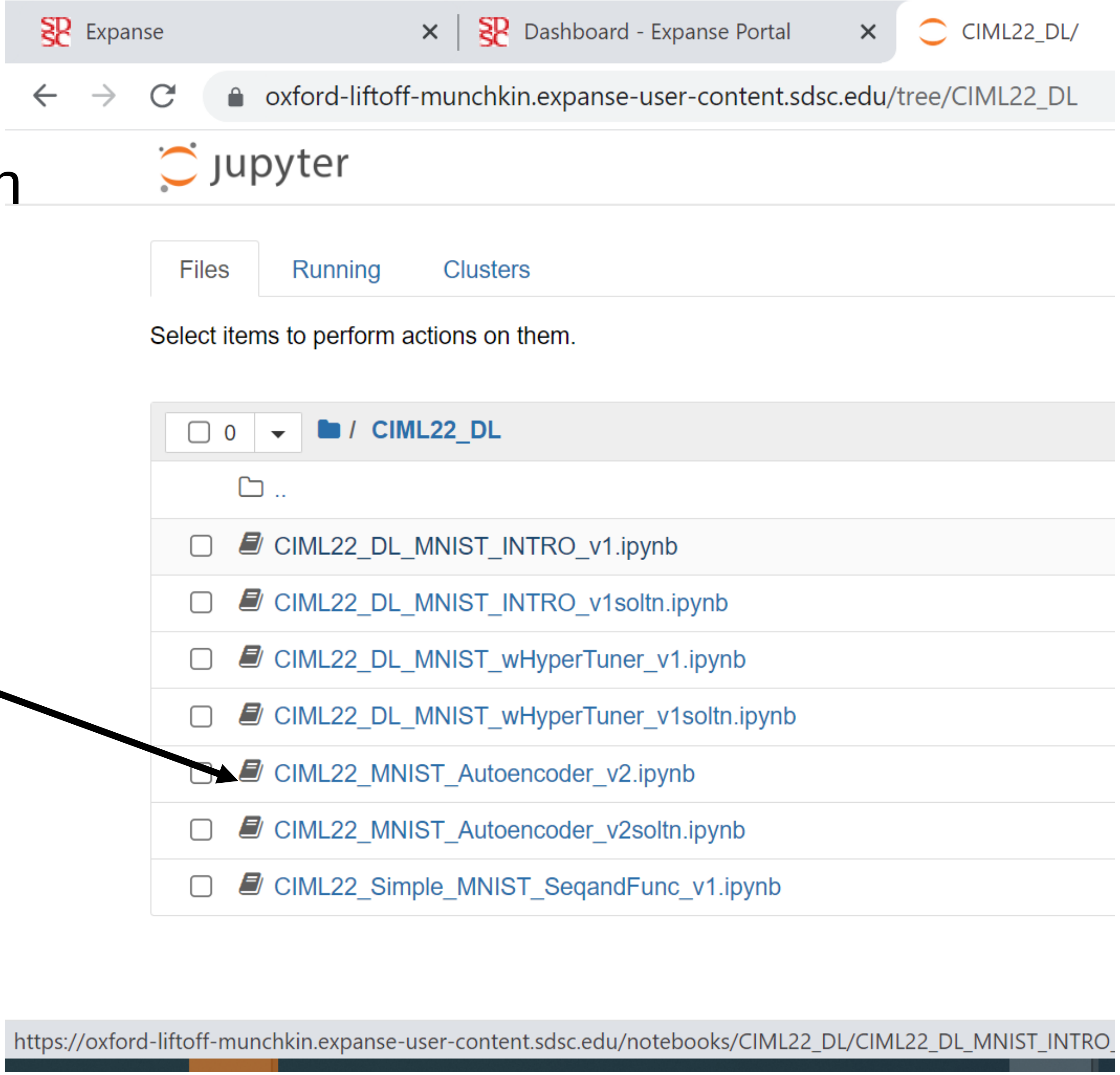
- Review outputs to see improvements

Login to expanse and start a notebook on gpu-shared queue

$ jupyter-gpu-shared-tensorflow

In jupyter notebook session open the MNIST_Autoencoder notebook

Follow instructions in the notebook



Quick overview of code

```
def encoder(inputs):
    '''Defines the encoder with two Conv2D and max pooling layers.'''
    conv_1 = tf.keras.layers.Conv2D(filters=64, kernel_size=(3,3), activation='relu', padding='same')(inputs)
                                                                      #padding same produces same output size
    max_pool_1 = tf.keras.layers.MaxPooling2D(pool_size=(2,2))(conv_1) #max pooling does the downsampling
```

Encoder function -

has convolution and pooling layers

```
def decoder(inputs, enc_conv1,enc_conv2):
    '''Defines the decoder path to upsample back to the original image size.'''
    #Notice that padding = same keeps the output same size as input

    conv_1      = tf.keras.layers.Conv2D(filters=128, kernel_size=(3,3), activation='relu', padding='
    up_sample_1 = tf.keras.layers.UpSampling2D(size=(2,2))(conv_1)
```

Decoder function -

has up sampling (deconvolution) layers

```python
def encoder(inputs):
    '''Defines the encoder with two Conv2D and max pooling layers.'''
    conv_1 = tf.keras.layers.Conv2D(filters=64, kernel_size=(3,3), activation='relu', padding='same')(inputs)
                                                              #padding same produces same output size
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    conv_2 = tf.keras.layers.Conv2D(filters=128, kernel_size=(3,3), activation='relu', padding='same')(max_pool_1)
    max_pool_2 = tf.keras.layers.MaxPooling2D(pool_size=(2,2))(conv_2)

    return max_pool_2, conv_1, conv_2
```

Encoder returns final and intermediate layer outputs to be skipped ahead

```python
def decoder(inputs, enc_conv1,enc_conv2):
    '''Defines the decoder path to upsample back to the original image size.'''
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Encoder returns final and intermediate layer outputs to be skipped ahead

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    up_sample_1 = tf.keras.layers.UpSampling2D(size=(2,2))(conv_1)
```

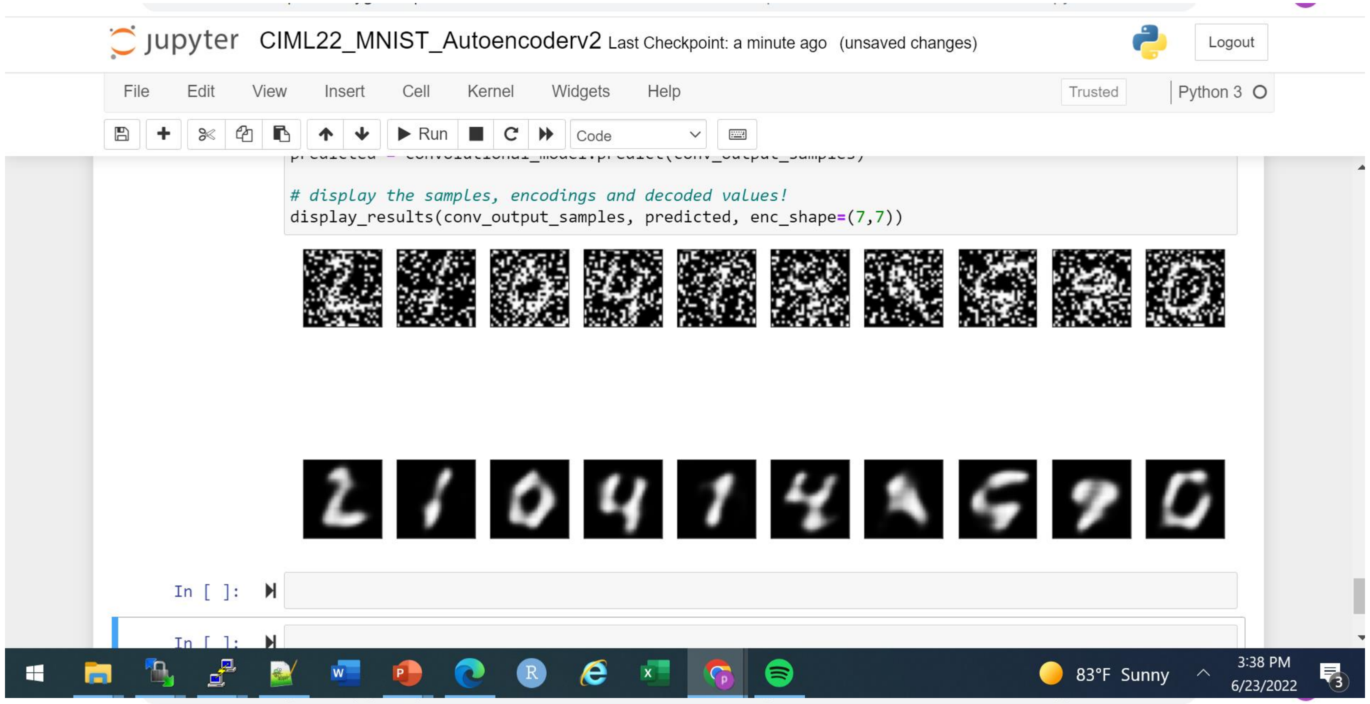
. . .

. . .

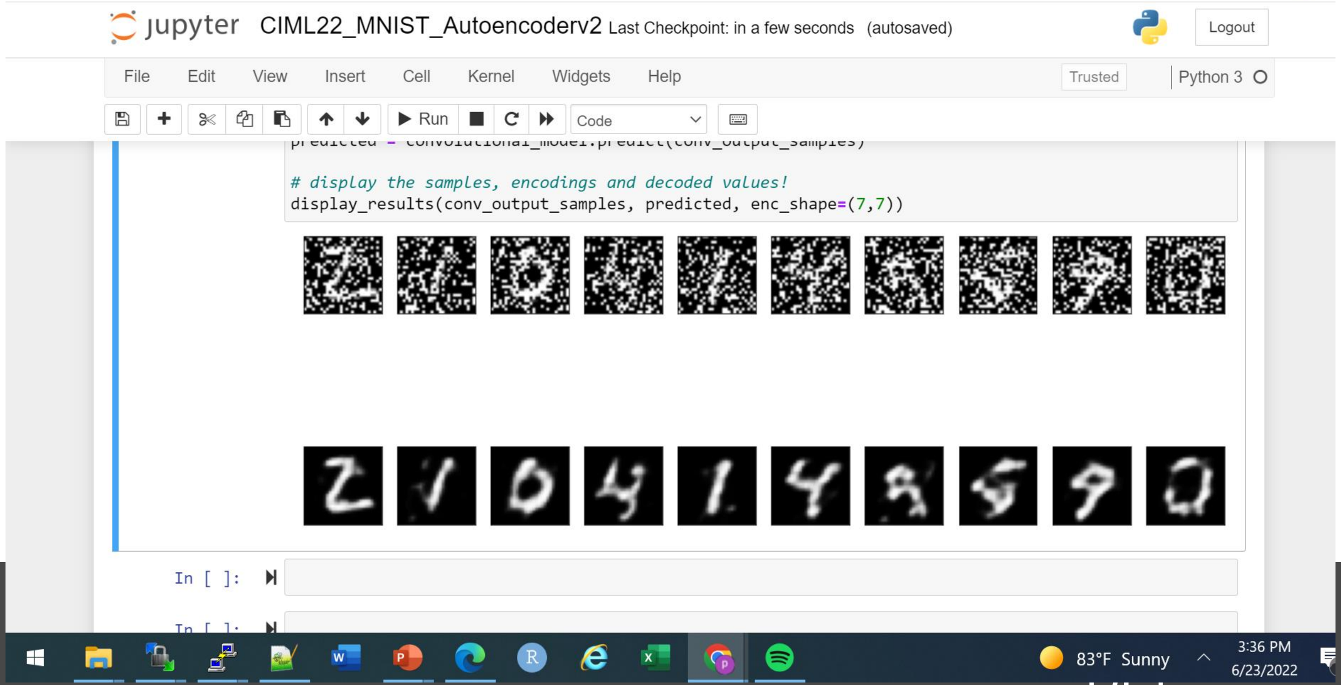
```python
    skip_concat_1 = tf.keras.layers.concatenate([up_sample_1, enc_conv2])
    conv_2        = tf.keras.layers.Conv2D(filters=64, kernel_size=(3,3), activation='relu', padding='s
                            # ---------->>>> and change the input into conv_2
```

You can pass intermediate layers to decoder,

then use it in concatenation layer



With out skip
20 epochs
Loss 0.1664



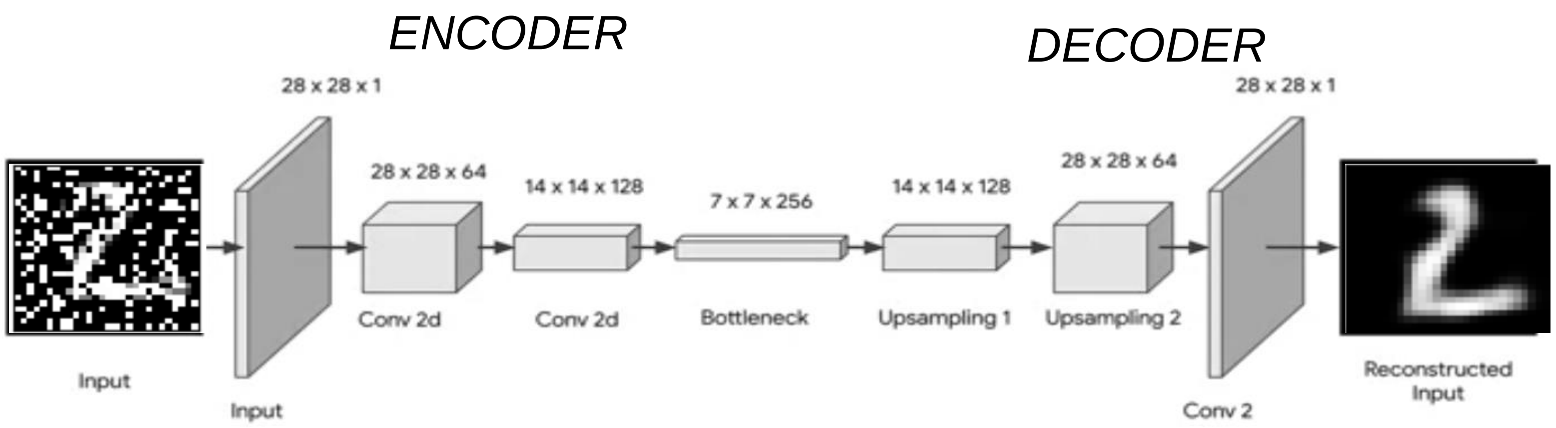
With skip,
20 epochs loss 0.14

Are the numbers a little bit more reconstructed?

Autoencoding with Stable Diffusion

- Let’s introduce the concepts and intuition behind stable diffusion

In principle, our denoising autoencoder removed noise pixels and/or filled in digit pixels



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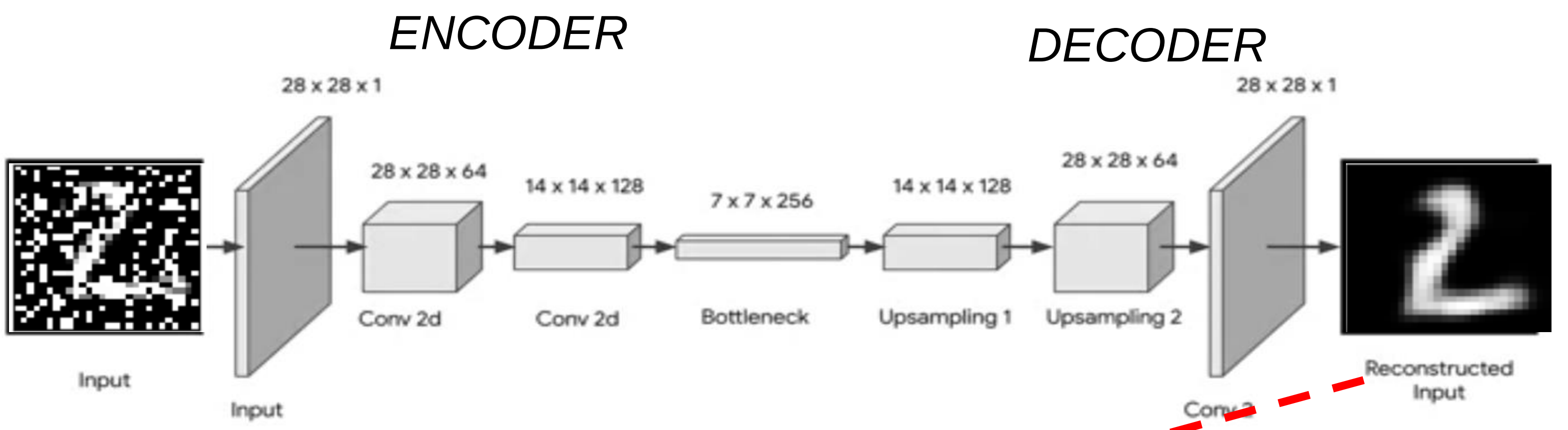
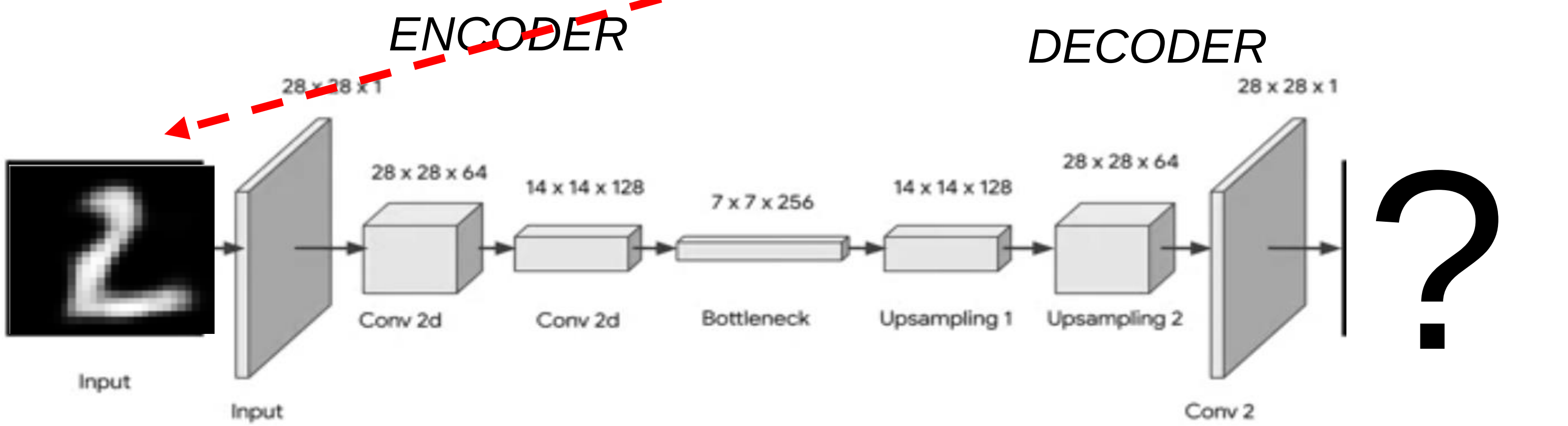
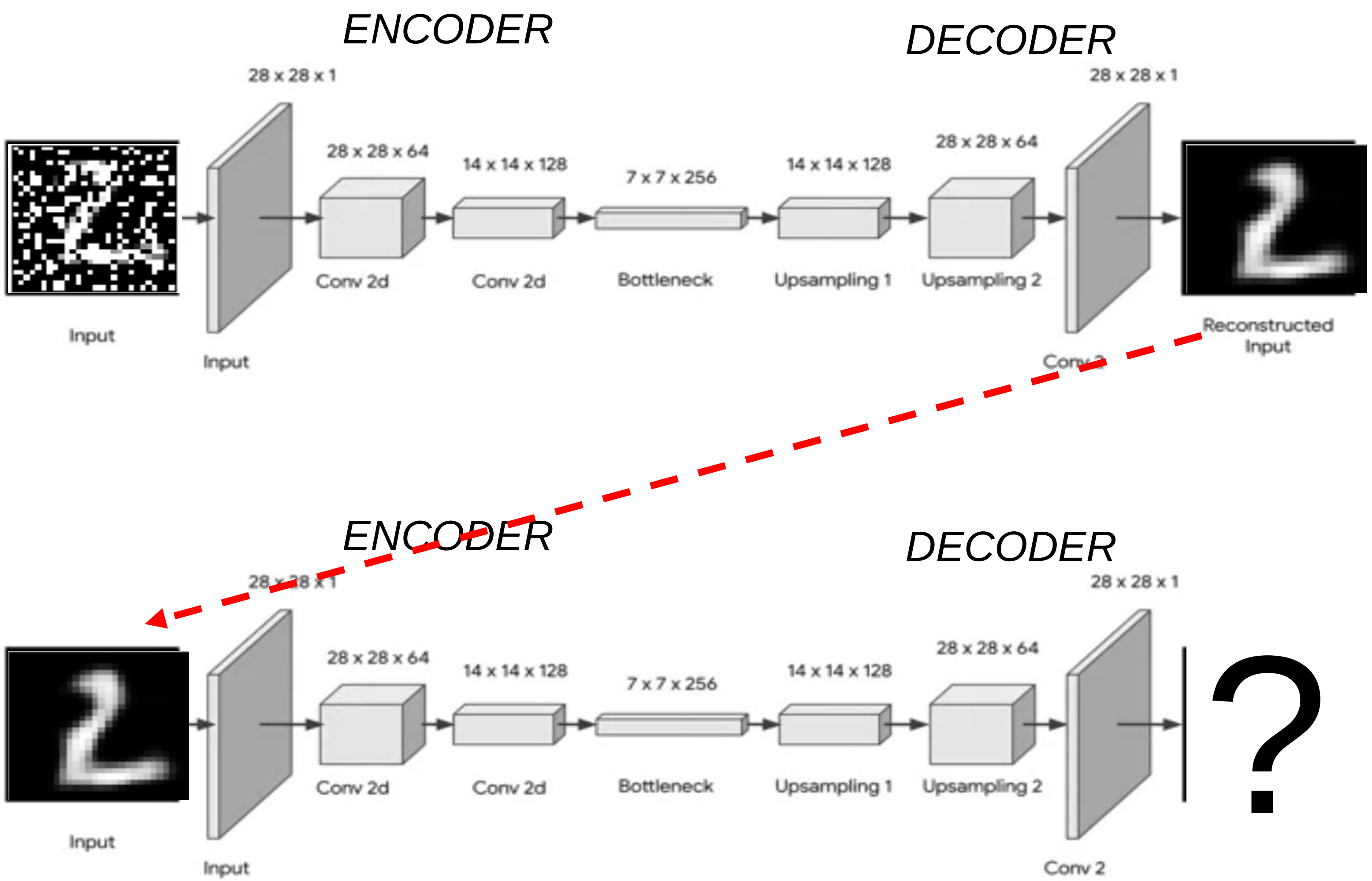


What would would happen if we fed the denoised output back into the autoencoder?



In principle, our denoising autoencoder removed noise pixels and/or filled in number pixels



What would would happen if we fed the denoised output back into the autoencoder?

A: better reconstruction

B: all pixels would be removed

C: all pixels would be filled in

First step of denoising

first step of denoising

1 more step of denoising

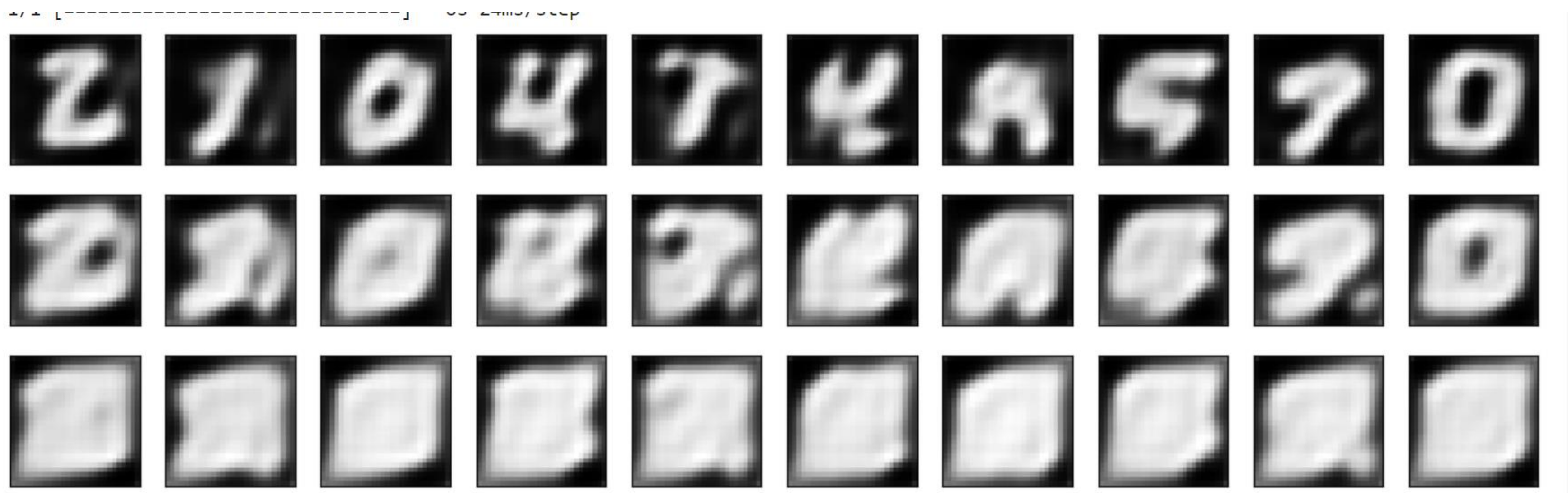
Is it better?

First step of denoising

3 more steps of denoising

Frist step of denoising

3 more steps of denoising



Let’s make this more stable, by training a network to just remove a little noise. It is like training to predict noise diffusion.

Stable Diffusion for Image Reconstruction

Jonathan Ho, Ajay Jain, and Pieter Abbeel. Denoising diffusion probabilistic models. 2020.

- **Concept:**

create a sequence of images with noise, t=1…T

t=1 → t=T

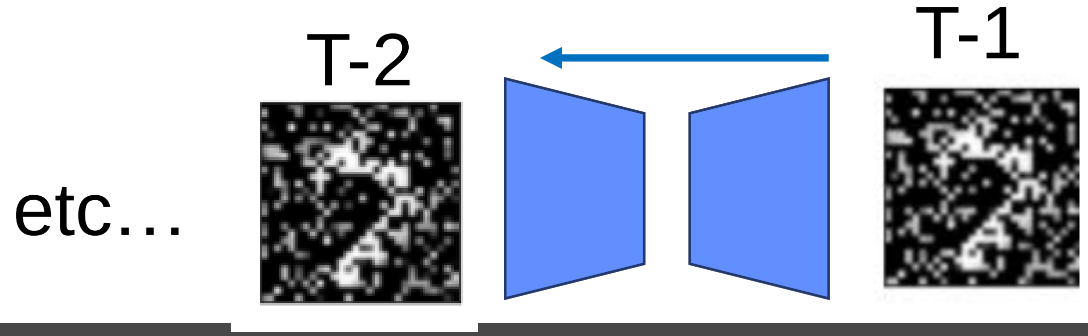
Stable Diffusion for Image Reconstruction

Jonathan Ho, Ajay Jain, and Pieter Abbeel. Denoising diffusion probabilistic models. 2020.

- **Concept:**

create a sequence of images with noise, t=1…T

train the network to reconstruct image t-1 from image t



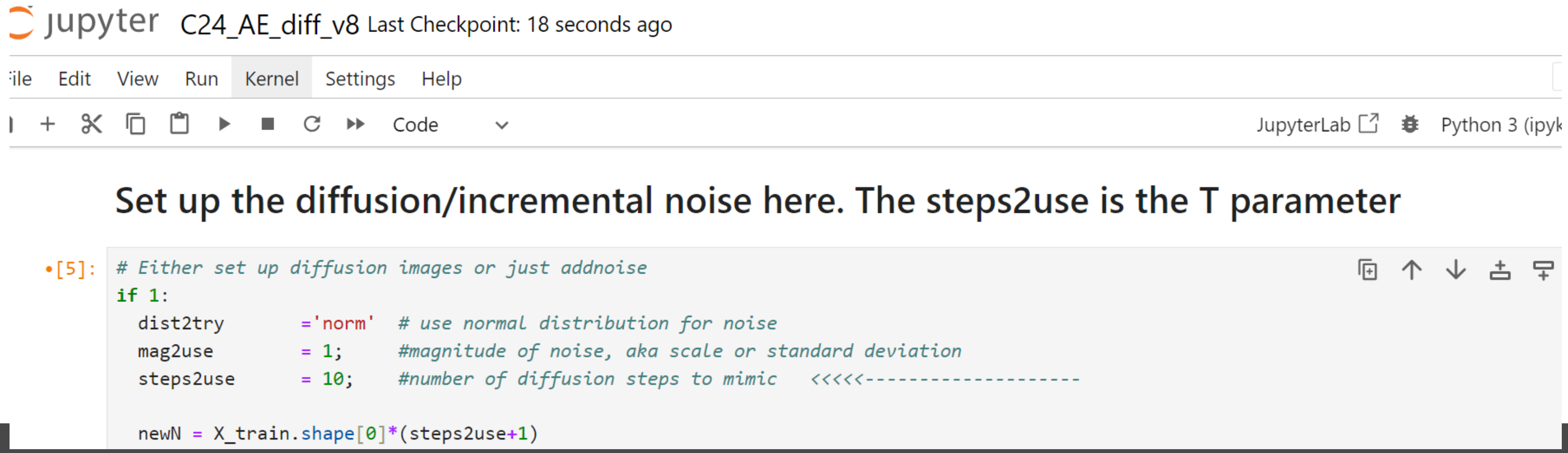
Note: this example is in pixel space, but it is often applied in embedding space

- **From Ho et al. 2020**

Early denoising steps add overall structure
Later denoising steps add more detail

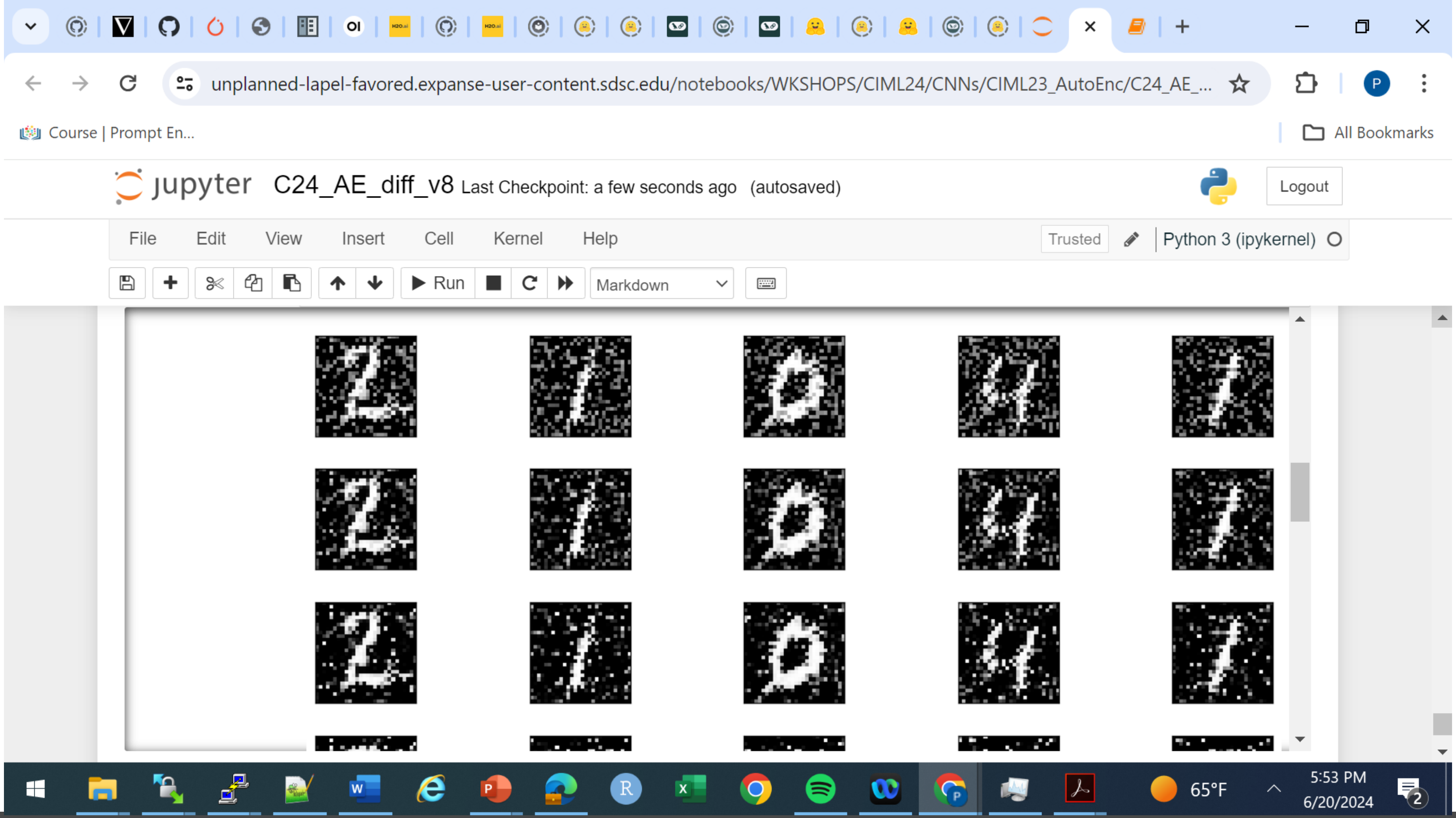
Exercise

- **MNIST stable diffusion, or incremental denoising**
- **Open and run the notebook**
- **Try changing T parameter (steps2use)**



Sample output where T1,T2, are going down the columns

What would happen if the input was completely random?



end