Dynamic Routing Between Capsules

Sara Sabour, Nicholas Frosst, and Geoffrey E. Hinton. NIPS, 2017

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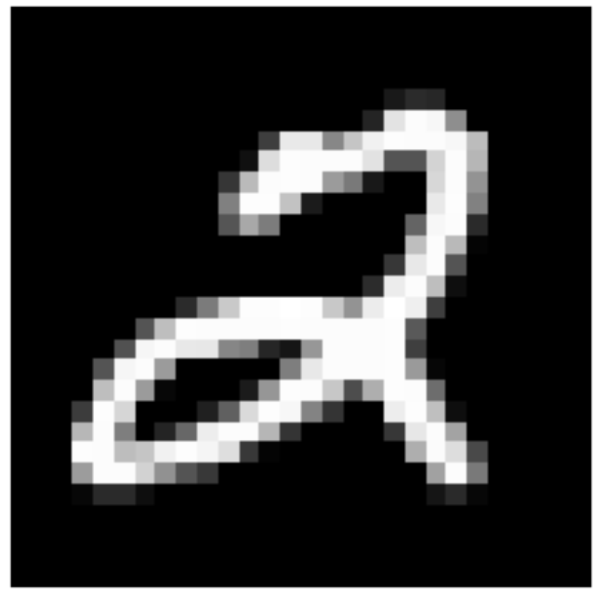
05/18/2022

Background

Image Classification

- MNIST: dataset of handwritten digits



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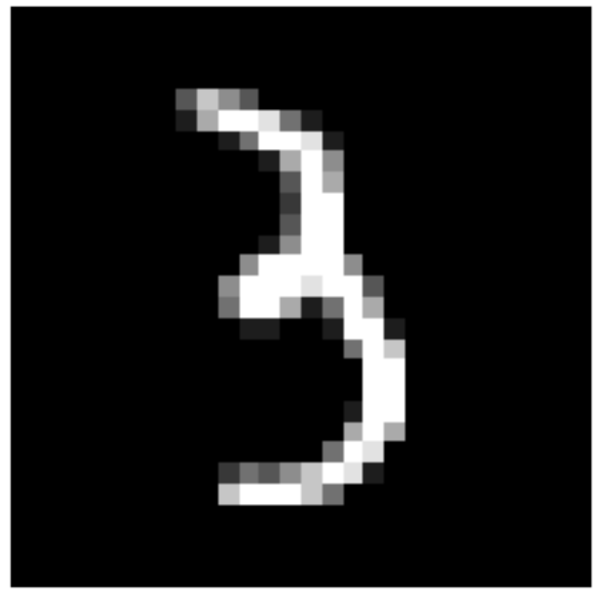

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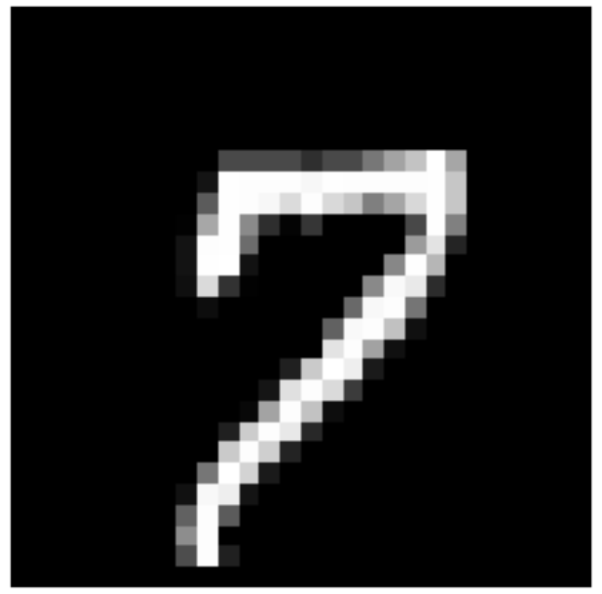

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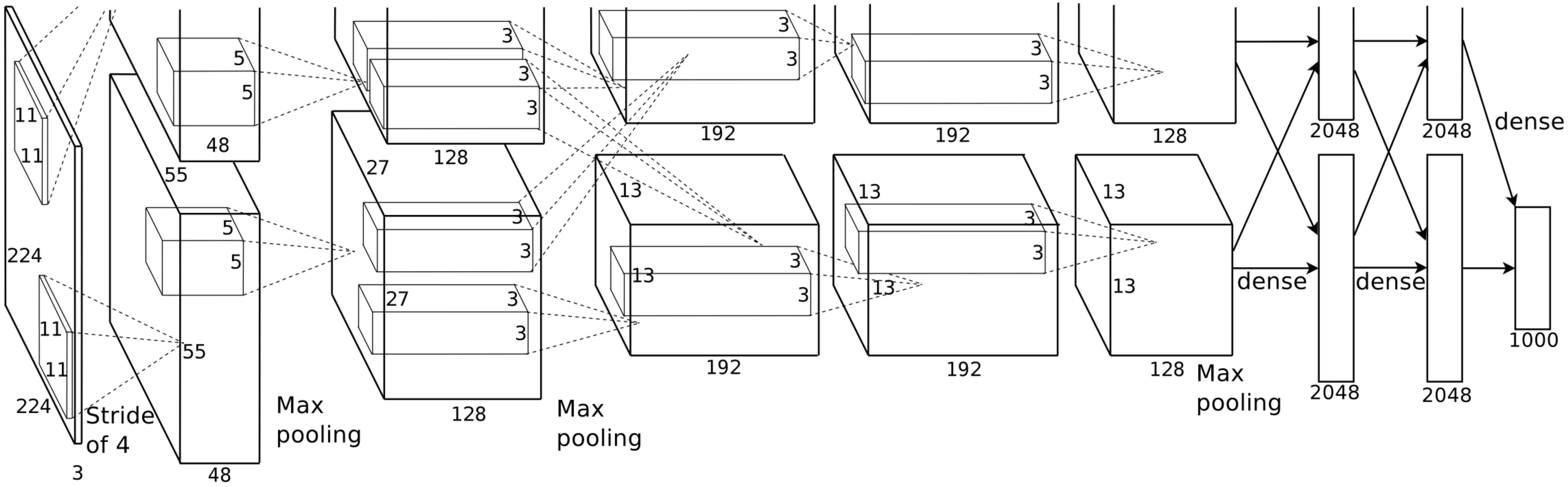
Yann LeCun, Corinna Cortes, and Christopher JC Burges. The mnist database of handwritten digits. 1998

Background

Convolutional Neural Networks for Image Classification

- AlexNet



Alex Krizhevsky, Ilya Sutskever, and Geoffrey E. Hinton. ImageNet Classification with Deep Convolutional Neural Networks. NIPS, 2012

Background

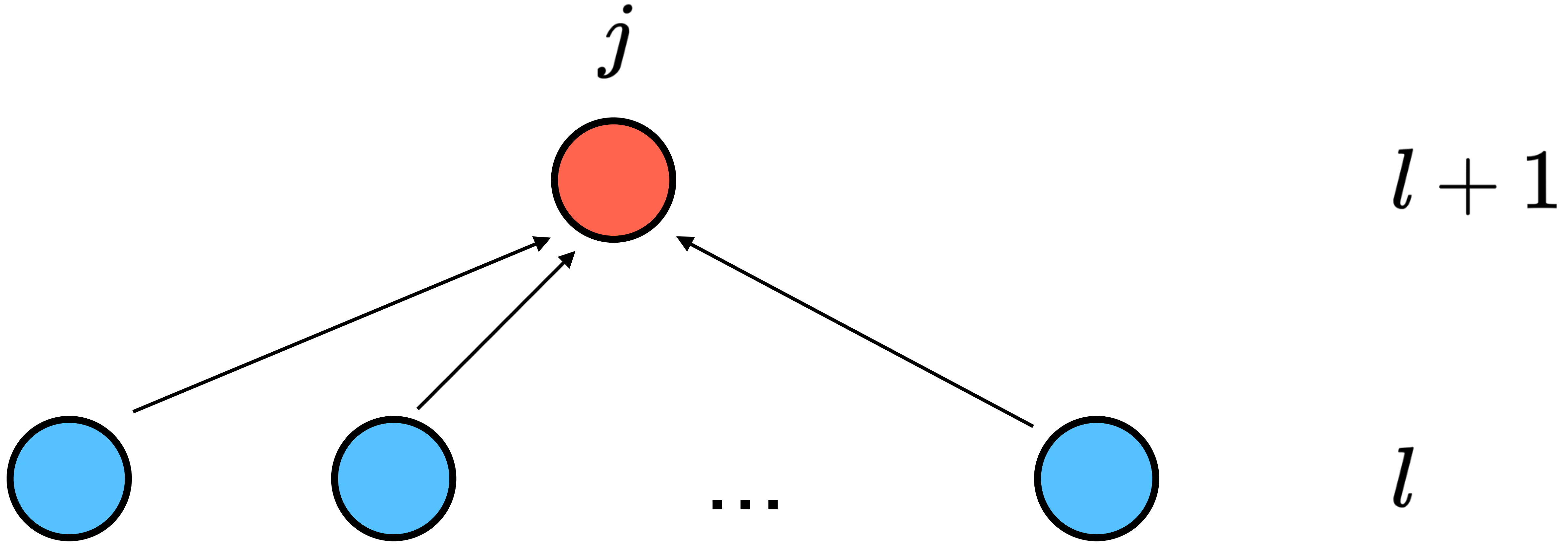
What about Capsule Network?

- Explainability: capsules are designed to be interpretable
- Great at representing hierarchic architectures
- Great at multi-label classification
- Not so deep and abundant in parameters

Background

One More Thing

- Attention in Transformers: distributing attention from deeper neurons to earlier

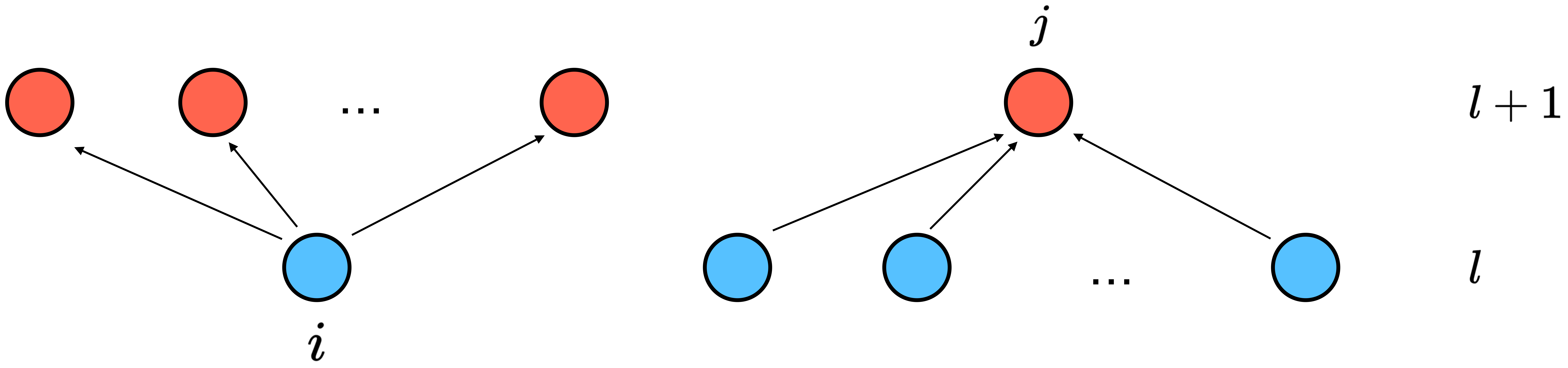


$$\text{output}_j = \sum_i c_{ij} a_i, \sum_i c_{ij} = 1$$

Background

One More Thing

- Routing algorithm: distributing influence from earlier neurons into deeper



$$\sum_j c_{ij} = 1$$

$$\text{output}_j = \sum_i c_{ij} a_i$$

Method

Capsule and Routing Algorithm

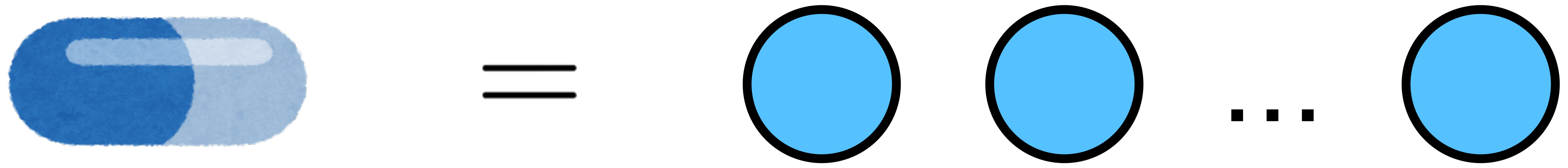
- Capsule vs. neurons
- Routing algorithm vs. traditional forward propagation

- Forward propagation between layers of neurons $y = f(Wx + b)$
- Routing between layers of capsules

Method

Capsule

- Neuron: outputs a number
- Capsule: outputs a vector

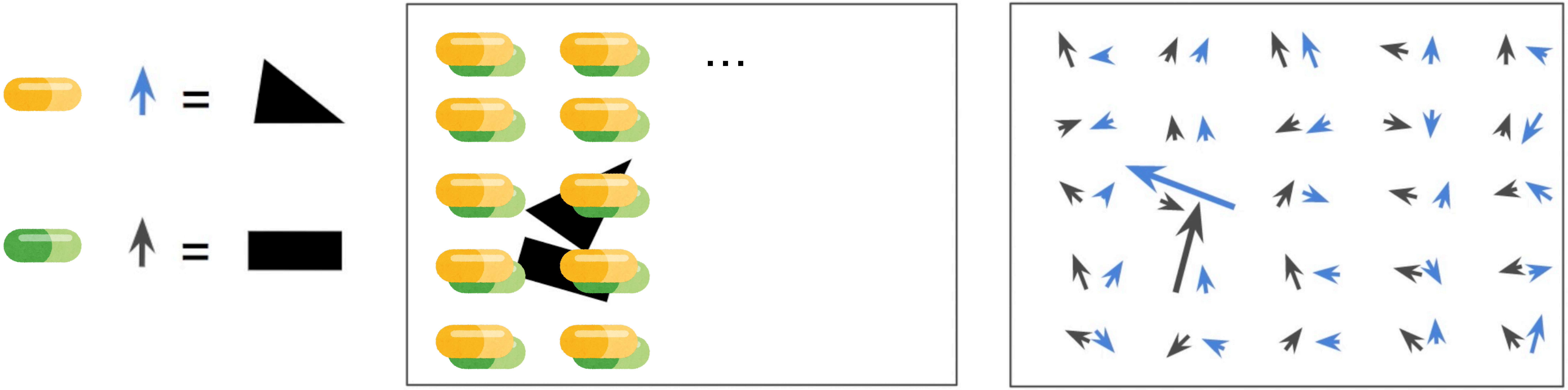


- Neurons activate separately, while capsules activate as a whole

Method

Capsule

- Capsule activation vector:
  length/norm represents the probability
  orientation represents the instantiation parameters



Aurélien Géron. Capsule Networks (CapsNets) – Tutorial. https://www.youtube.com/watch?v=pPN8d0E3900

Method

Capsule

- Capsule activation function: squash

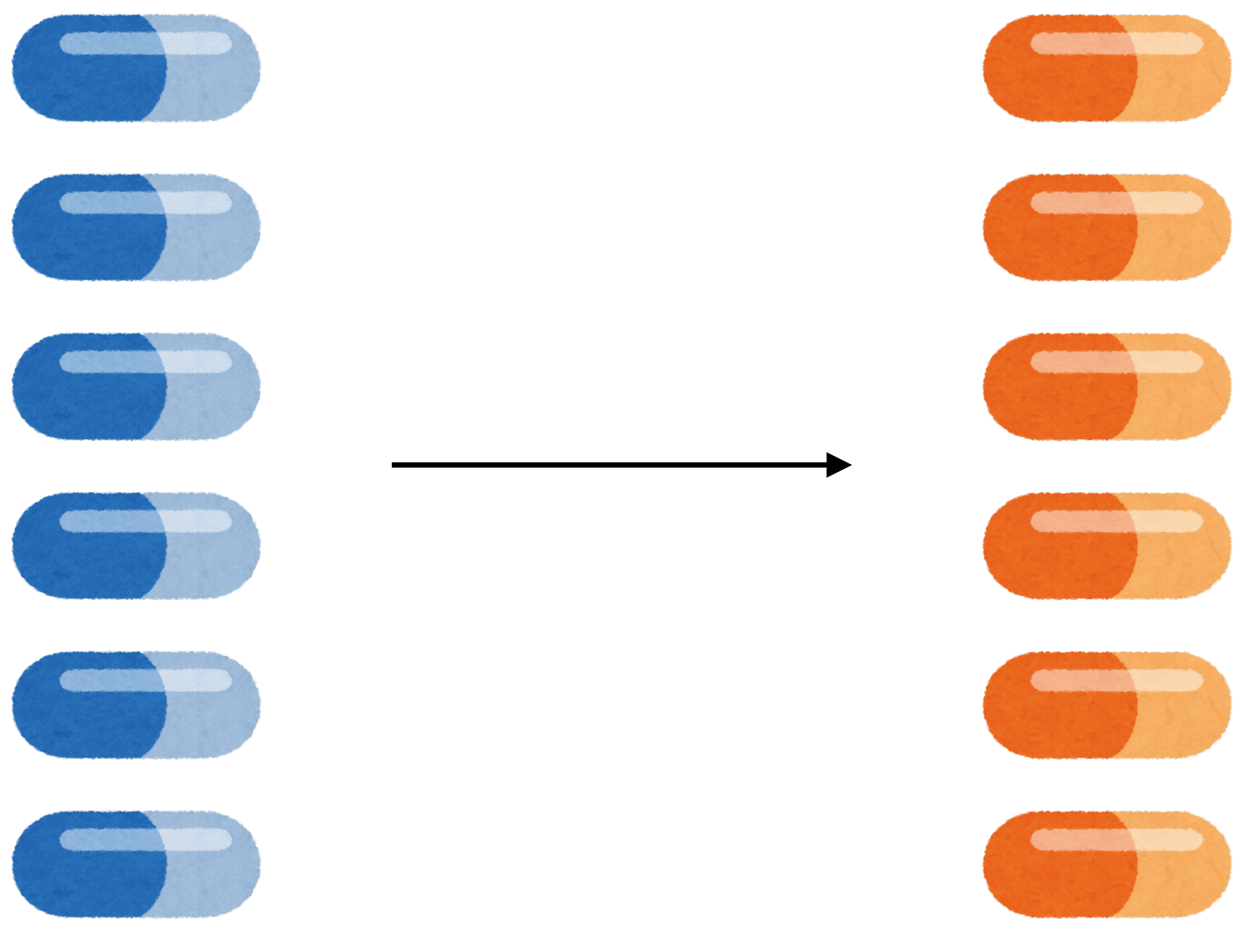
$$\mathbf{v}_j = \frac{||\mathbf{s}_j||^2}{1 + ||\mathbf{s}_j||^2} \frac{\mathbf{s}_j}{||\mathbf{s}_j||}$$

- Long vectors —> 1
  Short vectors —> 0

Method

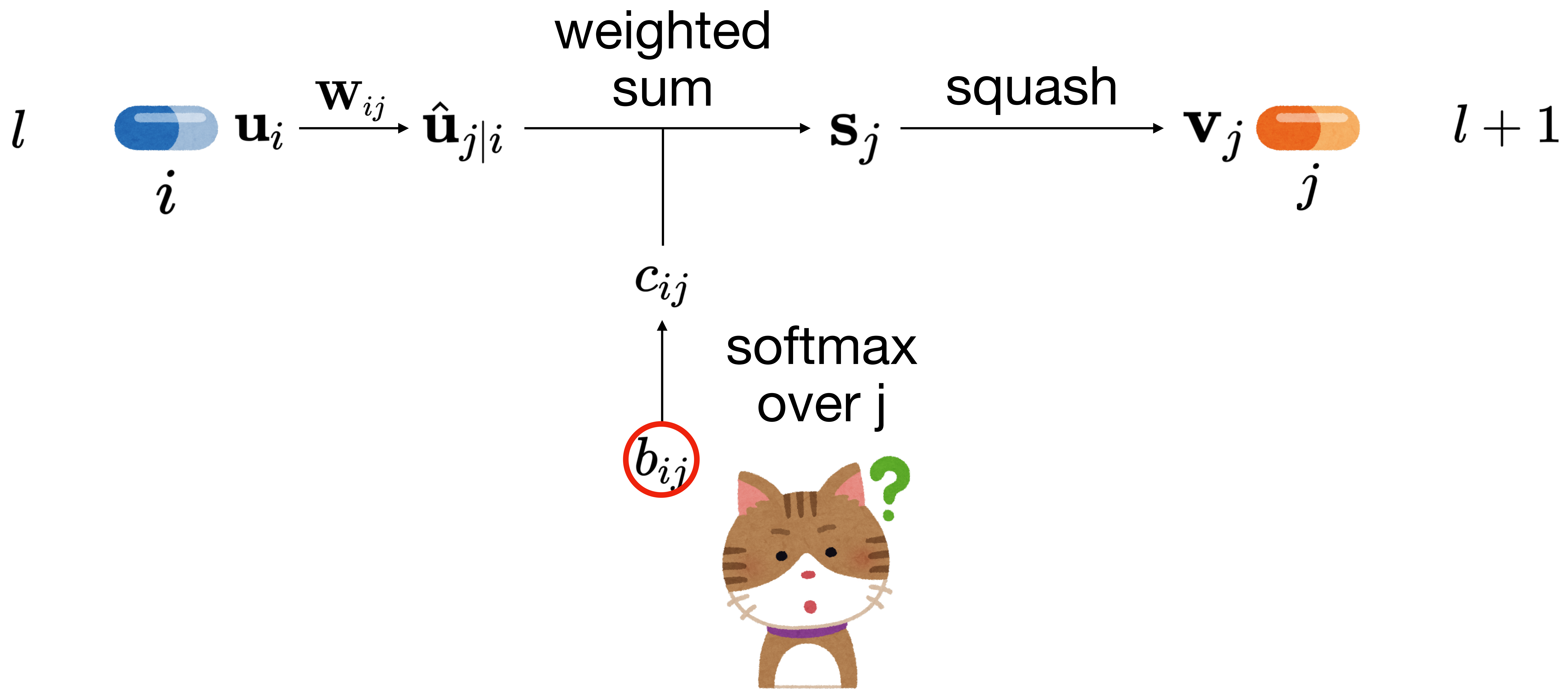
Routing

- Forward propagation between layers of capsules



Method

Routing



l $\mathbf{u}_i$ $\xrightarrow{\mathbf{W}_{ij}}$ $\hat{\mathbf{u}}_{j|i}$

weighted sum

$\mathbf{s}_j$

squash

$\mathbf{v}_j$ $l+1$

i

j

c_{ij}

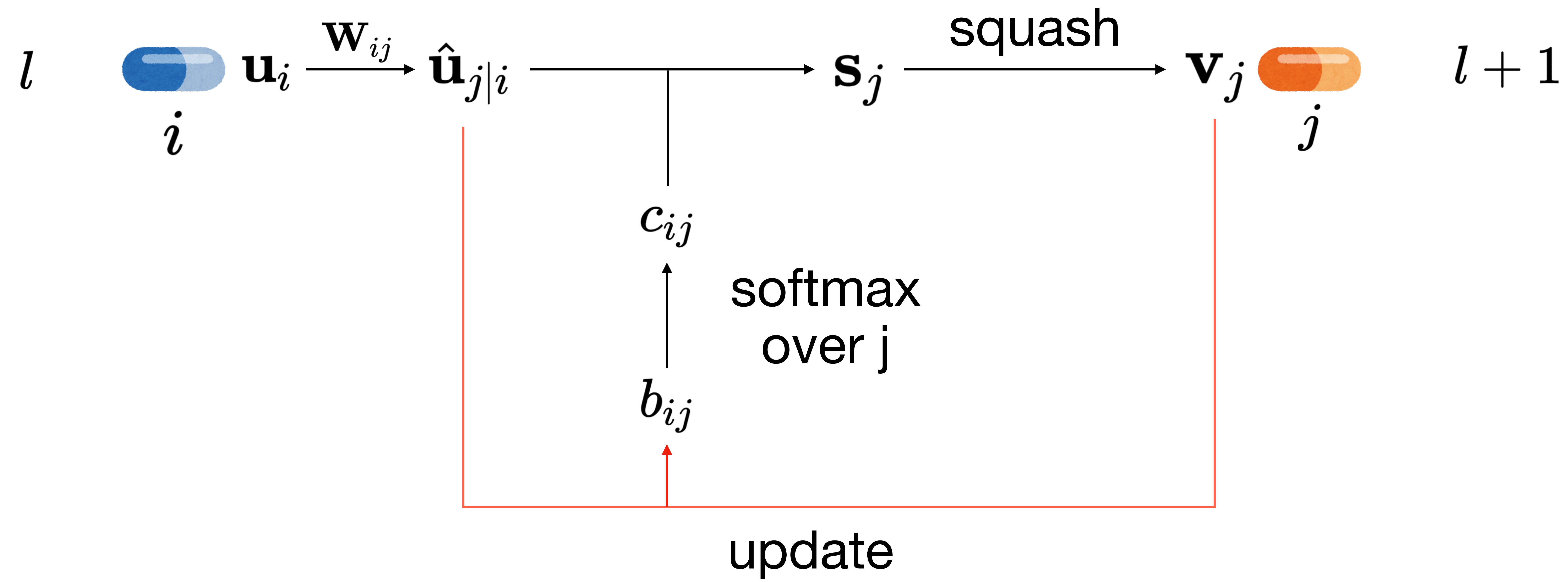
softmax over j

b_{ij}

Method

Routing

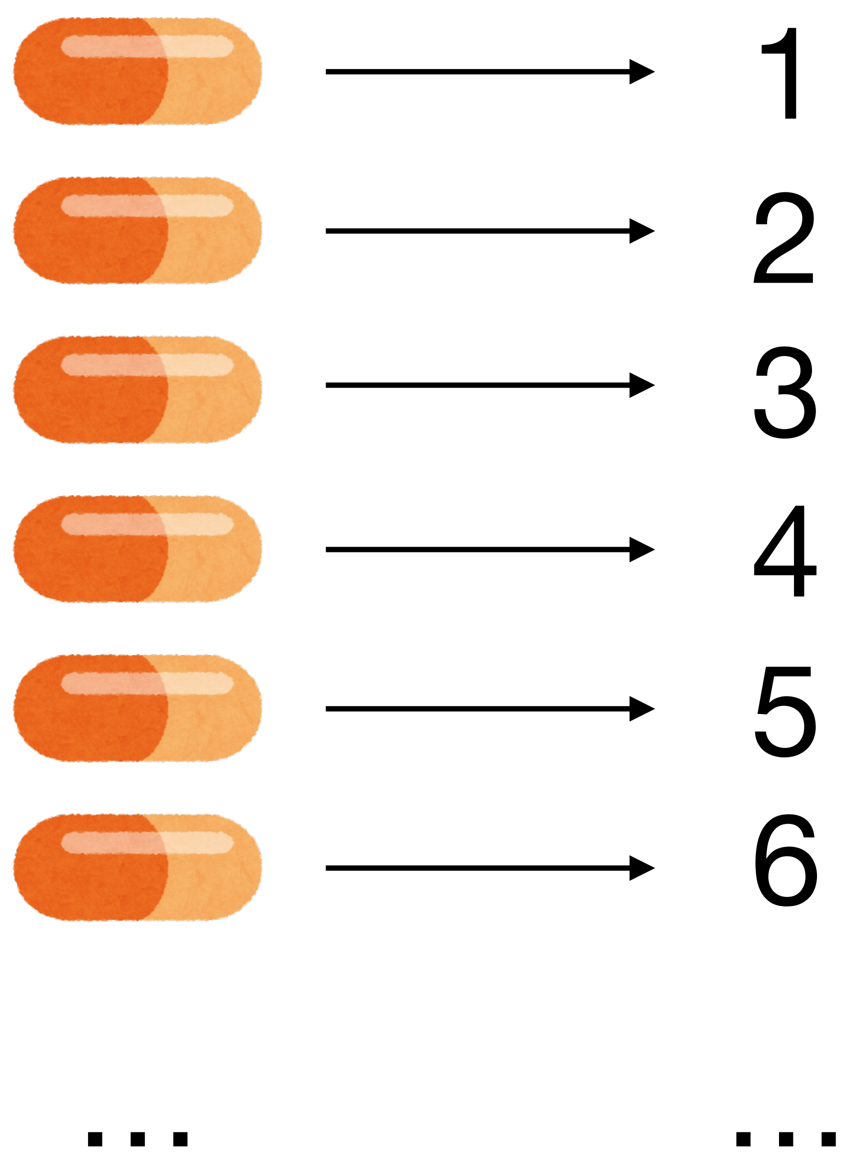
- b_{ij} initialized to 0, update by $b_{ij} \leftarrow b_{ij} + \hat{\mathbf{u}}_{j|i} \cdot \mathbf{v}_j$
- Each capsule is **routed** to its most similar one in the next layer



Method

Prediction

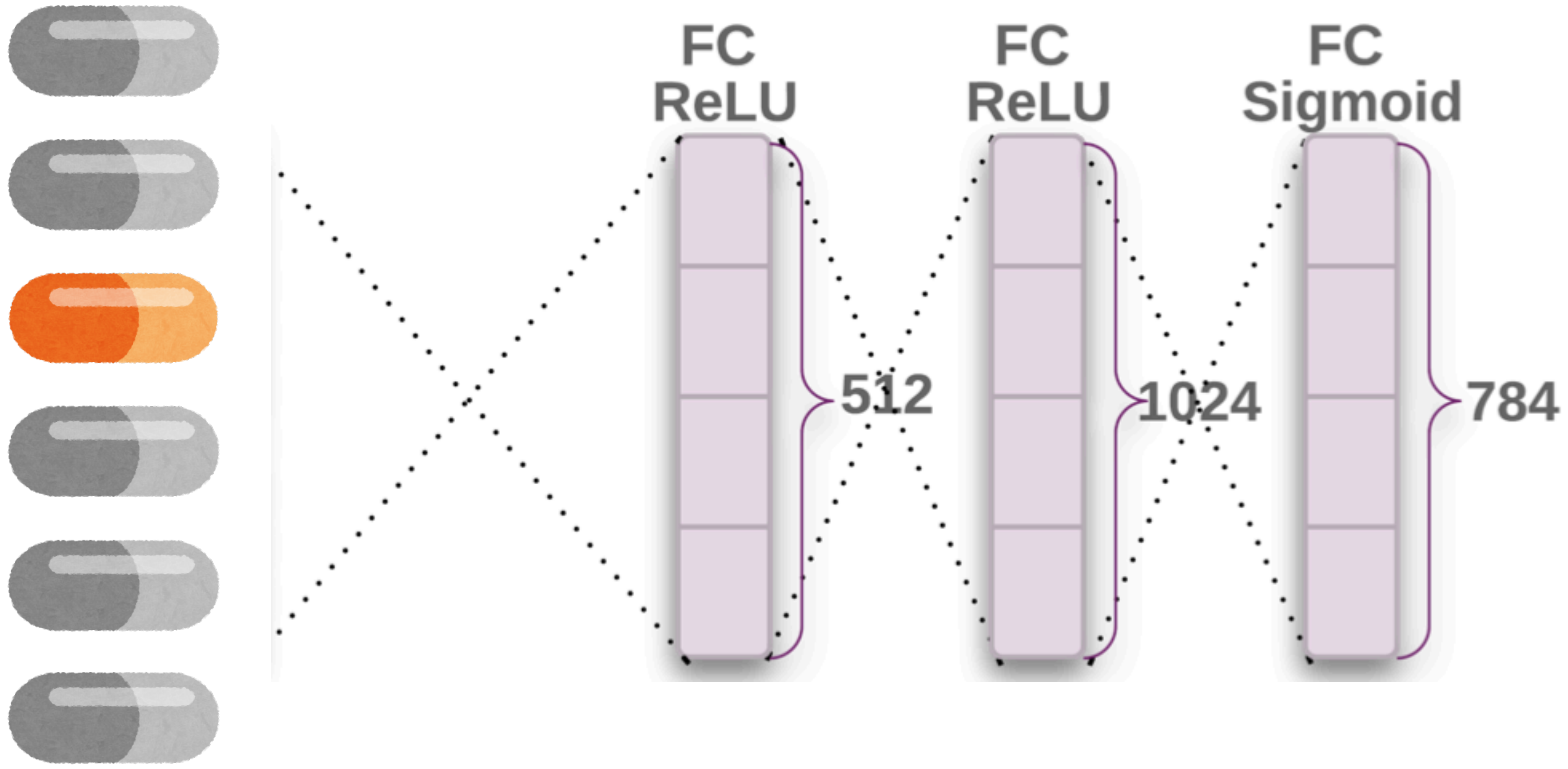
- The norm of vectors
- Classification loss $L_+ = \max(0, 0.9 - ||\mathbf{v}_k||)^2, L_- = \max(0, ||\mathbf{v}_k|| - 0.1)^2$



Method

Reconstruction

- Reconstruction loss: the sum of squared differences between reconstructed images and the original images



Result

Test Set Performance

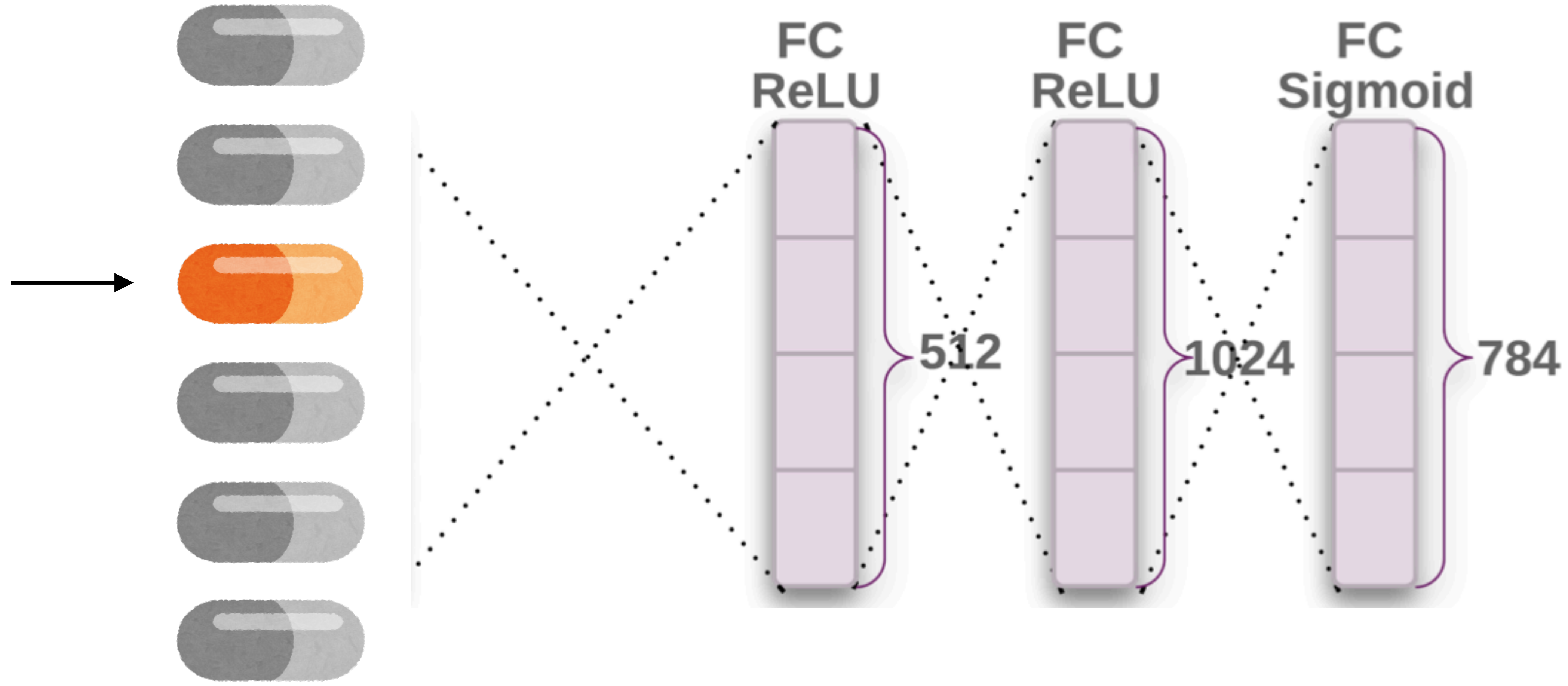
My Accuracy	Reported Accuracy
99.22%	99.75%

- Not enough training
- Choices of hyper-parameters

Result

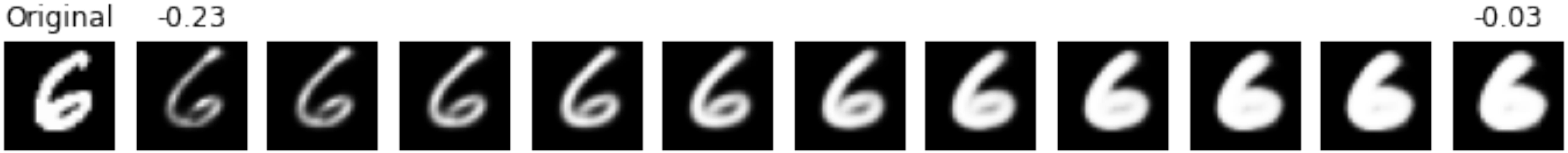
Tweaking One Value in the Classification Capsules

- Change a value in the capsule, and then reconstruct



Result

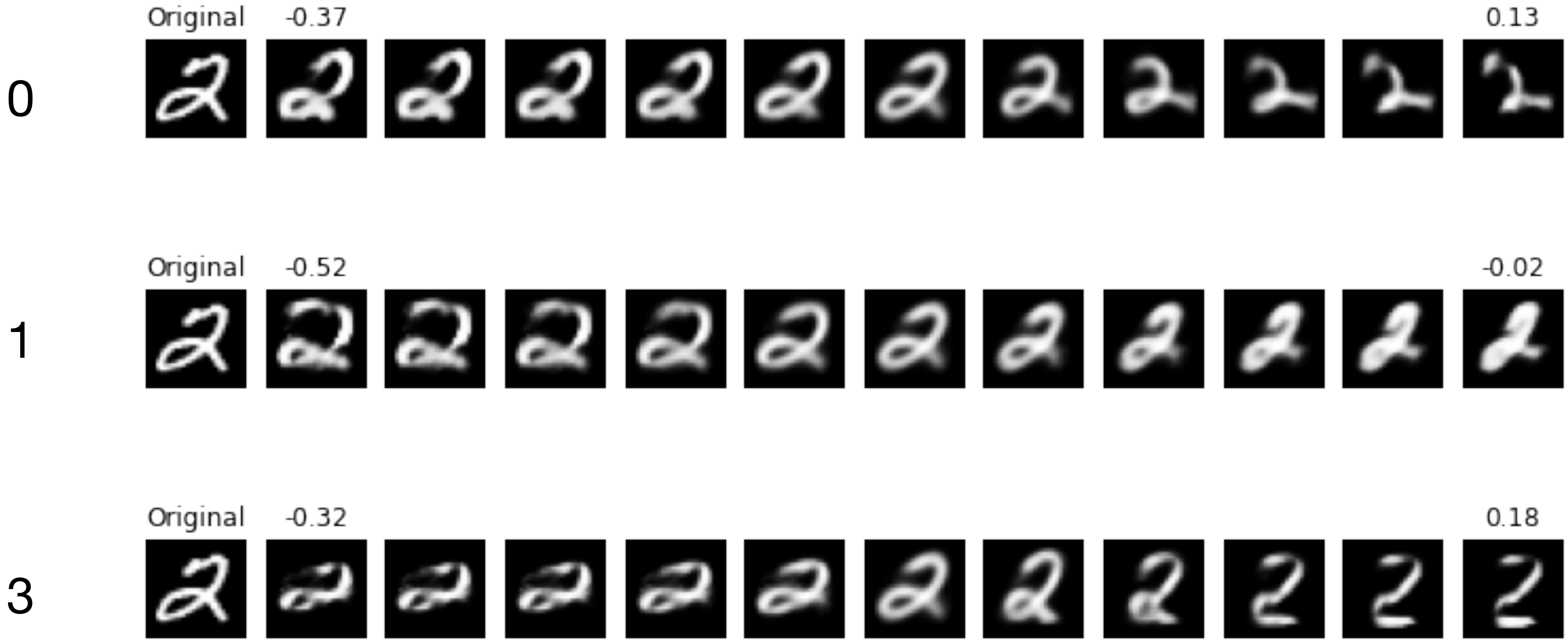
Tweaking One Value in the Classification Capsules



dimension 5 in vector 6

Result

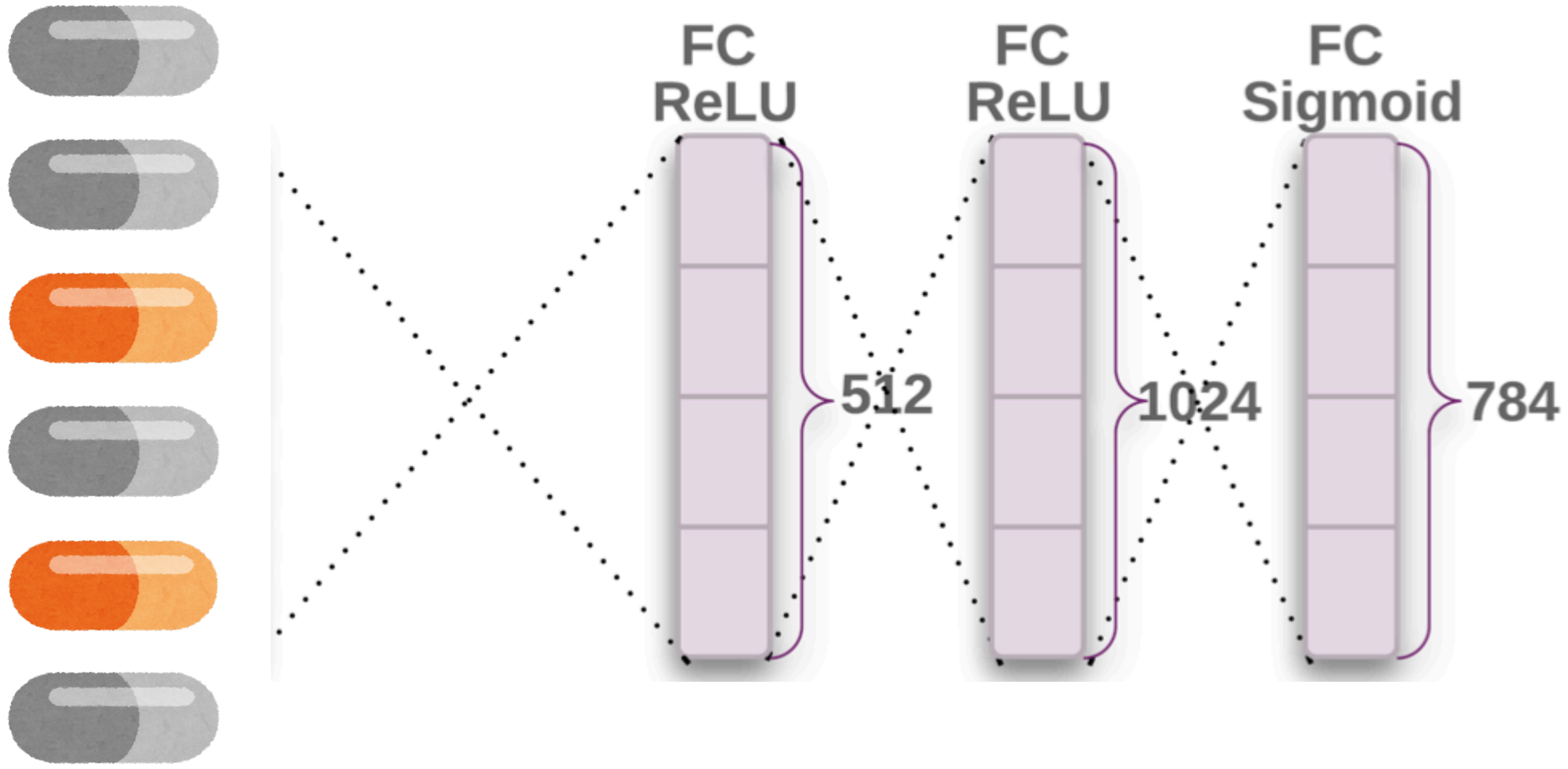
Tweaking One Value in the Classification Capsules



Result

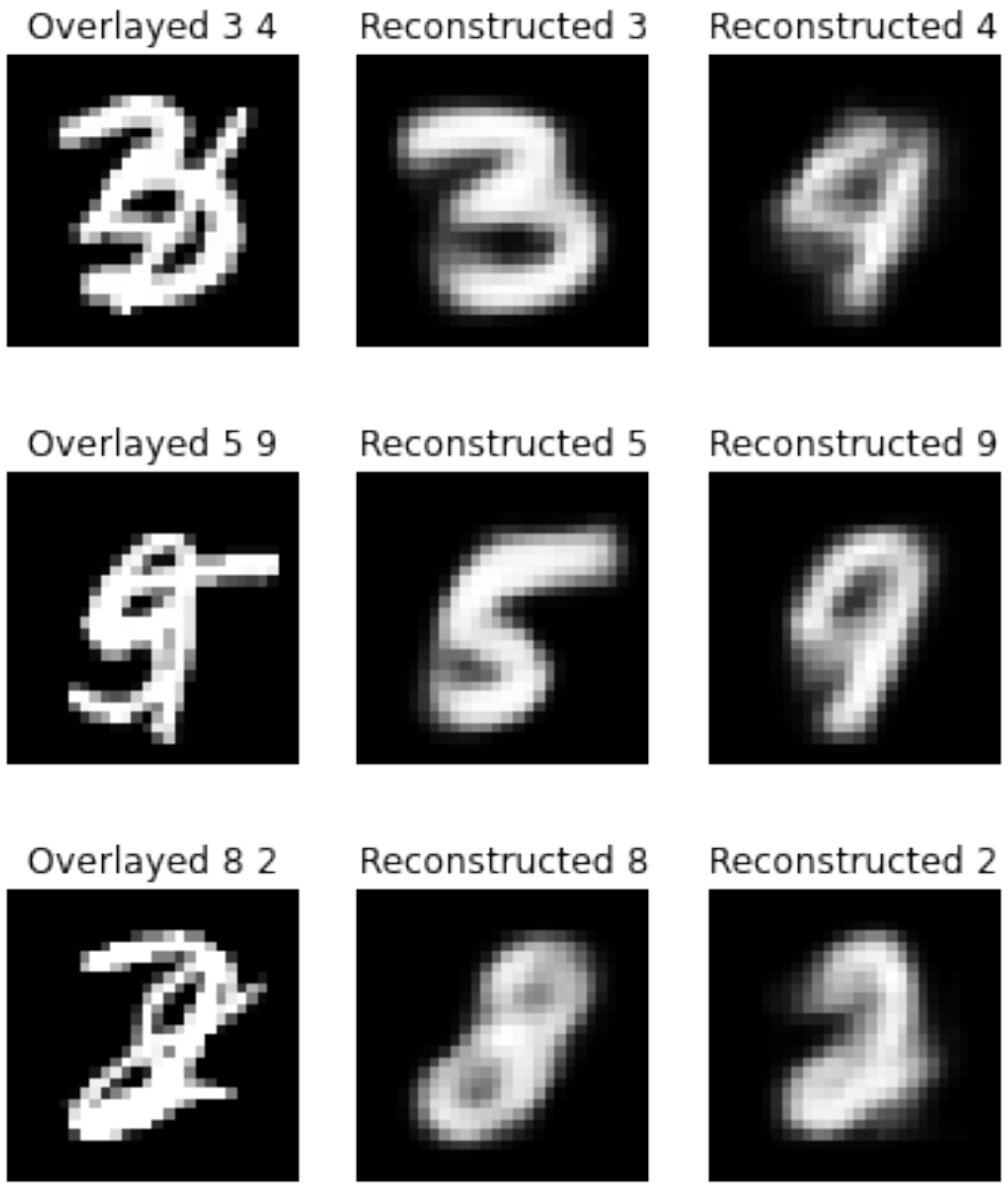
Multi-MNIST: Overlay of Two Images of Different Digits

- Classify the image with two digits, and reconstruct them separately



Result

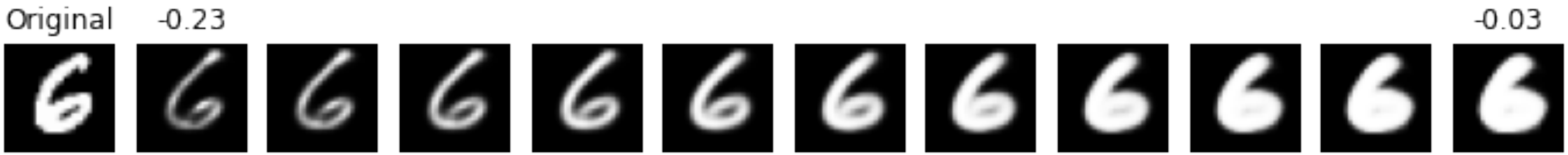
Multi-MNIST: Overlay of Two Images of Different Digits



Pull Request

That I Wish for

- An interactive interface for vector tweaking



Pull Request

That I Wish for

- An interactive interface for vector tweaking
- Any choices of hyper-parameters that can improve the performance
- A pipeline for multi-MNIST dataset training and testing

Thank you!