Capsule Networks

Aurélien Géron, November 2017

https://youtu.be/pPN8d0E3900

NIPS 2017 Paper

Dynamic Routing Between Capsules

by Sara Sabour, Nicholas Frosst, Geoffrey E. Hinton

October 2017: https://arxiv.org/abs/1710.09829

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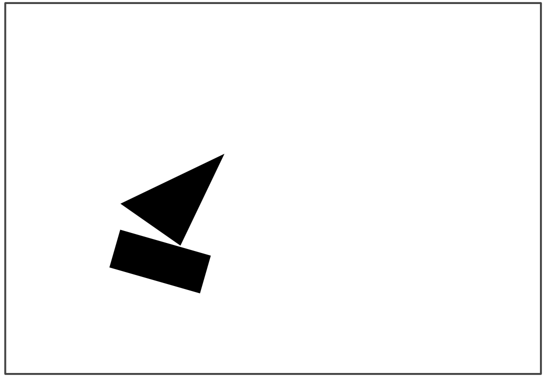
Computer Graphics

Rectangle

x=20
y=30
angle=16°

Triangle

x=24
y=25
angle=-65°



Instantiation parameters

Rendering

Image

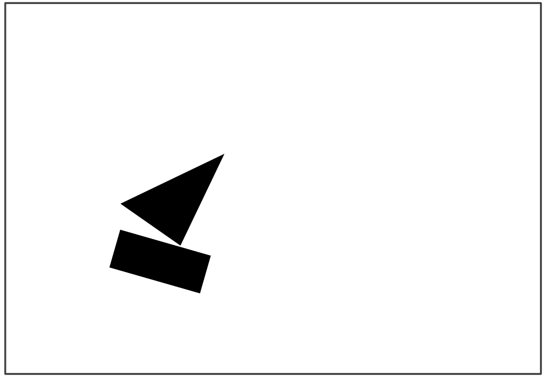
Inverse Graphics

Rectangle

x=20
y=30
angle=16°

Triangle

x=24
y=25
angle=-65°

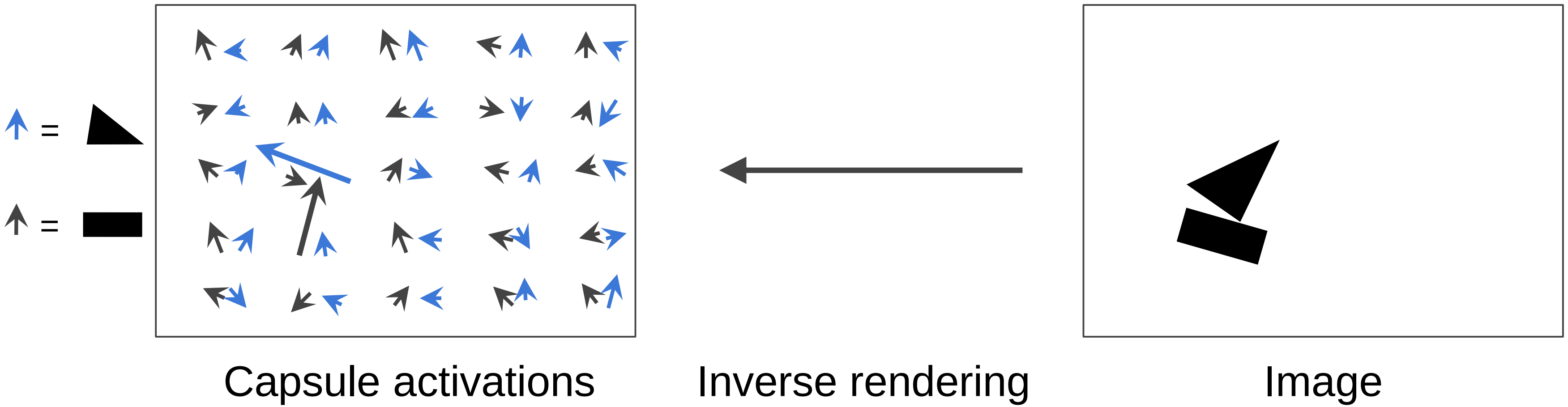


Instantiation parameters

Inverse rendering

Image

Capsules



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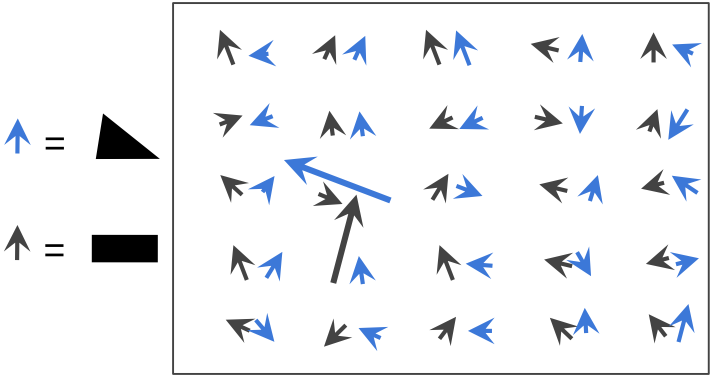
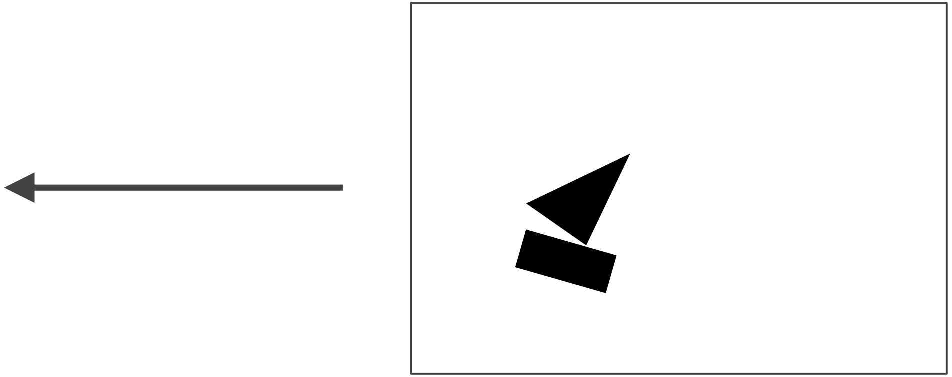
Capsules

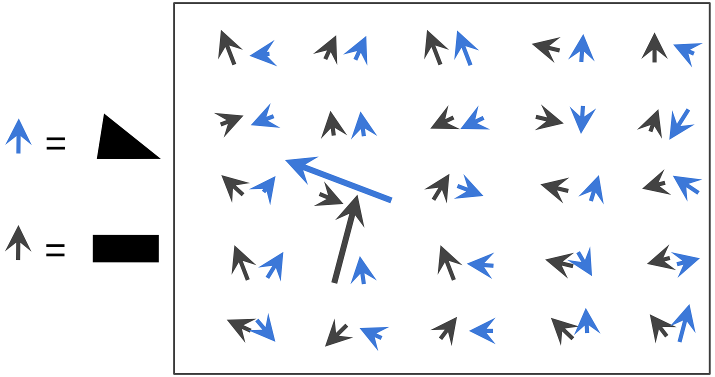




Activation vector:

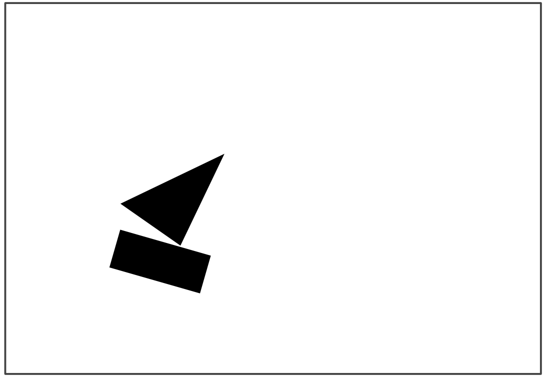
Length = estimated probability of presence
Orientation = object's estimated pose parameters

Capsules



Convolutional Layers

\+ Reshape
\+ Squash



$$\text{Squash}(\mathbf{u}) = \frac{\|\mathbf{u}\|^2}{1 + \|\mathbf{u}\|^2} \frac{\mathbf{u}}{\|\mathbf{u}\|}$$

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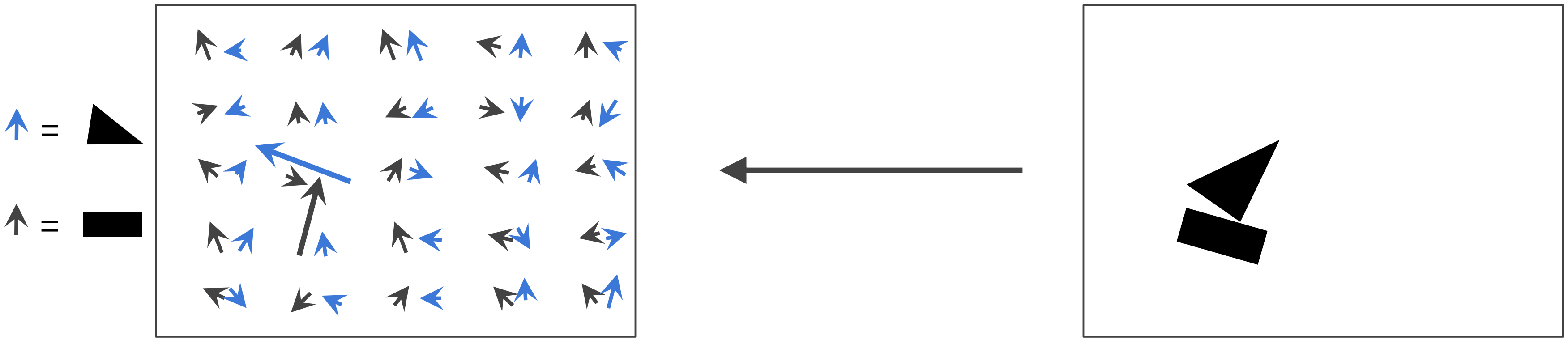
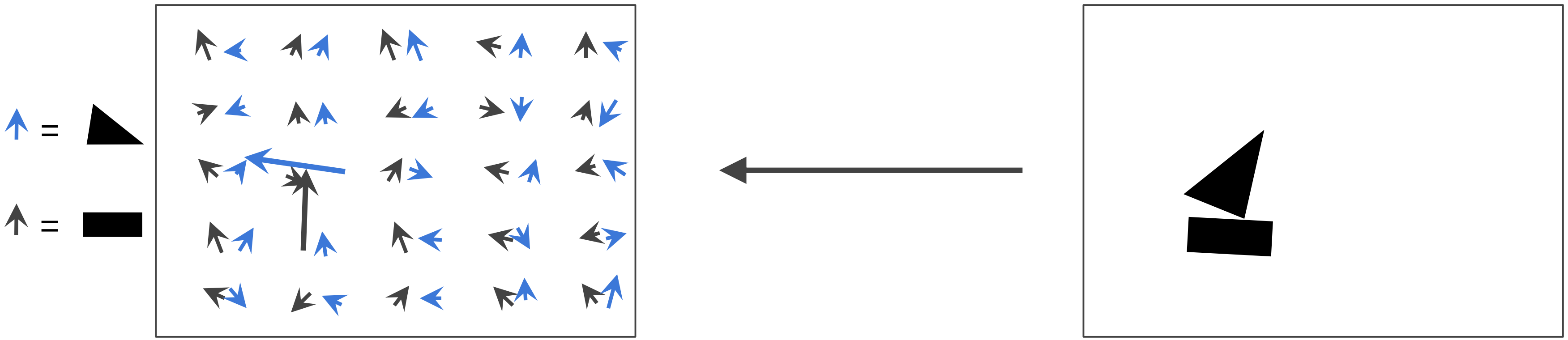
Equivariance



Equivariance



A hierarchy of parts

Boat

x=22
y=28
angle=16°

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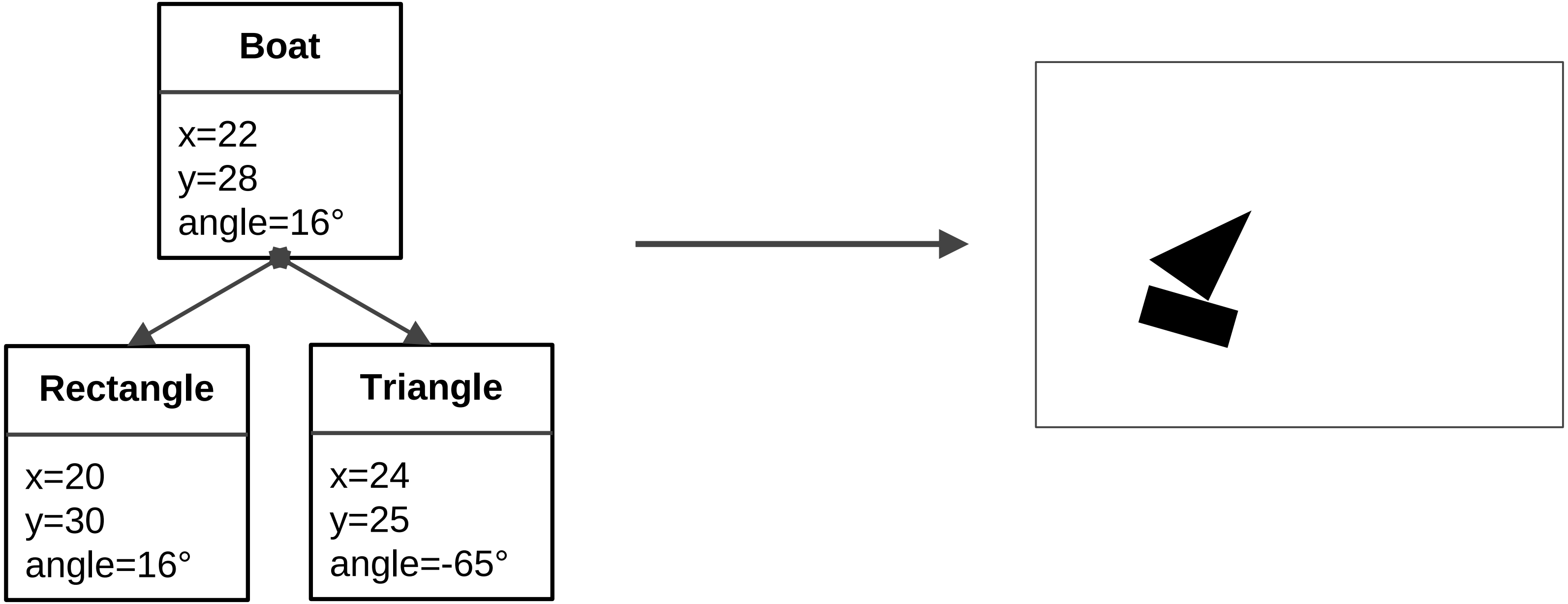
A hierarchy of parts



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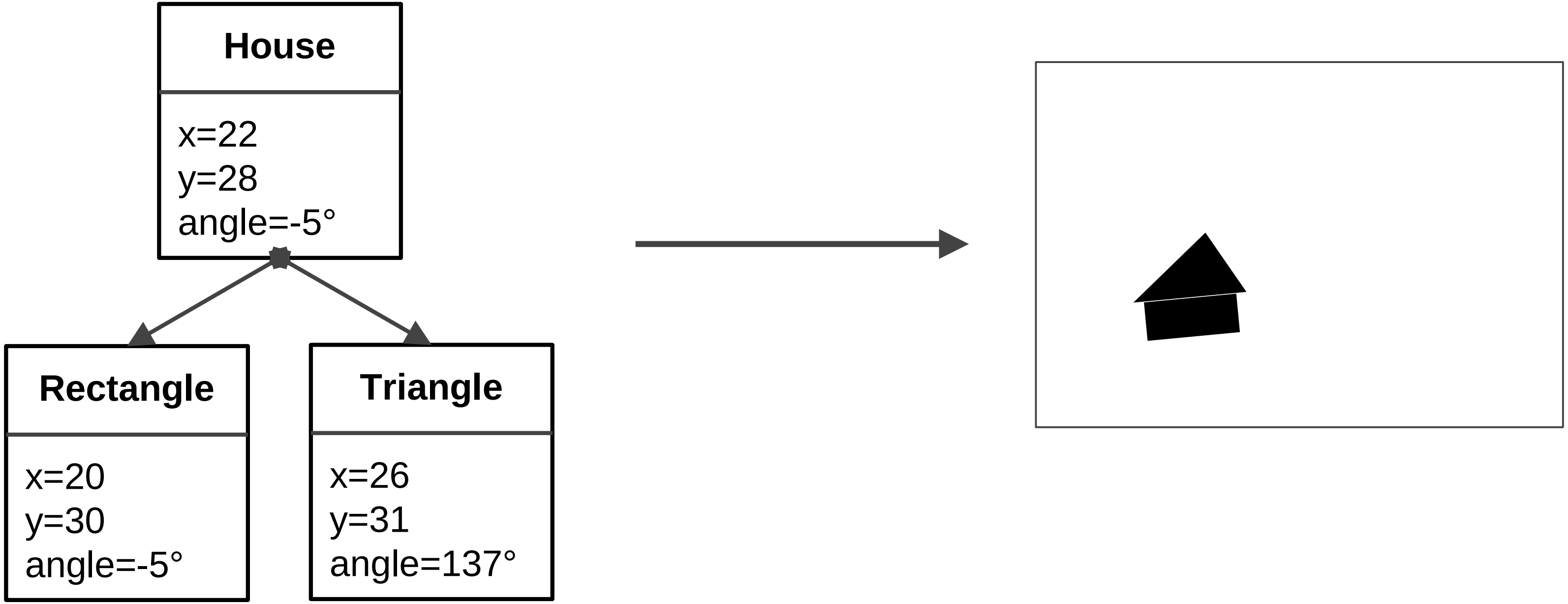
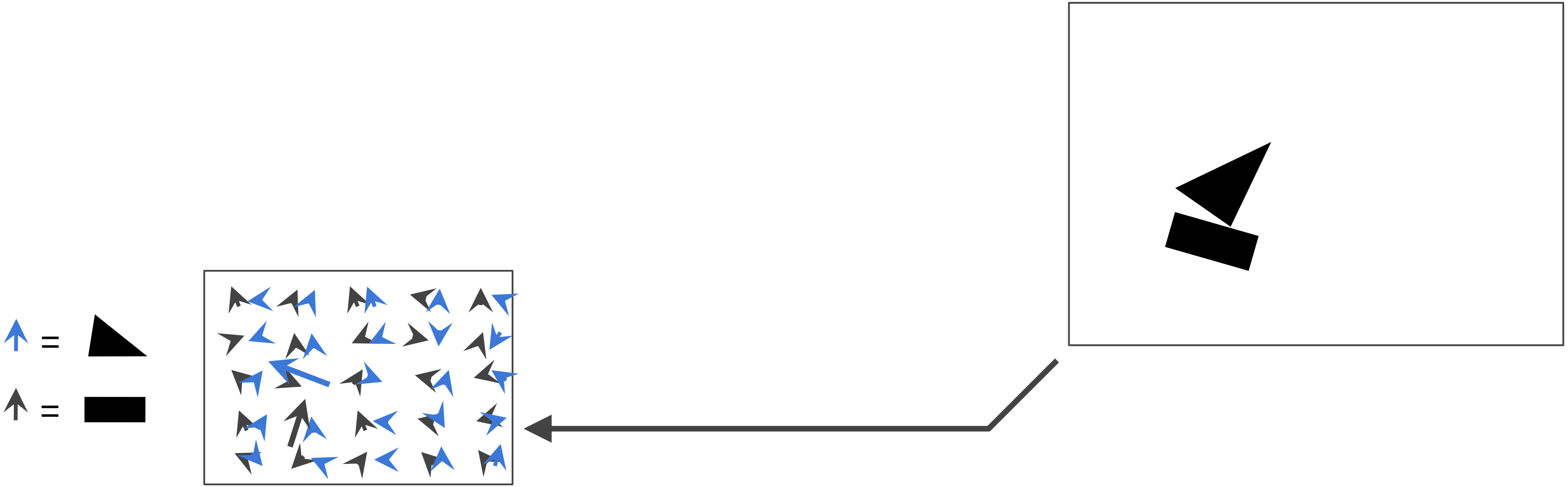
A hierarchy of parts



Primary Capsules



Primary Capsules

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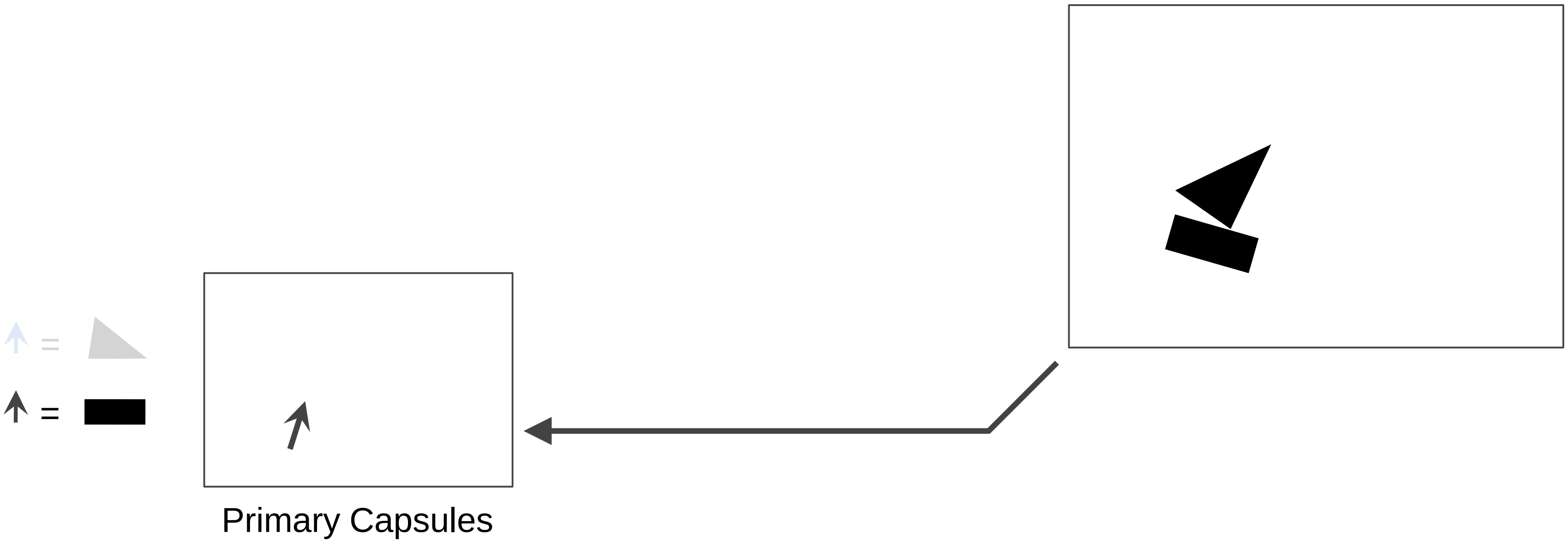
Predict Next Layer's Output



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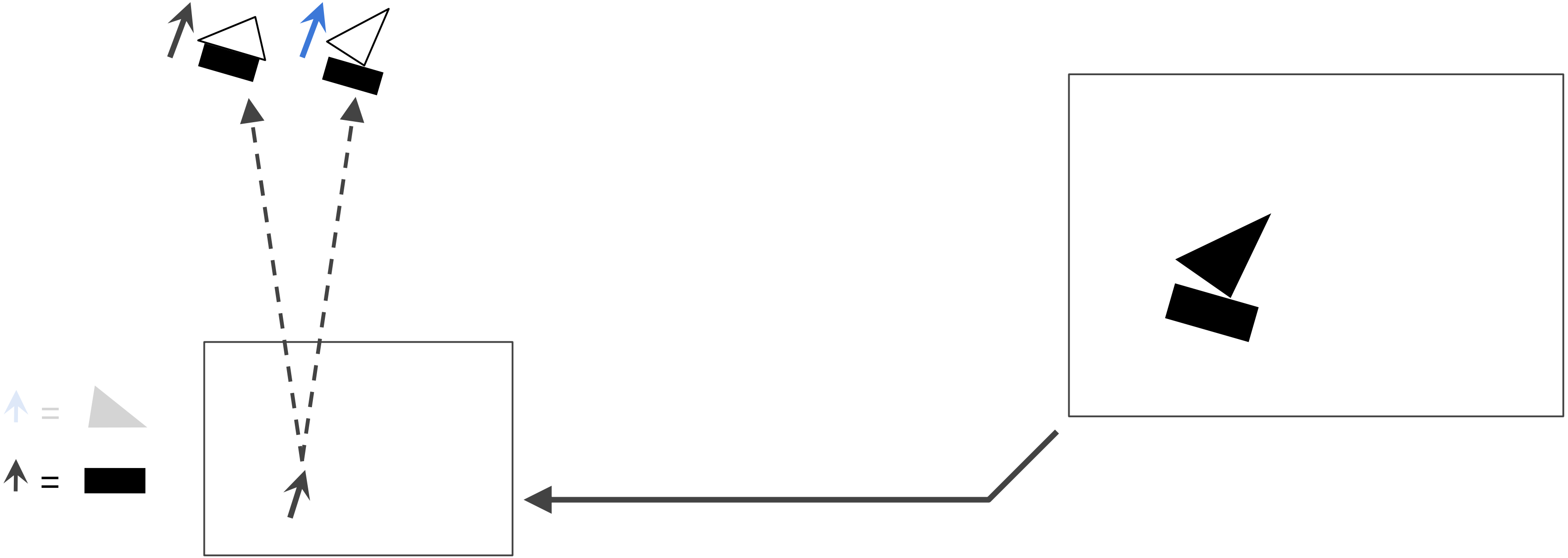
Predict Next Layer's Output



Primary Capsules

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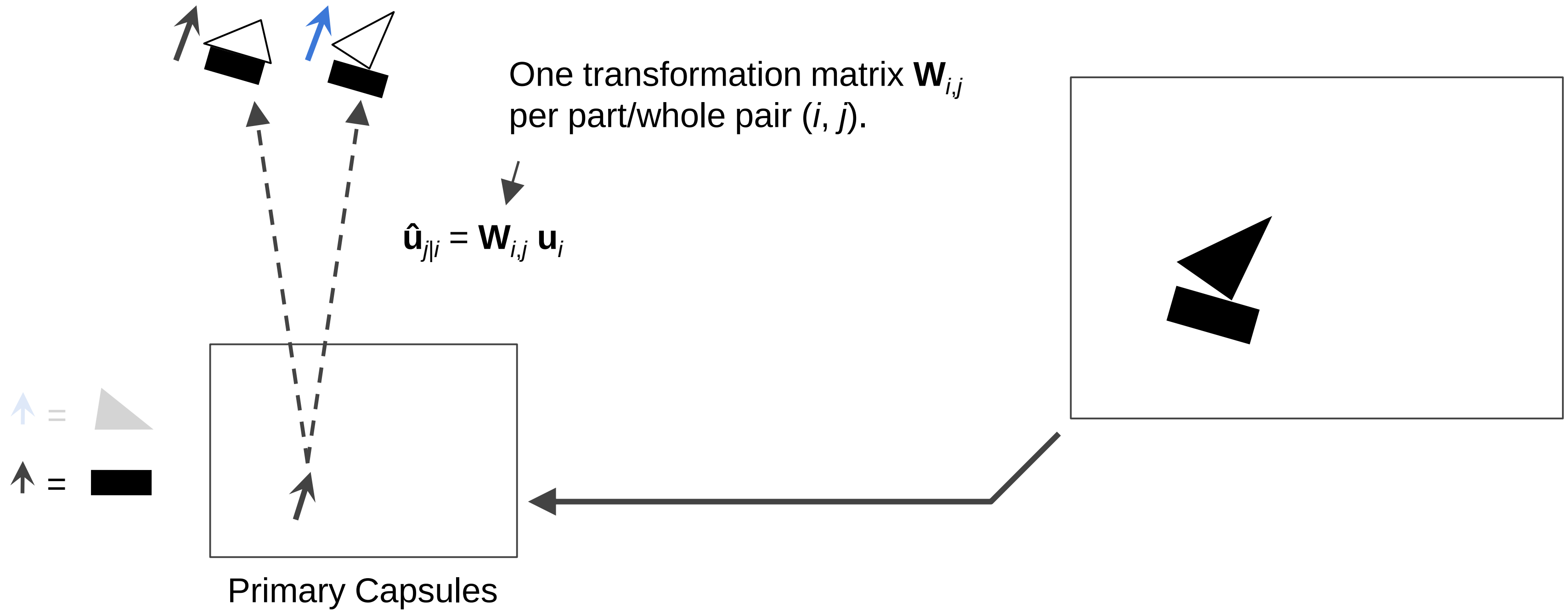
Predict Next Layer's Output



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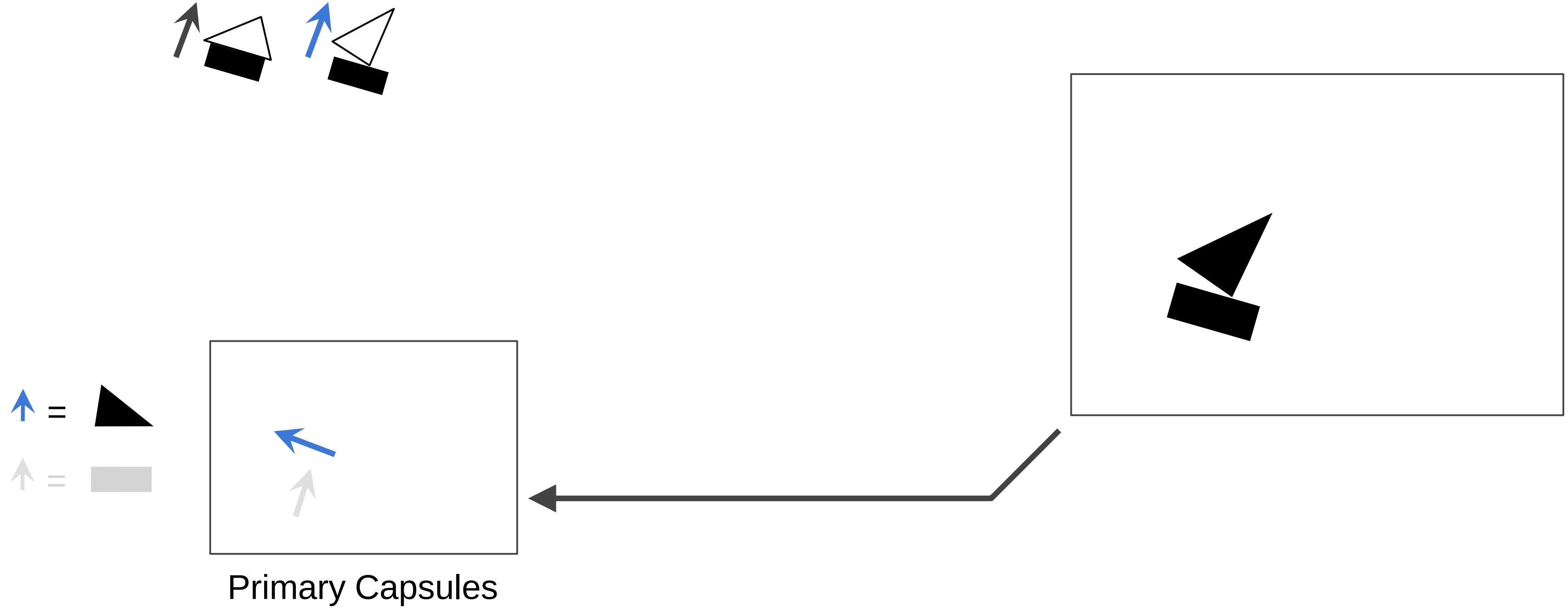
Predict Next Layer's Output



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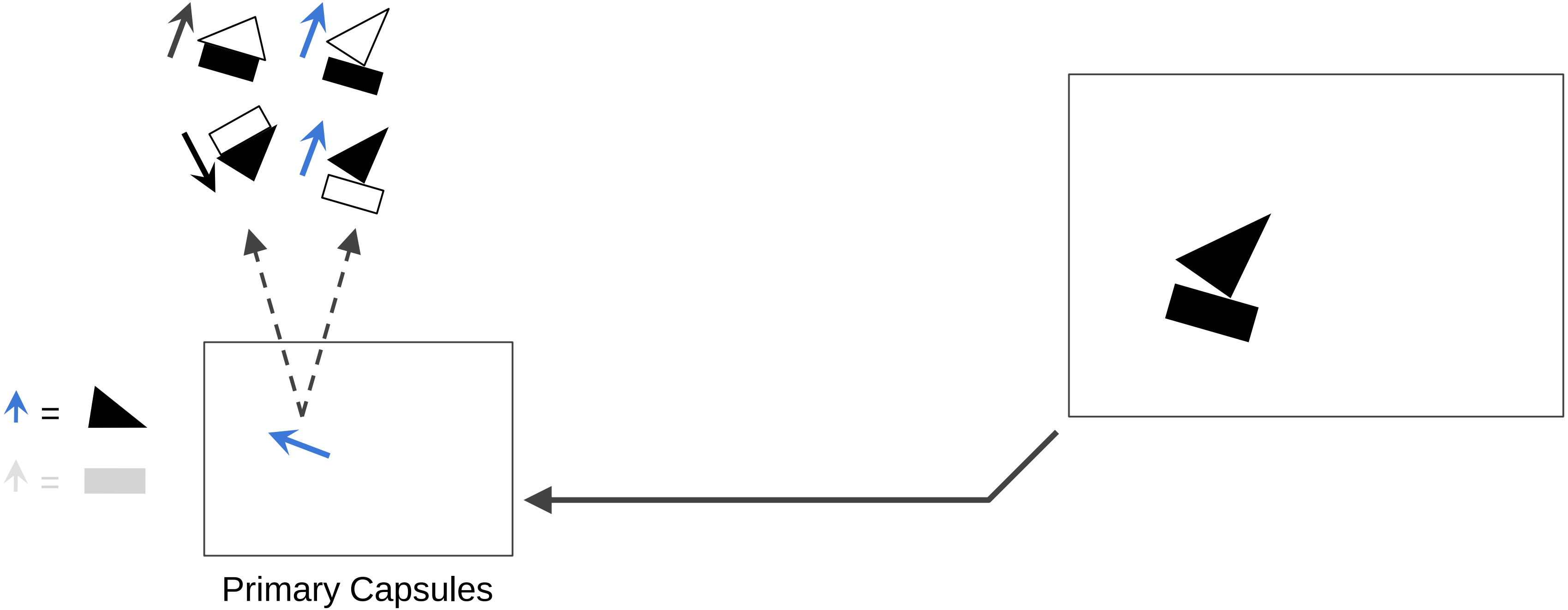
Predict Next Layer’s Output



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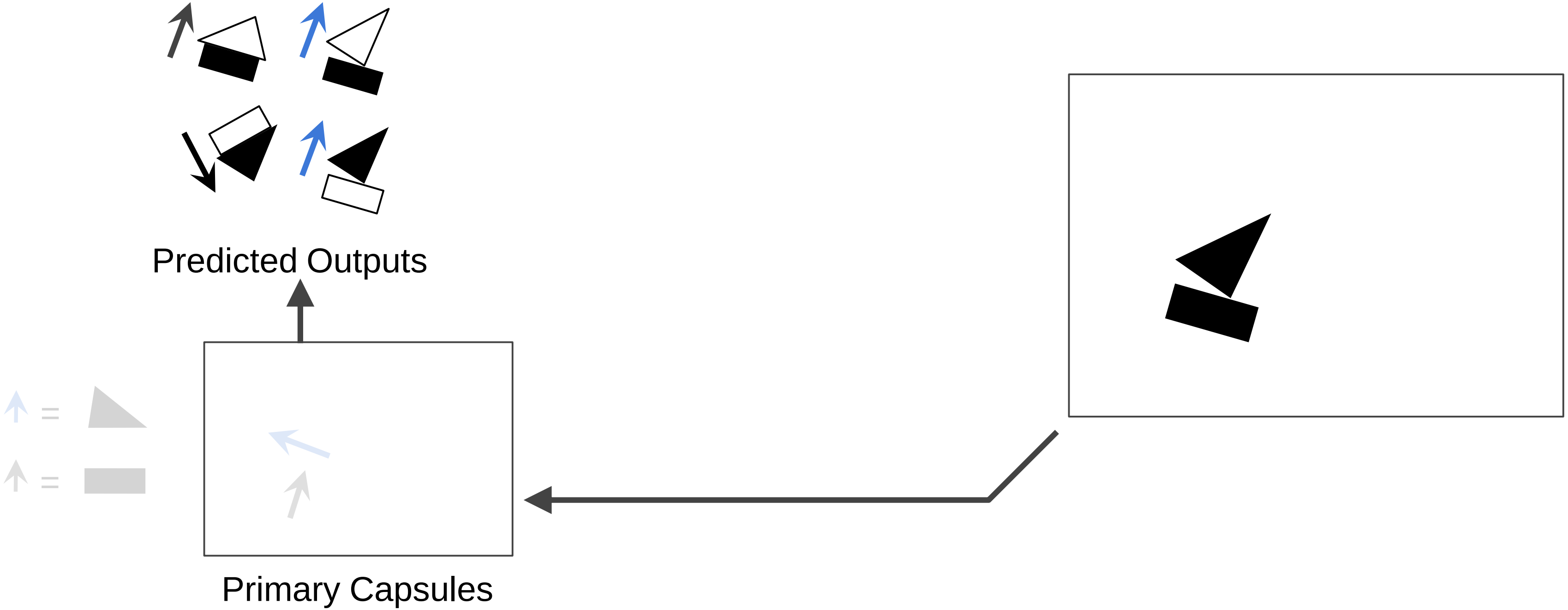
Compute Next Layer's Output



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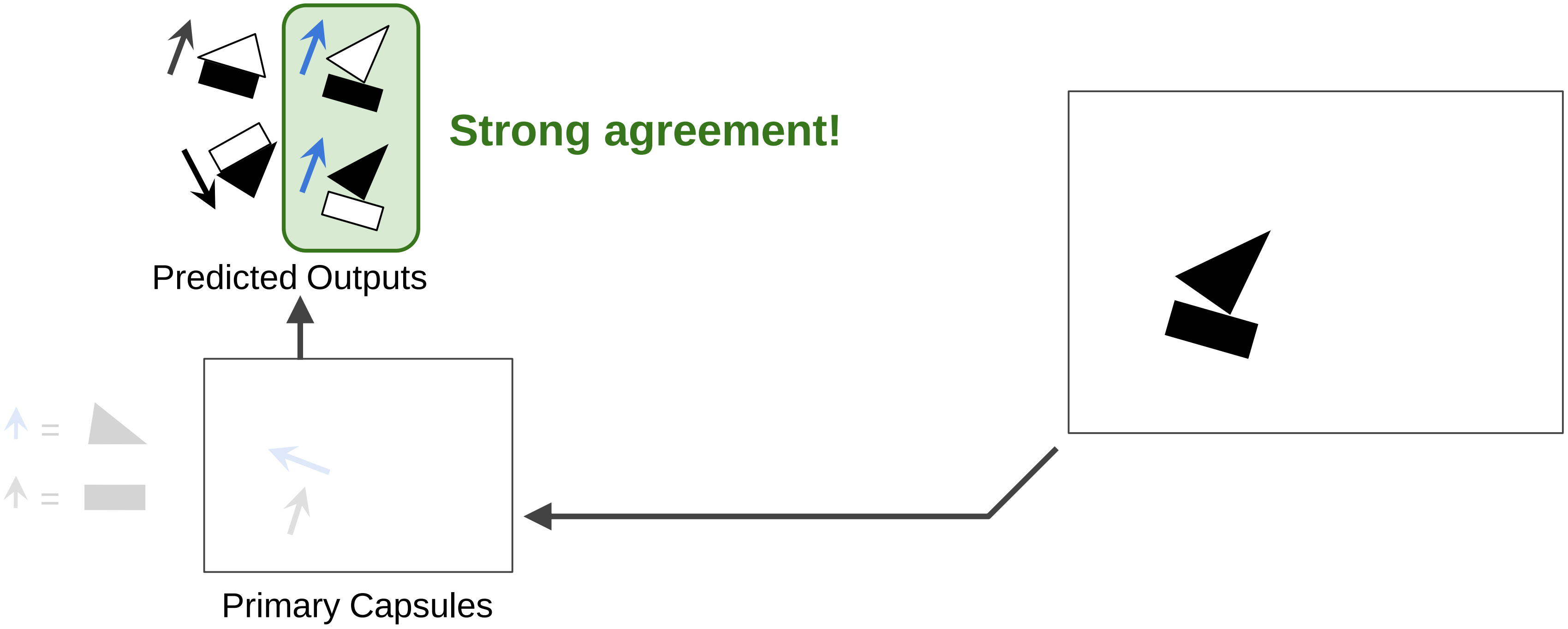
Routing by Agreement



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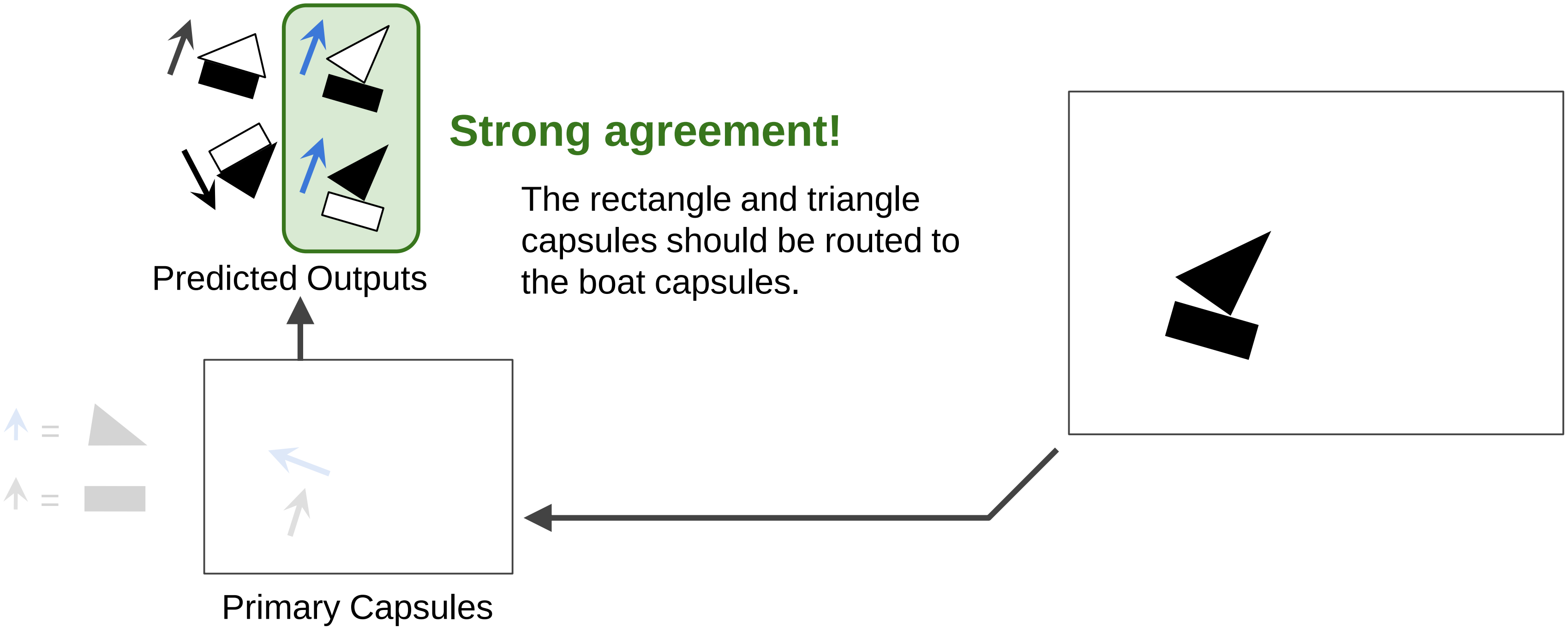
Routing by Agreement



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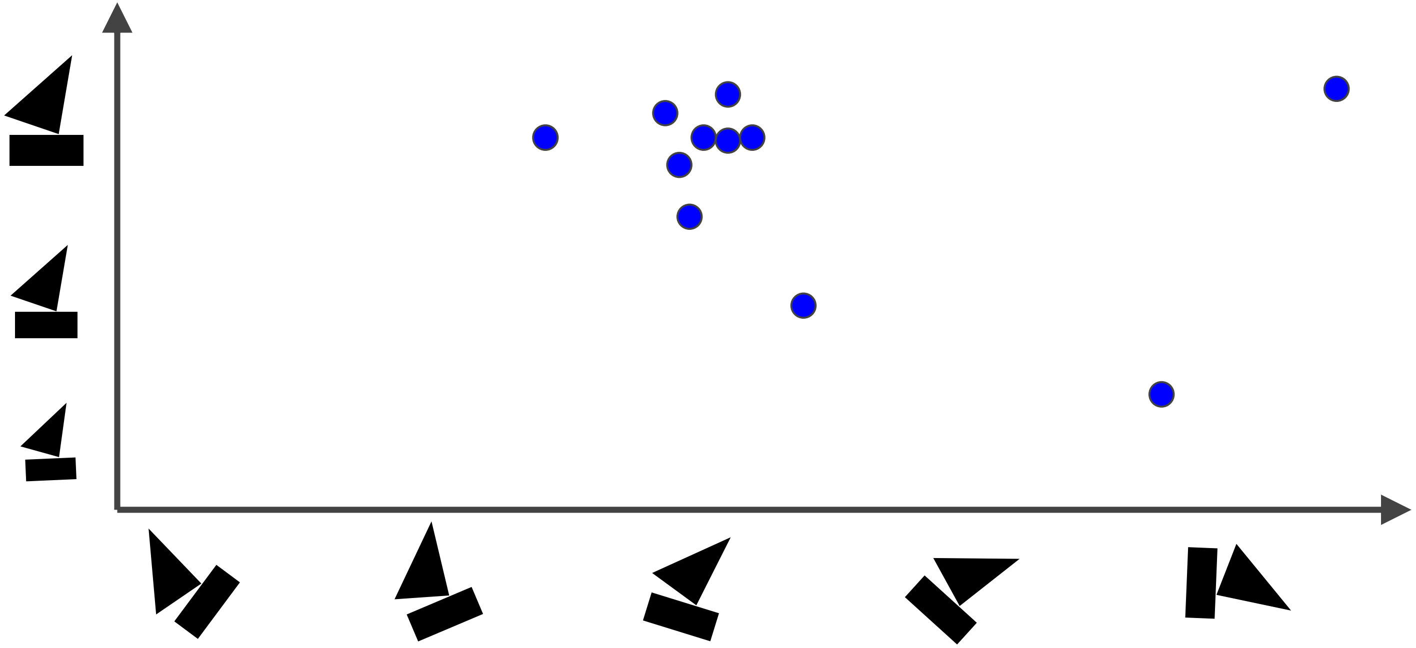
Clusters of Agreement



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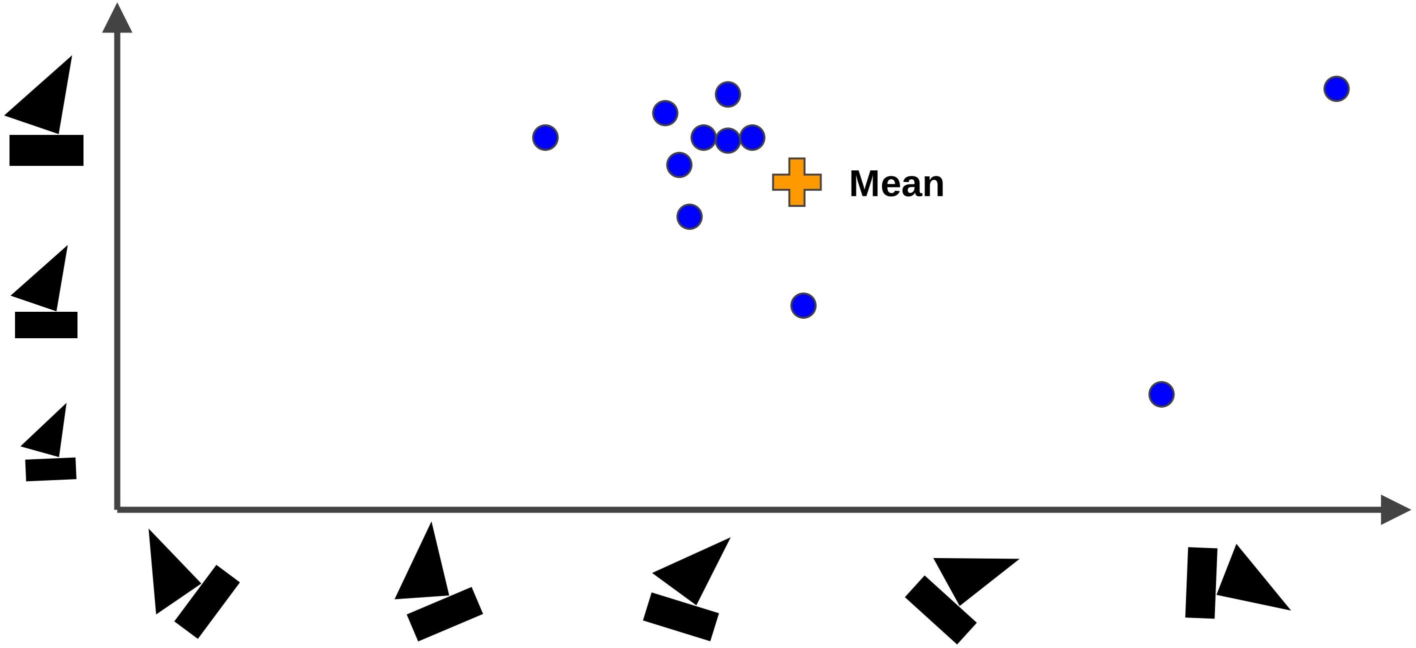

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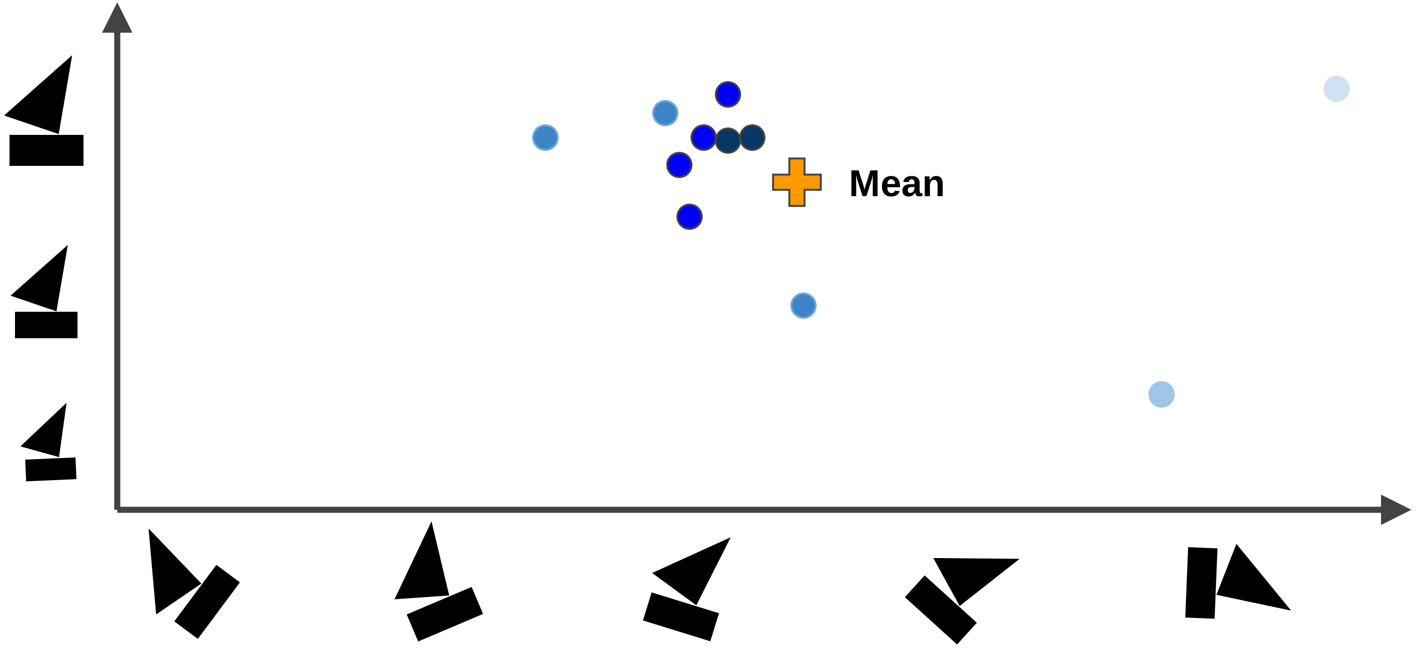

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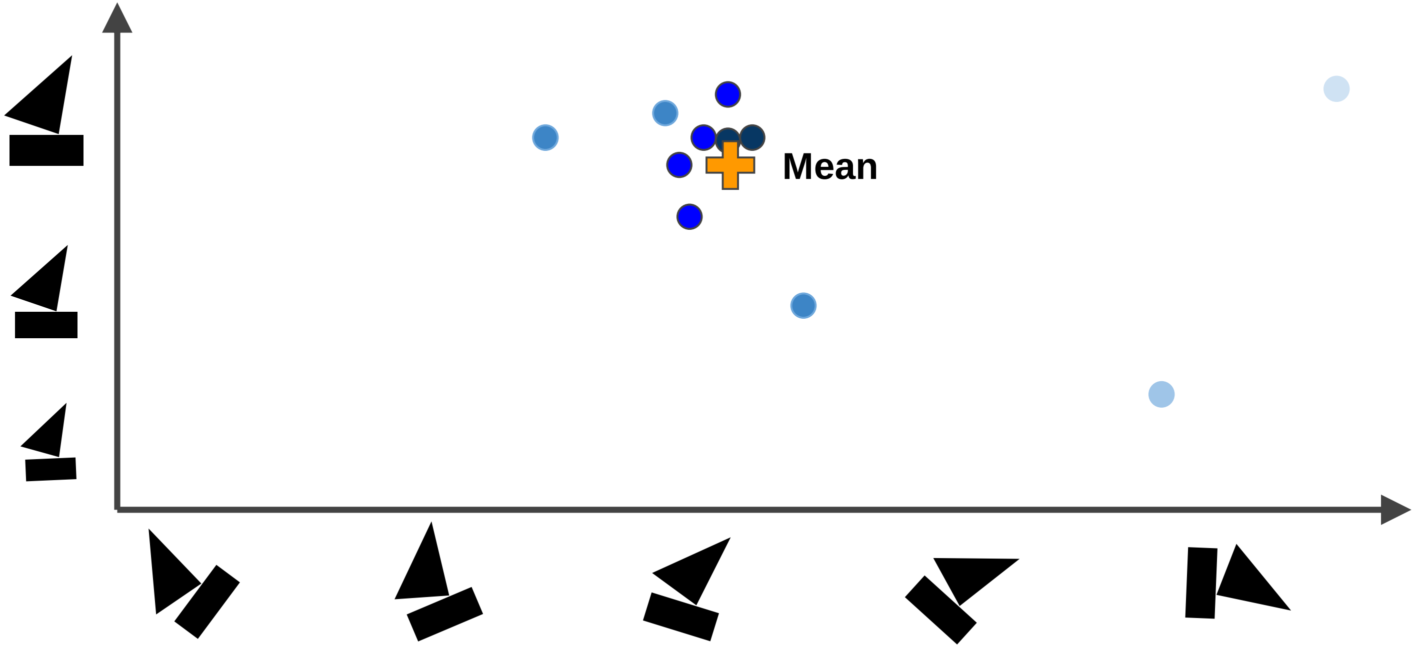

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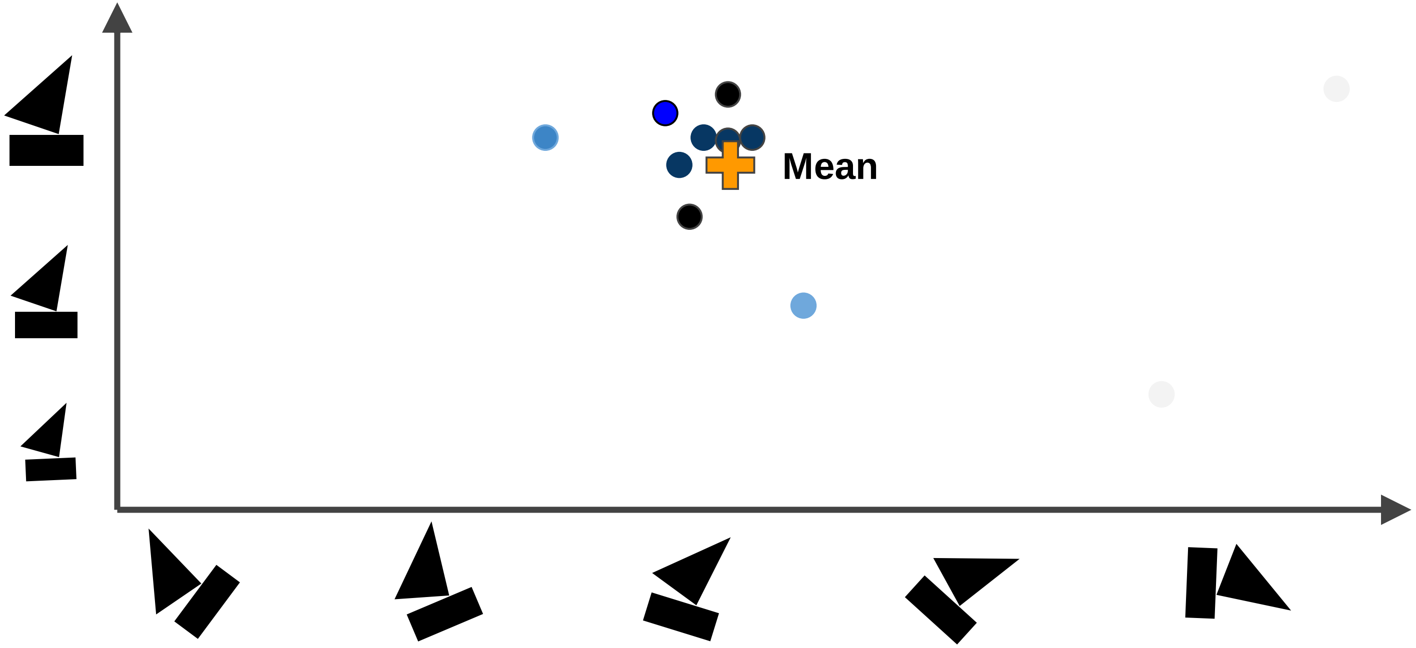

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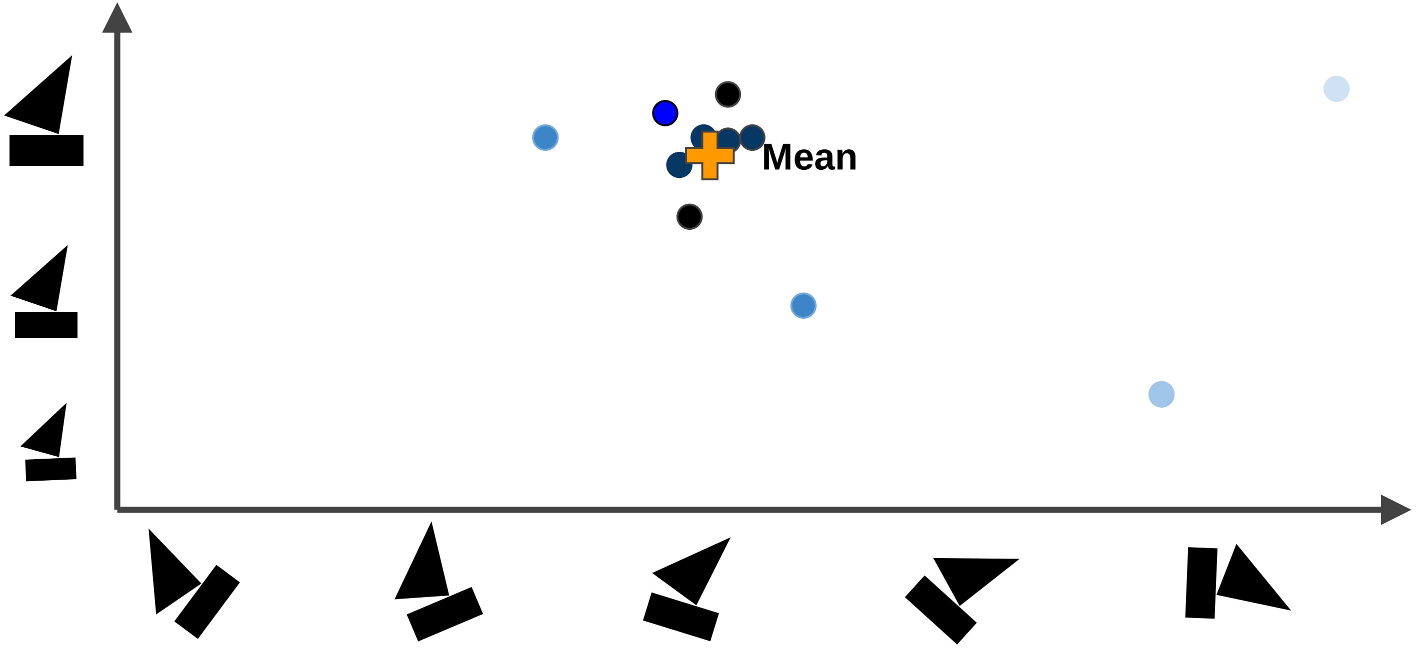
Clusters of Agreement



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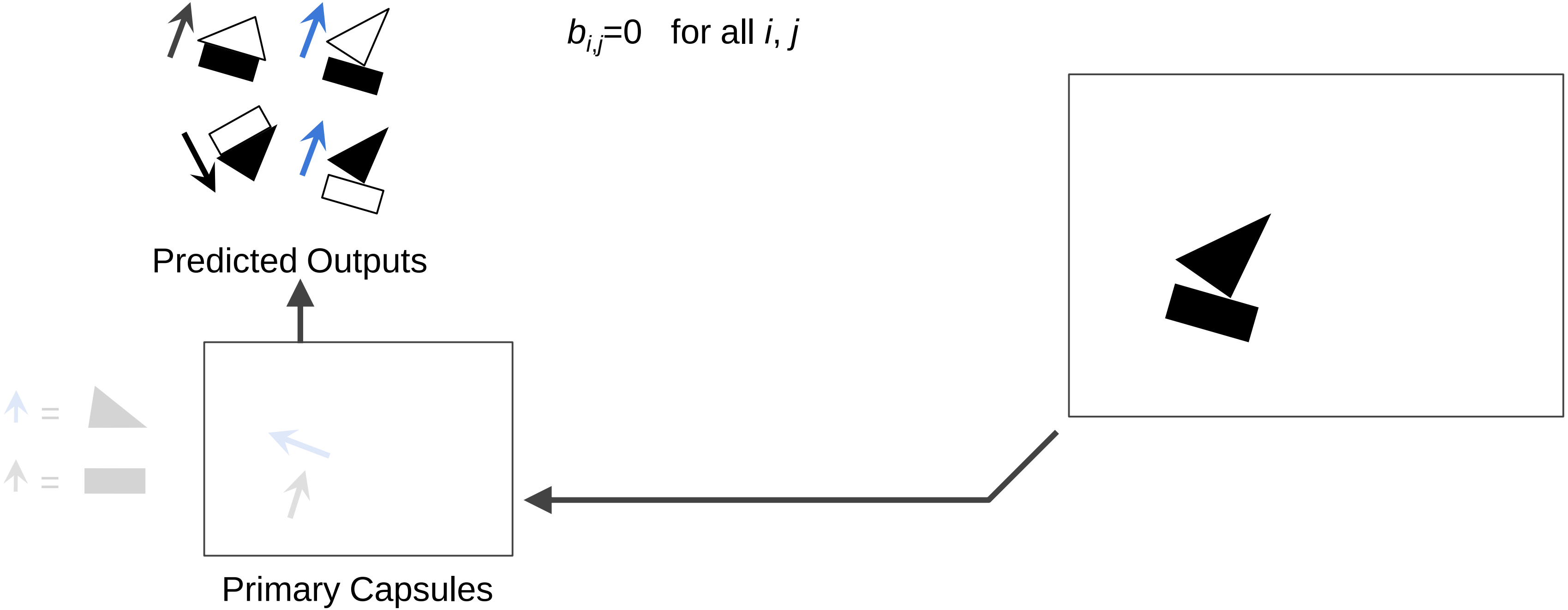
Routing Weights

$b_{i,j}=0$ for all i, j



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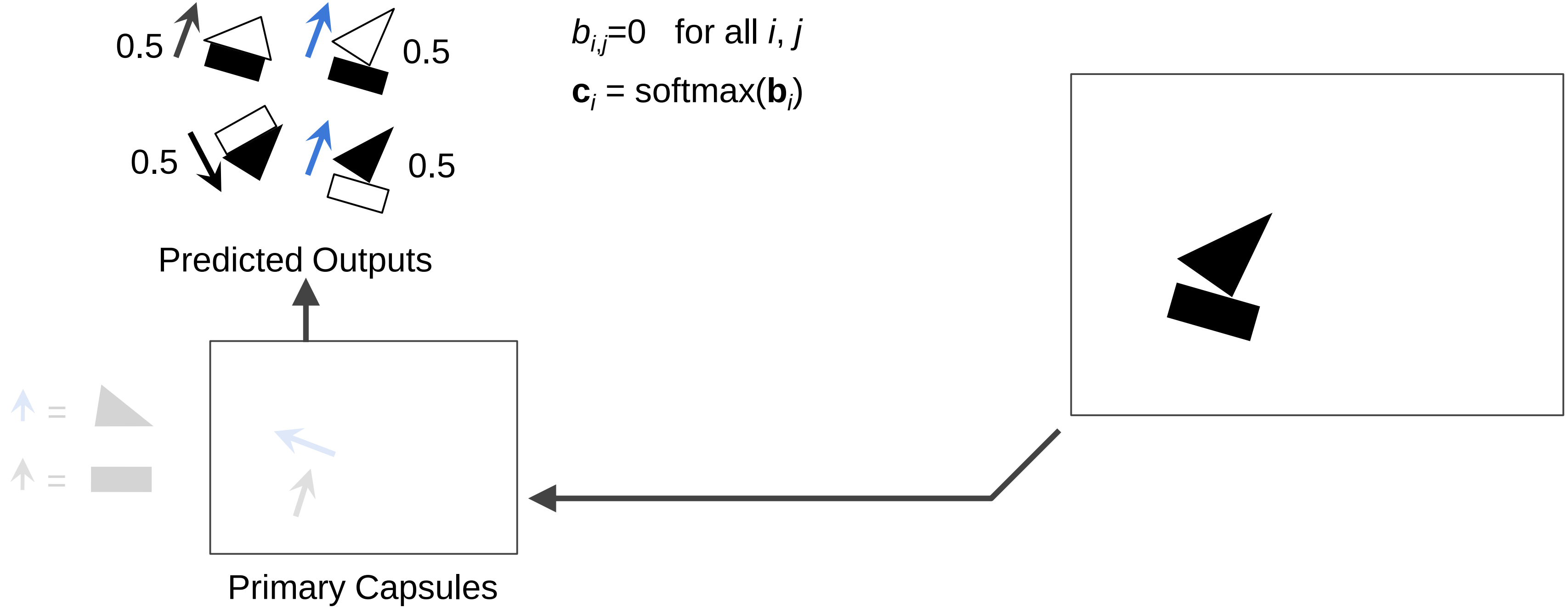
Routing Weights

$b_{i,j}=0$ for all i, j

$\mathbf{c}_i = \text{softmax}(\mathbf{b}_i)$



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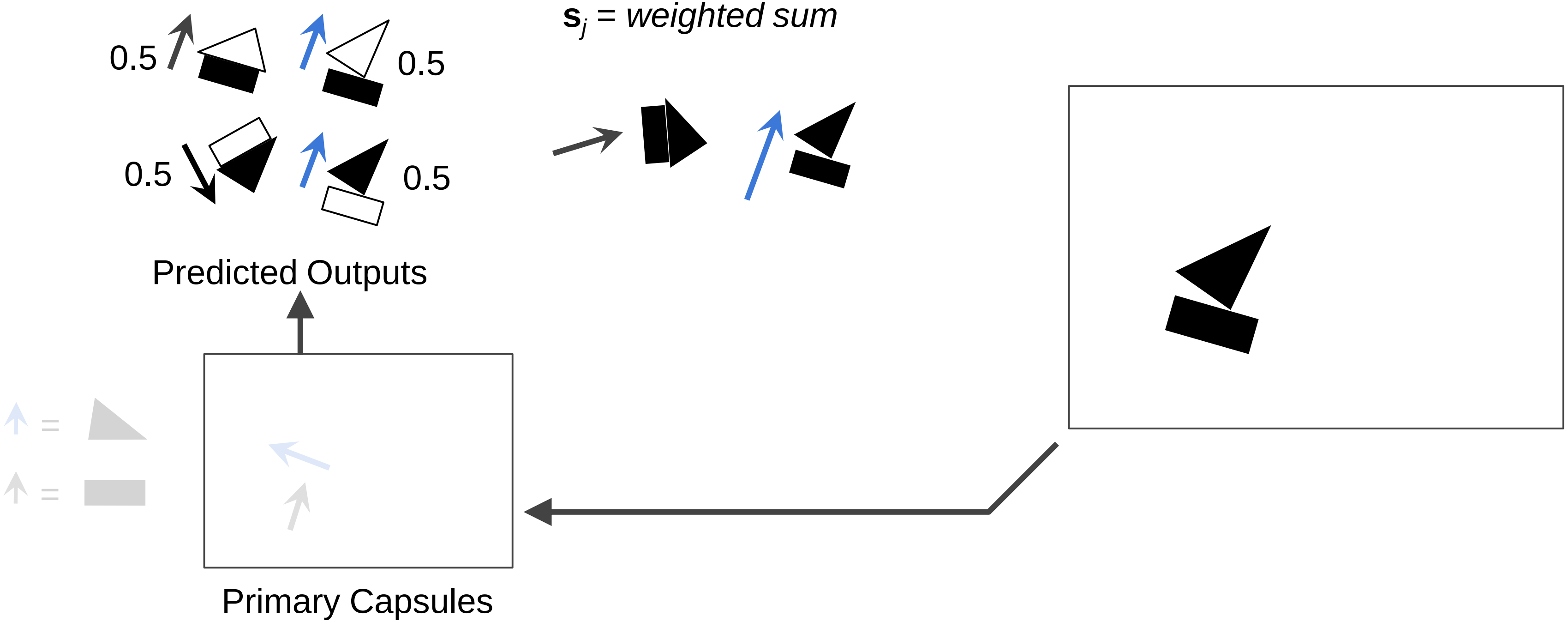
Compute Next Layer's Output



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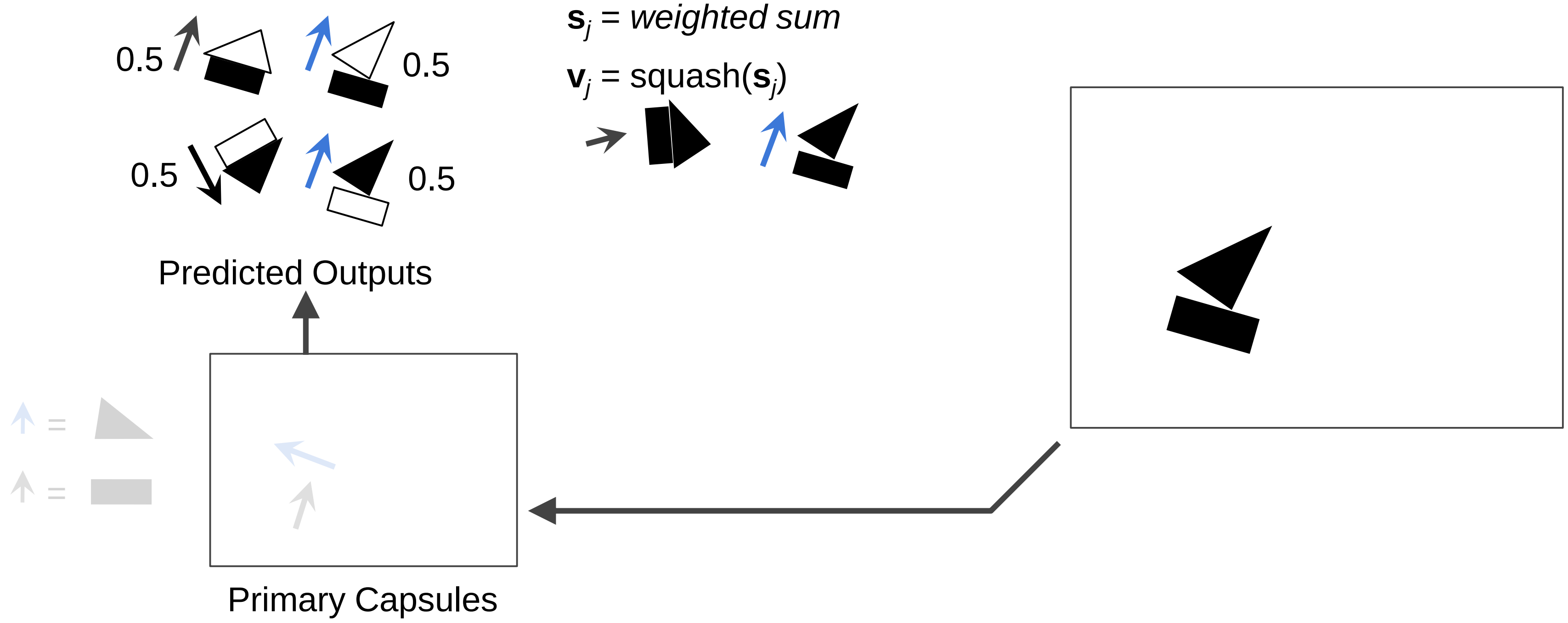

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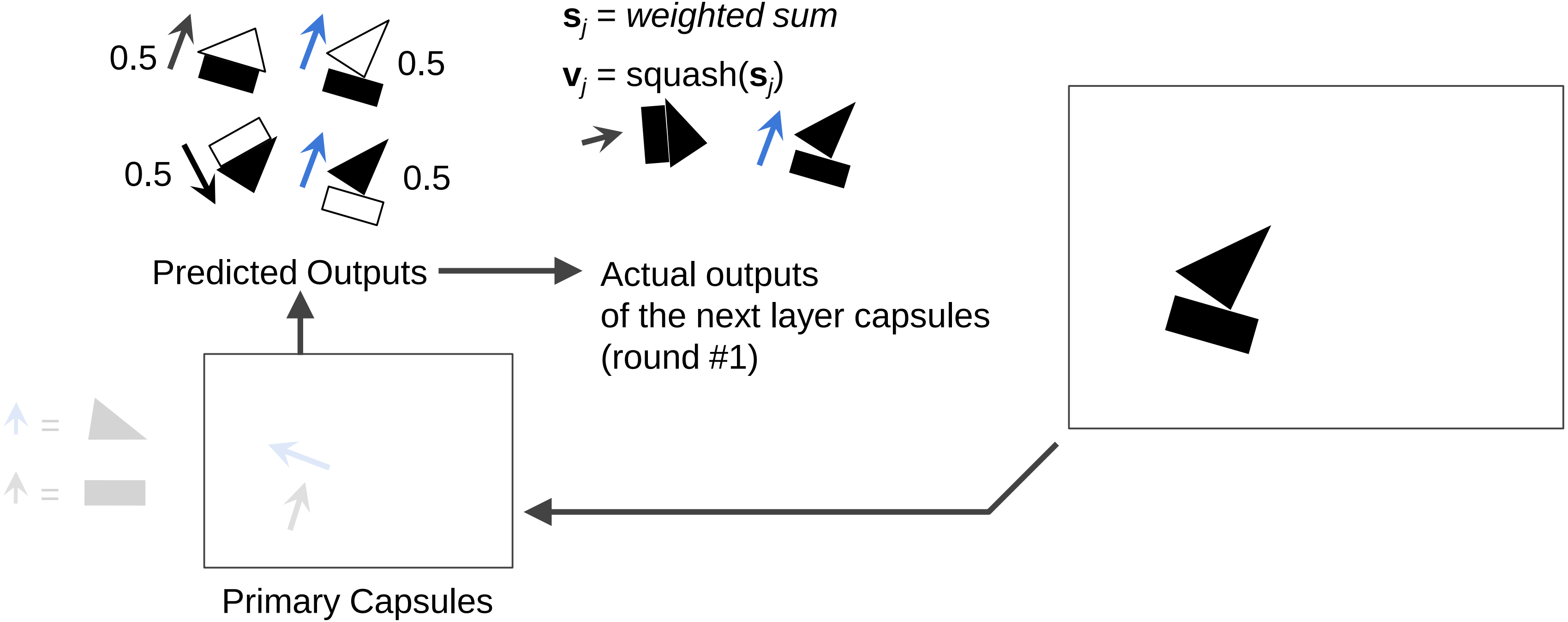

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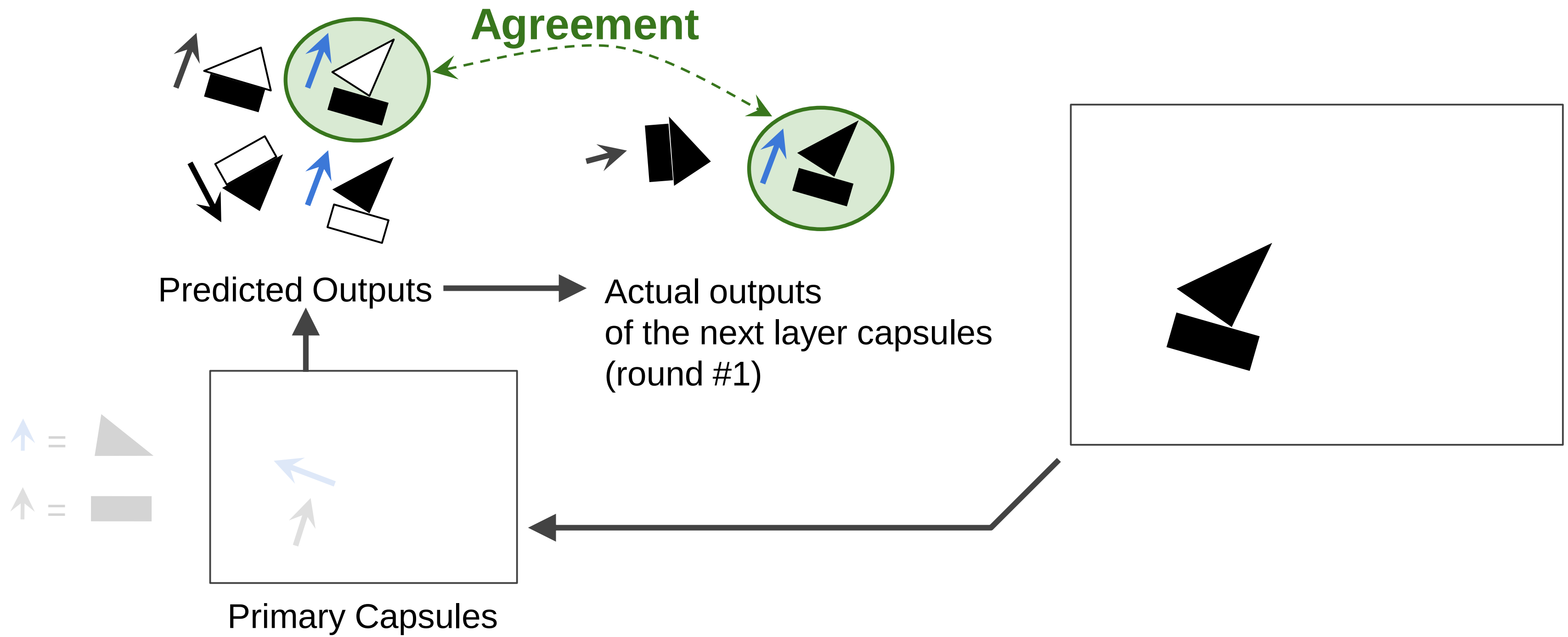
Update Routing Weights



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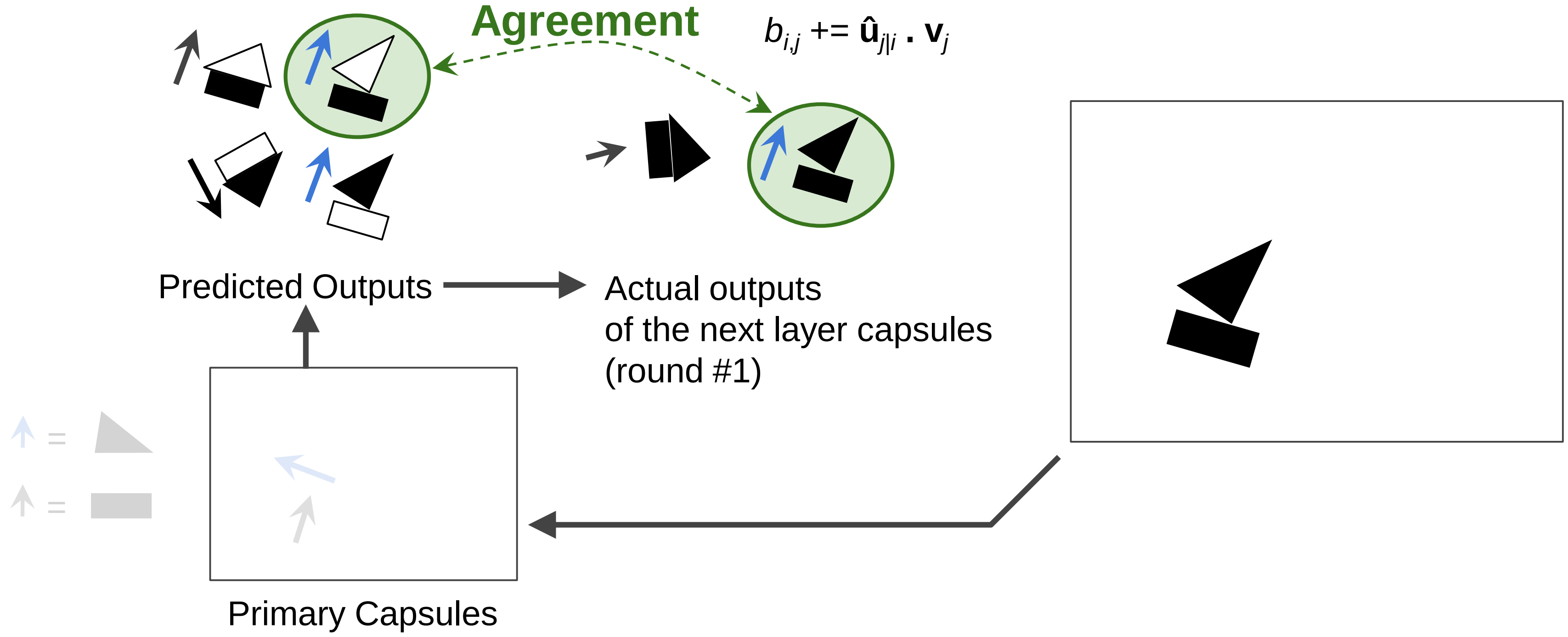
Update Routing Weights

$b_{i,j} \mathrel{+}= \hat{\mathbf{u}}_{j|i} \cdot \mathbf{v}_j$



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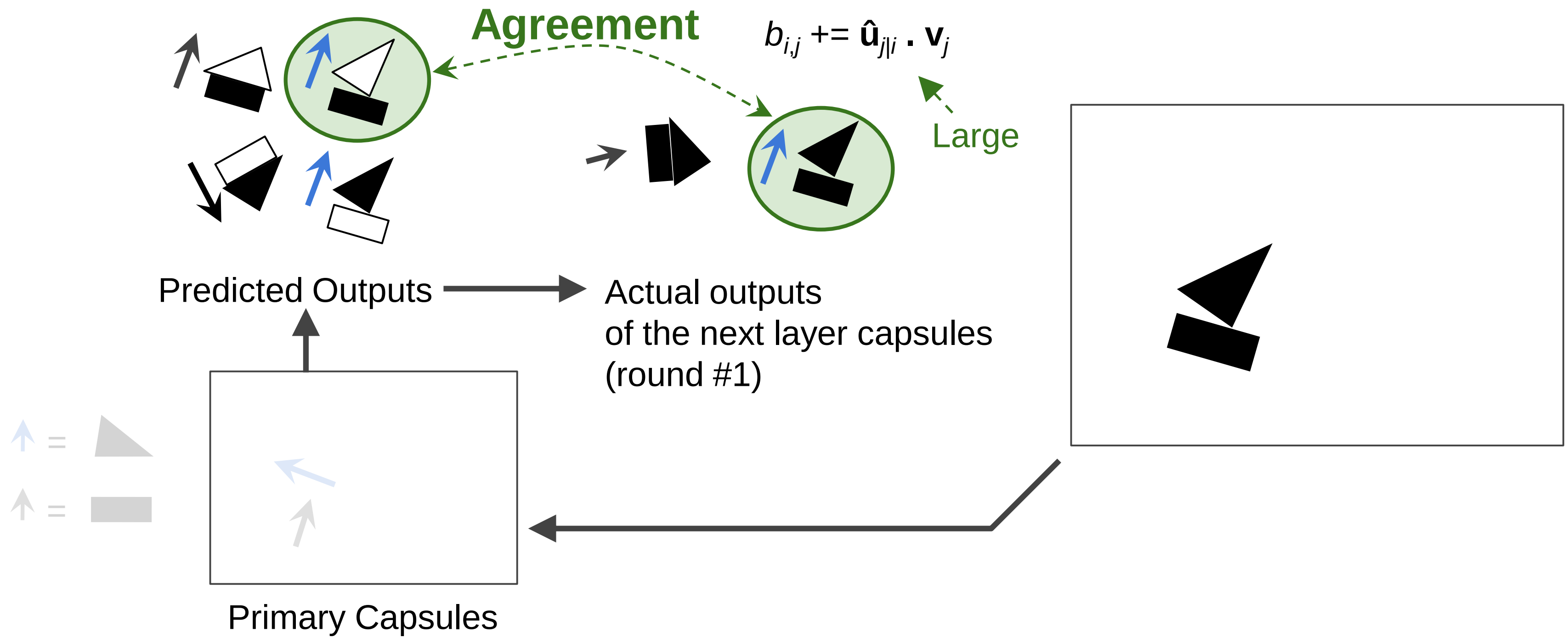

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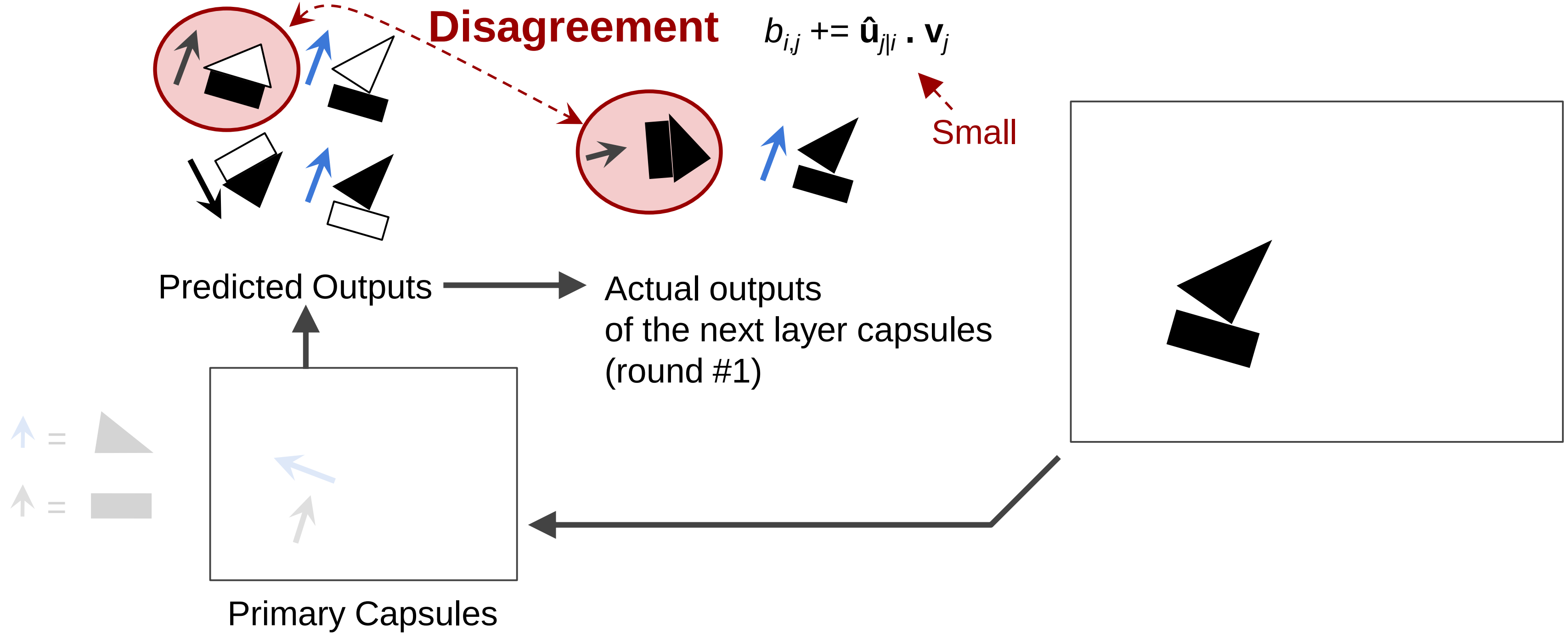

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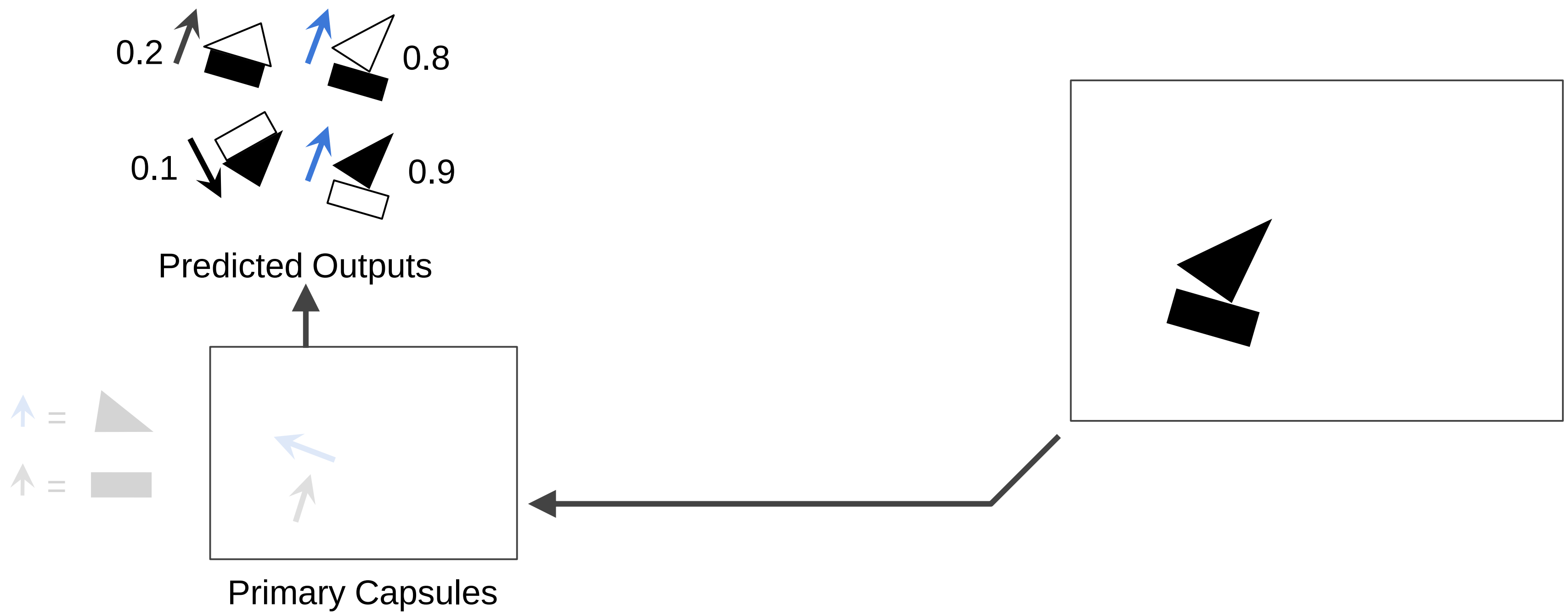

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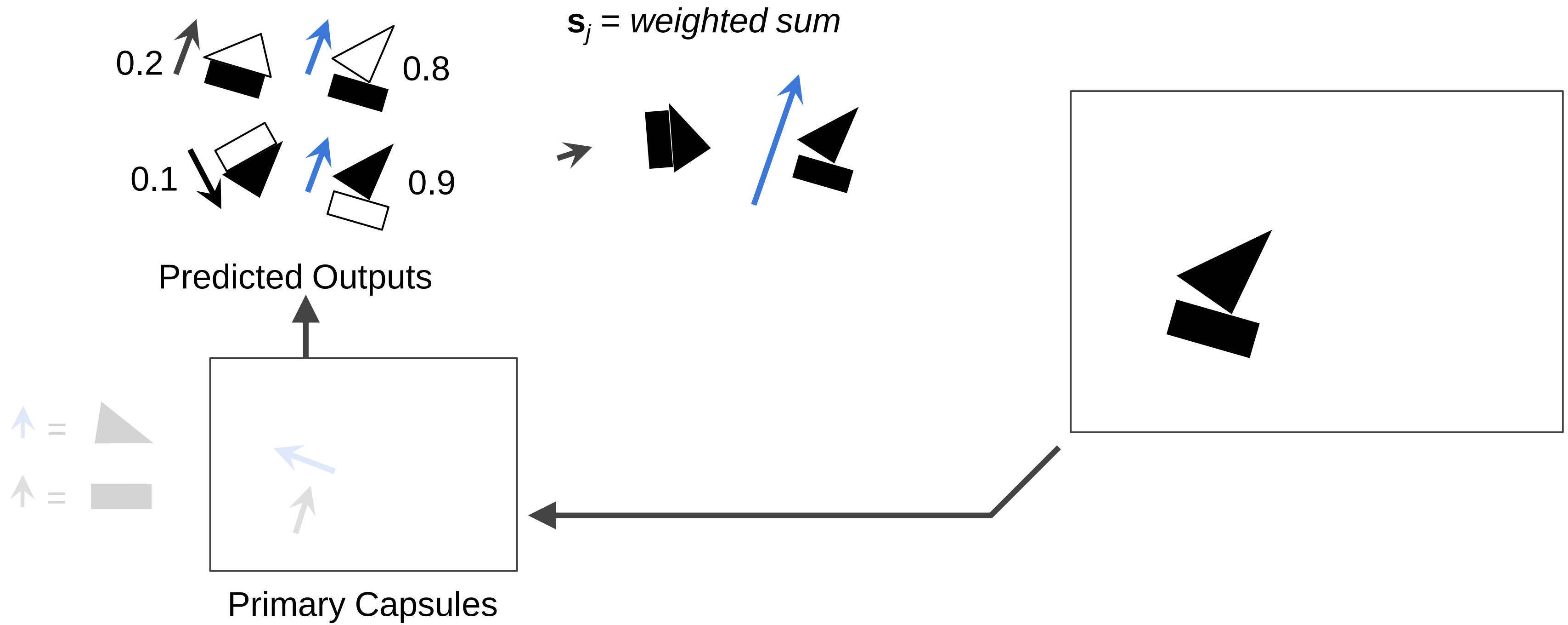

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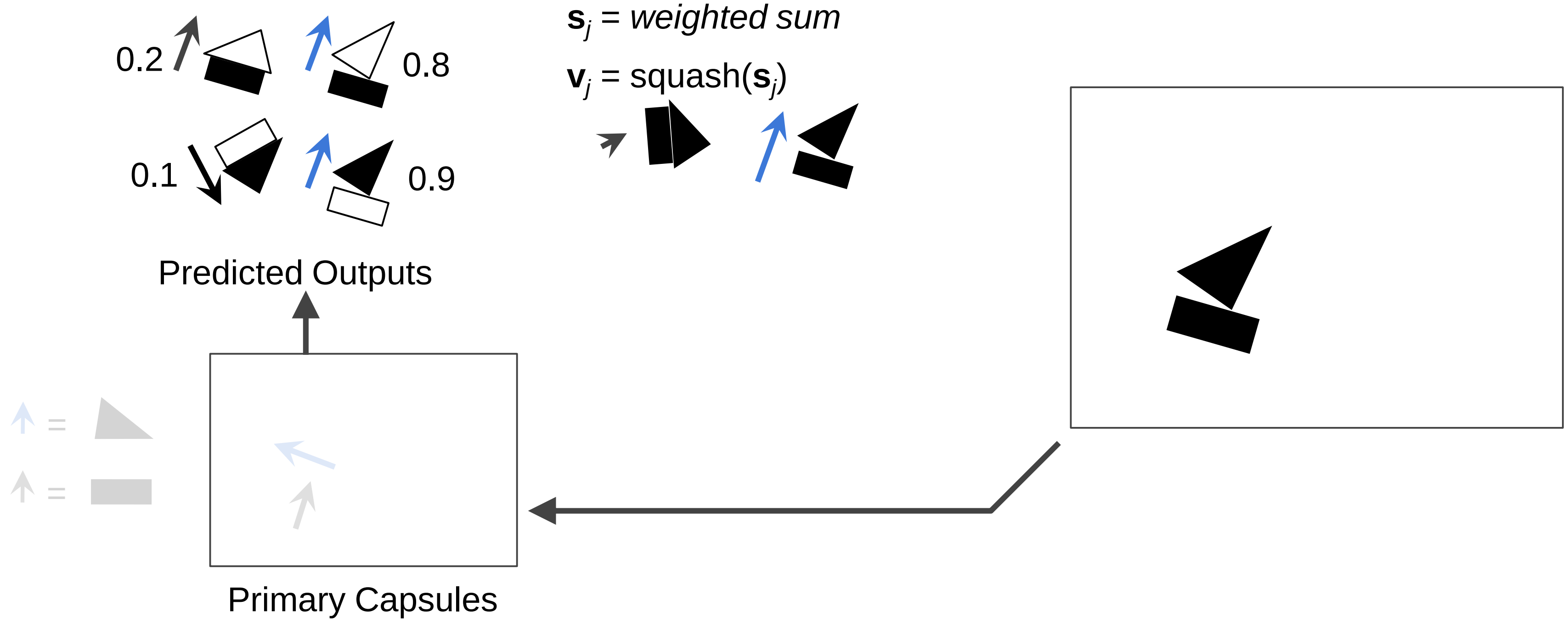

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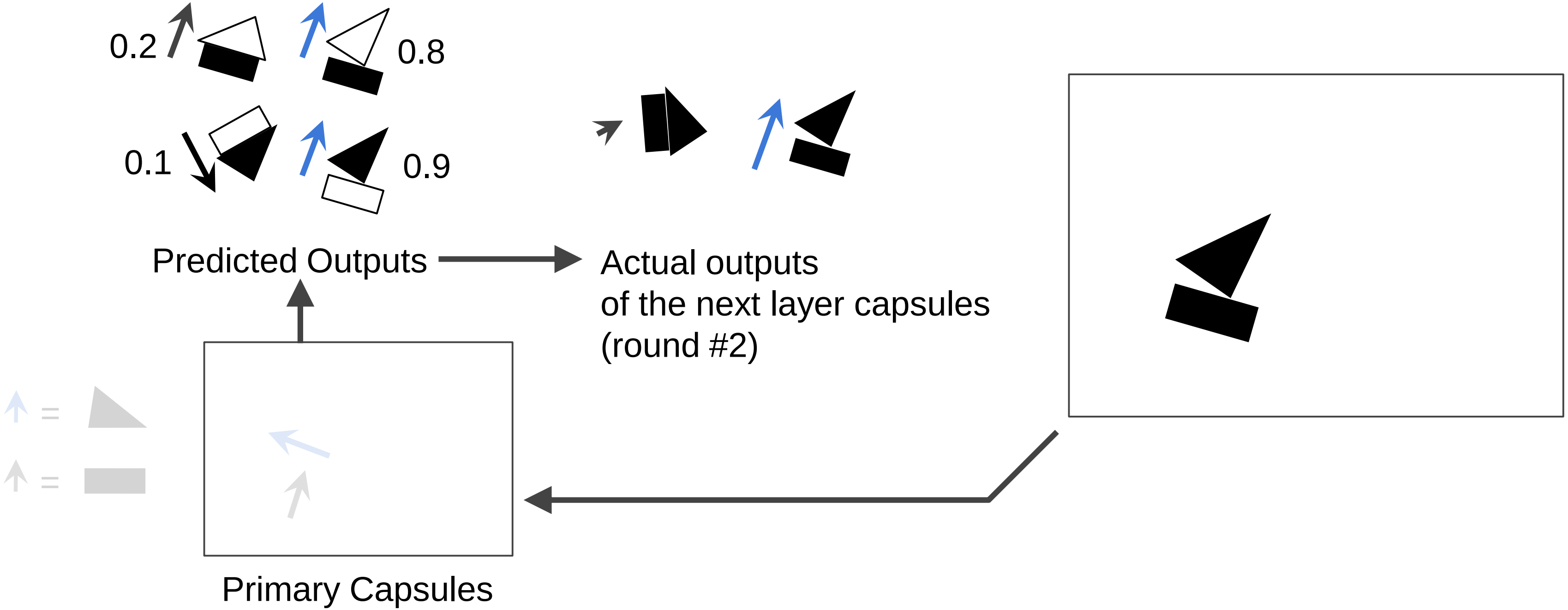
Compute Next Layer's Output



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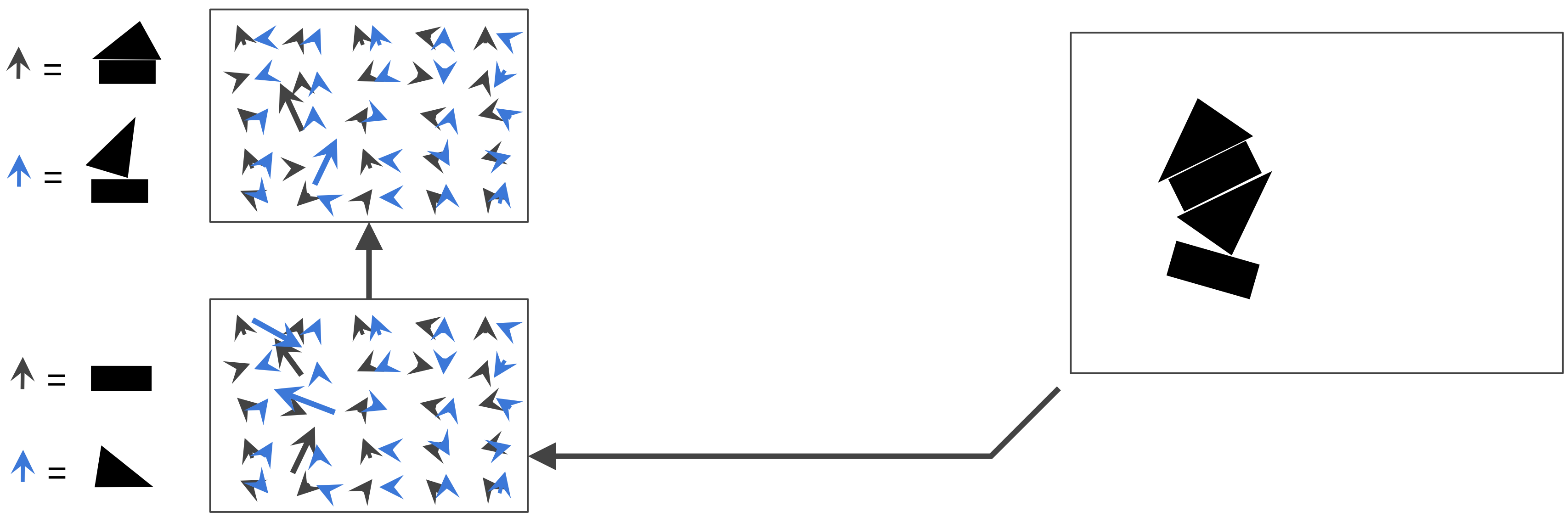
Handling Crowded Scenes



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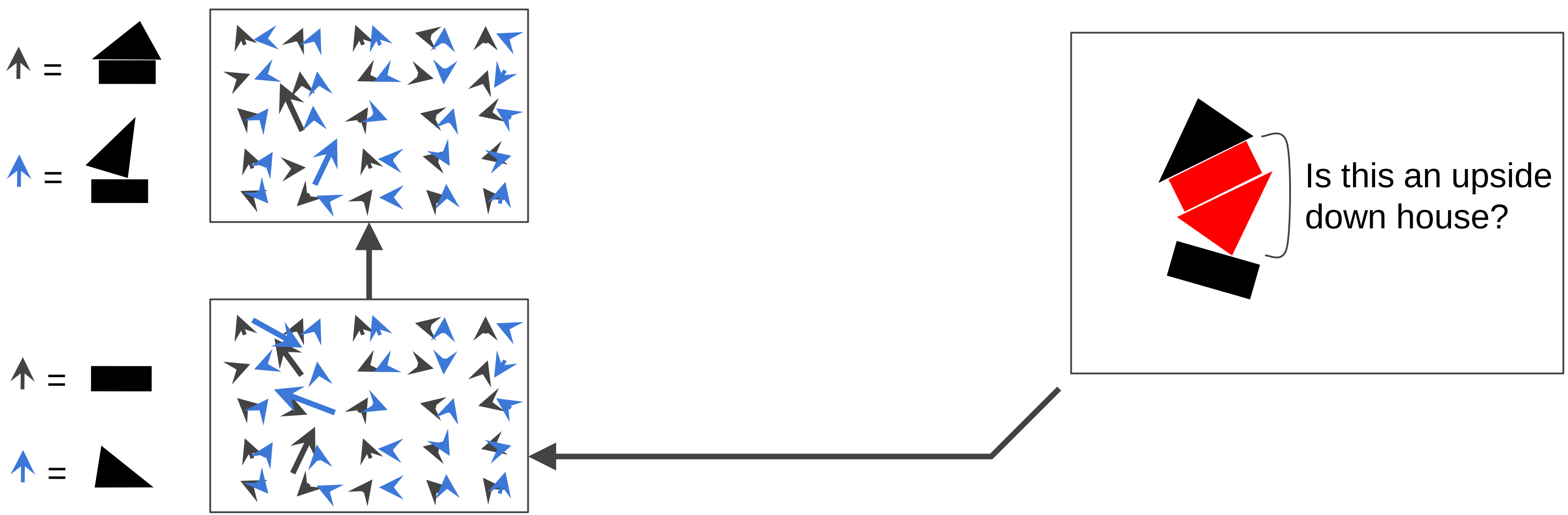
Handling Crowded Scenes



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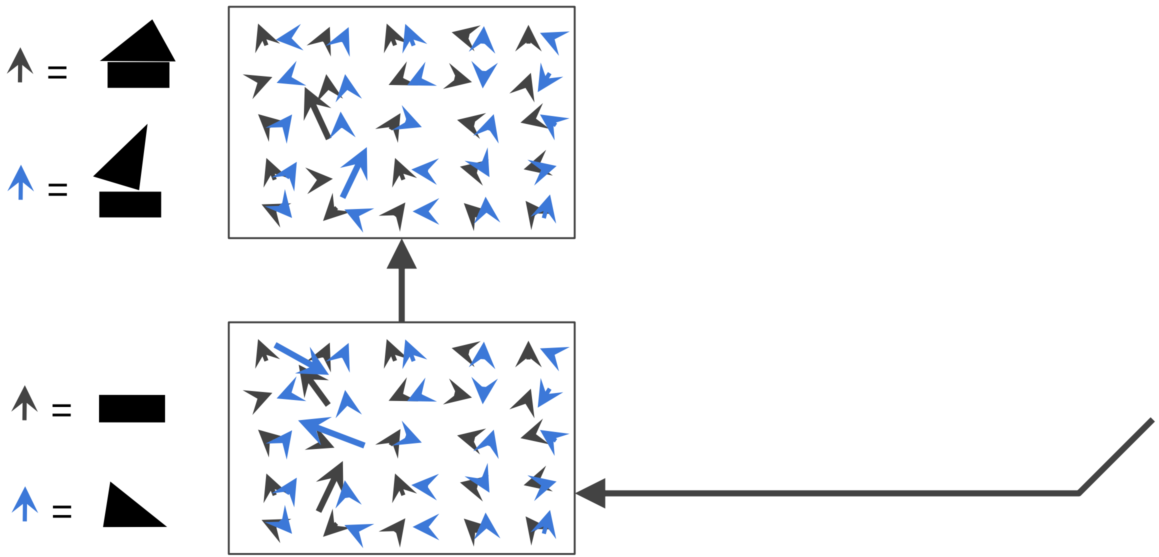
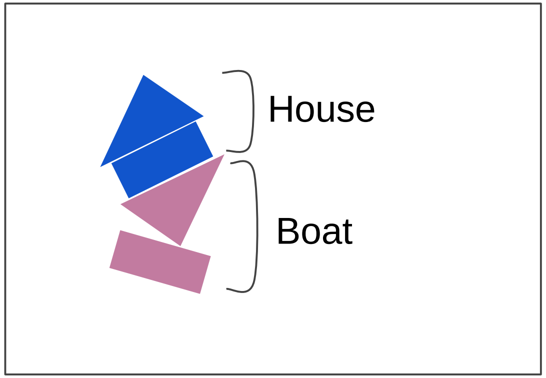
Handling Crowded Scenes





Thanks to routing by agreement, the ambiguity is quickly resolved (explaining away).

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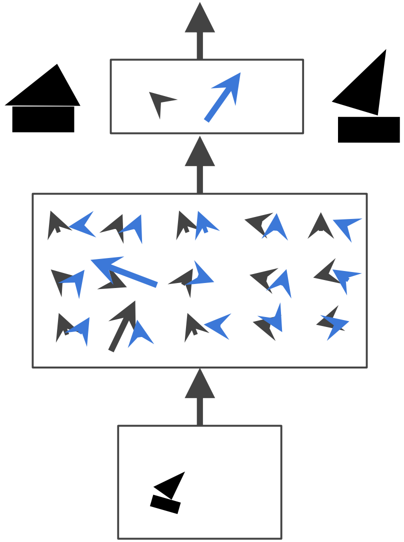
Classification
CapsNet

$|| \ell_2 ||$ Estimated Class Probability



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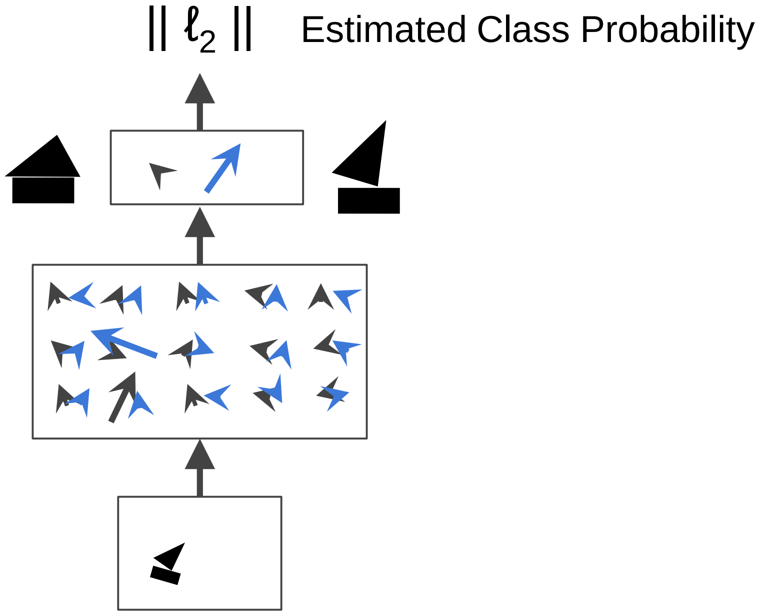
Training



To allow multiple classes, minimize margin loss:

$L_k = T_k \max(0, m^+ - ||\mathbf{v}_k||^2)$

$+ \lambda (1 - T_k) \max(0, ||\mathbf{v}_k||^2 - m^-)$

$T_k = 1$ iff class k is present

In the paper:

$m^- = 0.1$

$m^+ = 0.9$

$\lambda = 0.5$

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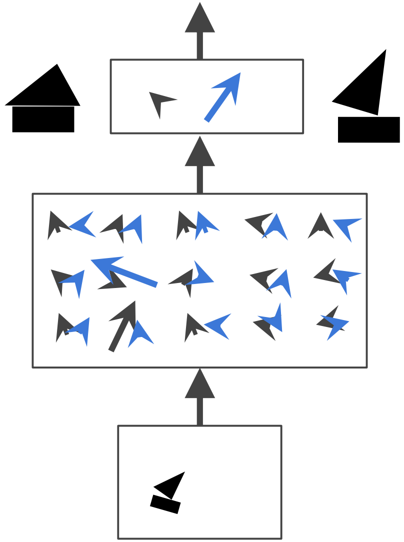
Training

$\| \ell_2 \|$ Estimated Class Probability



Translated to English:

"If an object of class k is present, then $\|\mathbf{v}_k\|^2$ should be no less than 0.9. If not, then $\|\mathbf{v}_k\|^2$ should be no more than 0.1."

To allow multiple classes, minimize margin loss:

$$L_k = T_k \max(0, m^+ - \|\mathbf{v}_k\|^2)$$
$$+ \lambda\, (1 - T_k) \max(0, \|\mathbf{v}_k\|^2 - m^-)$$

$T_k = 1$ iff class k is present

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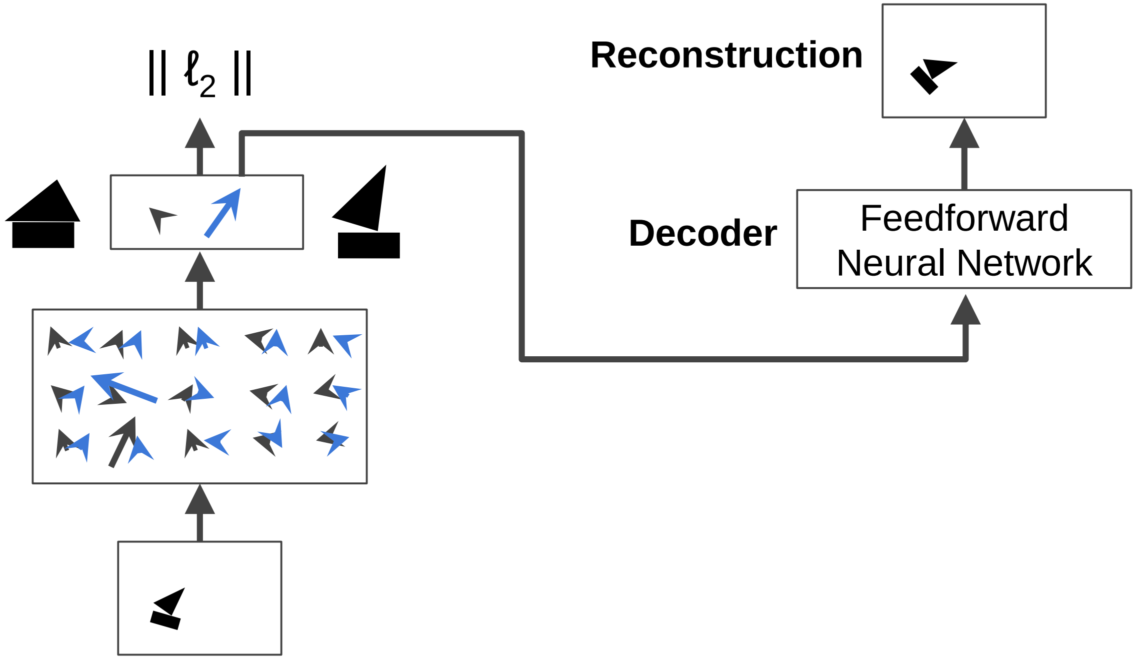
Regularization by Reconstruction



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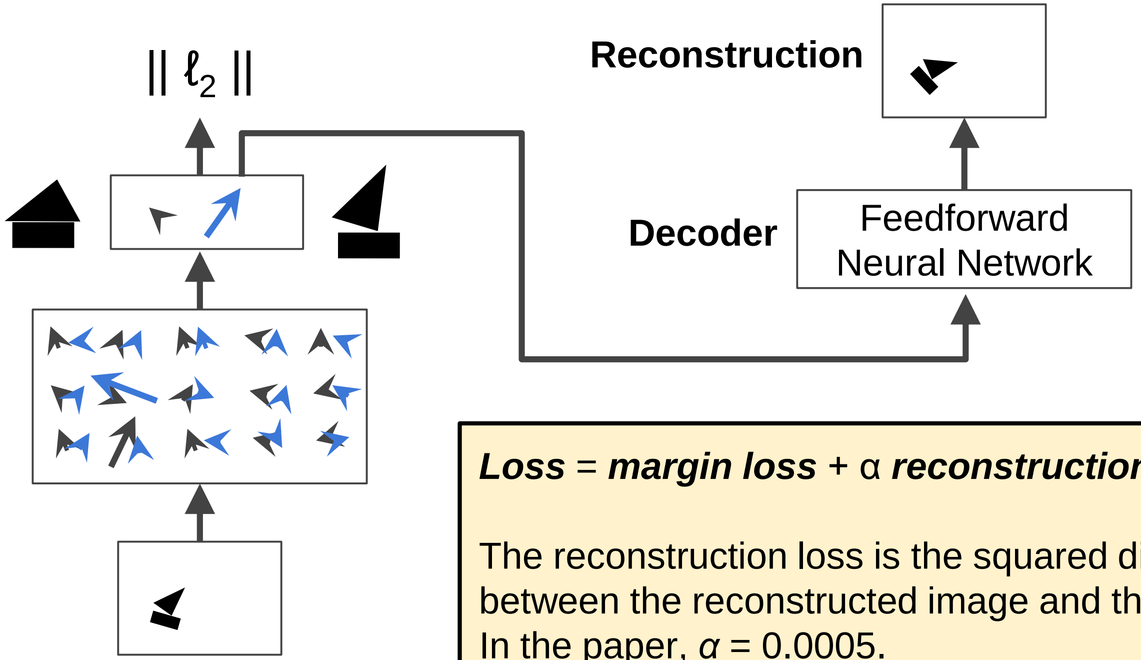
Regularization by Reconstruction



Loss = ***margin loss*** + α ***reconstruction loss***

The reconstruction loss is the squared difference between the reconstructed image and the input image. In the paper, α = 0.0005.

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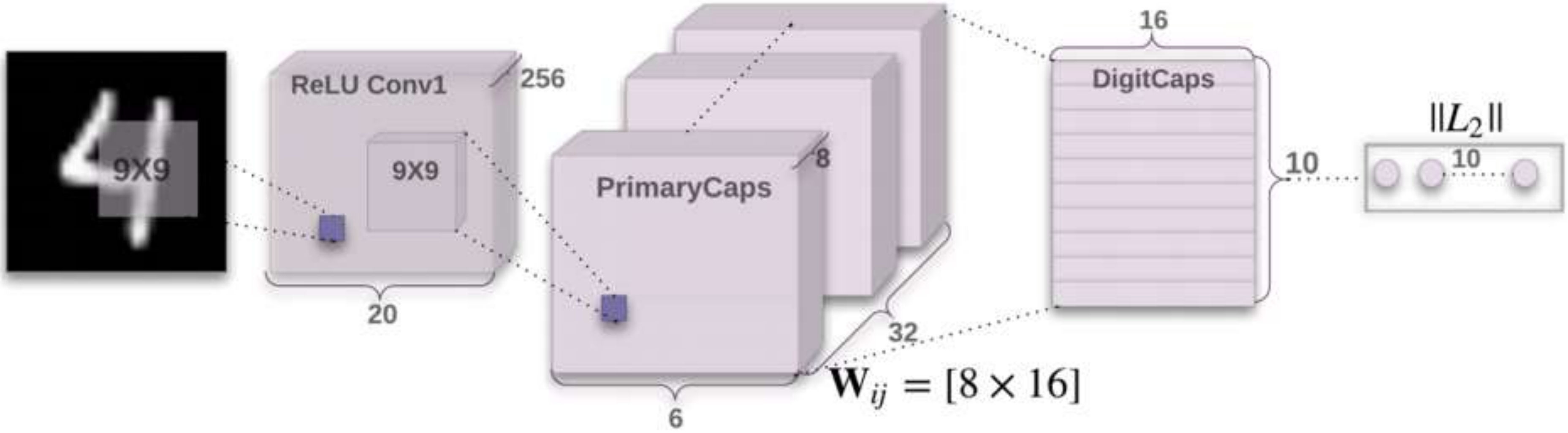
A CapsNet for MNIST



(Figure 1 from the paper)

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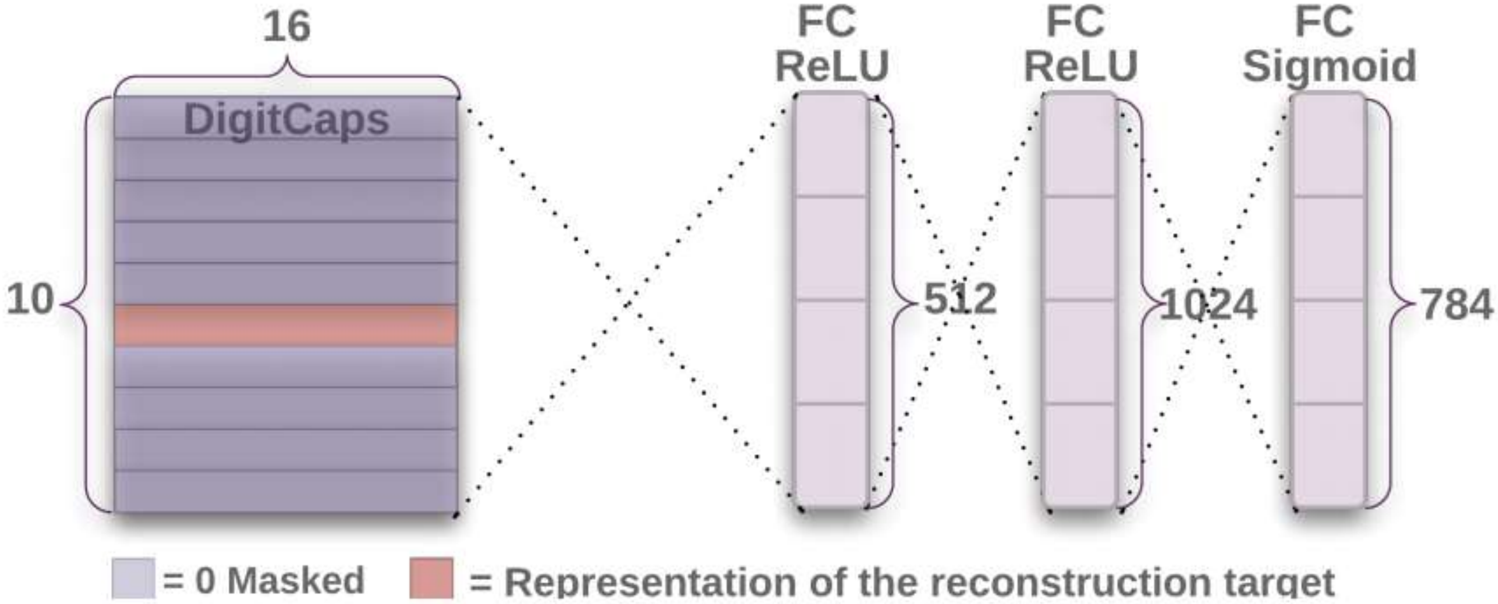
A CapsNet for MNIST – Decoder



(Figure 2 from the paper)

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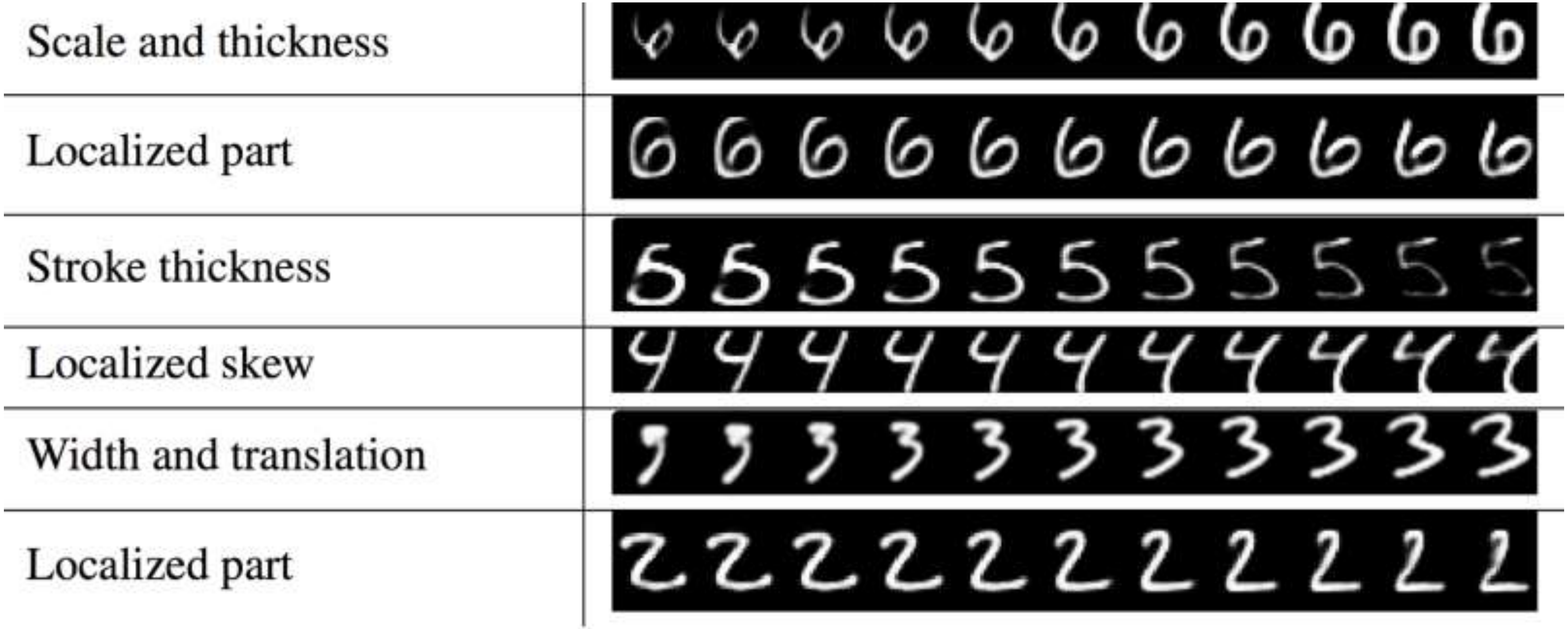
Interpretable Activation Vectors



(Figure 4 from the paper)

Pros

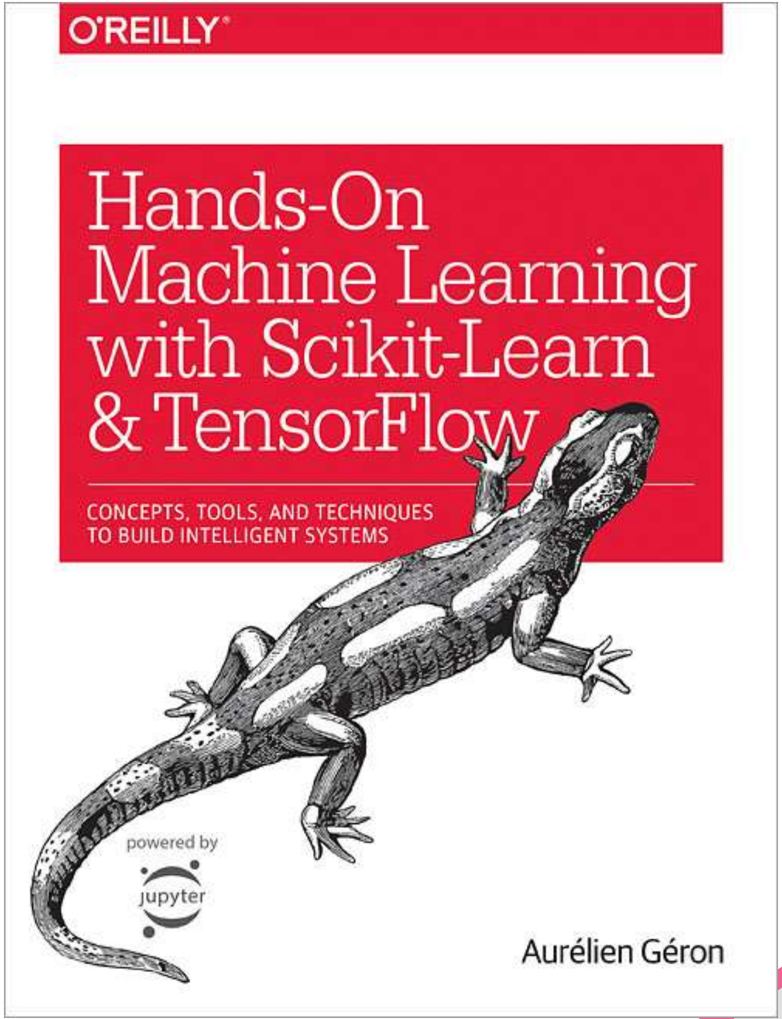
- Reaches high accuracy on MNIST, and promising on CIFAR10
- Requires less training data
- Position and pose information are preserved (equivariance)
- This is promising for image segmentation and object detection
- Routing by agreement is great for overlapping objects (explaining away)
- Capsule activations nicely map the hierarchy of parts
- Offers robustness to affine transformations
- Activation vectors are easier to interpret (rotation, thickness, skew…)
- It’s Hinton! ;-)

Cons

- Not state of the art on CIFAR10 (but it’s a good start)
- Not tested yet on larger images (e.g., ImageNet): will it work well?
- Slow training, due to the inner loop (in the routing by agreement algorithm)
- A CapsNet cannot see two very close identical objects
    - This is called “crowding”, and it has been observed as well in human vision

Implementations

- Keras w/ TensorFlow backend: https://github.com/XifengGuo/CapsNet-Keras
- TensorFlow: https://github.com/naturomics/CapsNet-Tensorflow
- PyTorch: https://github.com/gram-ai/capsule-networks



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