



# Training Image Estimators *without* Image Ground-Truth

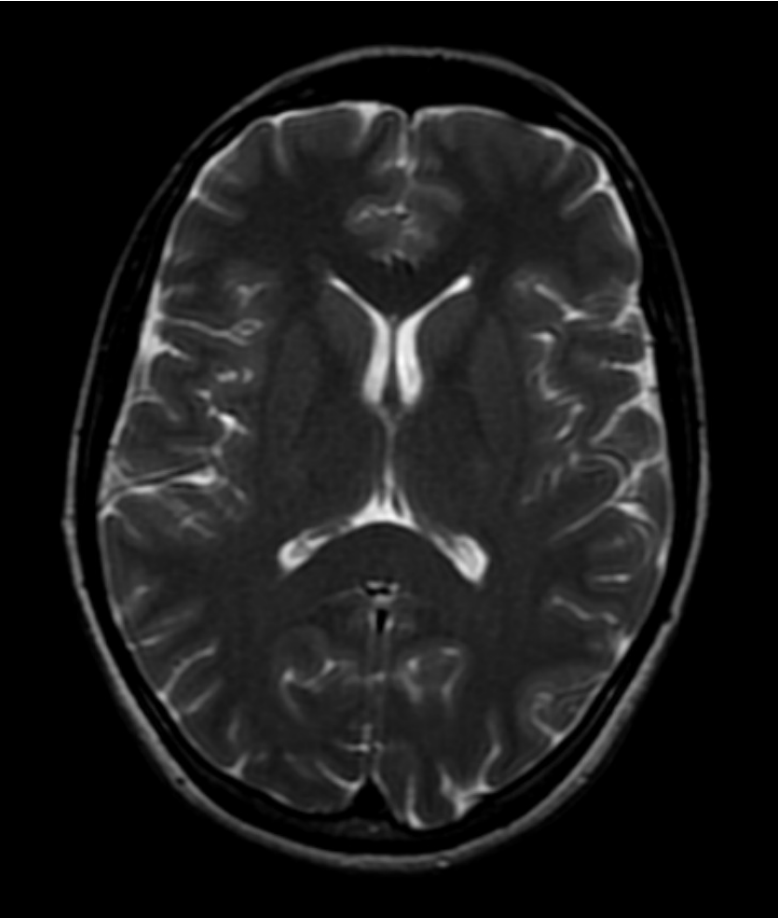
Zhihao Xia & Ayan Chakrabarti



Washington University in St. Louis  
**Vision & Learning Group**

Imaging + ML = ♥

diagnose  
quality  
High-Quality  
Images  
analyze  
RESOLUTION  
detect  
visualize  
recognize  
mapping



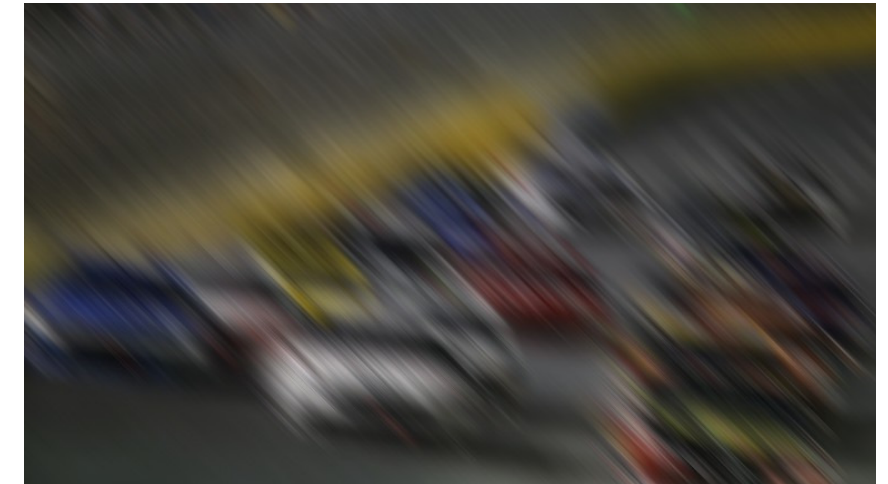
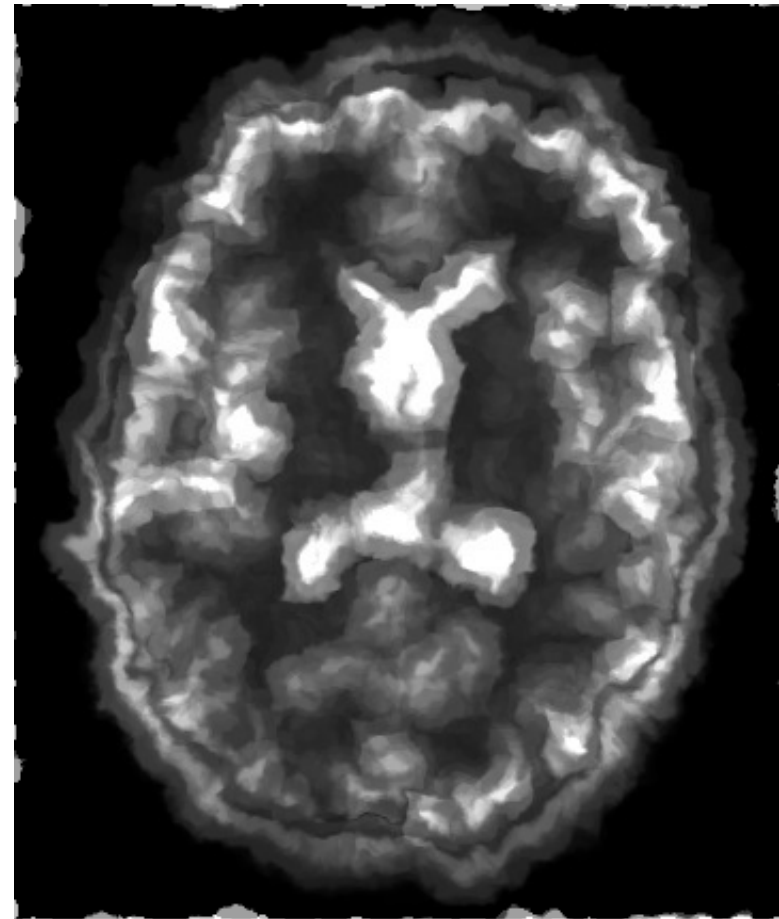


Imaging + ML = ♥

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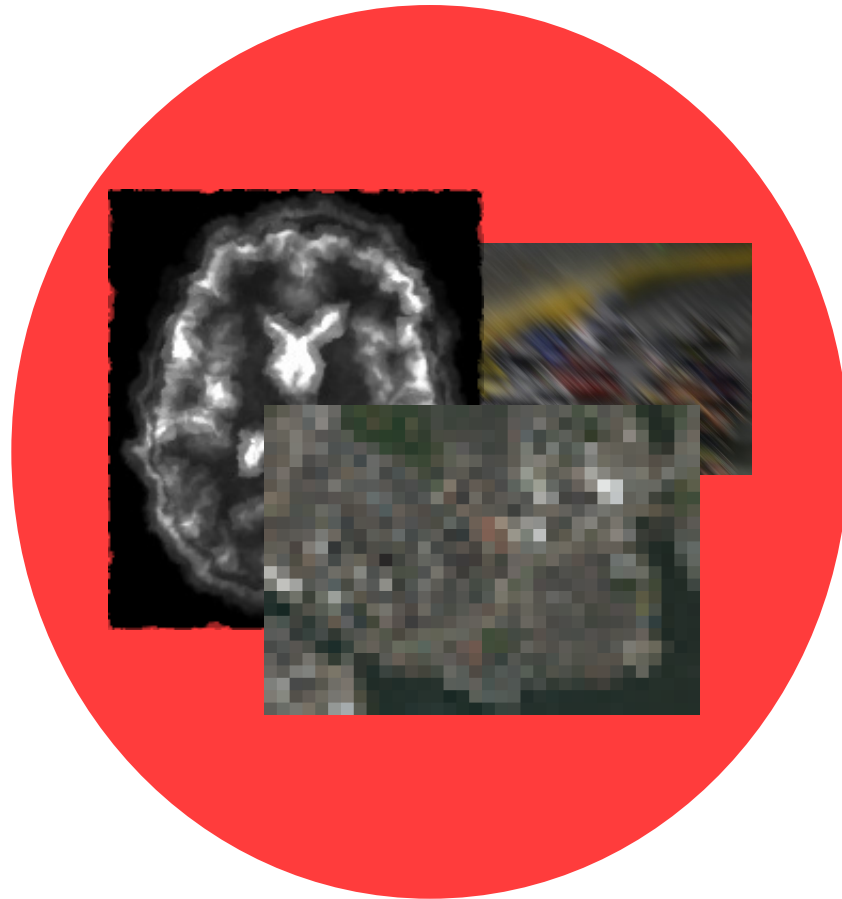
**Practical  
Measurements**

fast  
cheap  
frame-rate  
compact  
lightweight  
hand-held  
low-MOI



Imaging + ML = ♥

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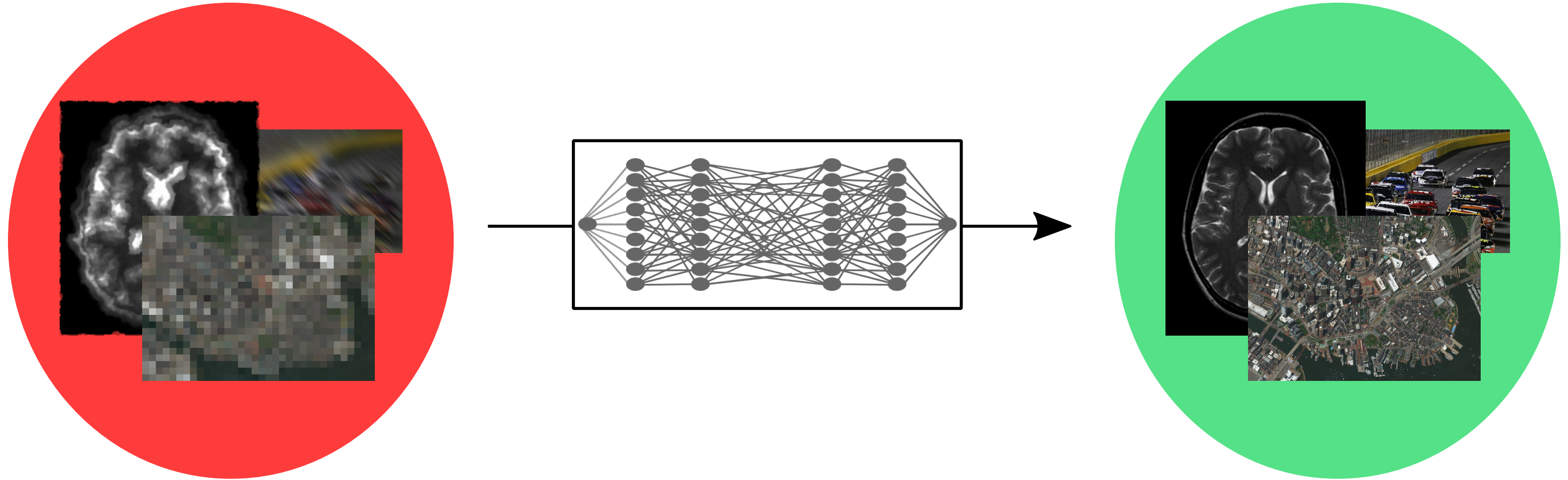
**Practical**  
**Low-Quality**



**High-Quality**  
**Impractical**

Imaging + ML = ♥

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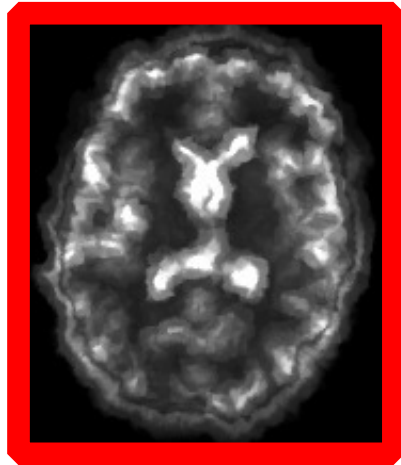


**Practical** Measurements & **High-Quality** Images

# Imaging + ML = ♥

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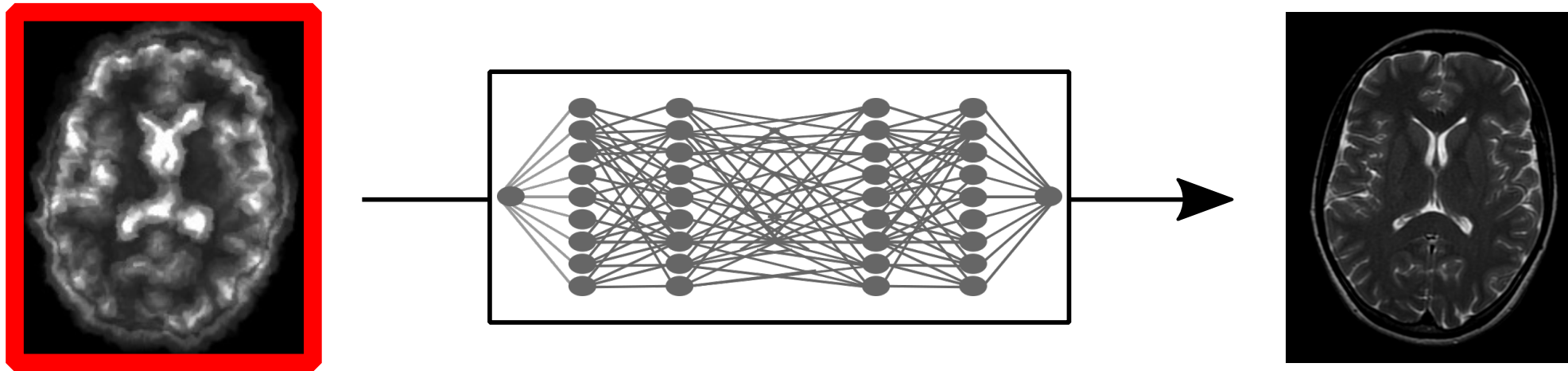
At test time,



# Imaging + ML = ♥

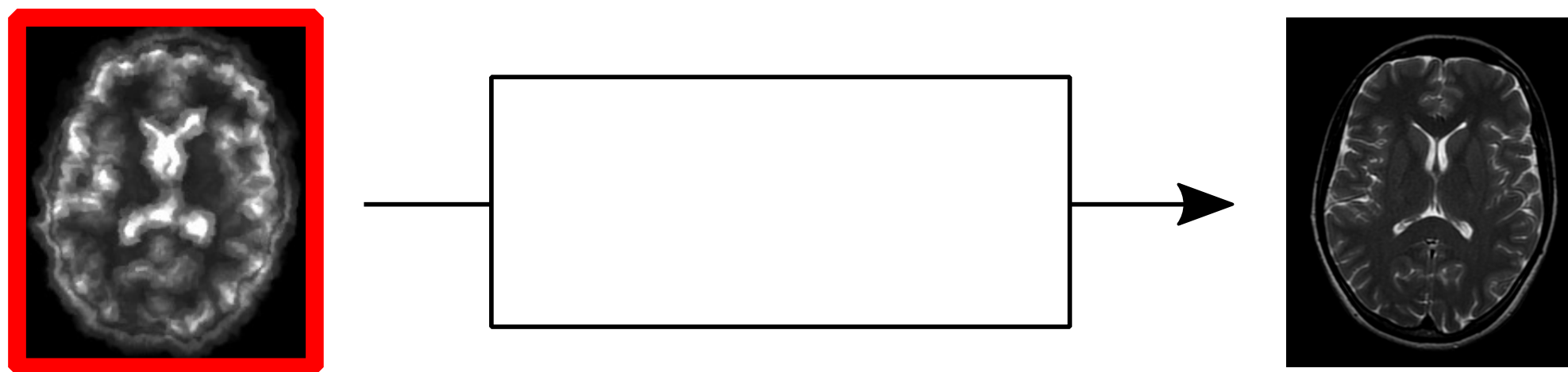
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At test time,



Imaging + ML = ♥

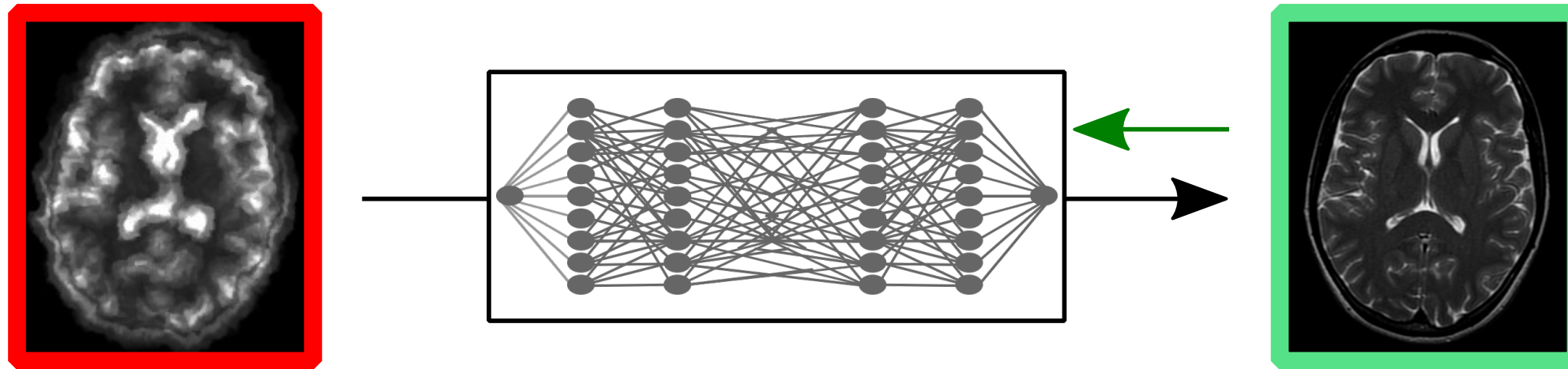
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# Imaging + ML = ♥

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Training requires  
high-quality ground-truth  
(impractical to measure)

Imaging + ML = ♥

Training requires  
many high-quality ground-truth images  
(impractical to measure)



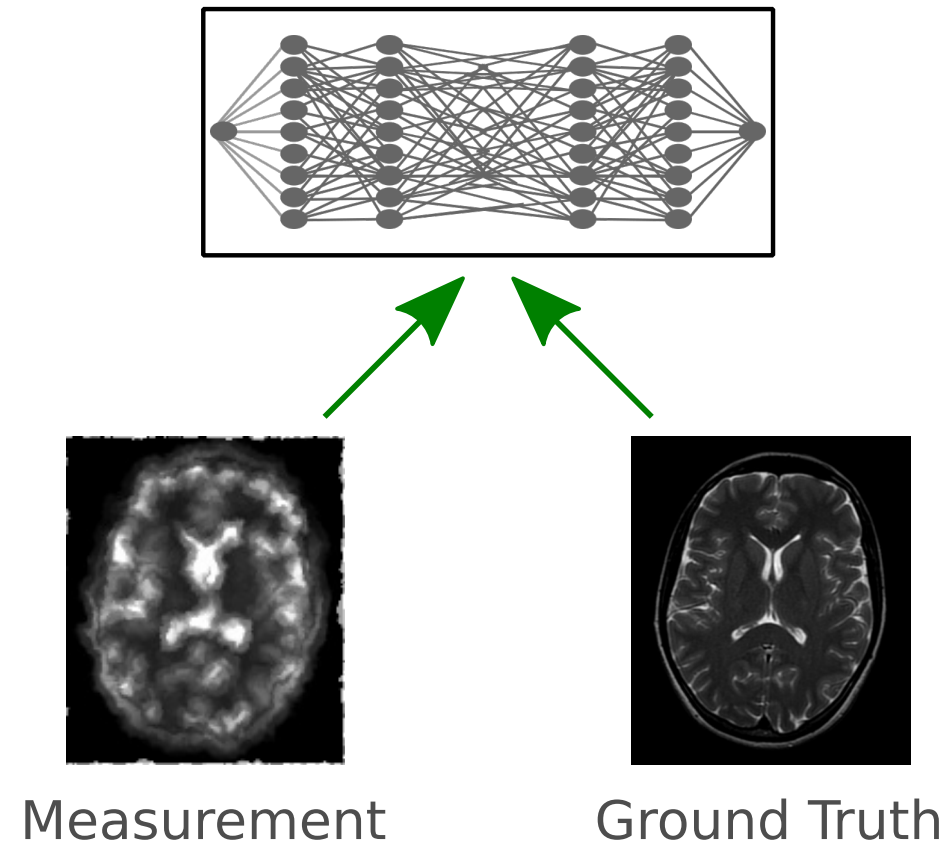
Imaging + ML = ♥

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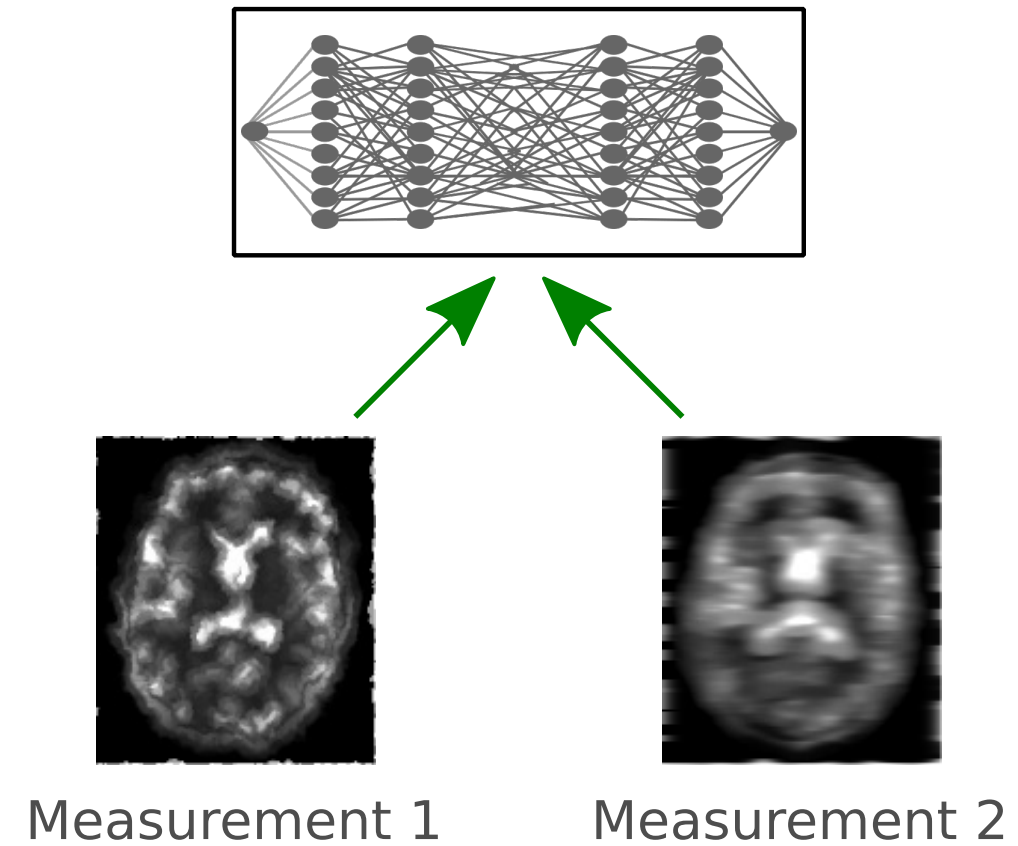
Training requires  
many many high-quality ground-truth images  
(impractical to measure)

# Unsupervised Learning

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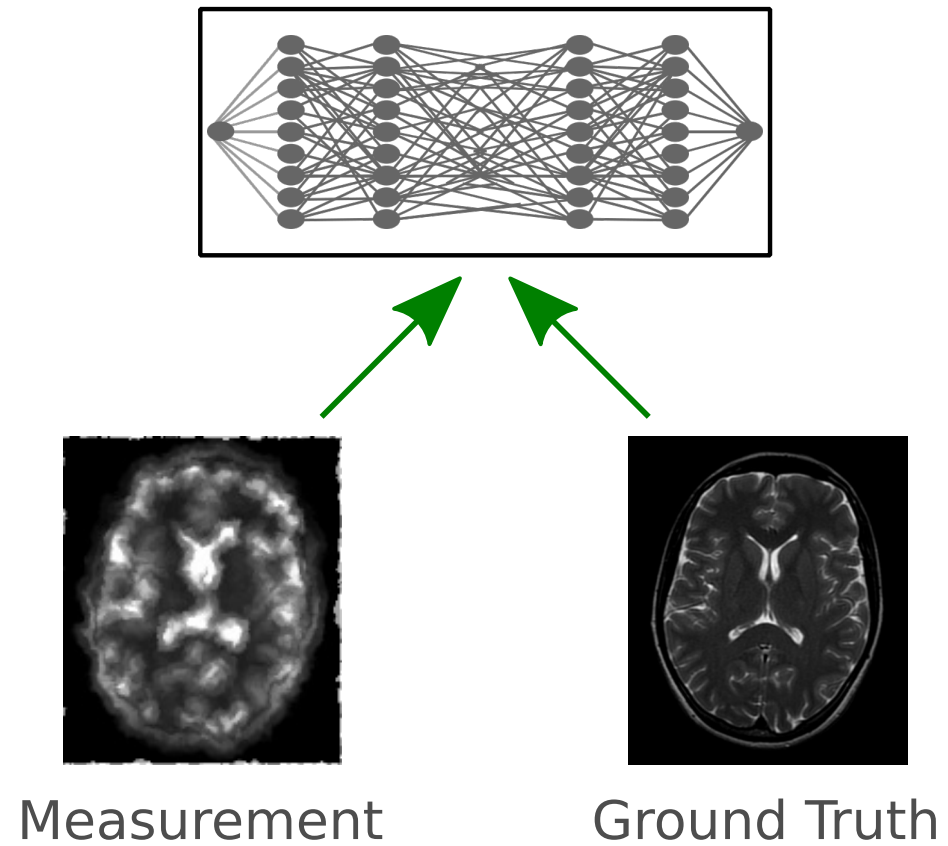
Standard  
Supervised Training



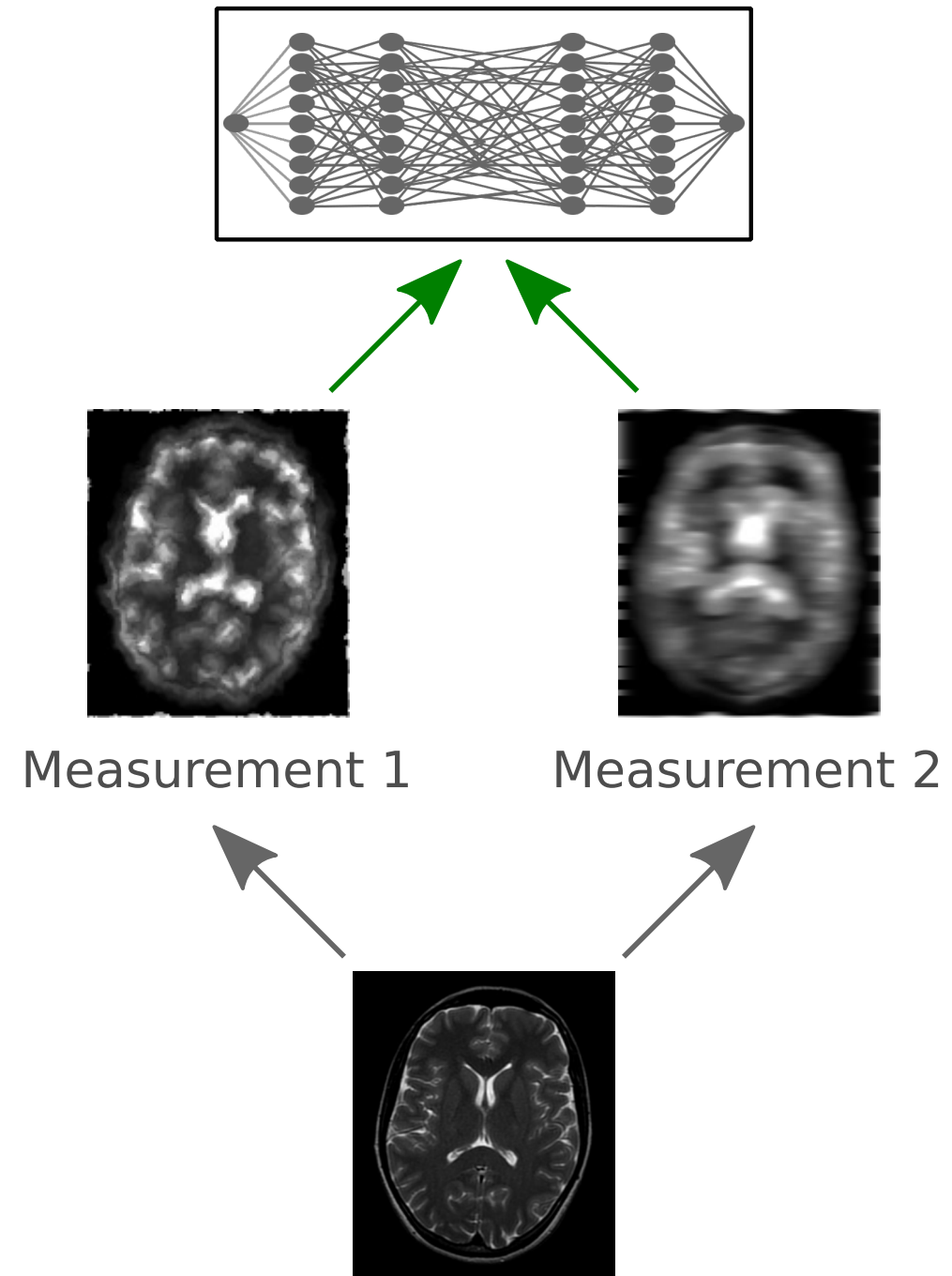
**Our Training  
Approach**



# Unsupervised Learning

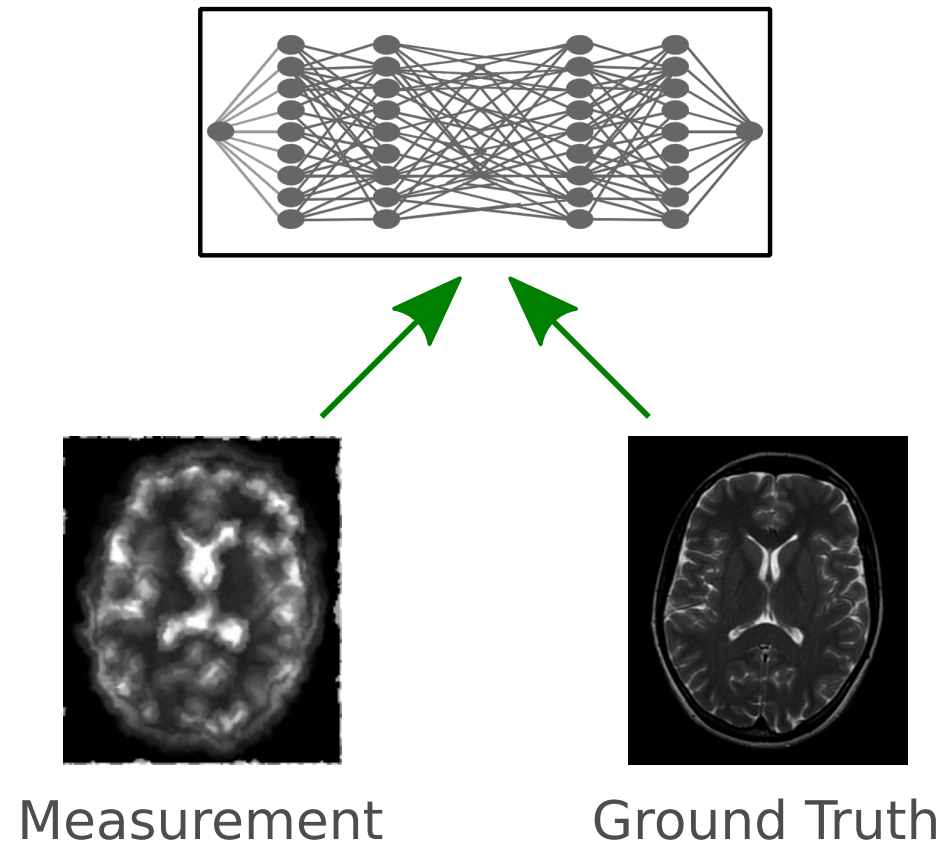


Standard  
Supervised Training

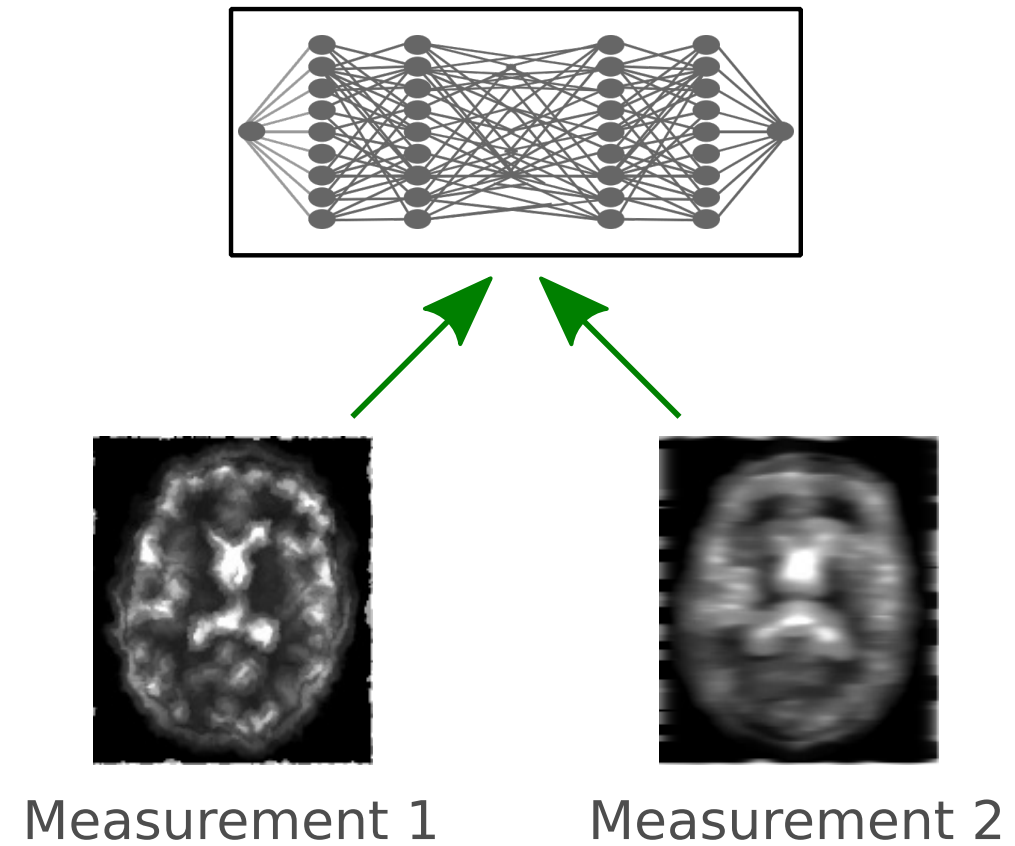


**Our Training  
Approach**

# Unsupervised Learning

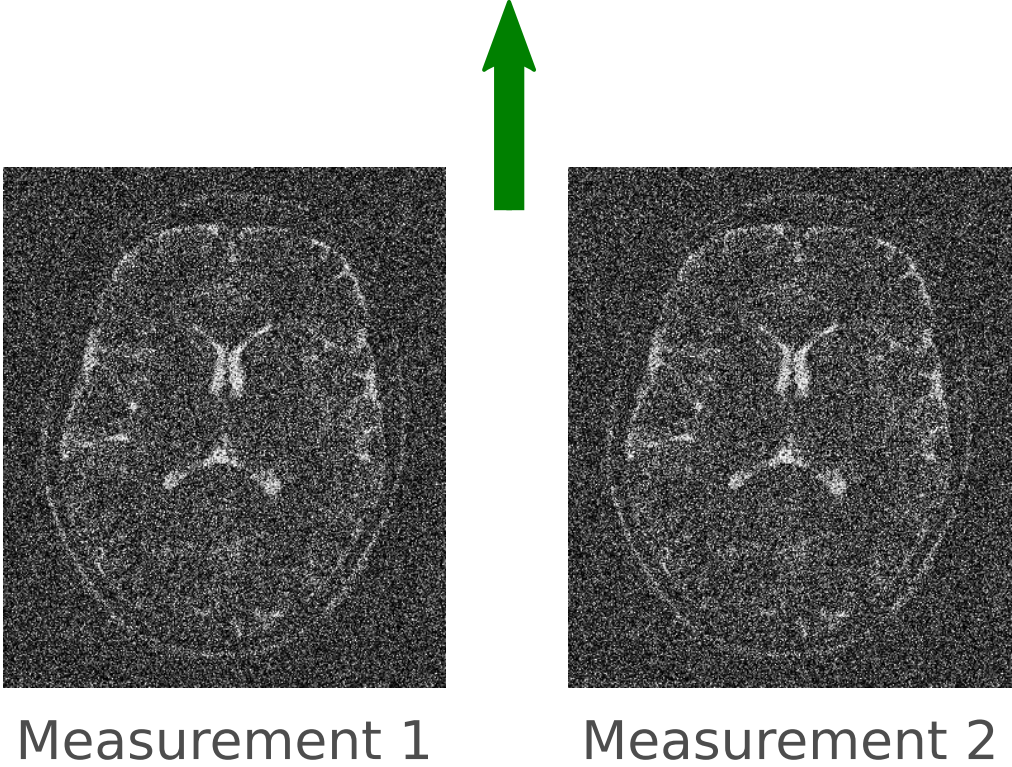


Standard  
Supervised Training

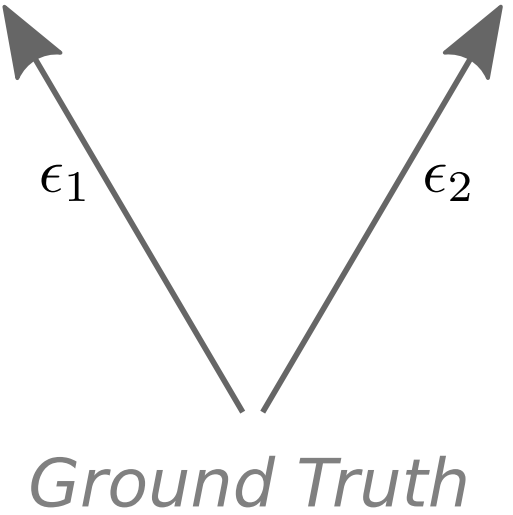


**Our Training  
Approach**

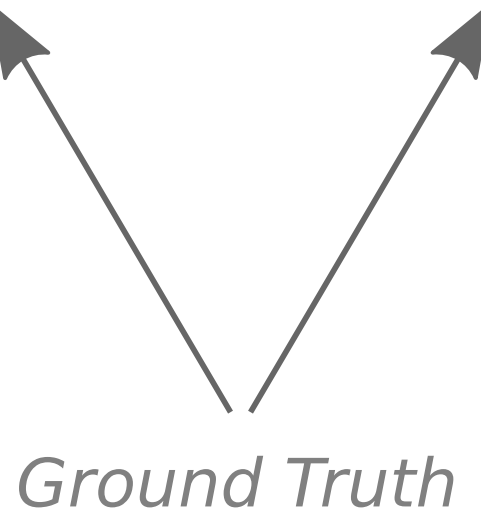
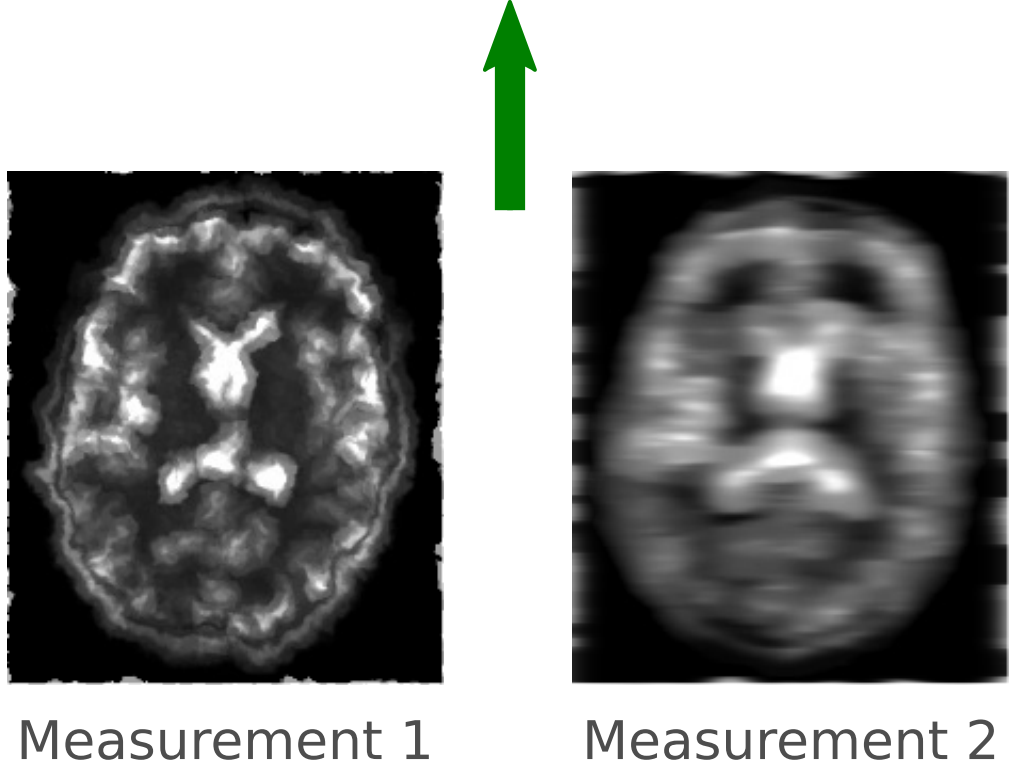
# Unsupervised Learning



$$y = x + \epsilon$$



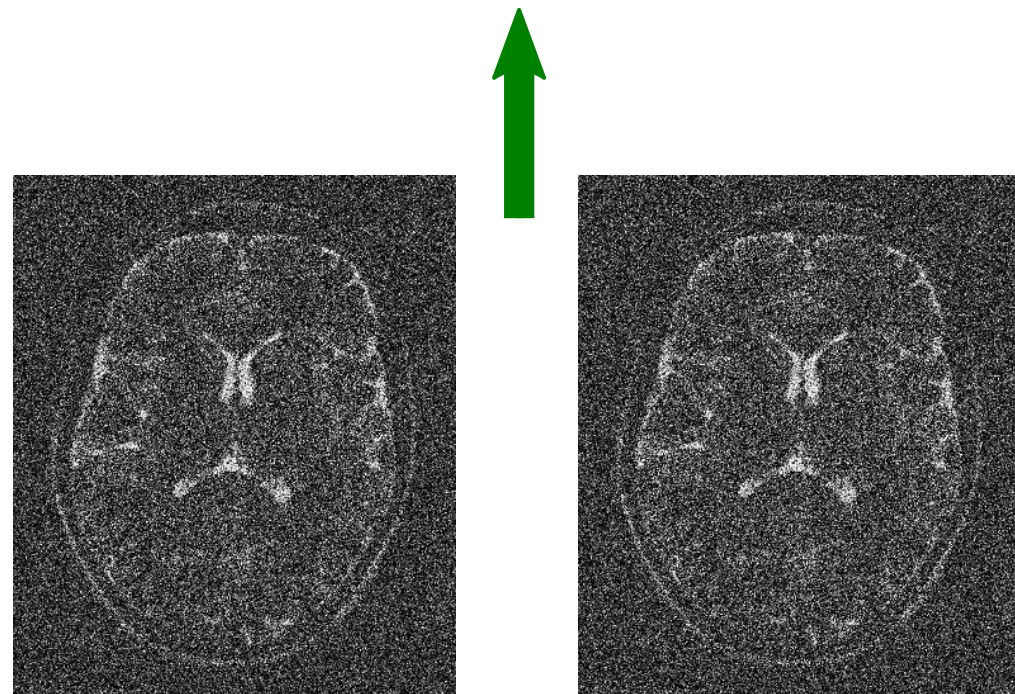
**Noise2Noise** [Lehtinen et al., ICML 2018]



**Our Training Approach**



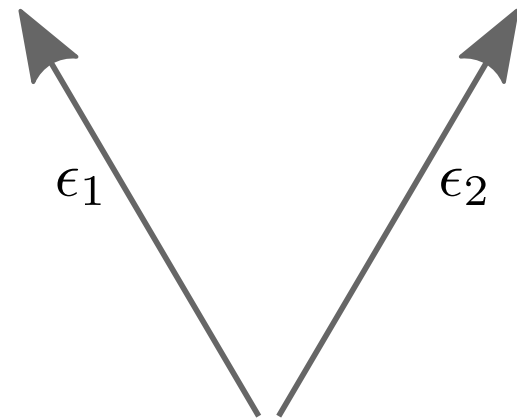
# Unsupervised Learning



Measurement 1

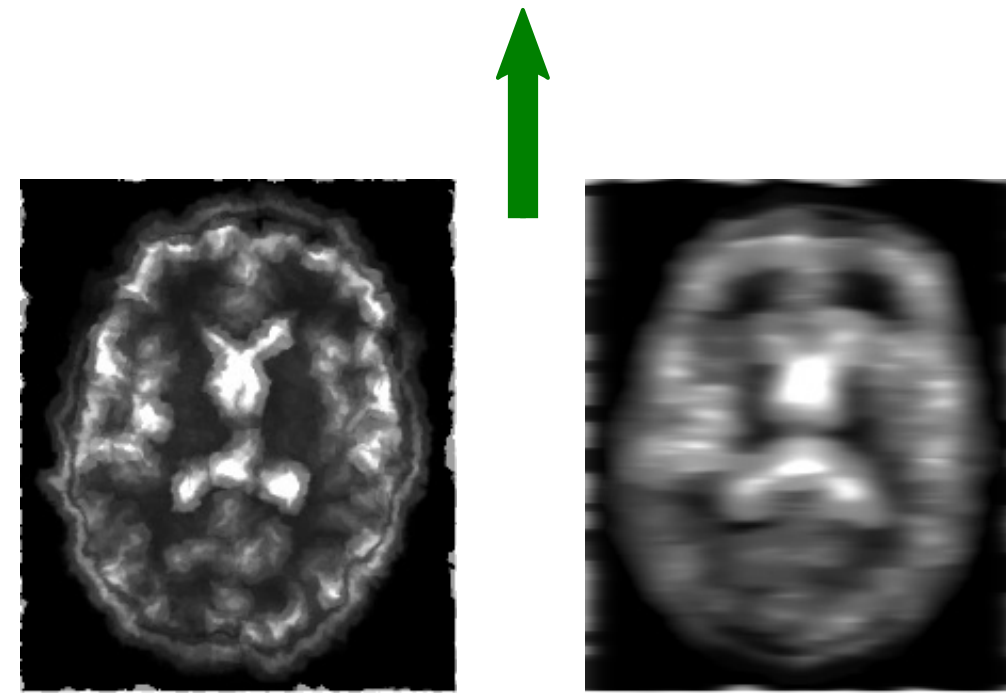
Measurement 2

$$\mathbf{y} = \mathbf{x} + \epsilon$$



*Ground Truth*

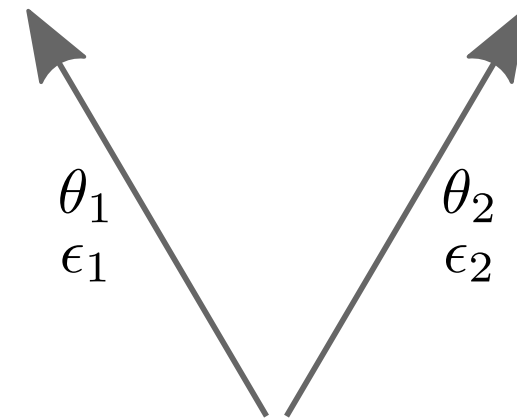
**Noise2Noise** [Lehtinen et al., ICML 2018]



Measurement 1

Measurement 2

$$\mathbf{y} = \theta \mathbf{x} + \epsilon$$



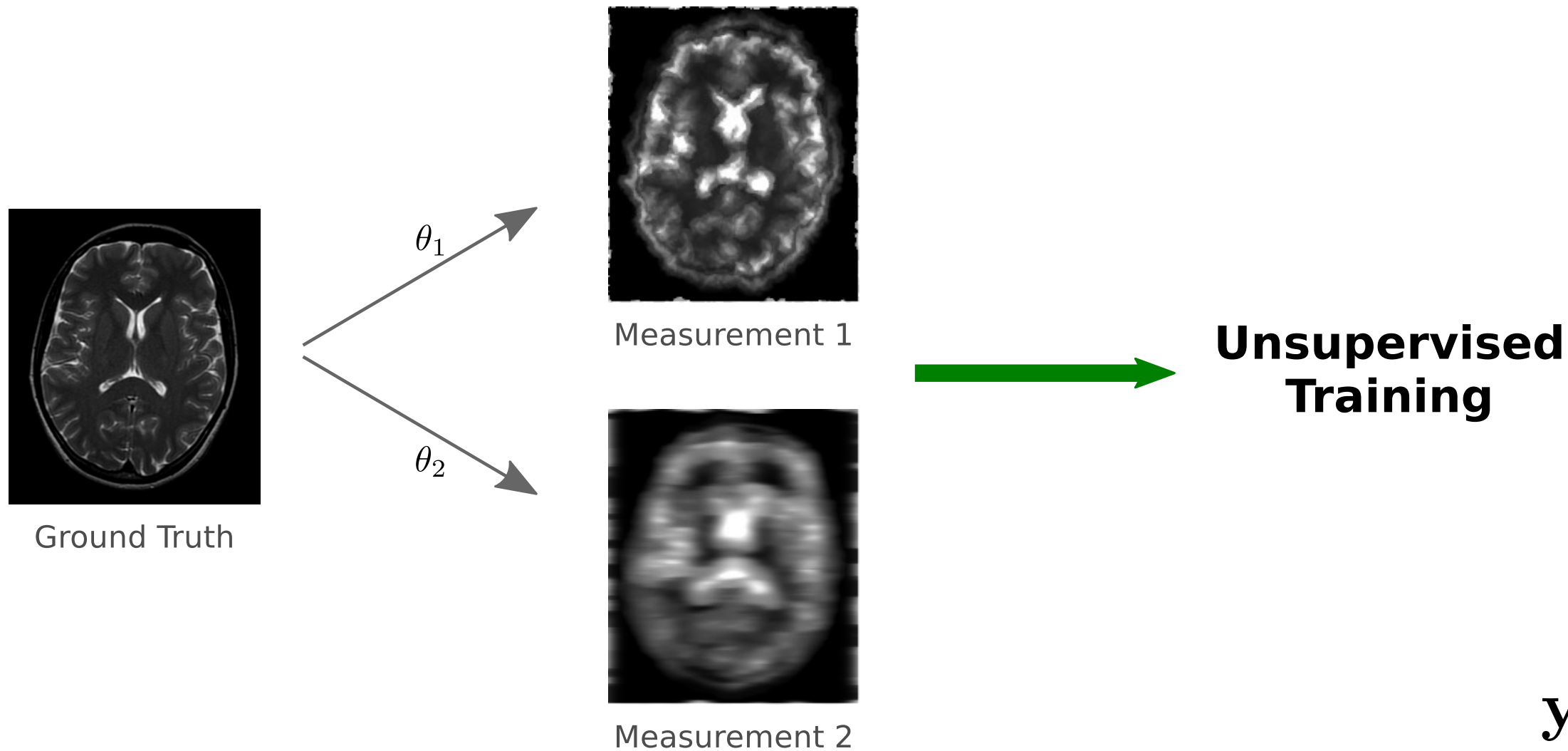
*Ground Truth*

**Our Training Approach**



# Unsupervised Learning

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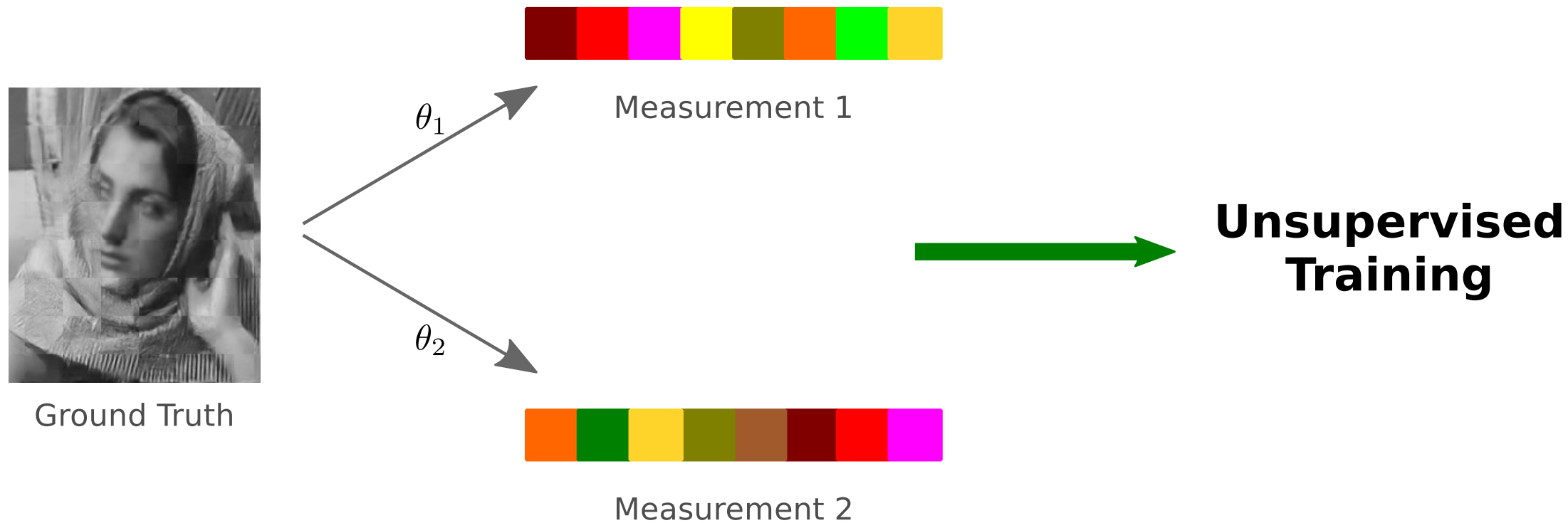


$$y = \theta x + \epsilon$$

General Linear  
Measurement Model

# Unsupervised Learning

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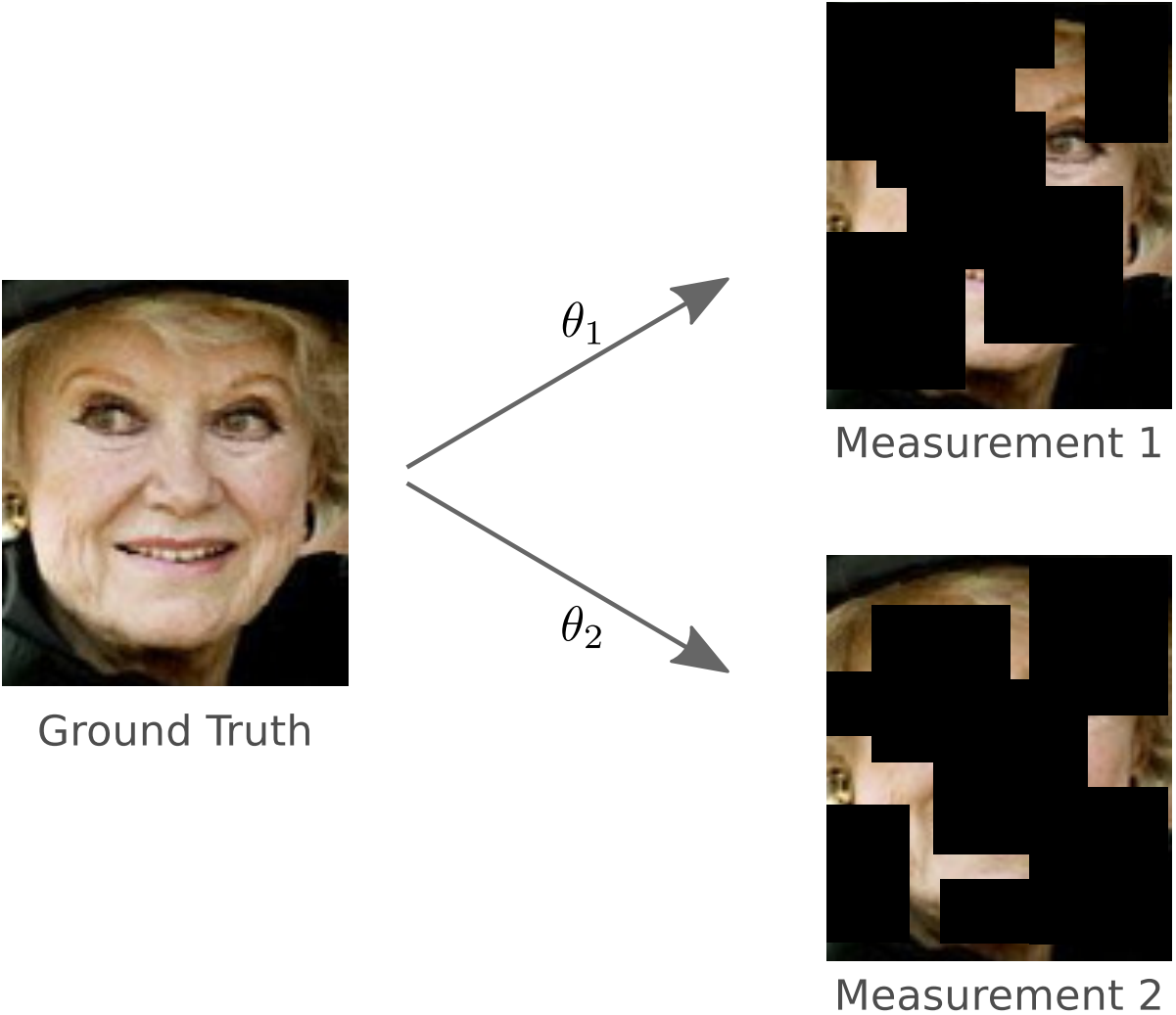
$$y = \theta x + \epsilon$$

**Compressive Sensing**  
(different sensing matrices)

General Linear  
Measurement Model

for images, videos, multispectral data ...

# Unsupervised Learning



**Unsupervised Training**

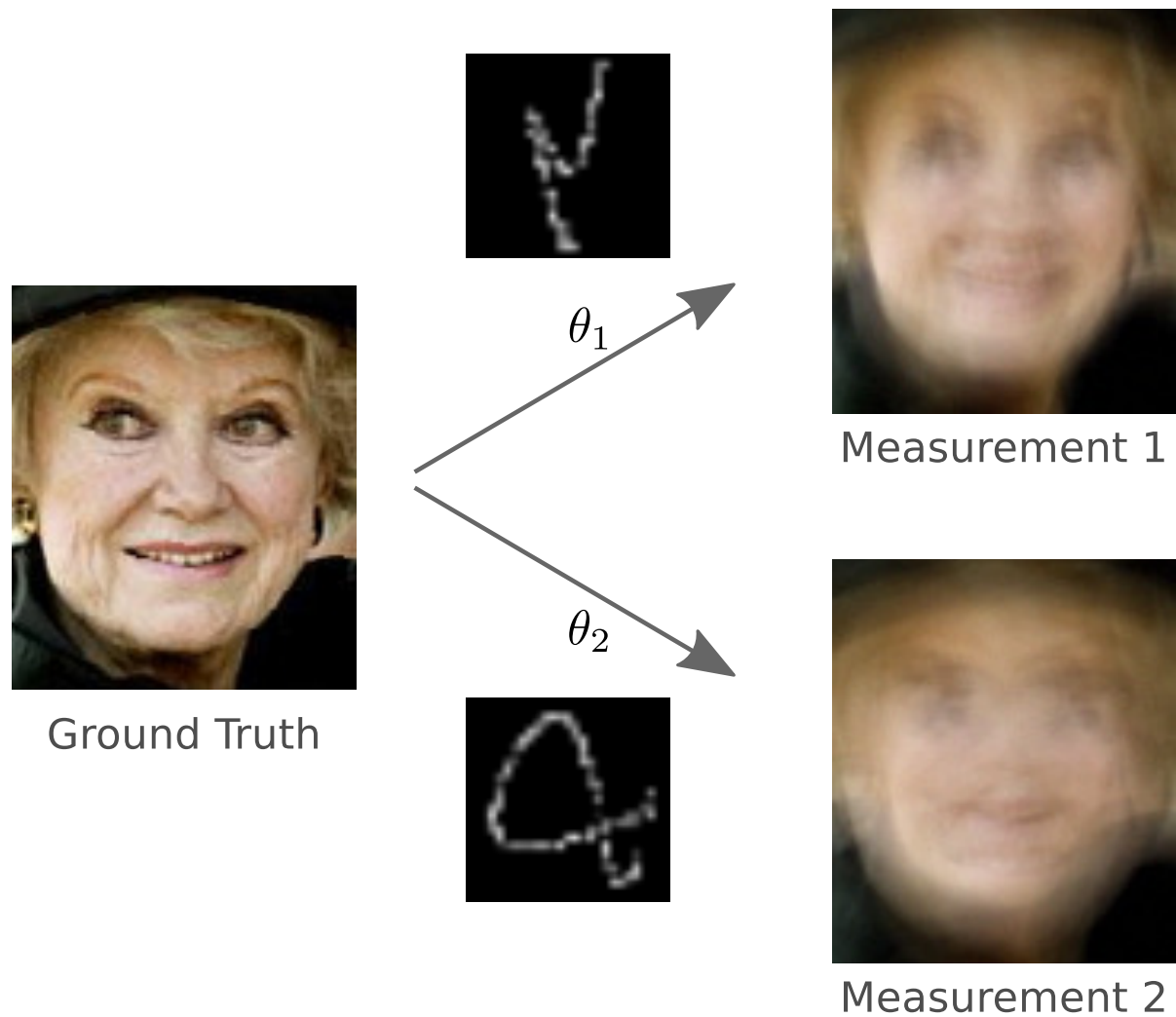
$$y = \theta x + \epsilon$$

General Linear Measurement Model

**In-painting**  
(different masked pixels)

# Unsupervised Learning

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**Unsupervised  
Training**

**Deblurring**  
(different blur kernels)

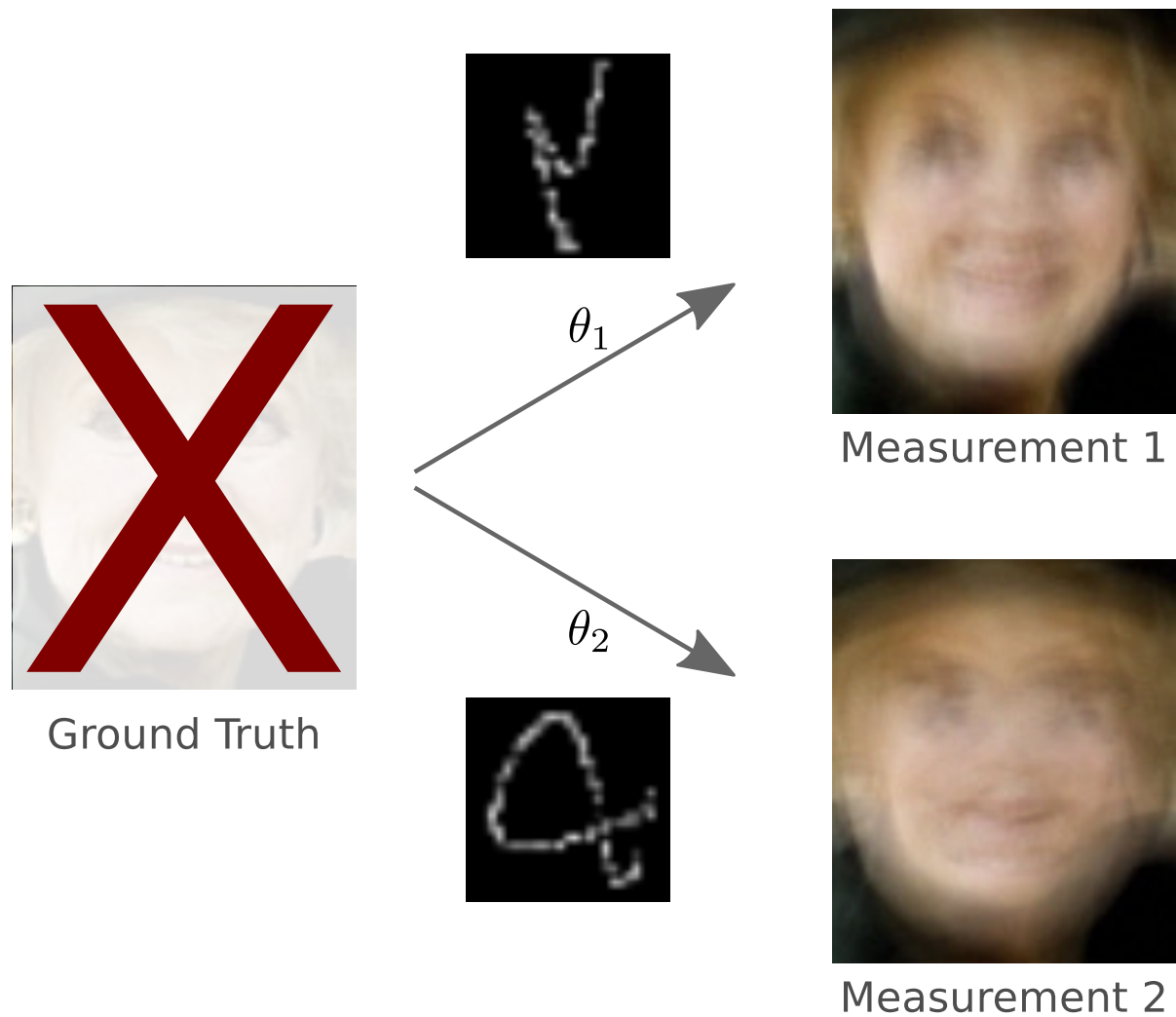
$$y = \theta x + \epsilon$$

General Linear  
Measurement Model



# Unsupervised Learning

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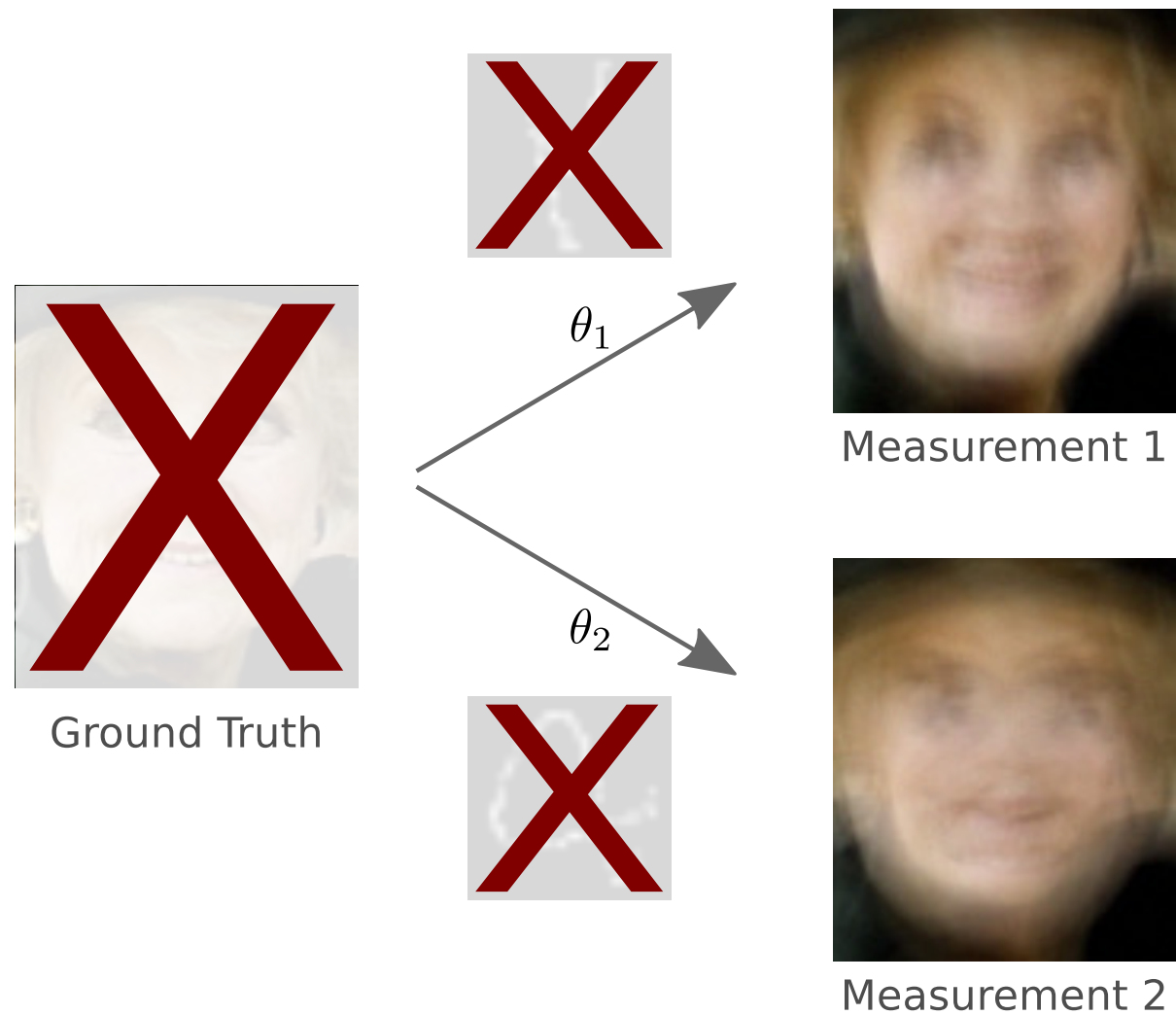


**Unsupervised  
Training**

$$y = \theta x + \epsilon$$

General Linear  
Measurement Model

# Unsupervised Learning



Measurement Parameters  
*also* unknown during training

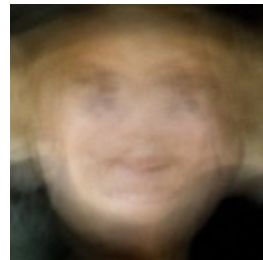
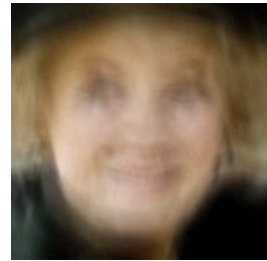
**Blind**  
**Unsupervised**  
**Training**

$$\mathbf{y} = \boldsymbol{\theta} \mathbf{x} + \epsilon$$

General Linear  
Measurement Model

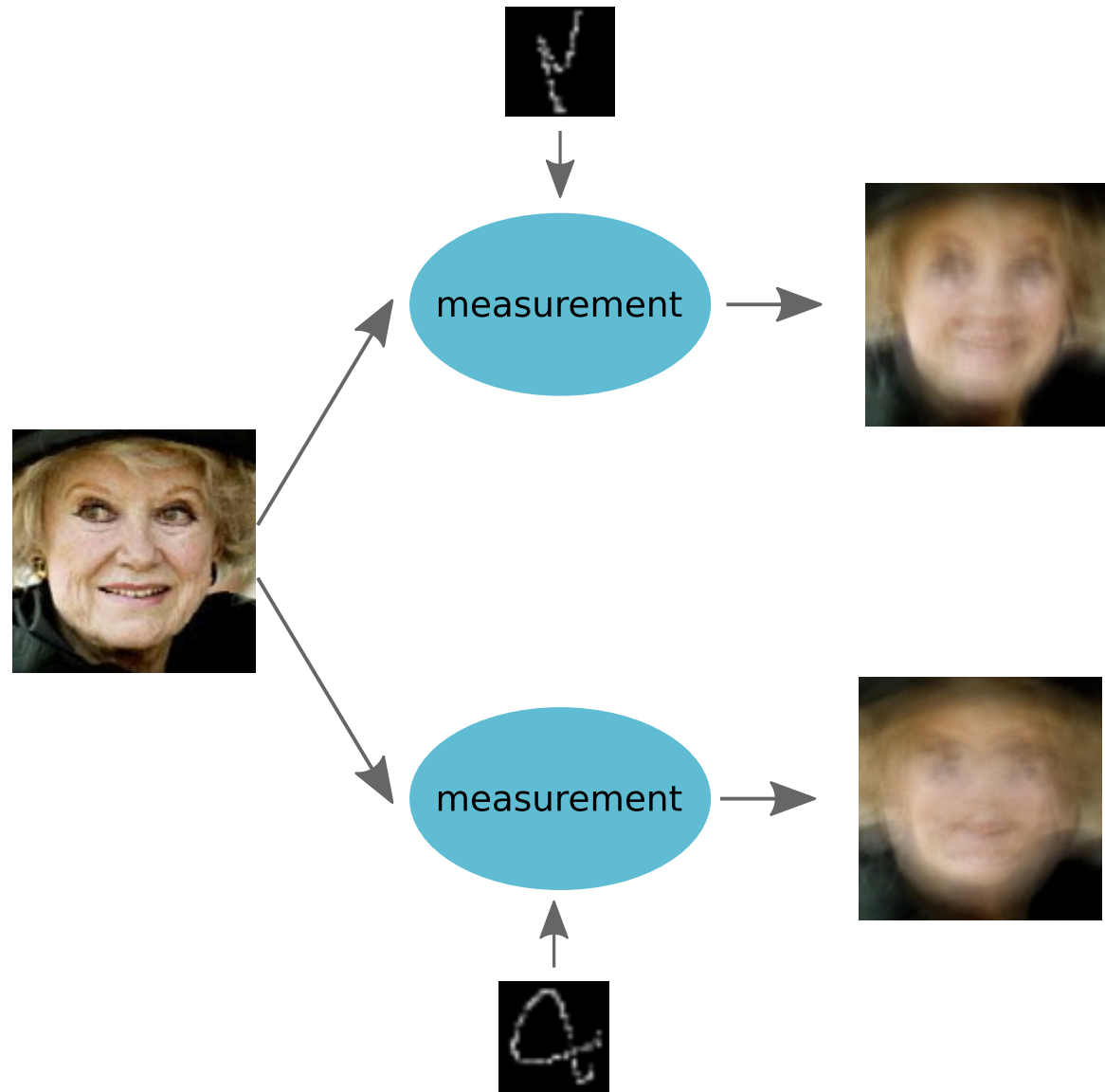
# Sketch of Training Approach

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# Sketch of Training Approach

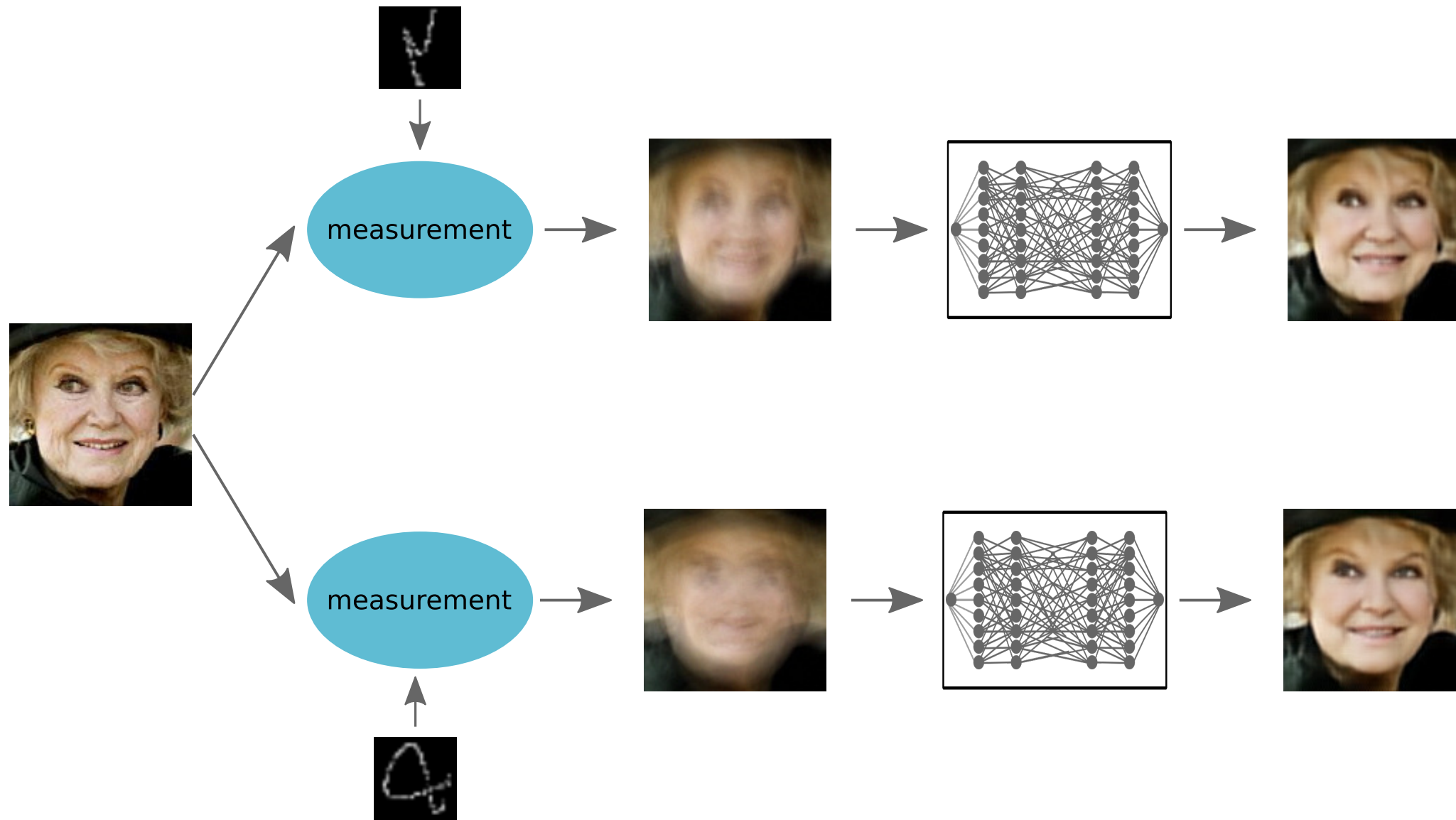
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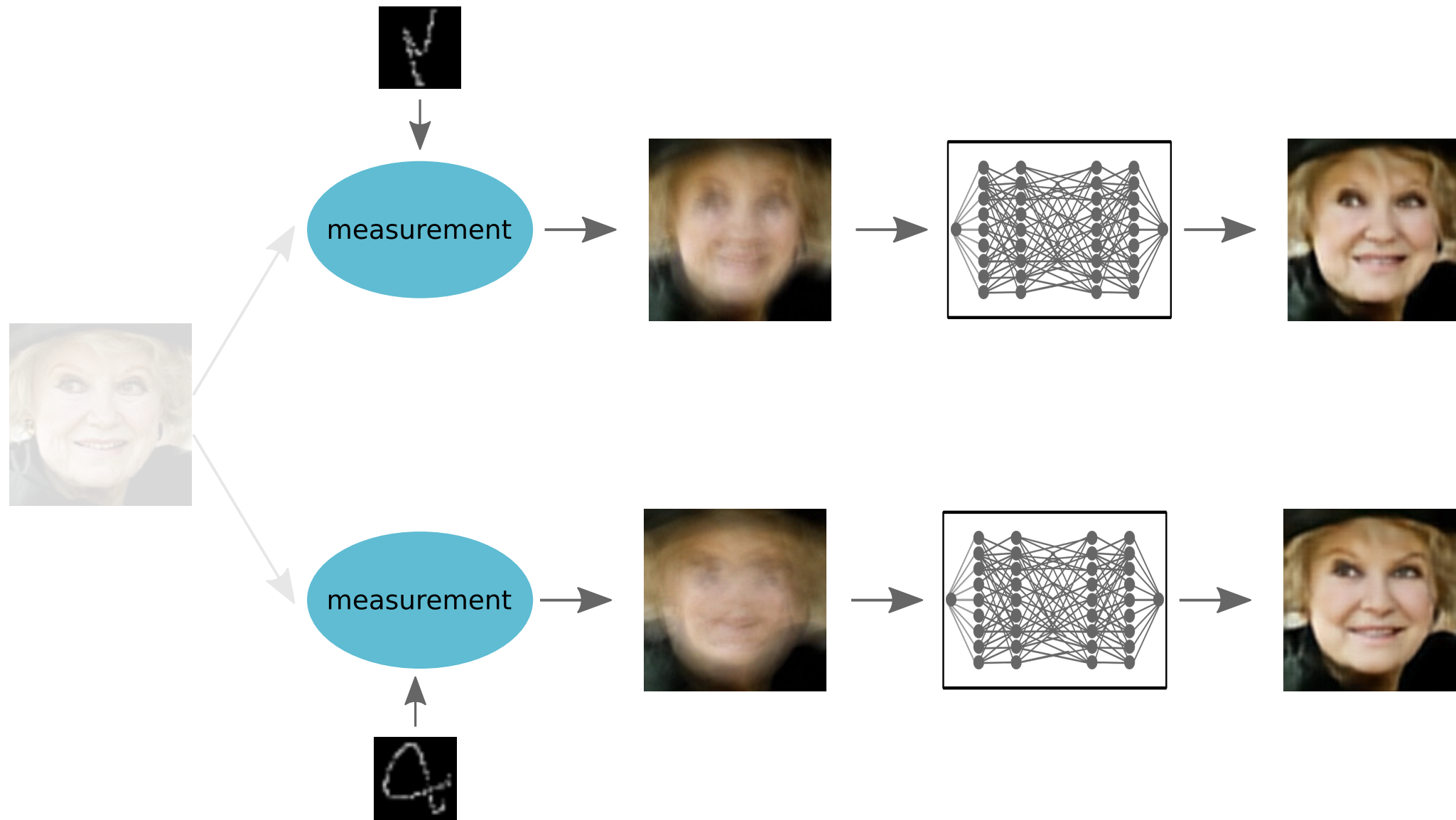
# Sketch of Training Approach

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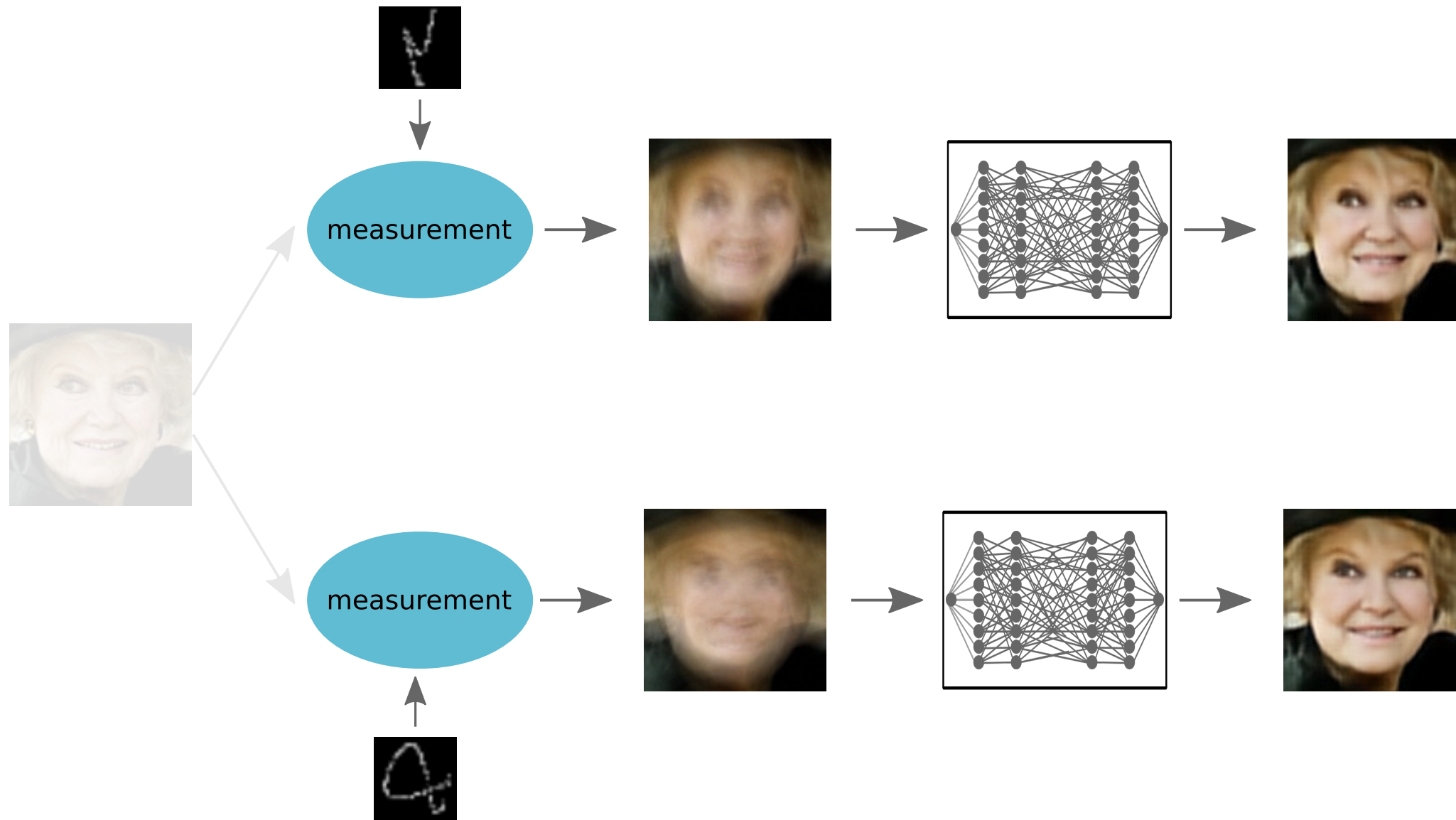
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# Sketch of Training Approach

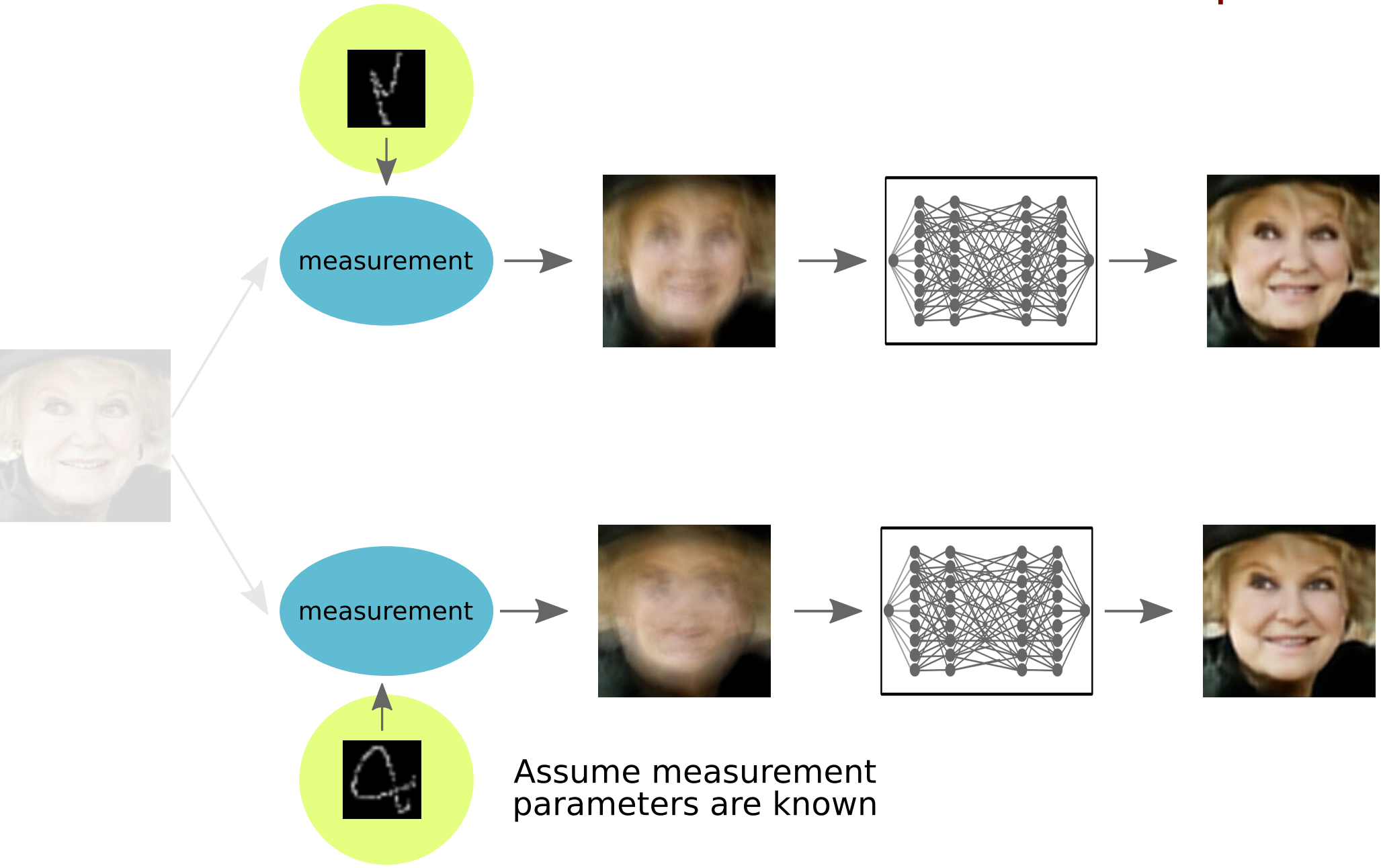
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Swap Loss



# Sketch of Training Approach

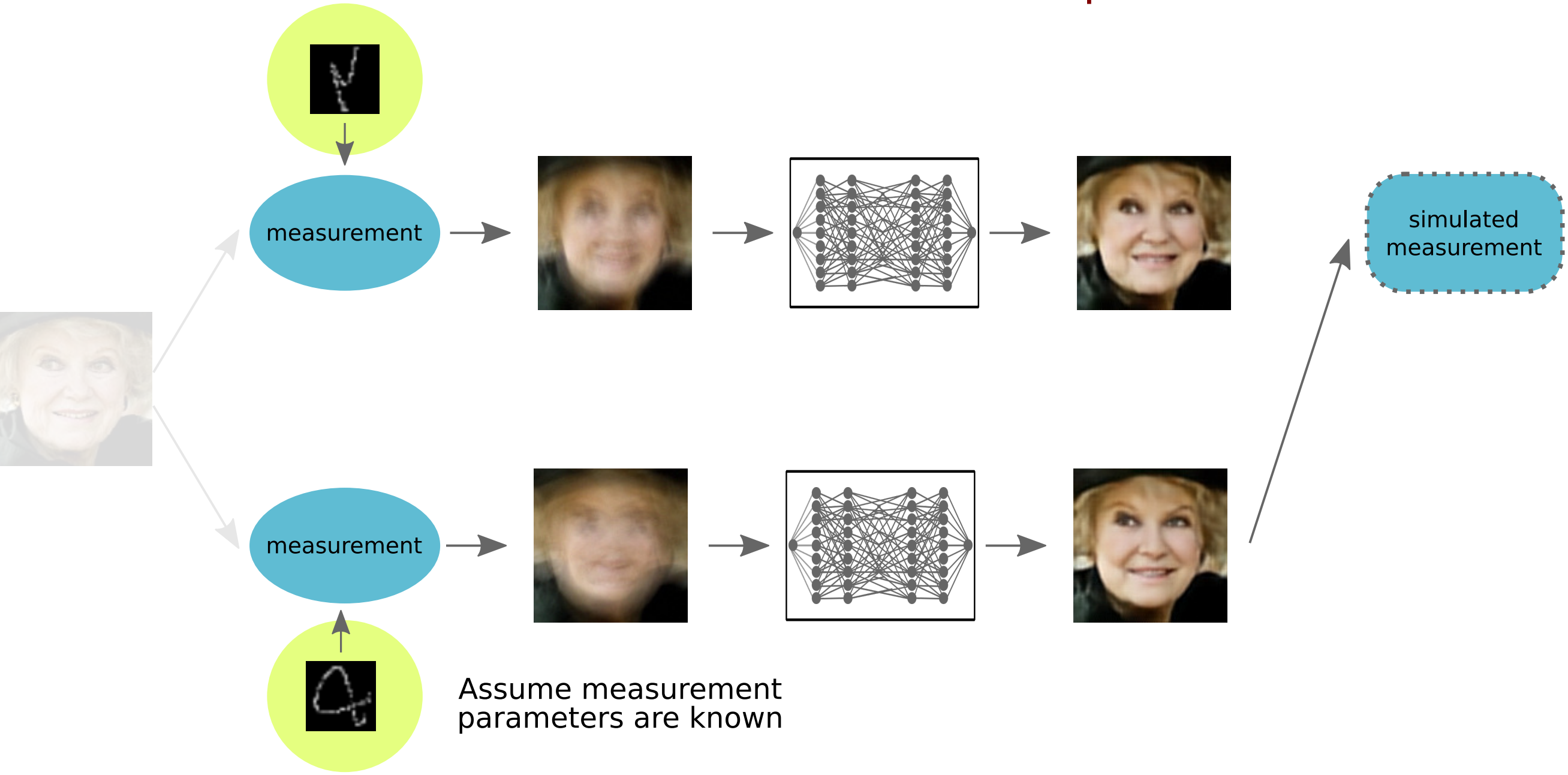
Swap Loss





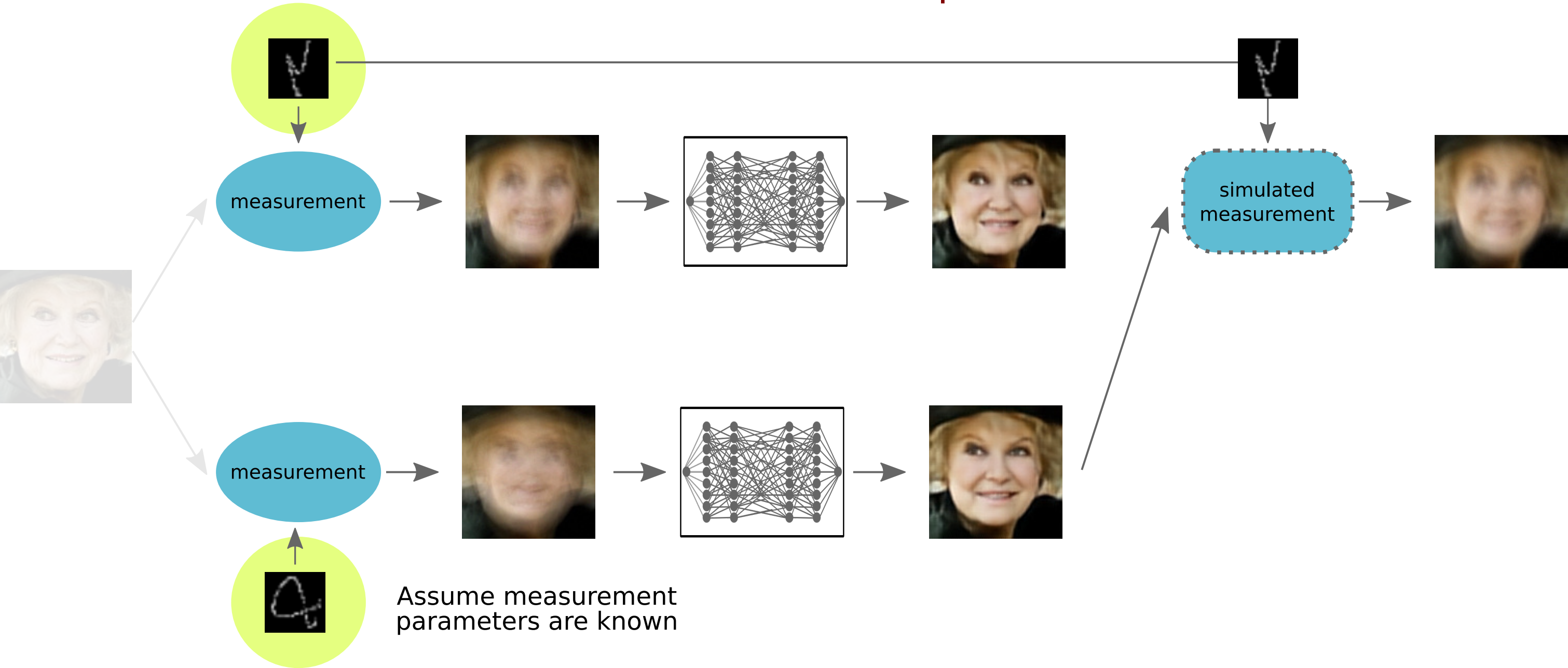
# Sketch of Training Approach

Swap Loss

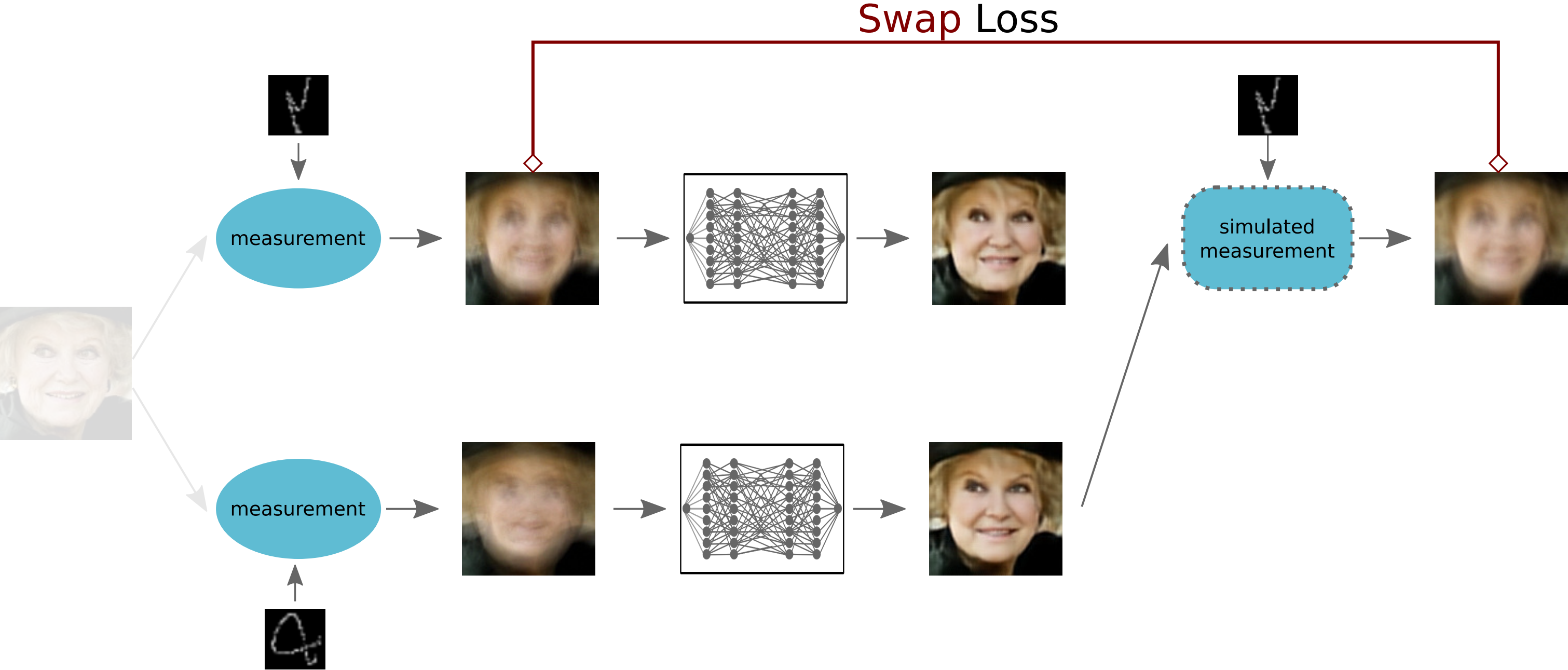


# Sketch of Training Approach

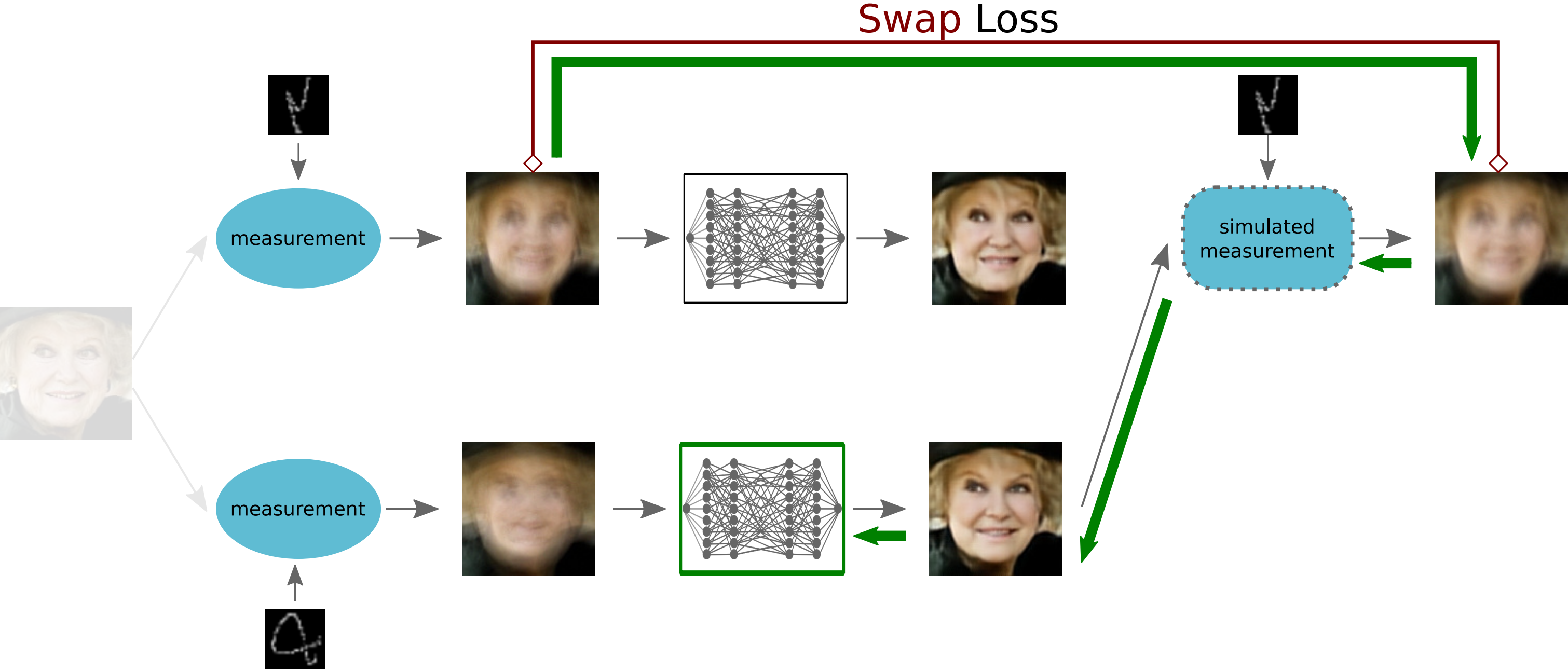
## Swap Loss



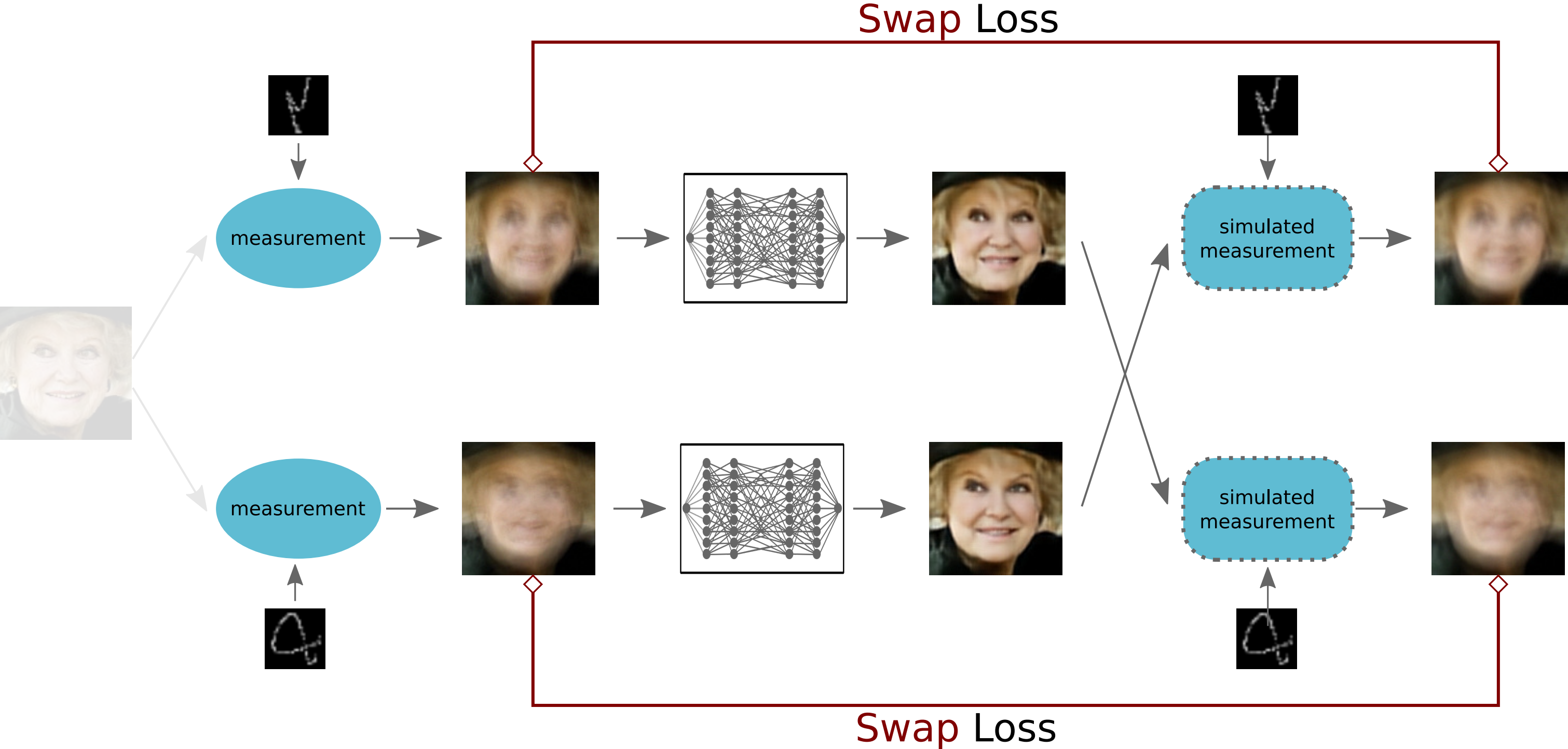
# Sketch of Training Approach



# Sketch of Training Approach



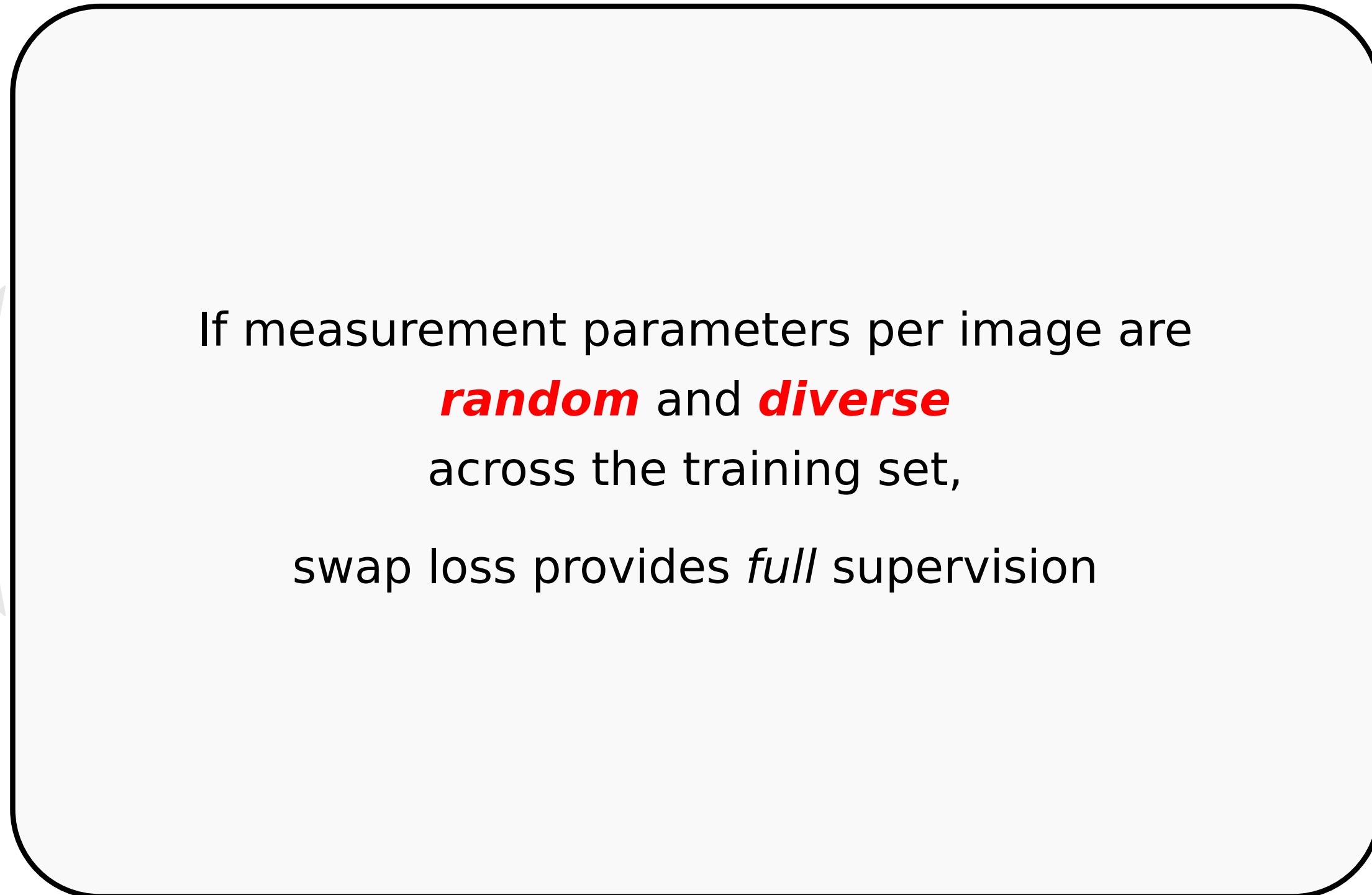
# Sketch of Training Approach



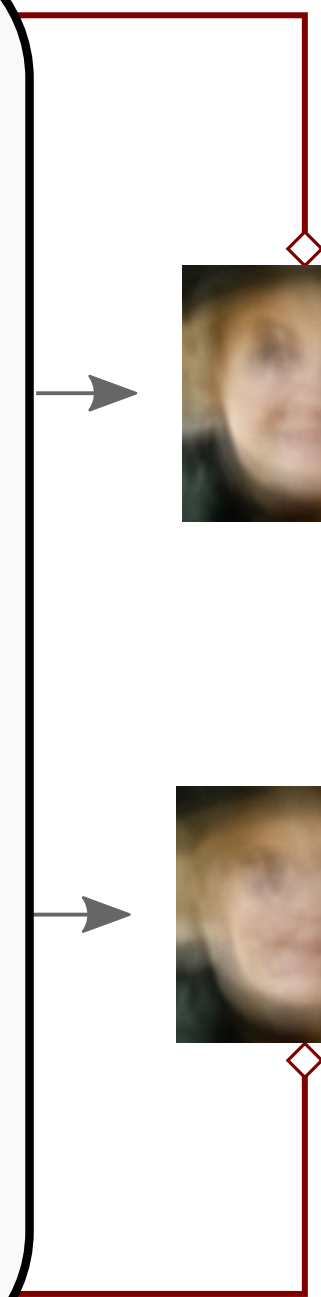
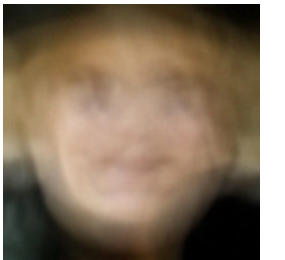
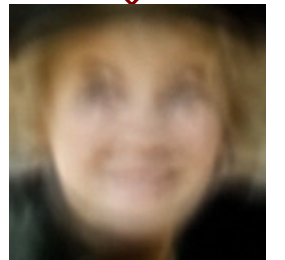


# Sketch of Training Approach

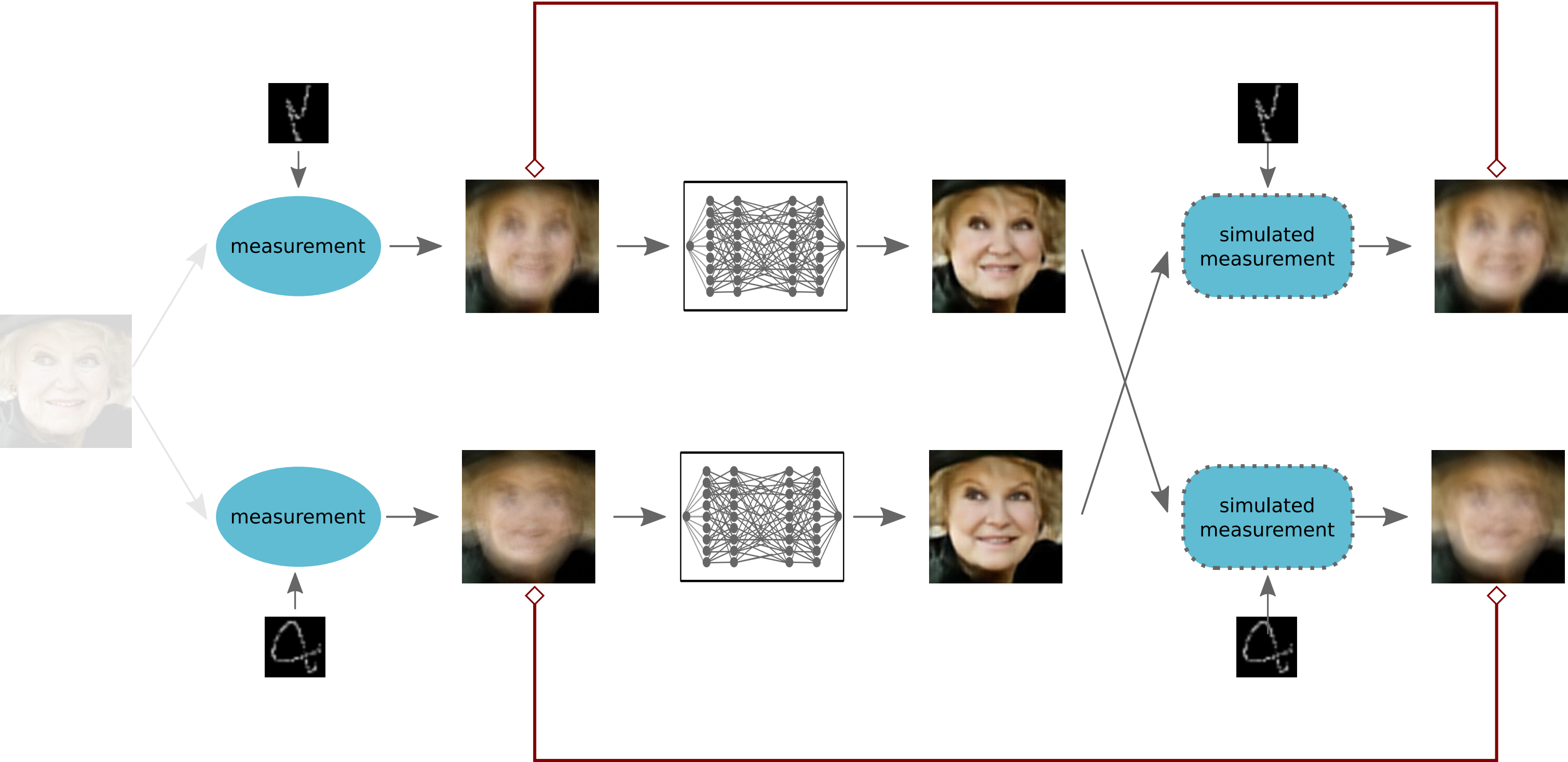
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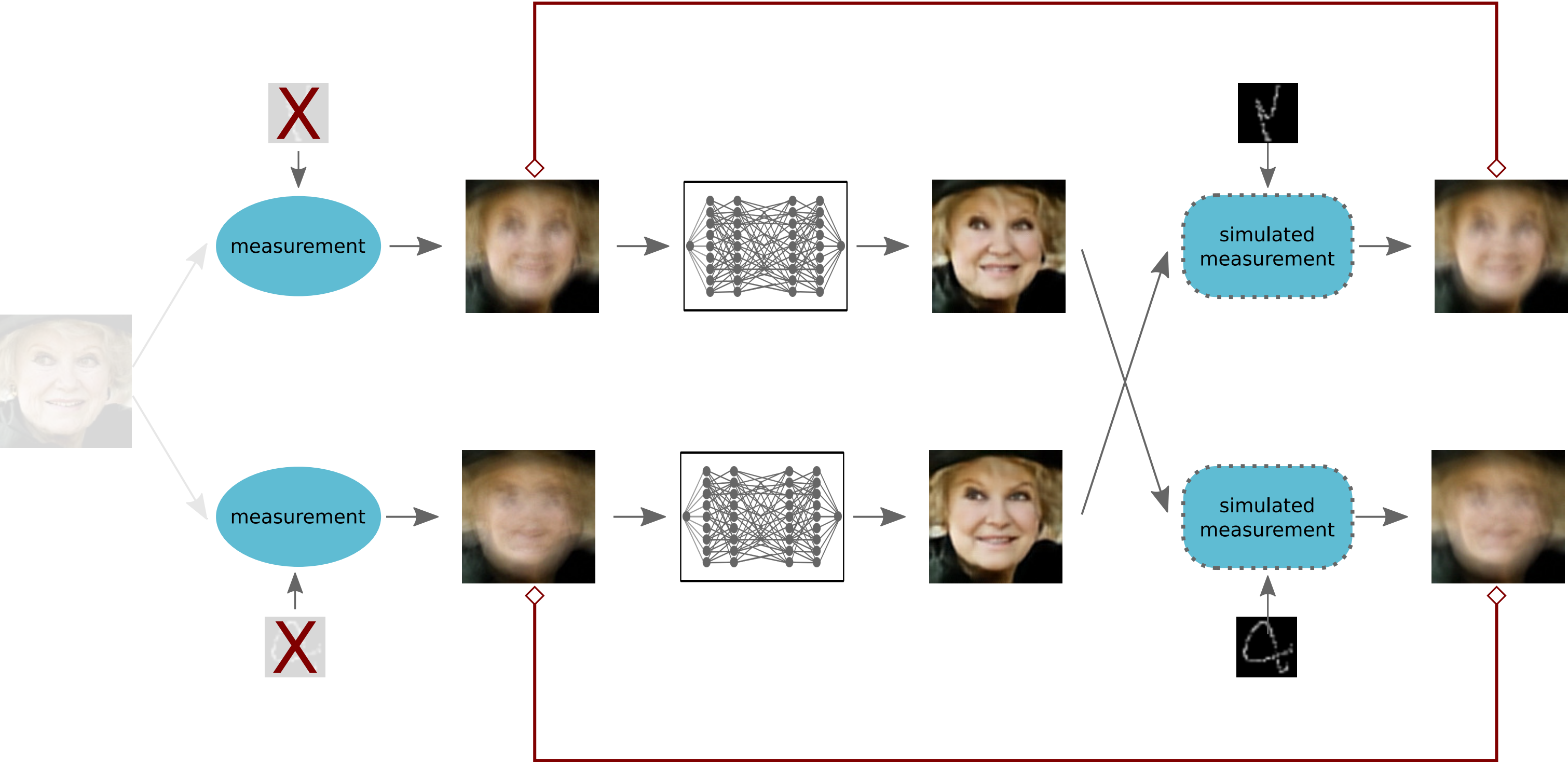
If measurement parameters per image are  
***random*** and ***diverse***  
across the training set,  
swap loss provides *full* supervision



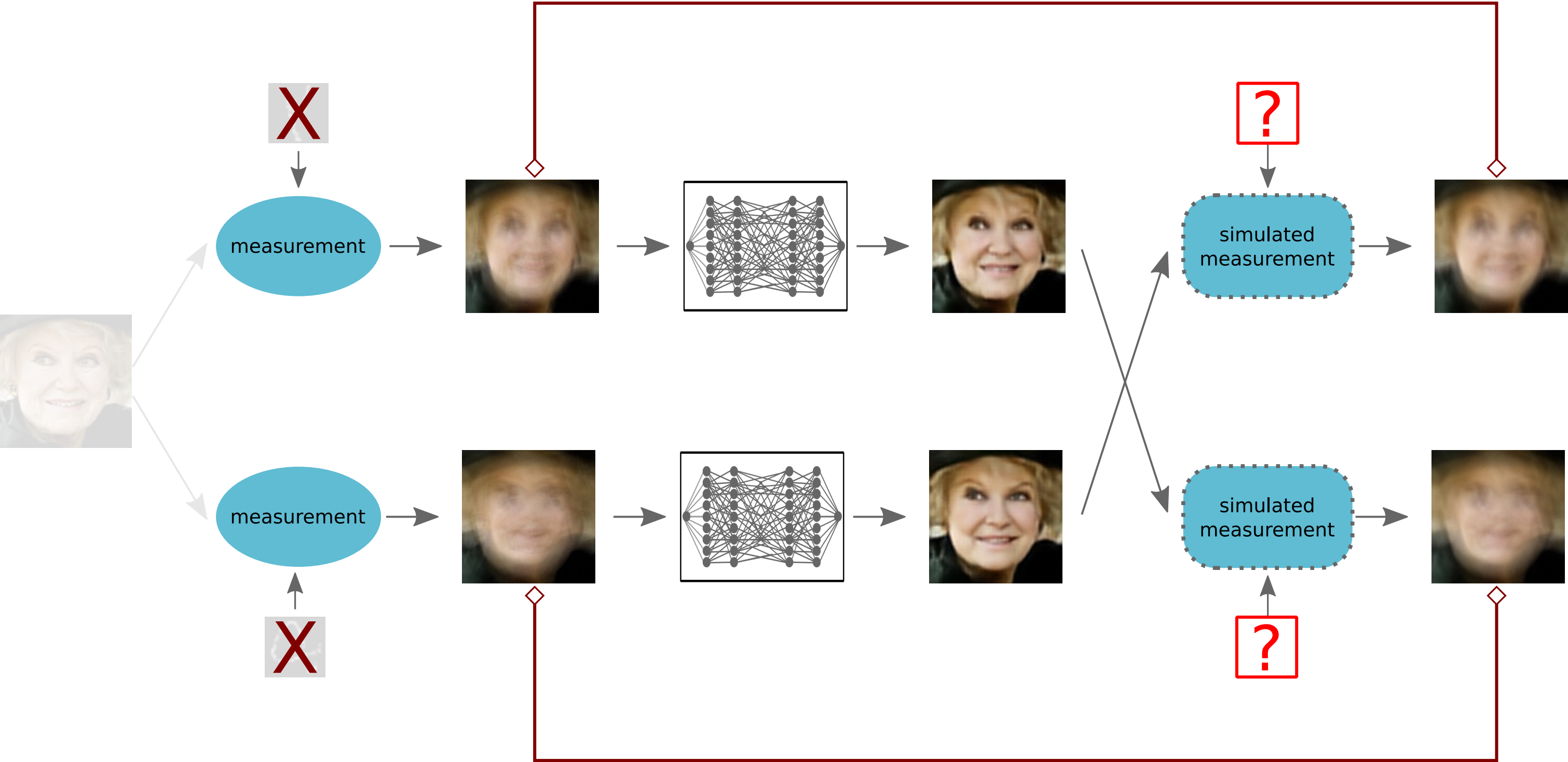
# Sketch of Training Approach



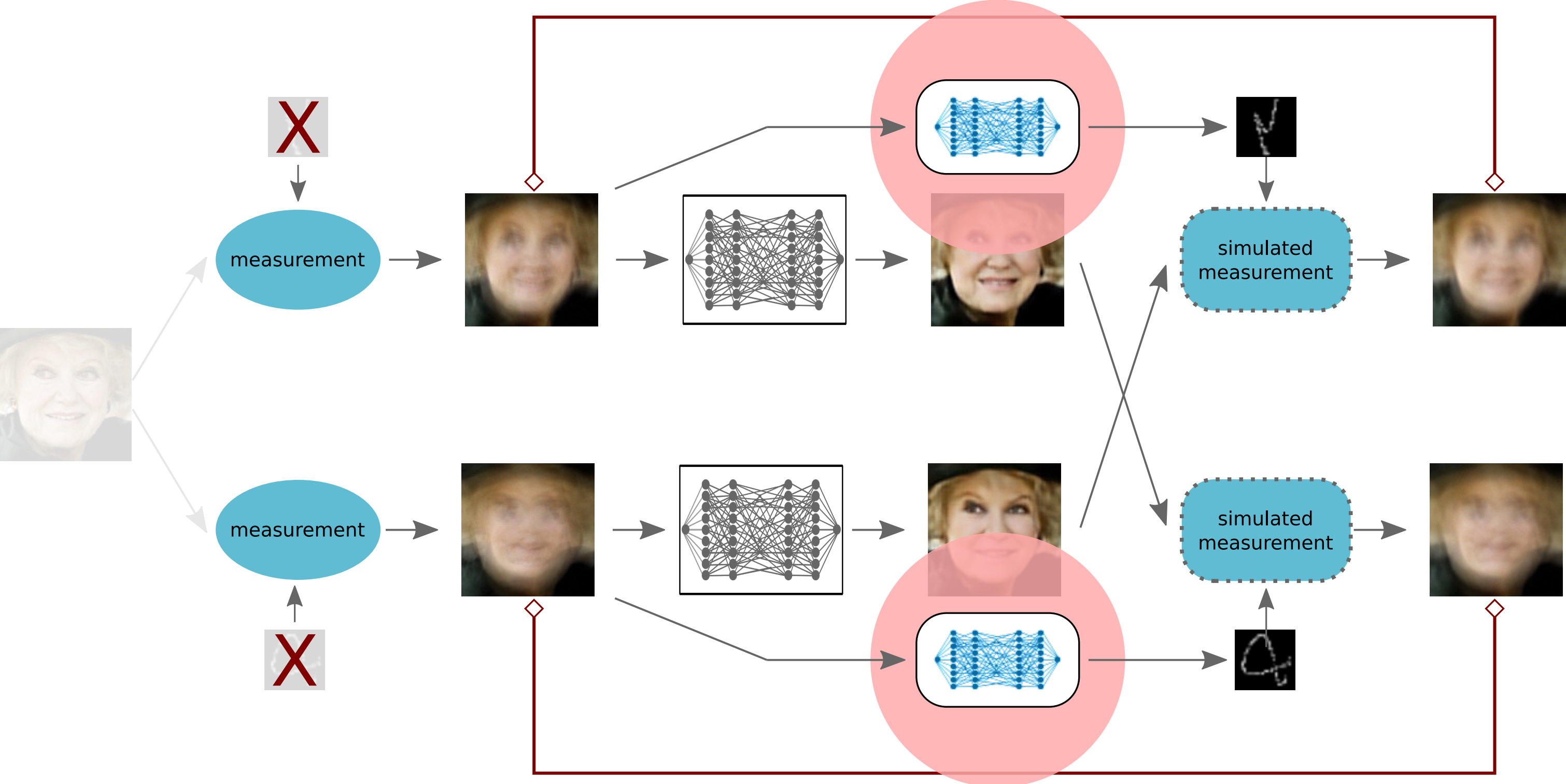
# Sketch of Training Approach: **Blind Setting**



# Sketch of Training Approach: **Blind Setting**



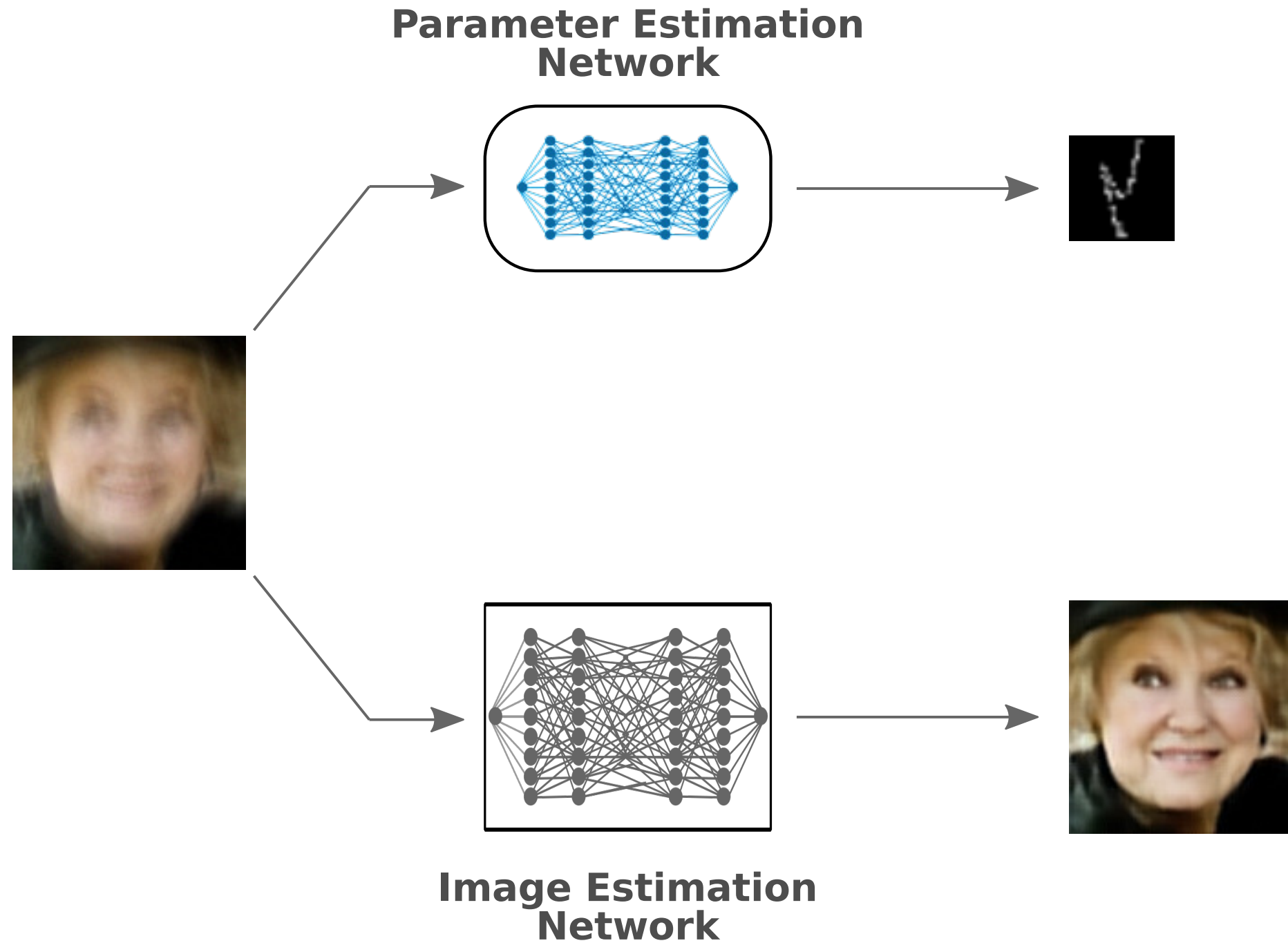
# Sketch of Training Approach: **Blind Setting**





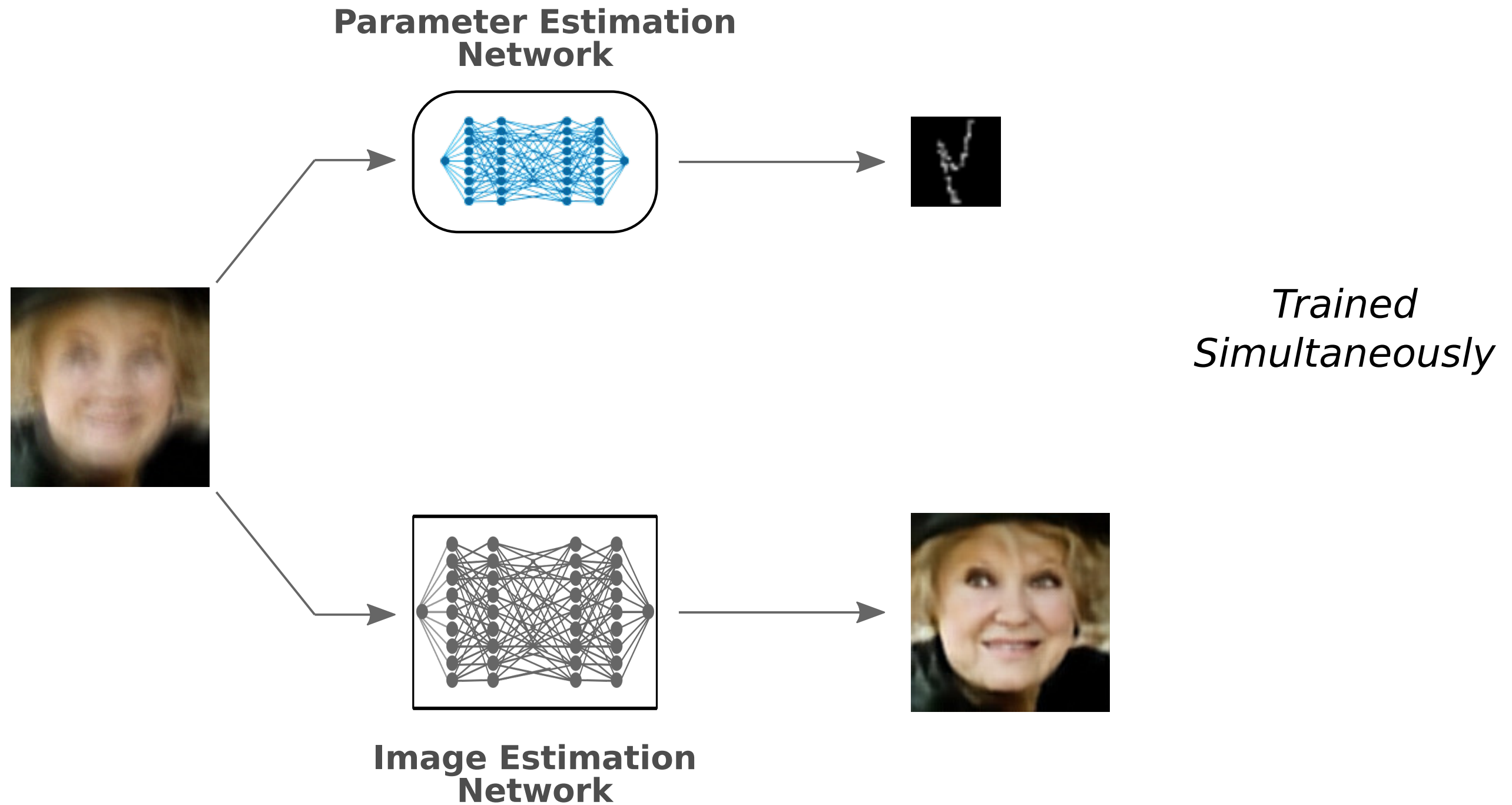
# Sketch of Training Approach: **Blind Setting**

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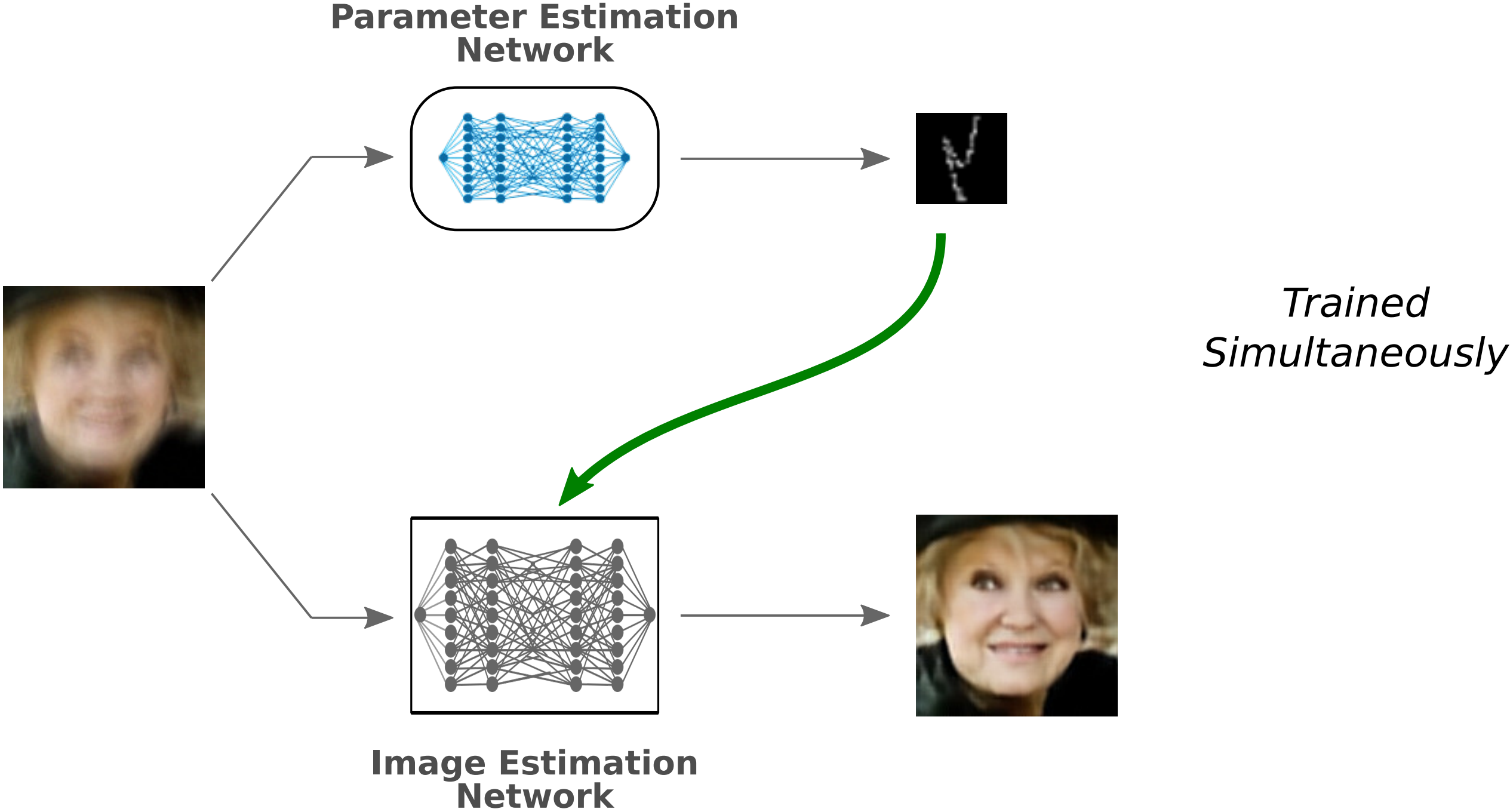


# Sketch of Training Approach: **Blind Setting**

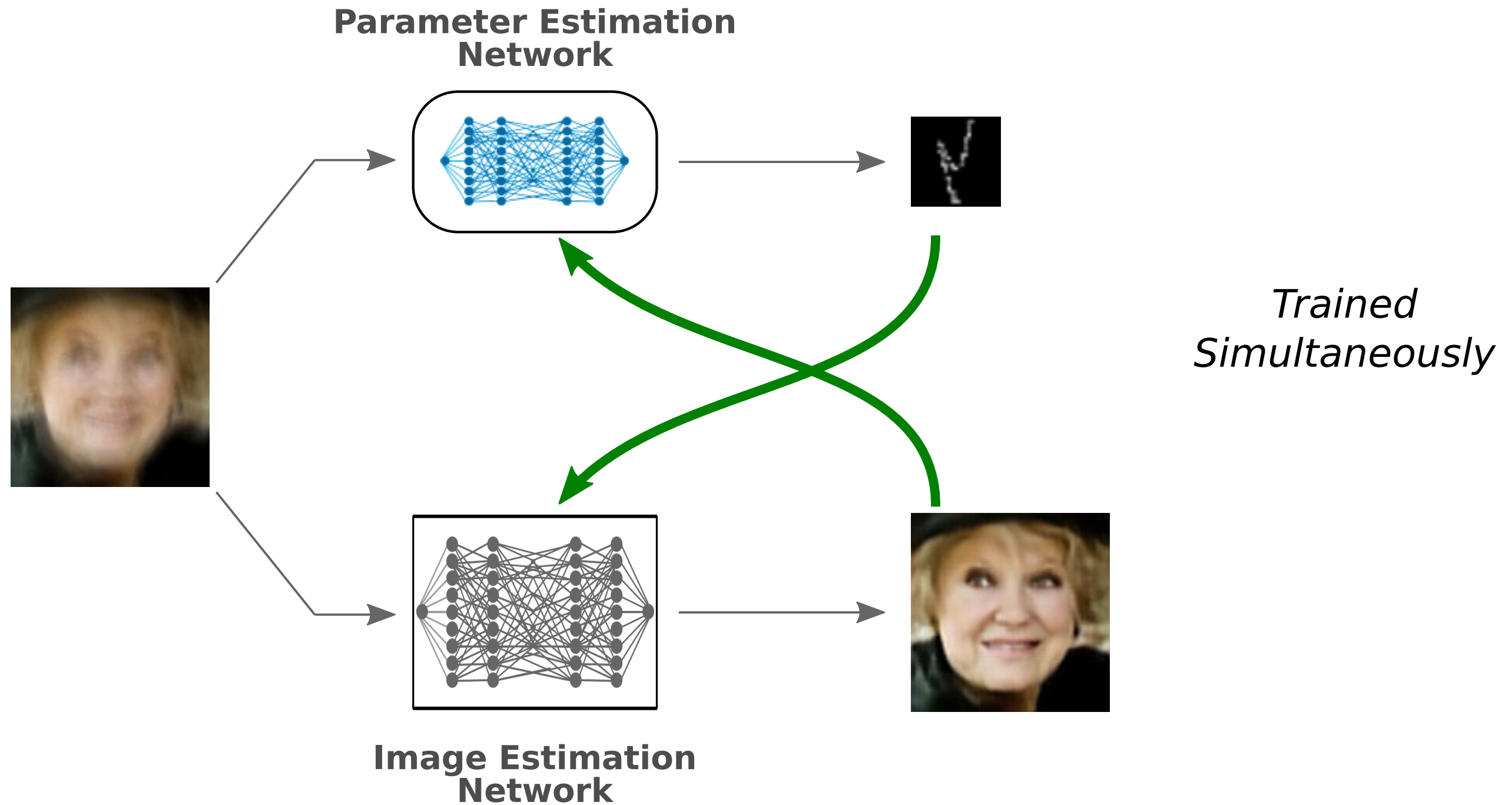
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# Sketch of Training Approach: **Blind Setting**



# Sketch of Training Approach: **Blind Setting**



# Experiments

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- Compressive Sensing Reconstruction

Non-blind unsupervised training

- Blind Motion Deblurring of Face Images

Non-blind and Blind unsupervised training

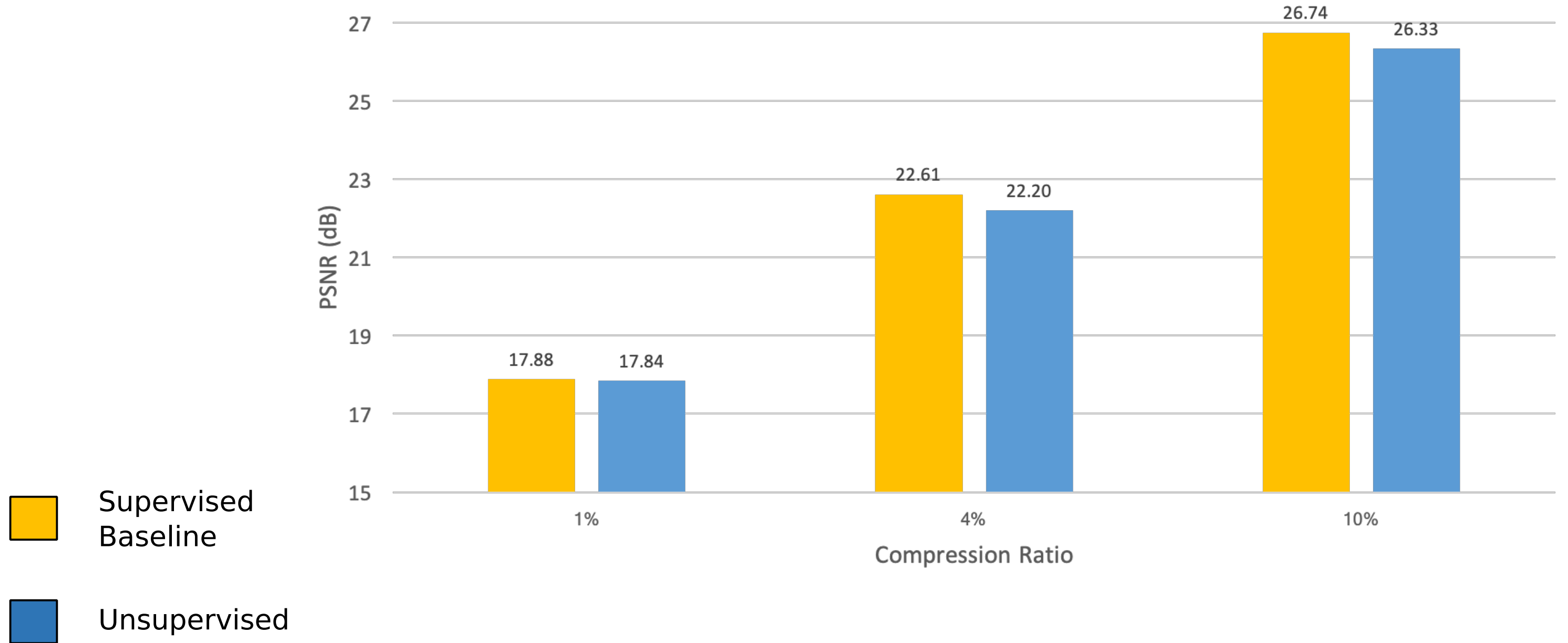


# Experiments: Compressive Sensing

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# Experiments: Compressive Sensing

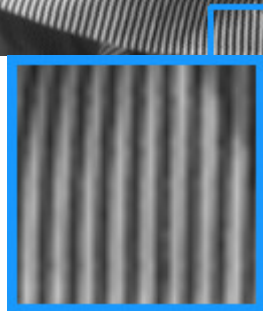
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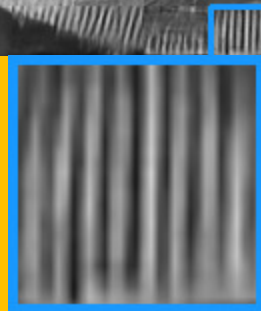
# Experiments: Compressive Sensing

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Ground Truth



Supervised Baseline



Unsupervised

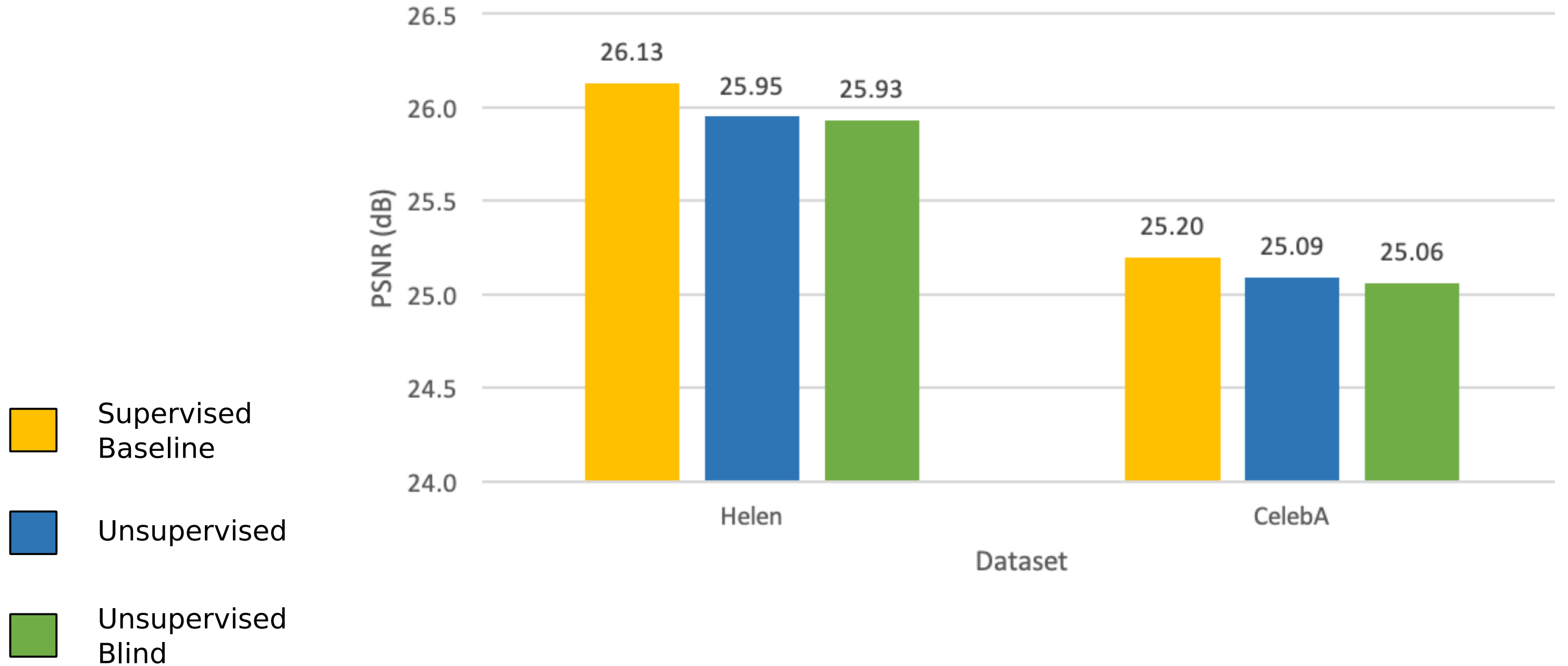


# Experiments: Blind Face Image Deblurring

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# Experiments: Blind Face Image Deblurring

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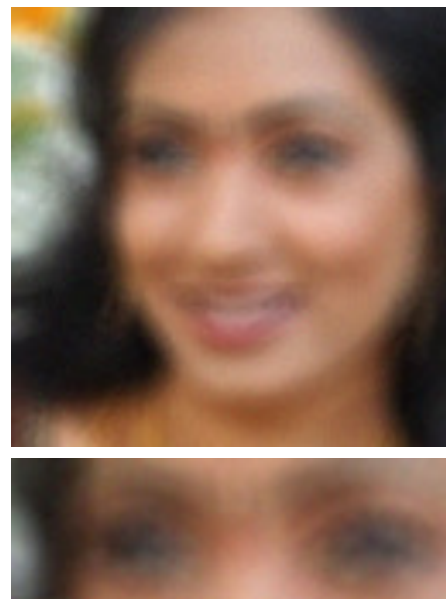
# Experiments: Blind Face Image Deblurring

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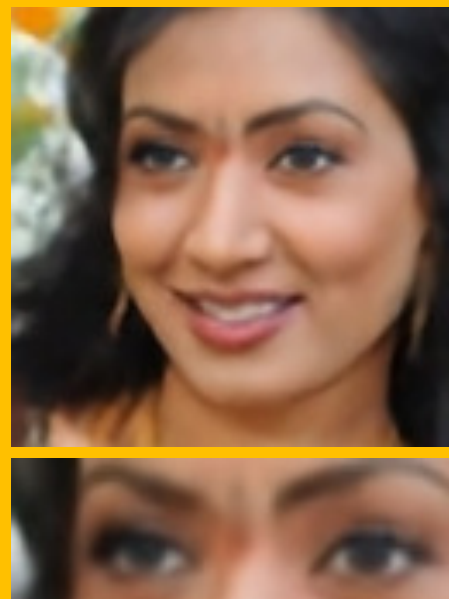
Ground Truth



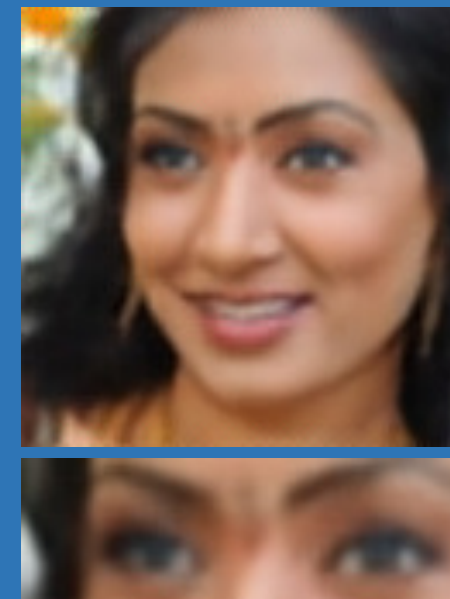
Blurry Input



Supervised  
Baseline



Unsupervised

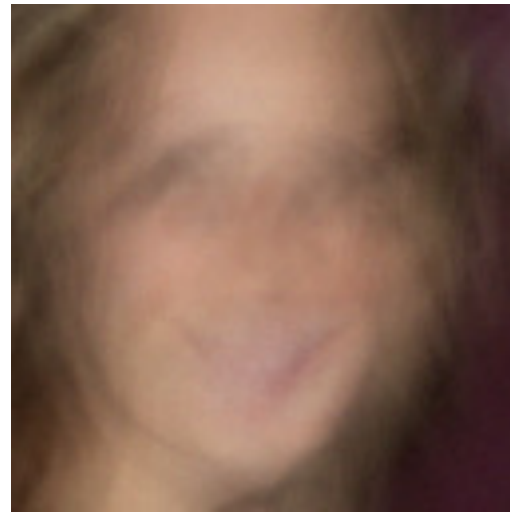


Unsupervised  
Blind



# Experiments: Blind Face Image Deblurring

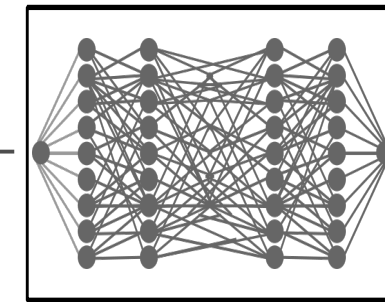
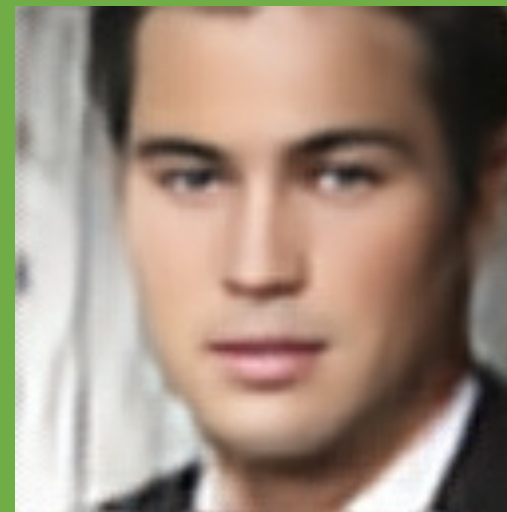
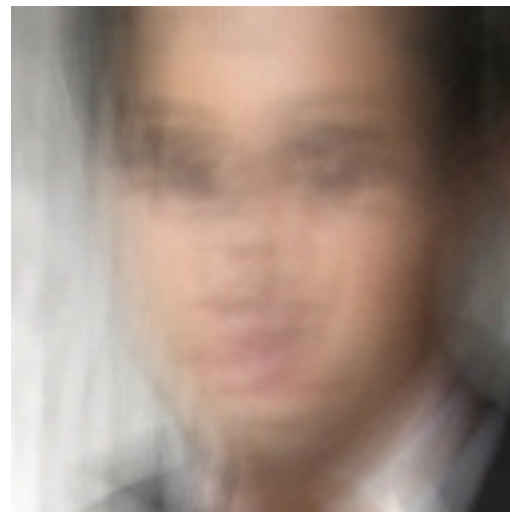
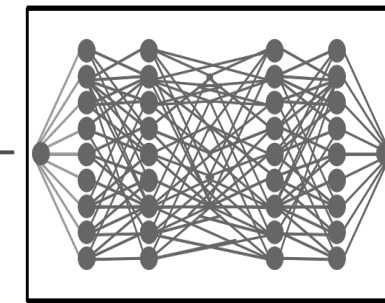
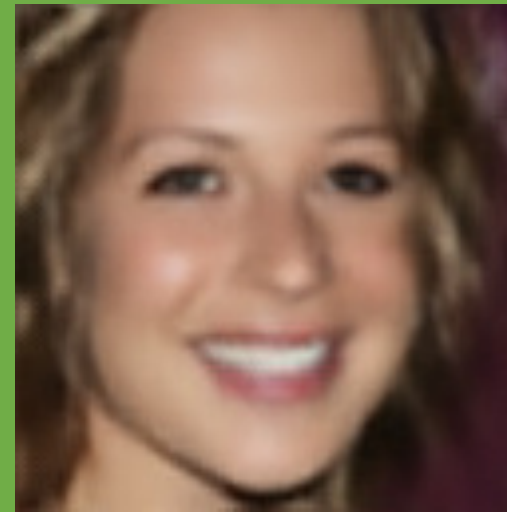
Blurry Input



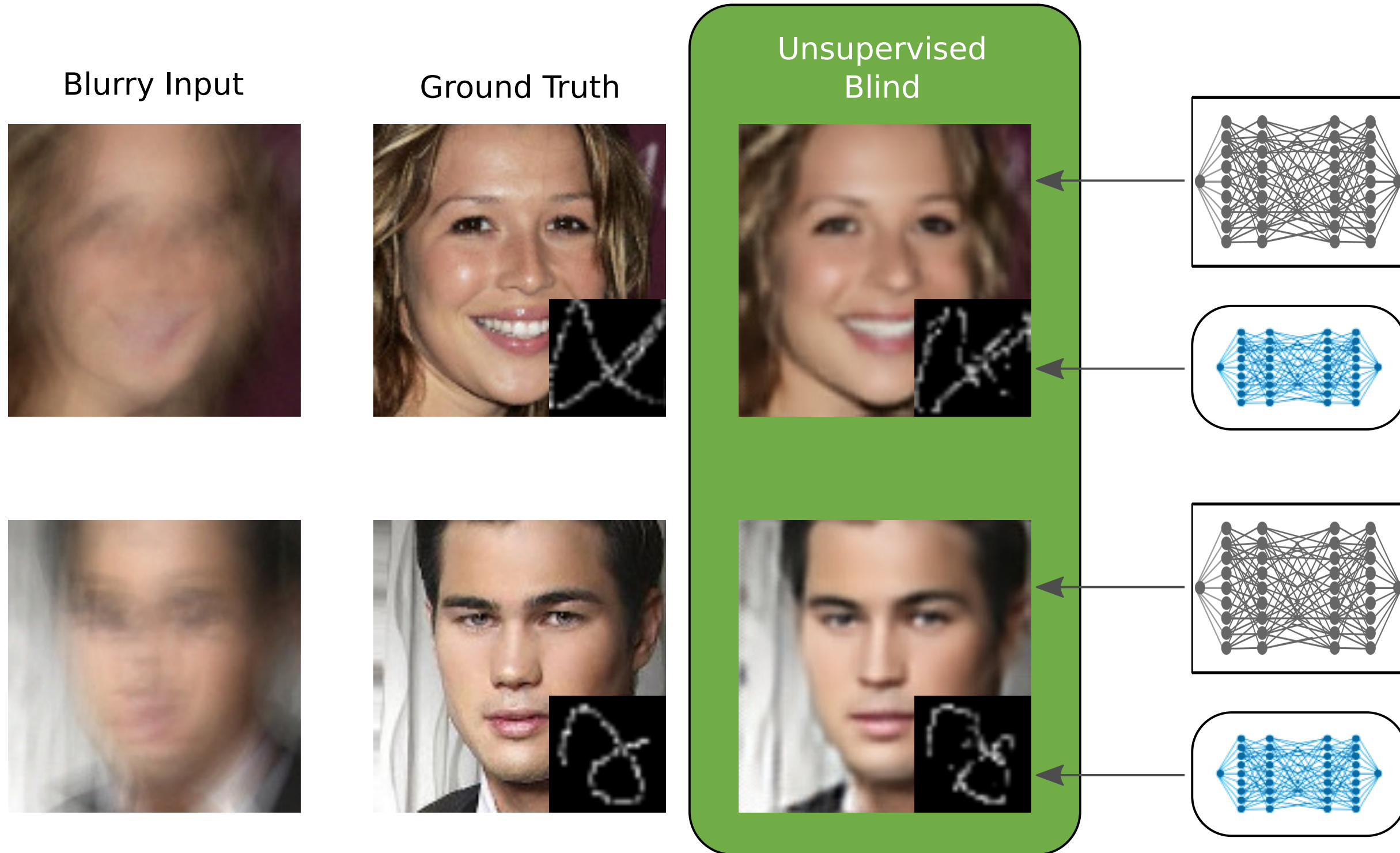
Ground Truth



Unsupervised  
Blind



# Experiments: Blind Face Image Deblurring



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