

Multi-Task Self-Supervised Methods for Label-Efficient Learning

Combining Contrastive and Pretext-Based Learning for Effective Encoders from
Unlabeled and Federated Data in Human Activity Recognition and Beyond

Alessandro Gobbetti

Advisor Prof. Marc Langheinrich

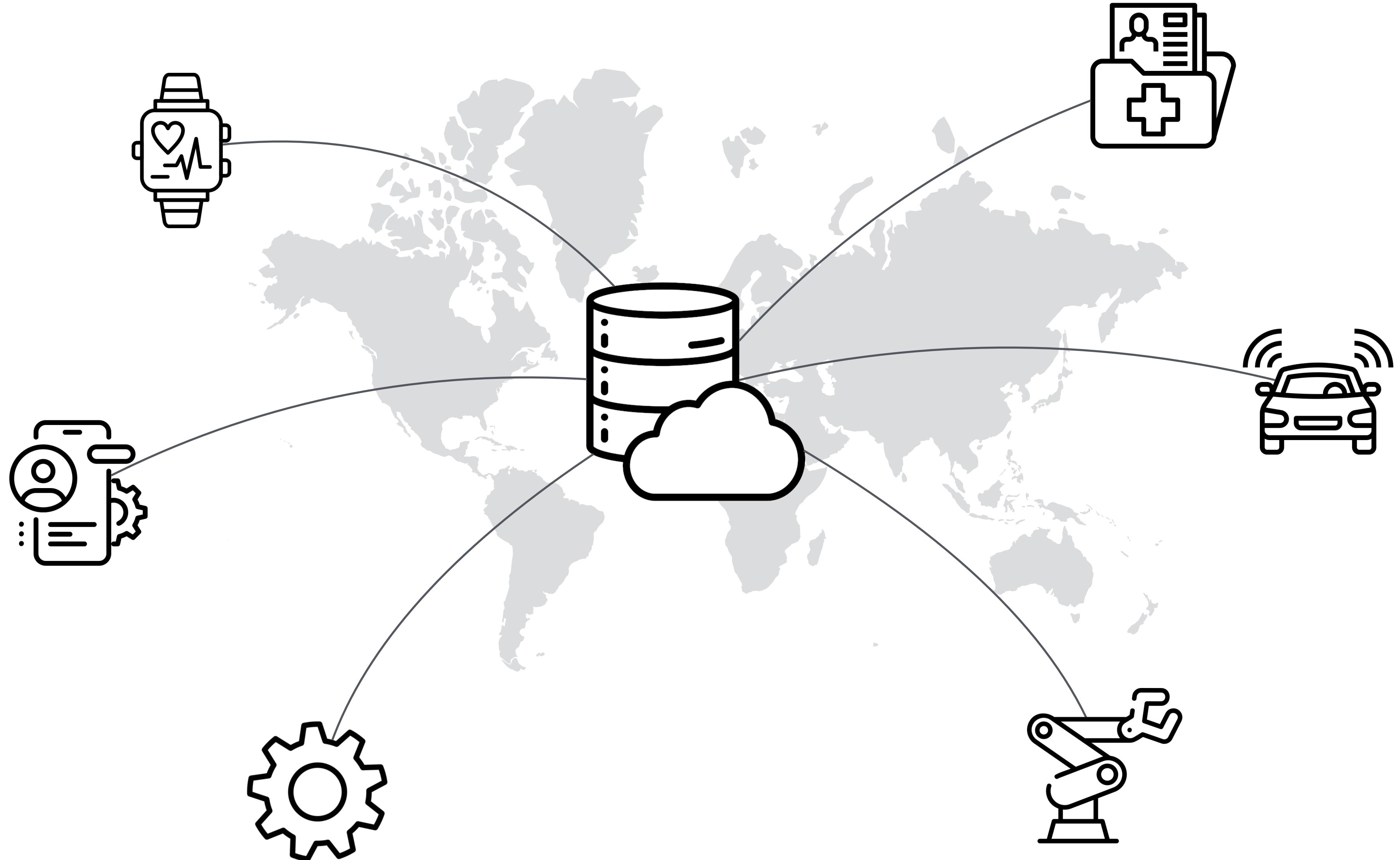
Co-Advisors Dario Fenoglio & Mohan Li

September 2025

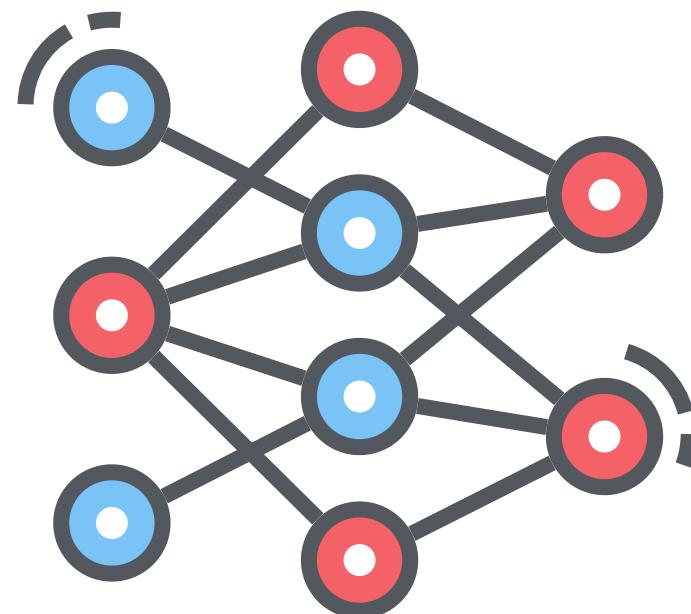
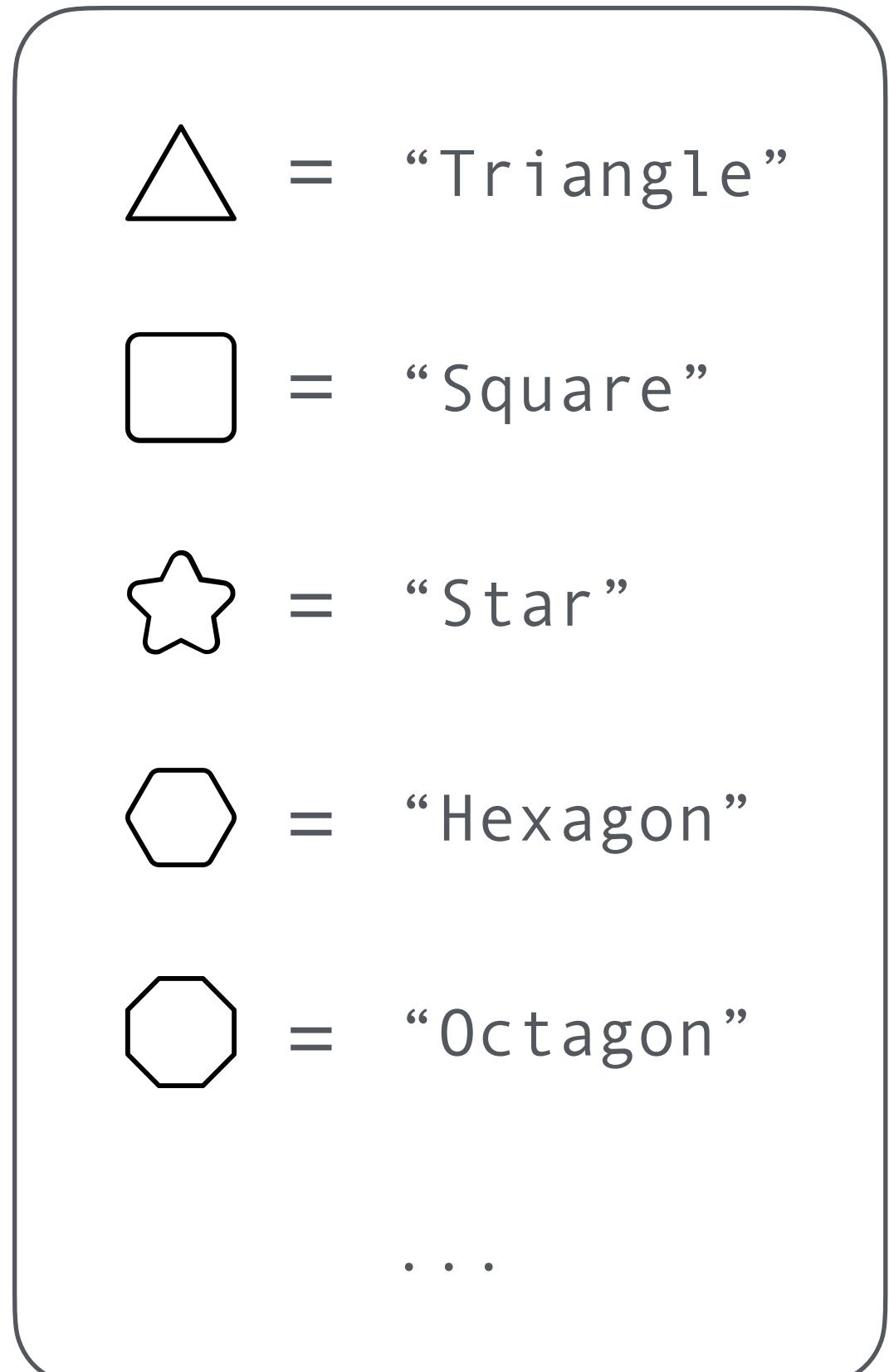
Master of Science in Informatics



Problem



Problem



- → “Circle”
- ★ → “Star”
- △ → “Triangle”
- → “Trapezium”

Problem

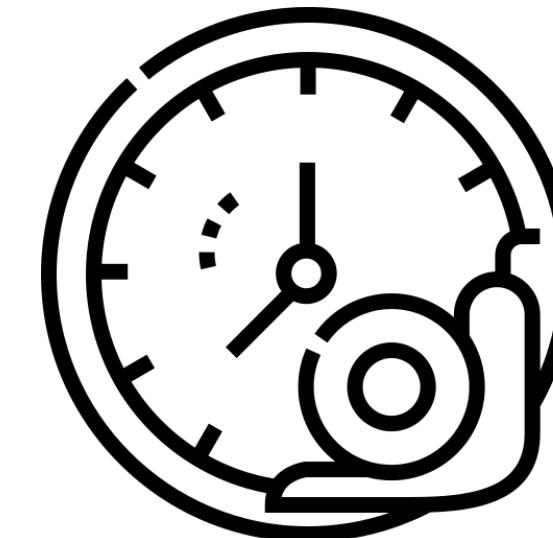
Need for large curated datasets!

Problem

Need for large curated datasets!



Expensive



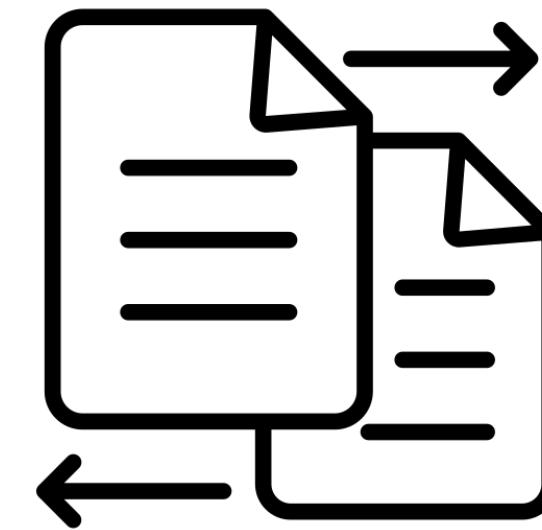
Time-consuming



Experts needed

Problem

Need for large curated datasets!

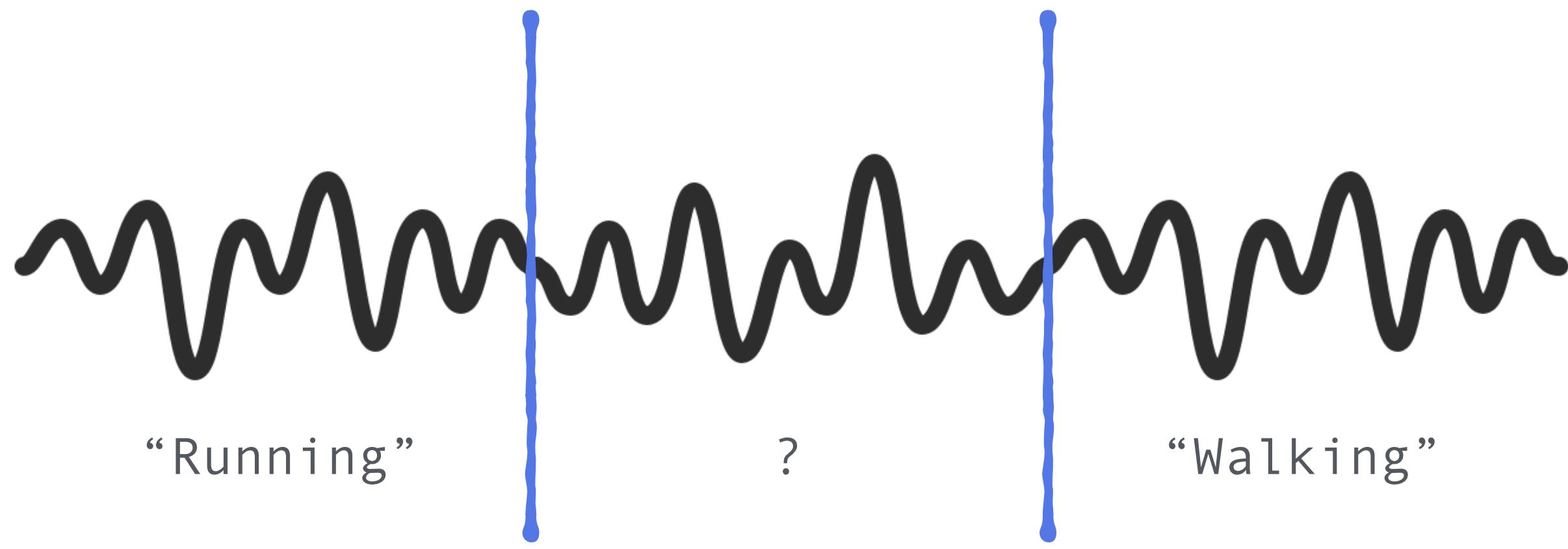


Data sharing

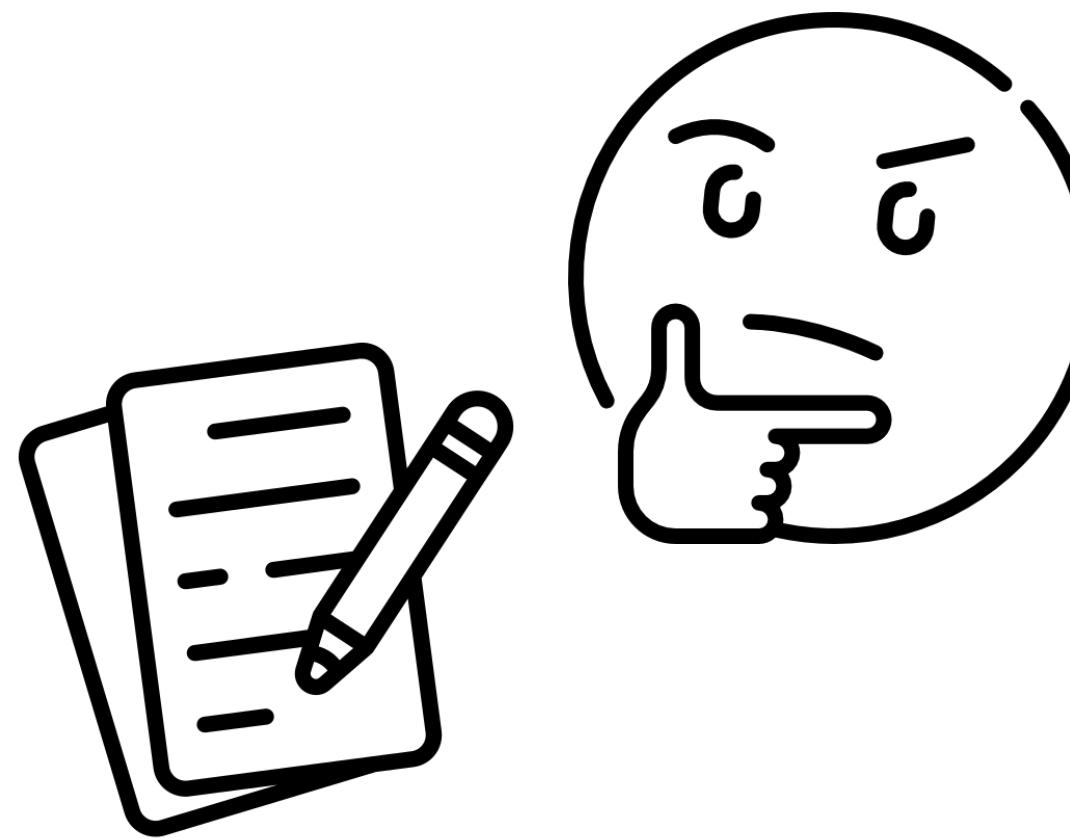
Human Activity Recognition



Human Activity Recognition



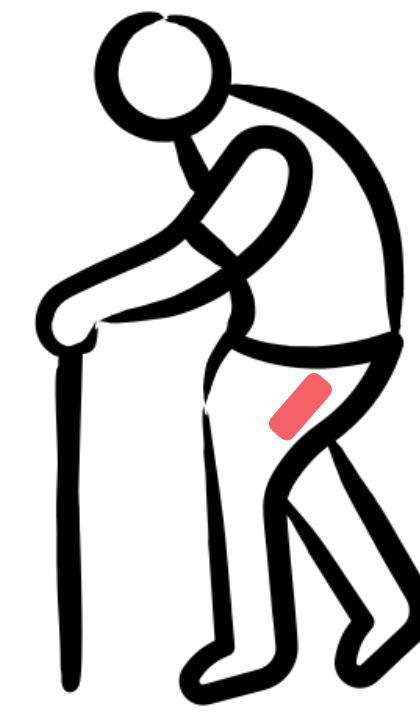
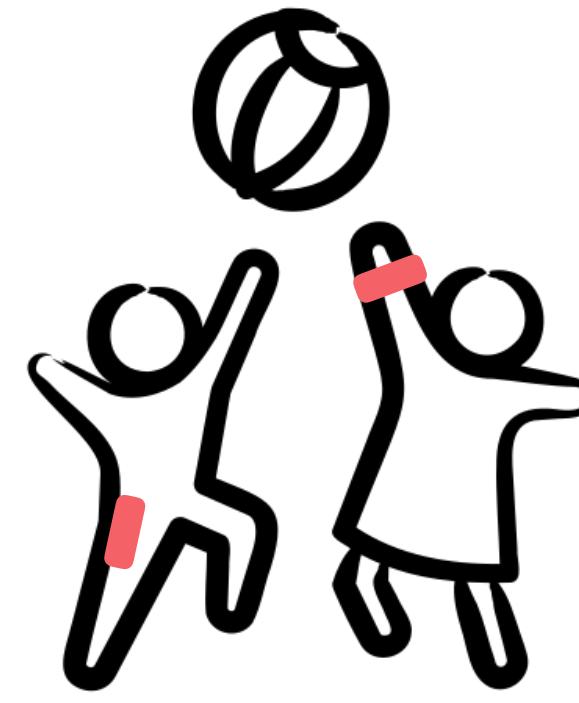
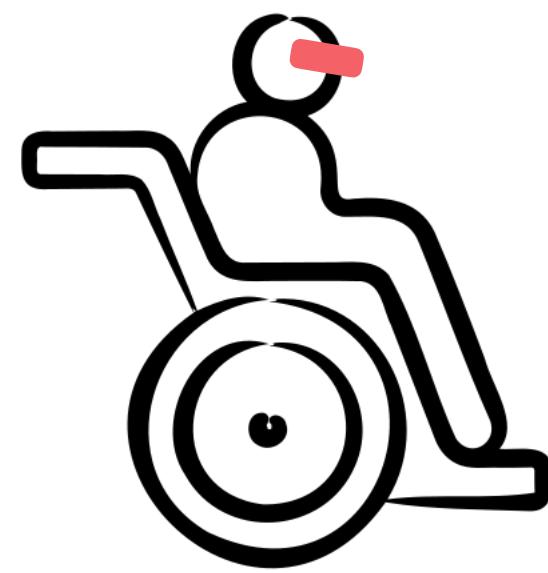
"Running" or "Walking"?



Human Activity Recognition



Human Activity Recognition

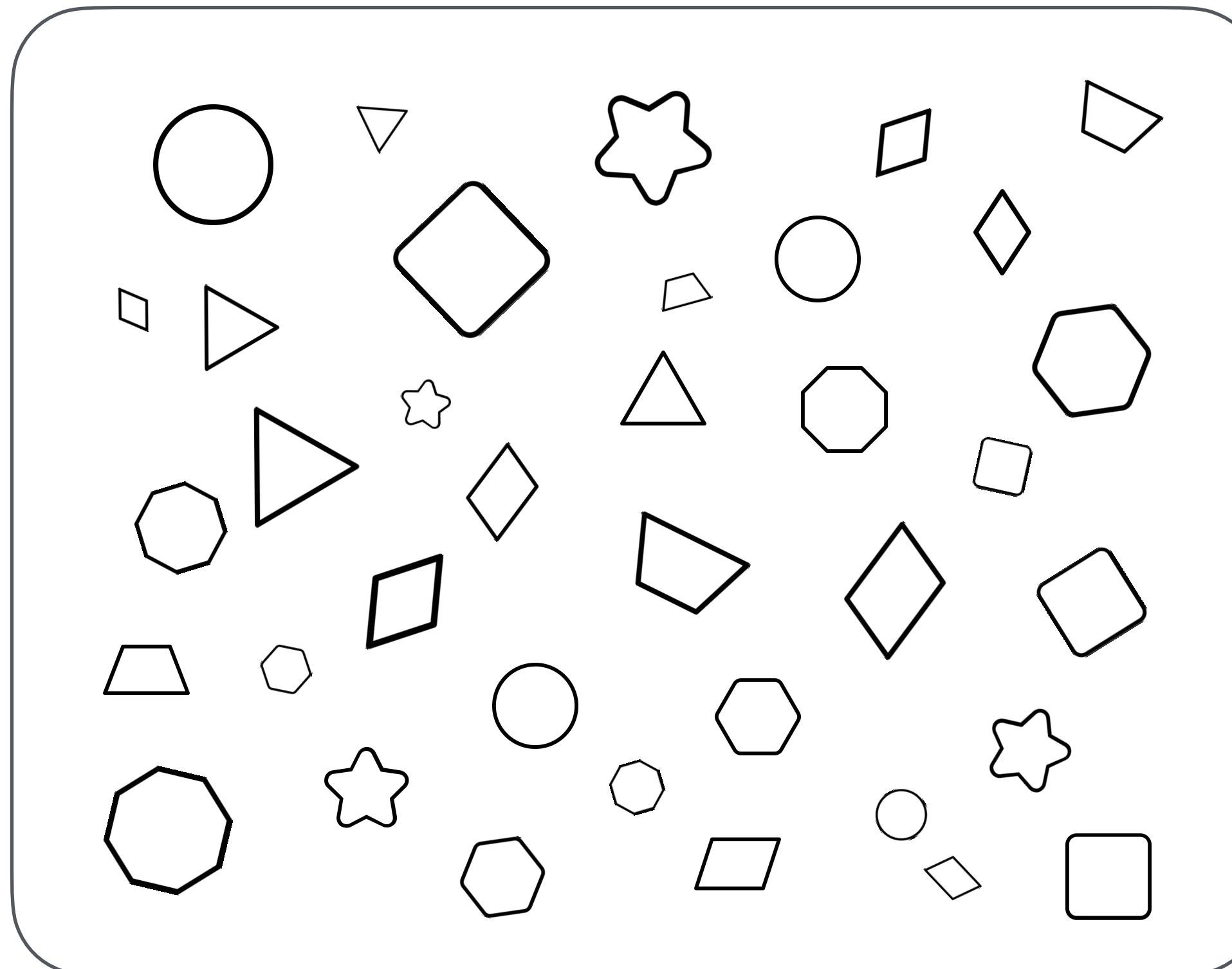


Human Activity Recognition



Problem

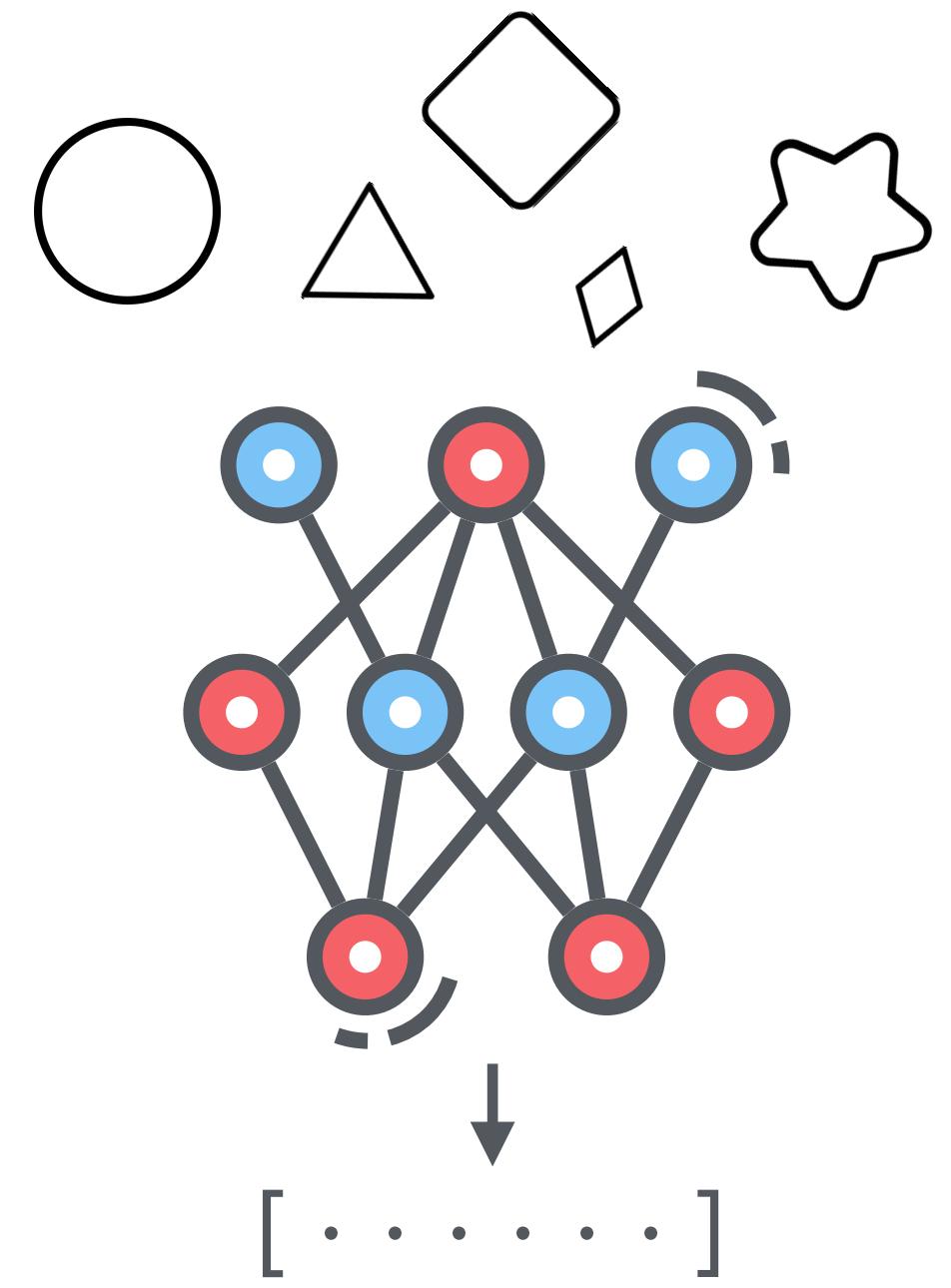
Large unlabeled data



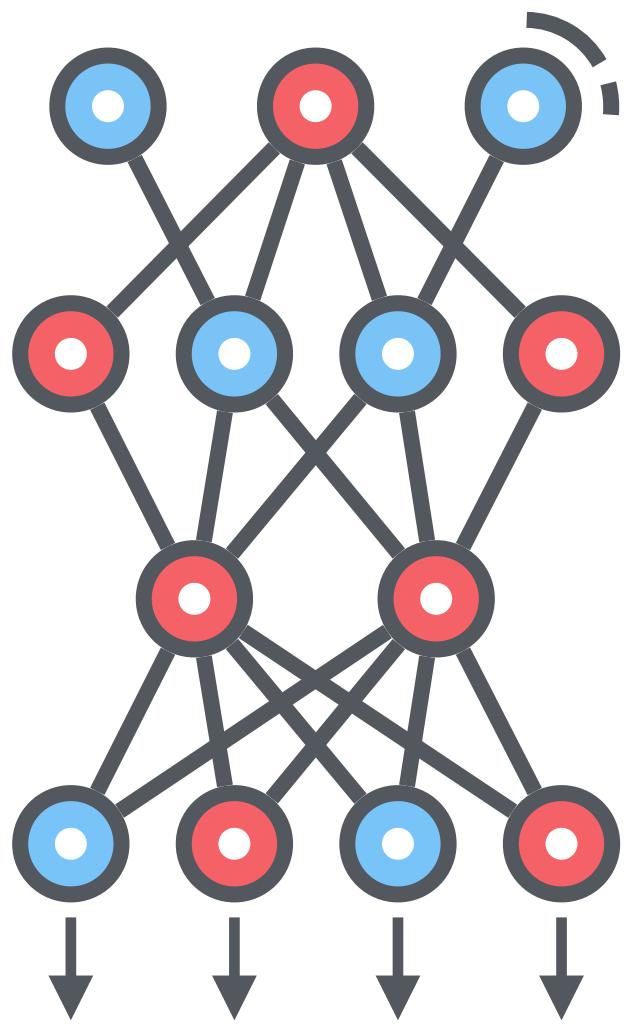
Small curated dataset

“Circle”	“Triangle”
“Star”	“Trapezium”
“Square”	“Parallelogram”
“Hexagon”	“Octagon”

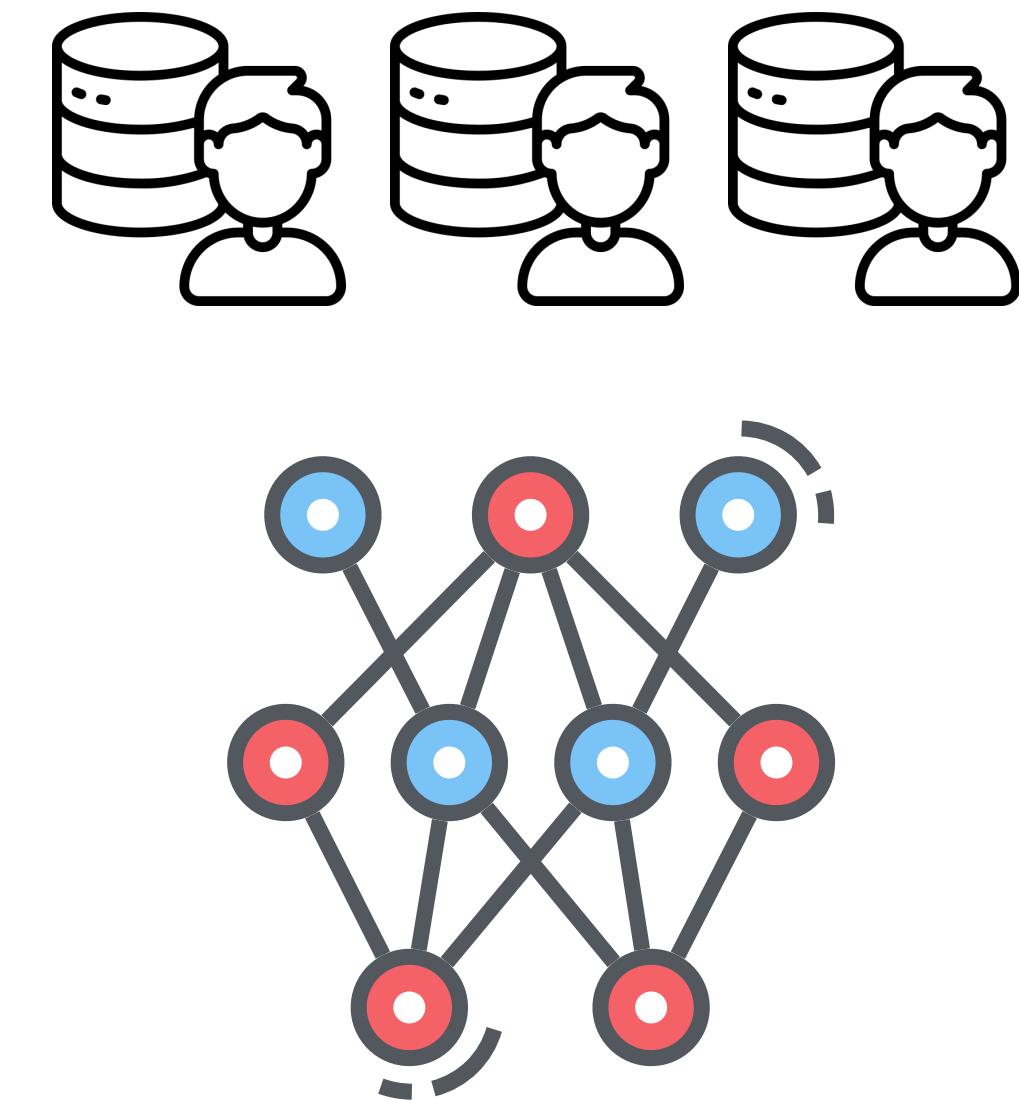
Objectives



Self-Supervised Learning



Multi-Task Learning



Federated Learning

Objectives



Human Activity Recognition

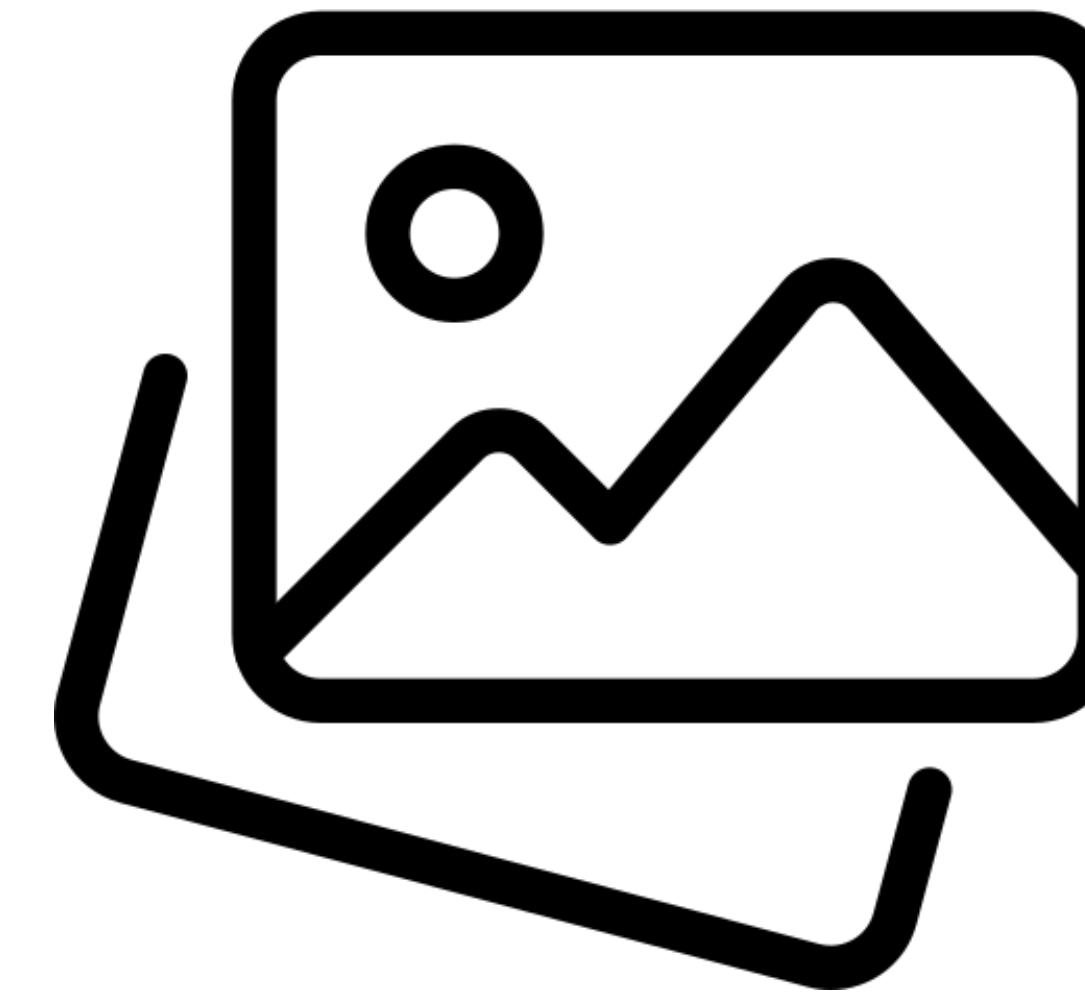


Image Recognition

Background & Related Work

Background & Related Work

Several topics:

- ▶ Human Activity Recognition
- ▶ Learning with limited data
 - ▶ Semi-Supervised Learning
 - ▶ Self-Supervised Learning
 - ▶ Multi-Task Learning
- ▶ ...
- ▶ Federated Learning

Background & Related Work

Several topics:

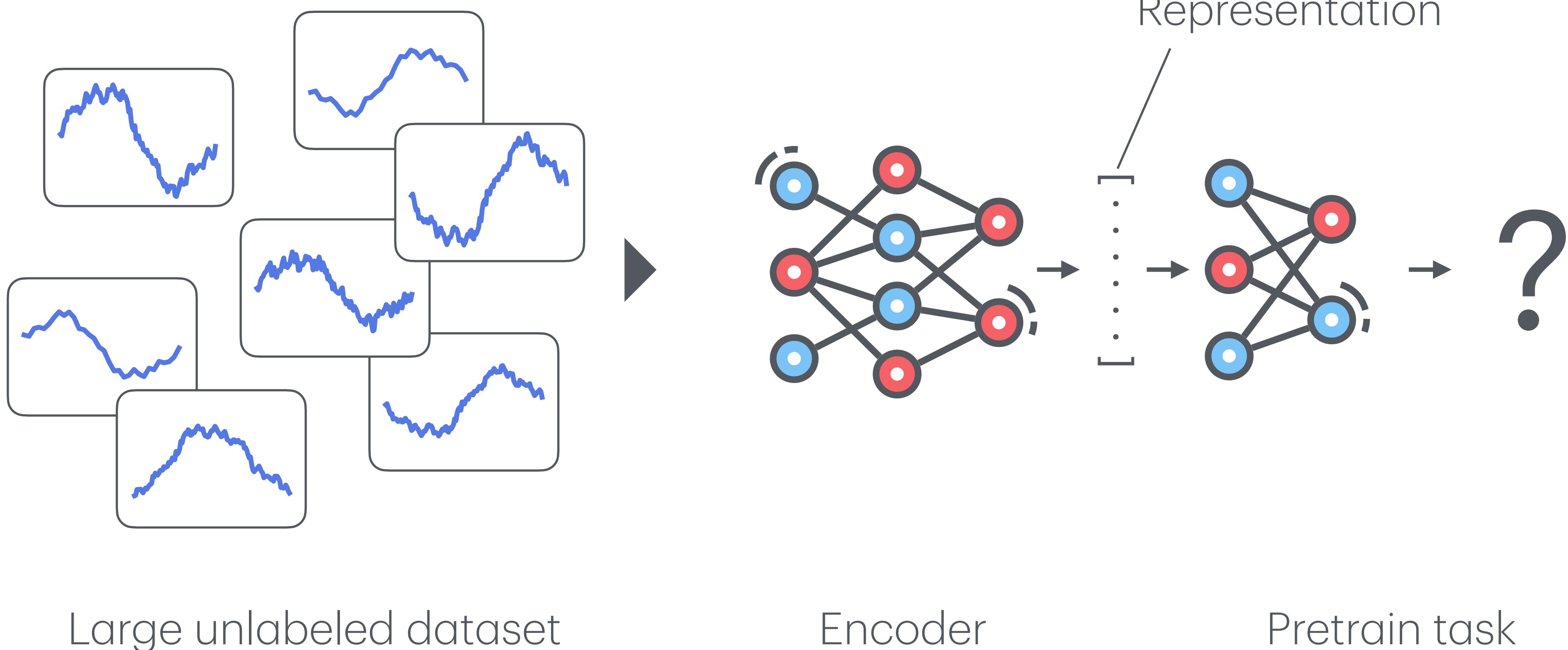
- ▶ Human Activity Recognition
- ▶ Learning with limited data
 - ▶ Semi-Supervised Learning
 - ▶ **Self-Supervised Learning**
 - ▶ **Multi-Task Learning**
- ▶ ...
- ▶ Federated Learning

Self-Supervised Learning

1. Pretraining Phase
2. Downstream Training Phase

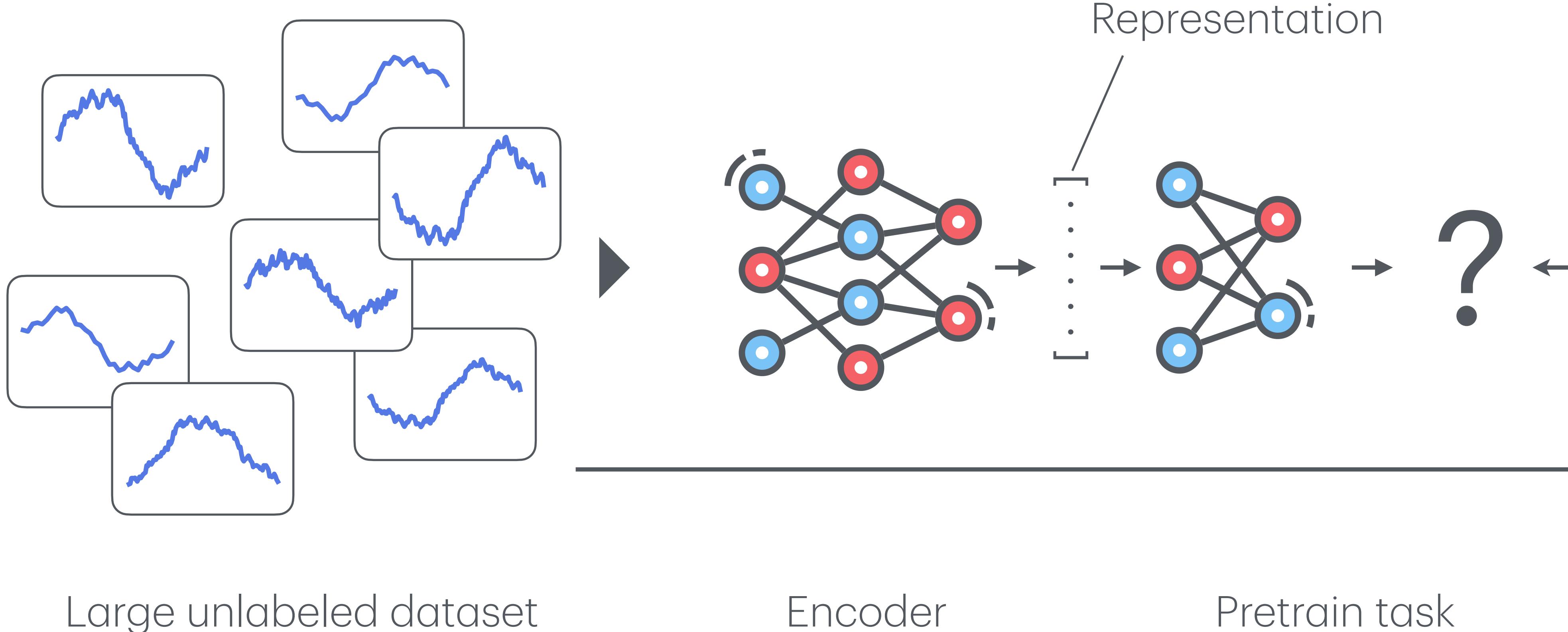
Self-Supervised Learning

1. Pretraining Phase



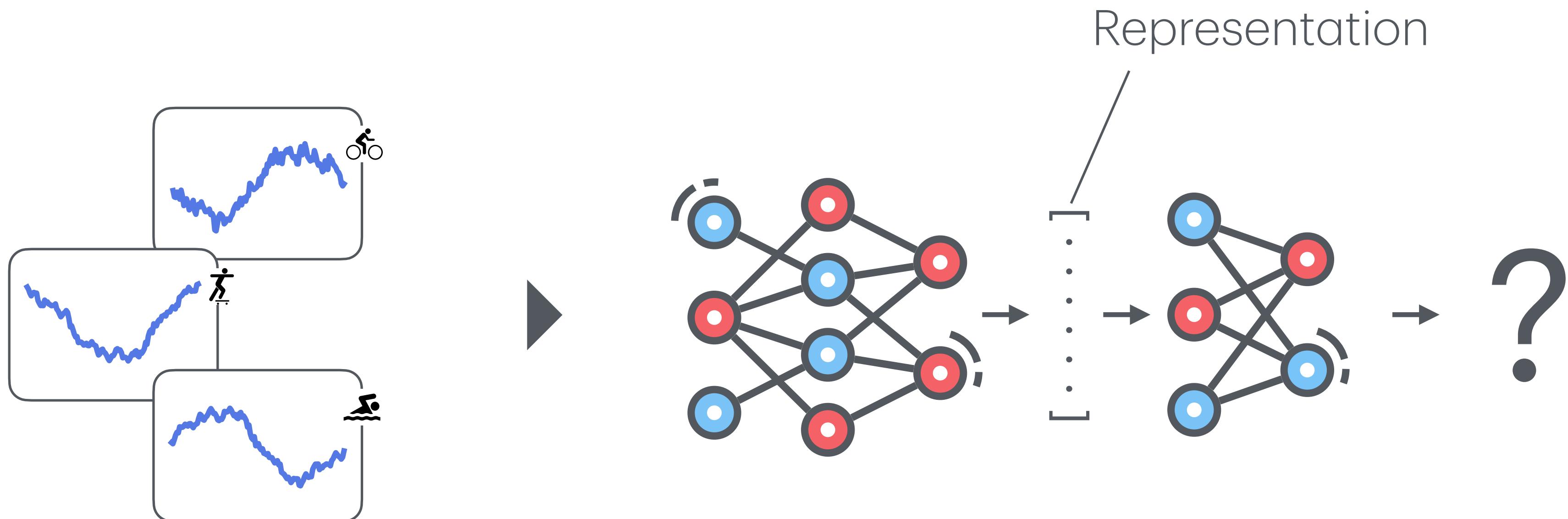
Self-Supervised Learning

1. Pretraining Phase



Self-Supervised Learning

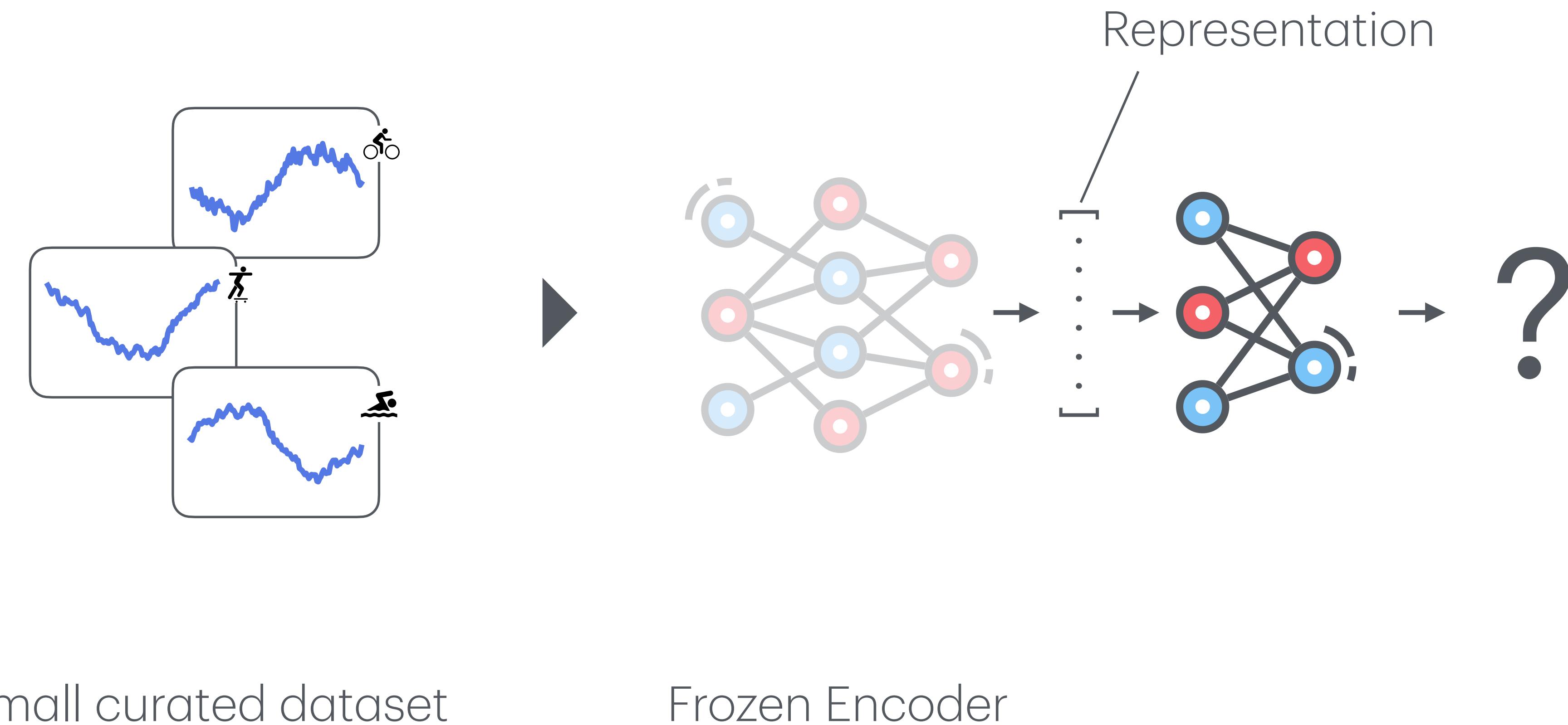
2. Downstream Phase



Small curated dataset

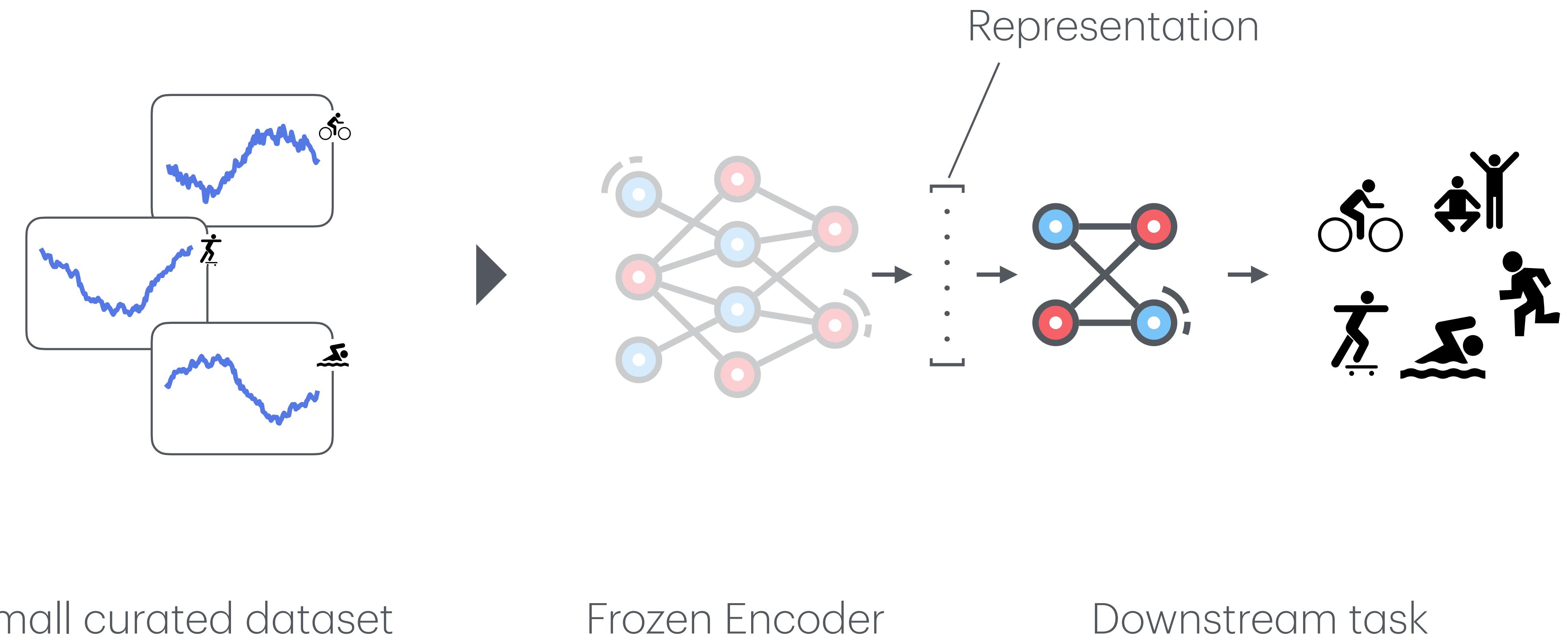
Self-Supervised Learning

2. Downstream Phase



Self-Supervised Learning

2. Downstream Phase

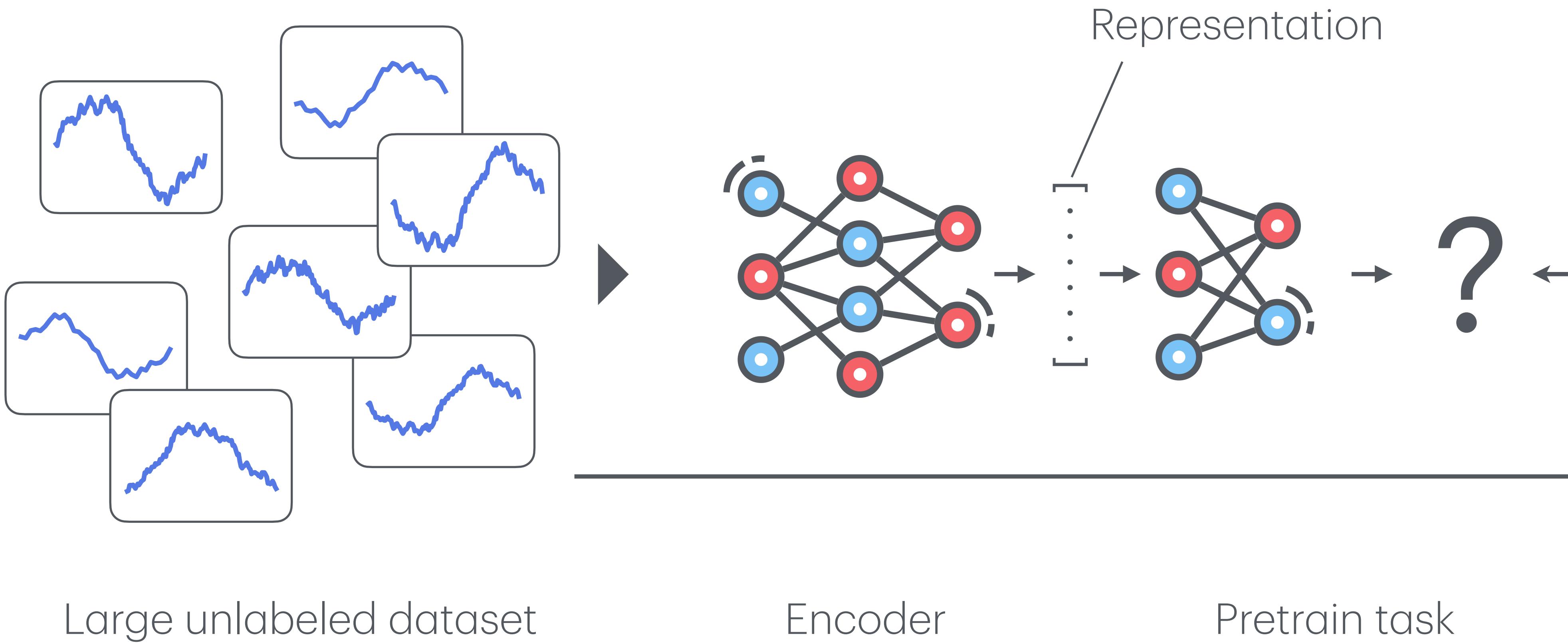


Small curated dataset

Frozen Encoder

Downstream task

SSL: Pretraining Phase



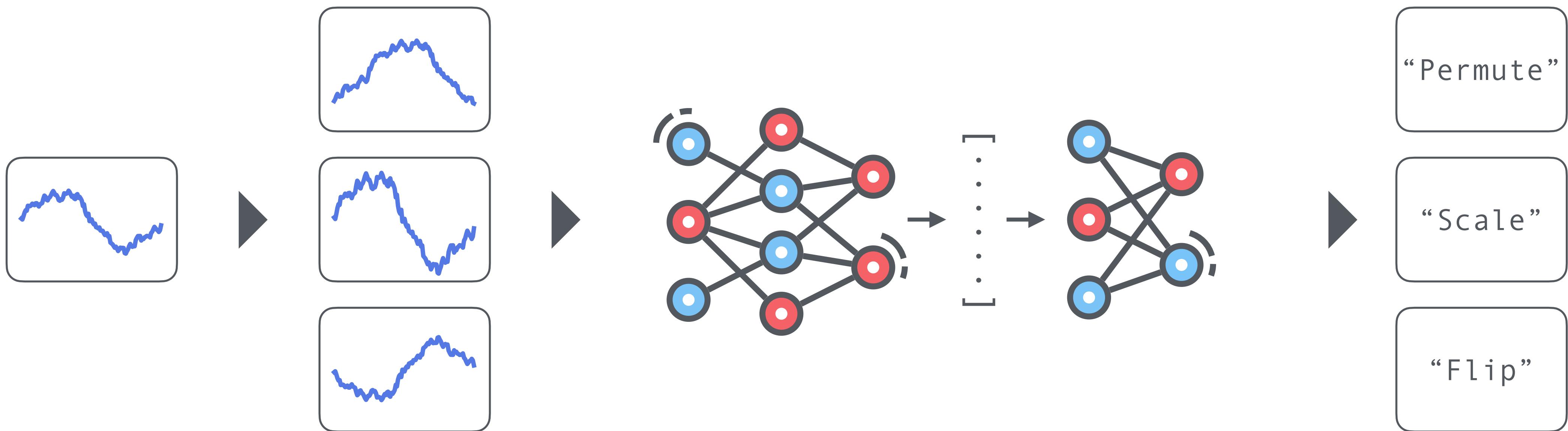
Self-Supervised Learning

- Pretext Tasks
- Contrastive Learning

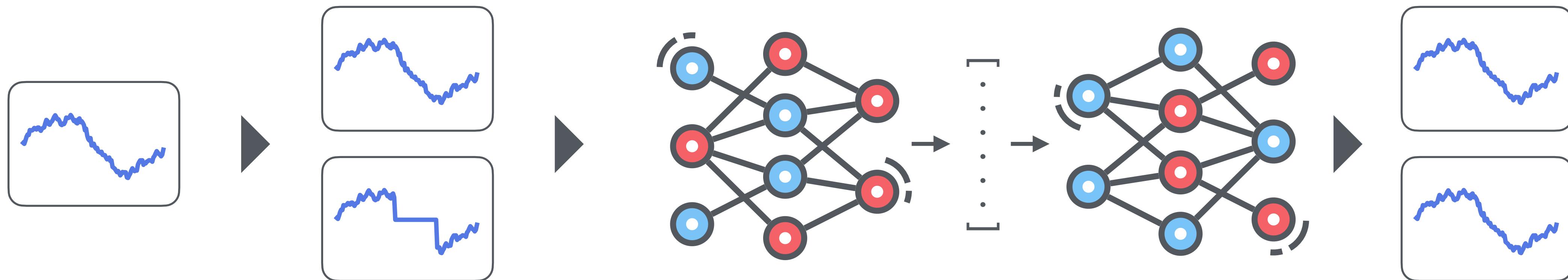
SSL: Pretext Tasks



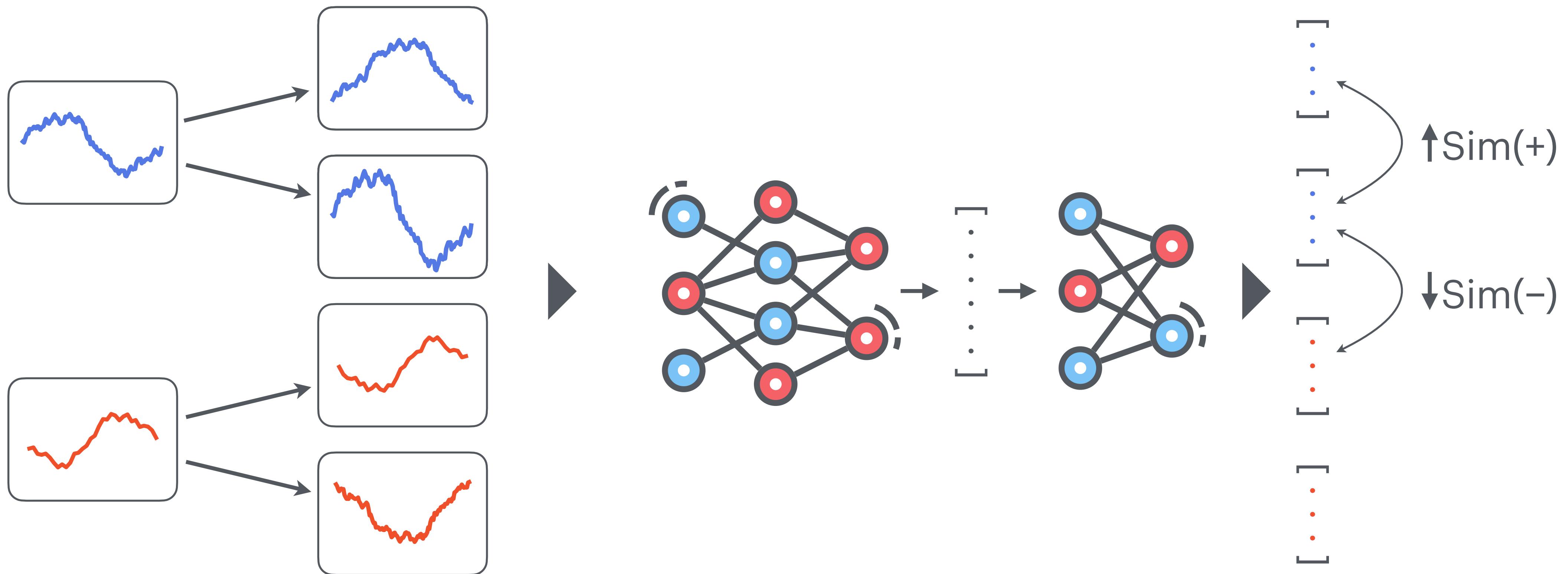
SSL: Classifying Augmentations



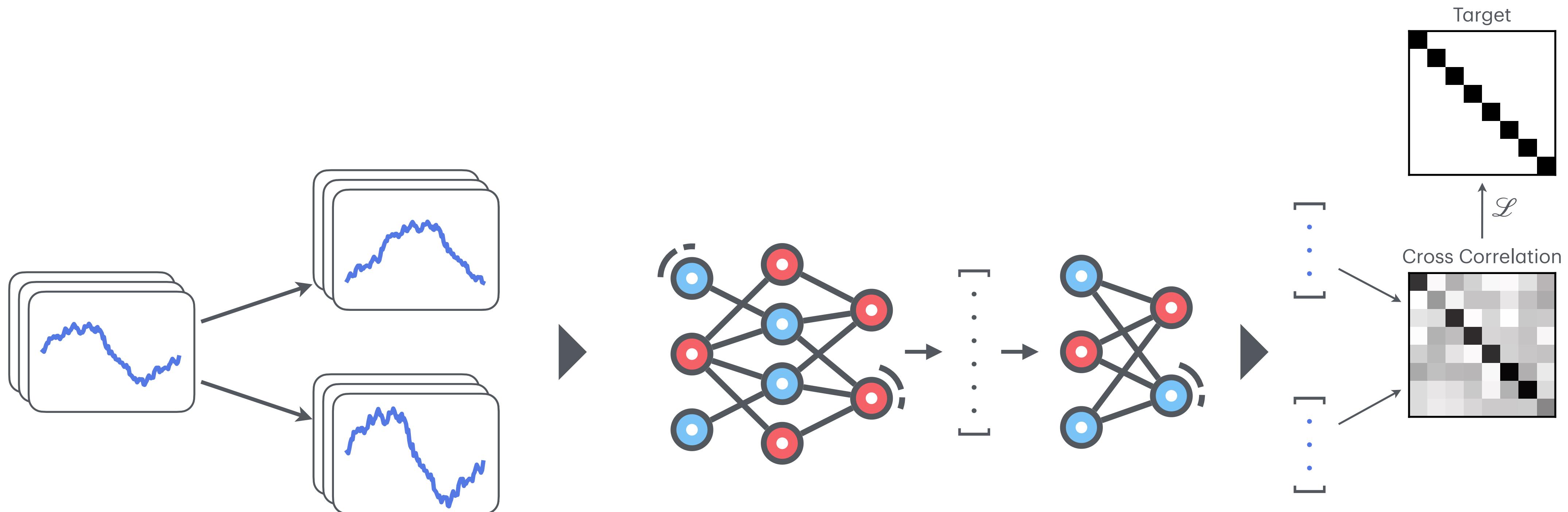
SSL: Reconstruction



SSL: Contrastive Learning



SSL: Barlow Twins & VICReg



SSL: Barlow Twins & VICReg

- Invariance:

$$\mathcal{L}_{\text{inv}}(Z^A, Z^B) = \frac{1}{n} \sum_{b=1}^n \|Z_b^A - Z_b^B\|^2$$

SSL: Barlow Twins & VICReg

- Invariance:

$$\mathcal{L}_{\text{inv}}(Z^A, Z^B) = \frac{1}{n} \sum_{b=1}^n \|Z_b^A - Z_b^B\|^2$$

- Covariance:

$$\mathcal{L}_{\text{cov}}(Z) = \frac{1}{d} \sum_{i \neq j}^n [C(Z)]_{ij}^2$$

SSL: Barlow Twins & VICReg

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- Variance:

$$\mathcal{L}_{\text{var}}(Z^A) = \frac{1}{d} \sum_{j=1}^d \max(0, \gamma - S(Z_j^A, \varepsilon))$$

SSL: Barlow Twins & VICReg

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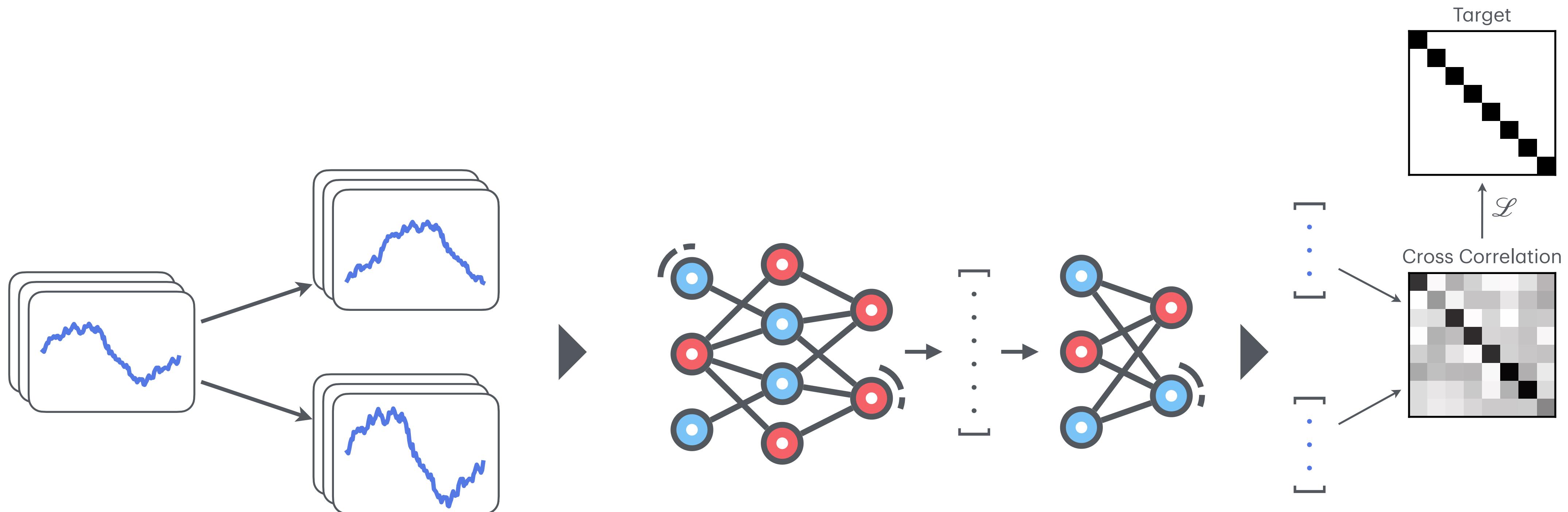
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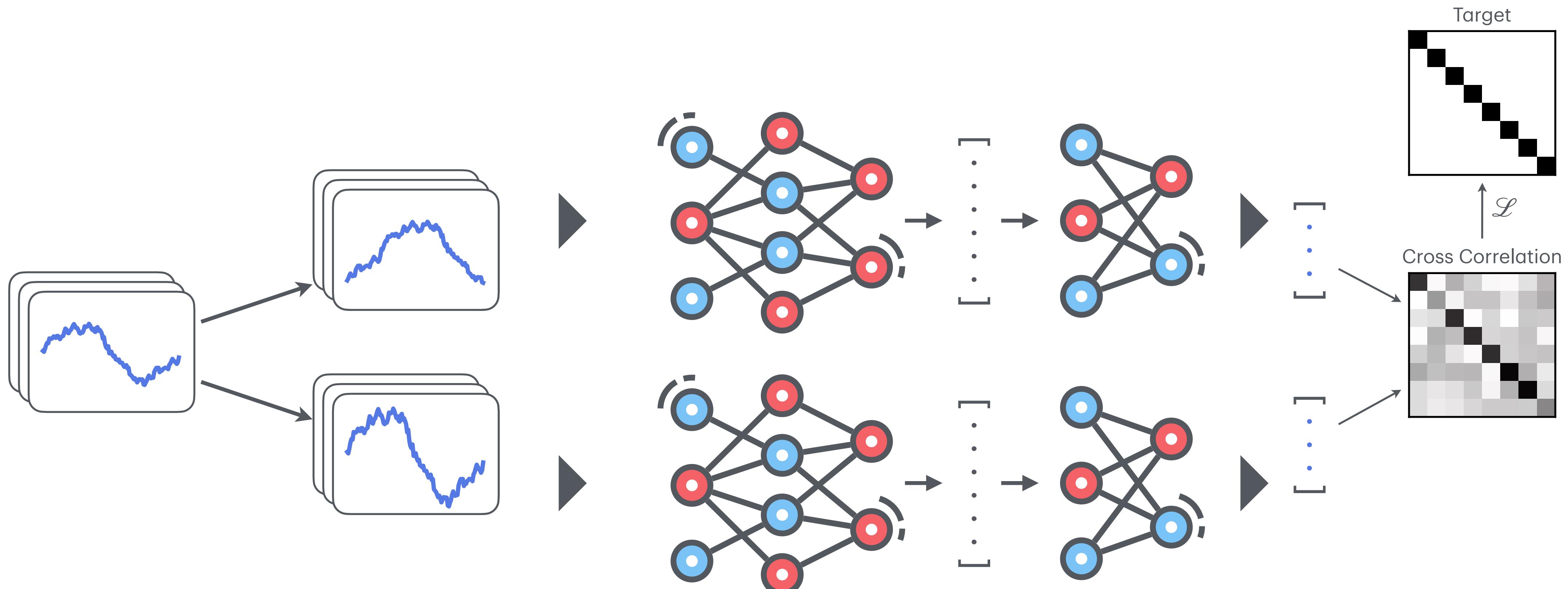
$$\mathcal{L}_{\text{VICReg}} = \mathcal{L}_{\text{inv}}(Z^A, Z^B) + \alpha (\mathcal{L}_{\text{var}}(Z^A) + \mathcal{L}_{\text{var}}(Z^B)) + \beta (\mathcal{L}_{\text{cov}}(Z^A) + \mathcal{L}_{\text{cov}}(Z^B))$$

SSL: Barlow Twins & VICReg



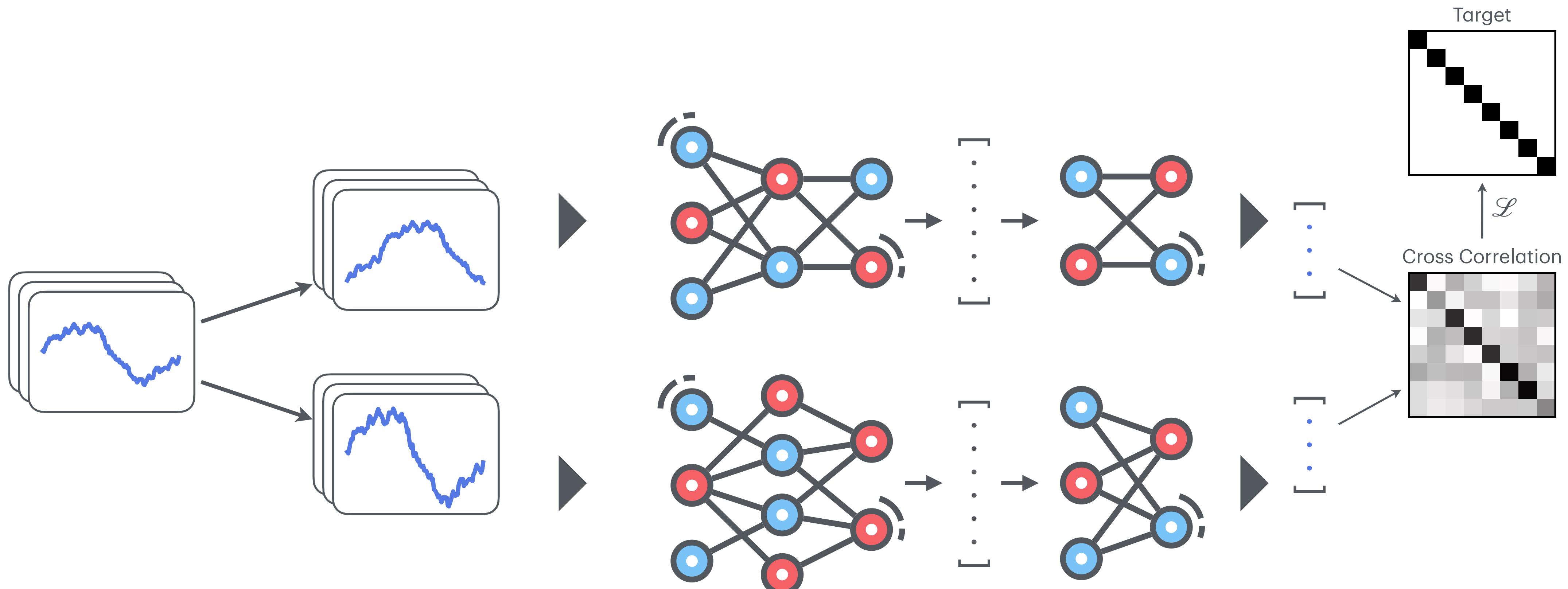
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SSL: Barlow Twins & VICReg



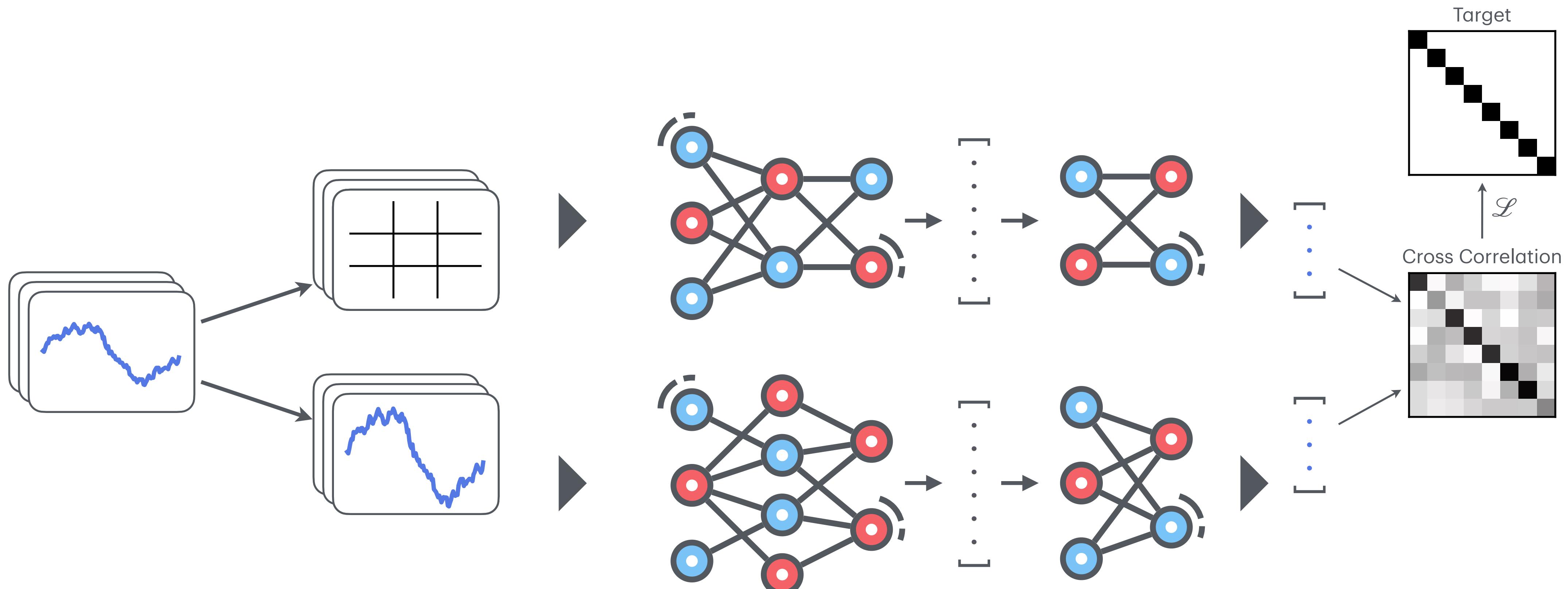
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SSL: Barlow Twins & VICReg



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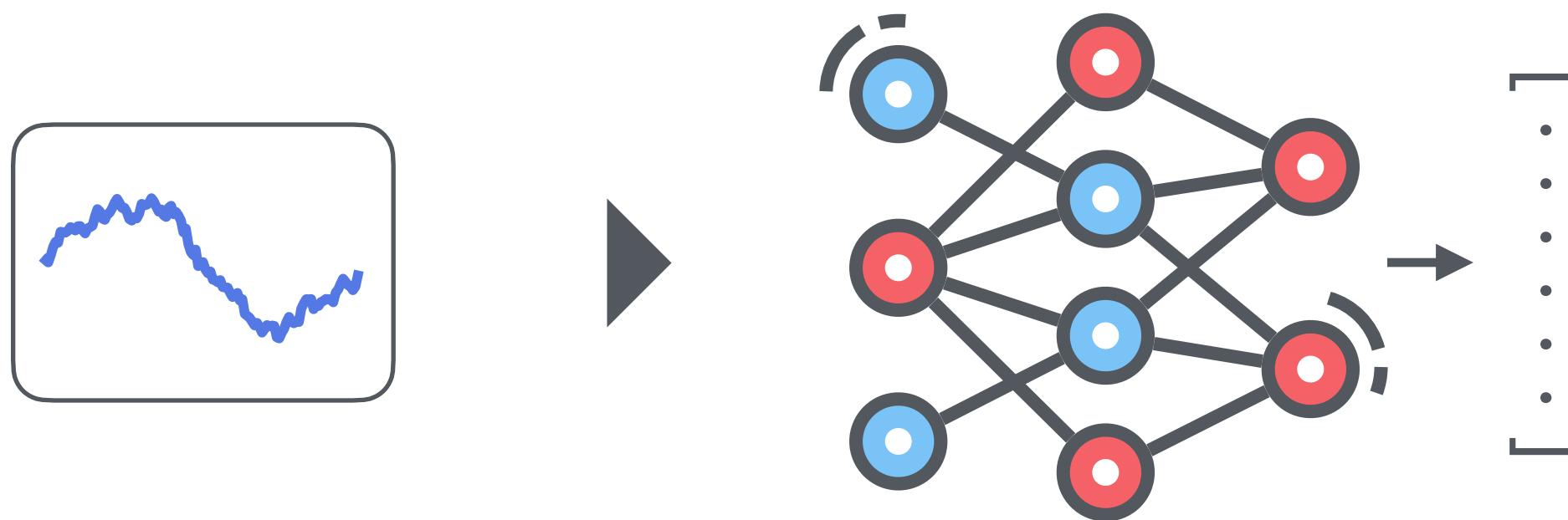
SSL: Barlow Twins & VICReg



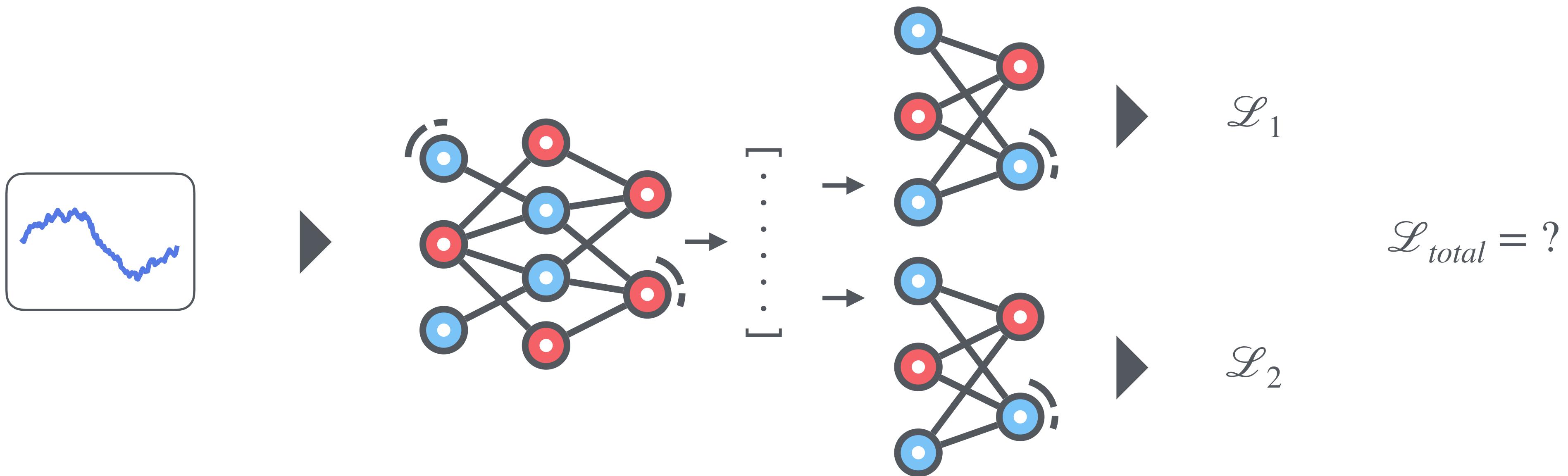
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[Zbontar et al., ICML 2021; Bardes et al., ArXiv 2022; Shwartz-Ziv et al., NeurIPS 2023] 38

Goal: Powerful Embedding



Multi-Task Learning



Multi-Task Learning

$$\mathcal{L}_{\text{total}} = \mathcal{L}_1 + \mathcal{L}_2$$

$$\mathcal{L}_{\text{total}} = \sum_{t=1}^T \mathcal{L}_t$$

Multi-Task Learning

$$\mathcal{L}_{\text{total}} = w_1 \mathcal{L}_1 + w_2 \mathcal{L}_2$$

$$\mathcal{L}_{\text{total}} = \sum_{t=1}^T w_t \mathcal{L}_t$$

Multi-Task Learning

$$\mathcal{L}_{\text{total}} = \frac{1}{2(\sigma_1)^2} \mathcal{L}_1 + \frac{1}{(\sigma_2)^2} \mathcal{L}_2 + \log \sigma_1 + \log \sigma_2$$

*Assuming one regression and one classification task

$$\mathcal{L}_{\text{total}} = \sum_{k=1}^K \left[\frac{1}{2(\sigma_k^{\text{reg}})^2} \mathcal{L}_k^{\text{reg}} + \log \sigma_k^{\text{reg}} \right] + \sum_{j=1}^J \left[\frac{1}{(\sigma_j^{\text{class}})^2} \mathcal{L}_j^{\text{class}} + \log \sigma_j^{\text{class}} \right]$$

Multi-Task Learning

$$\mathcal{L}_{\text{total}} = \frac{1}{2(\sigma_1)^2} \mathcal{L}_1 + \frac{1}{(\sigma_2)^2} \mathcal{L}_2 + \log \sigma_1 + \log \sigma_2$$

Dynamic weights Regularization terms

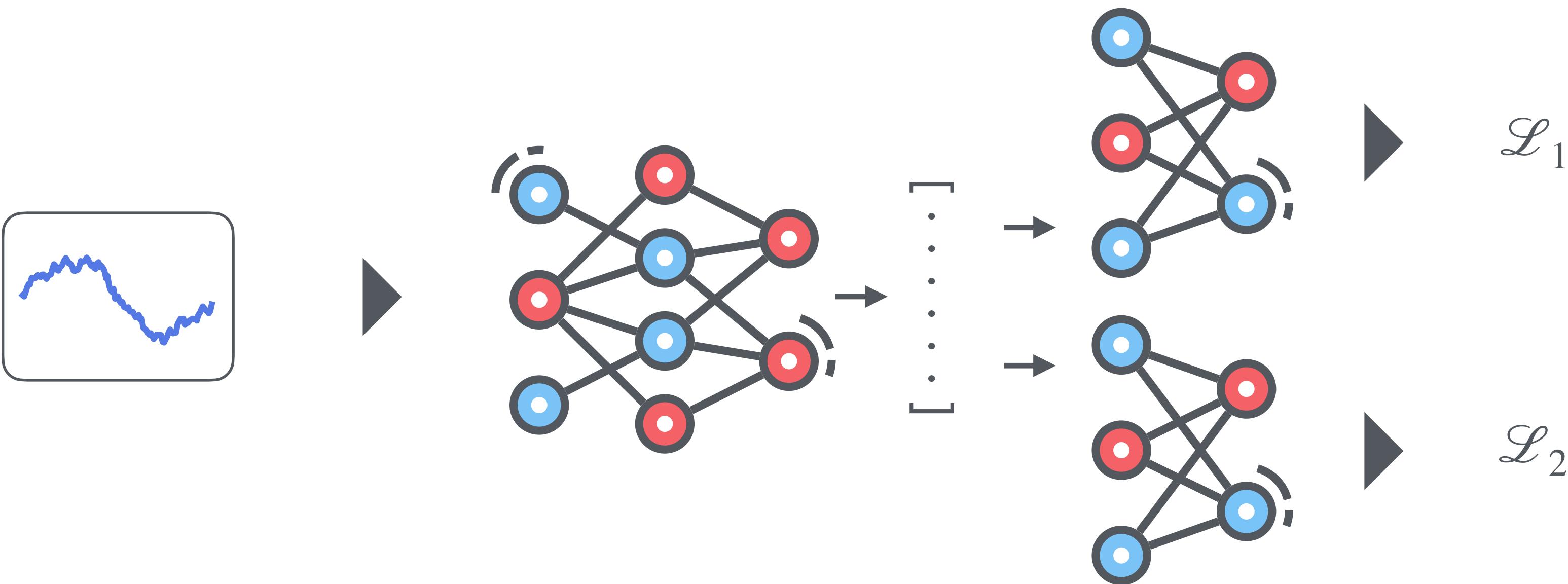
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$$\mathcal{L}_{\text{total}} = \sum_{k=1}^K \left[\frac{1}{2(\sigma_k^{\text{reg}})^2} \mathcal{L}_k^{\text{reg}} + \log \sigma_k^{\text{reg}} \right] + \sum_{j=1}^J \left[\frac{1}{(\sigma_j^{\text{class}})^2} \mathcal{L}_j^{\text{class}} + \log \sigma_j^{\text{class}} \right]$$

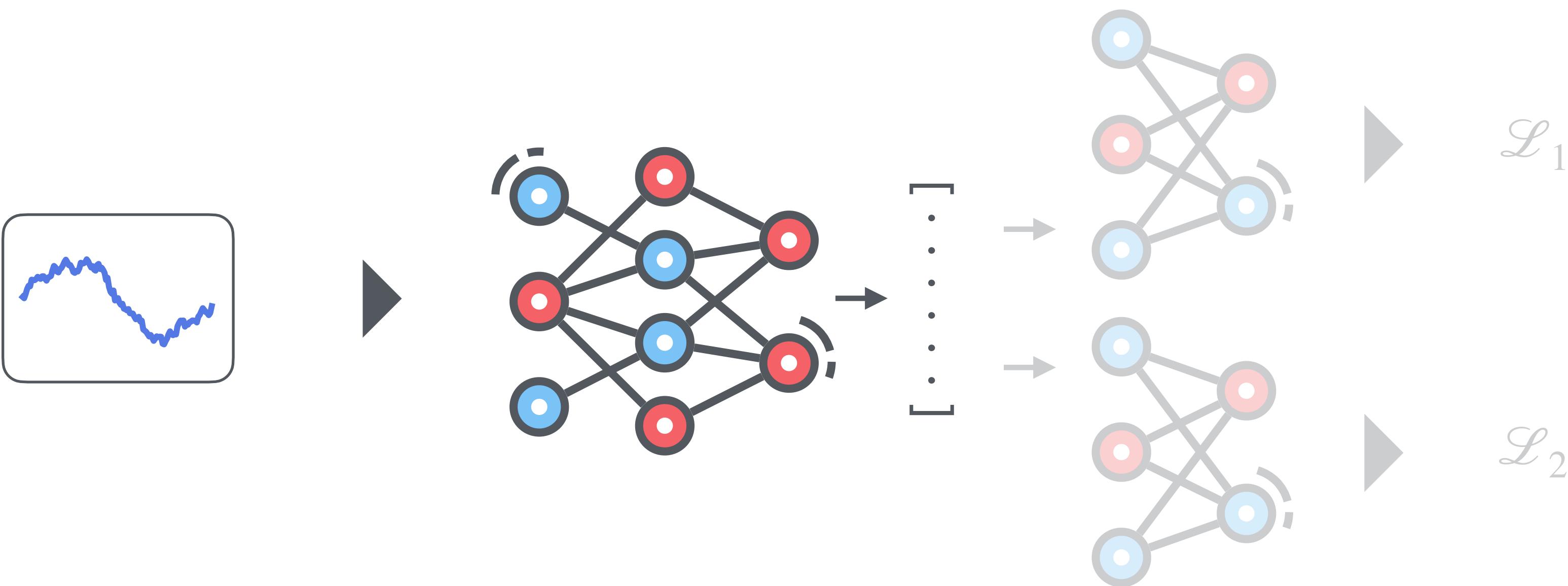
Multi-Task Learning

- Several other methods to:
 - combine losses (DTP [Guo et al., ECCV 2018], LSB [Lee et al., ICCV 2021], LDC-MTL [Xiao et al., ArXiv 2025])
 - find Pareto-optimal solution (MOO [Sener and Koltun, NeurIPS 2018])
 - act on gradients to mitigate conflicts (GradNorm [Chen et al., ICML 2018], PCGrad [Yu et al., NeurIPS 2020])

So...



So...



Experimental Setup

Objectives



Human Activity Recognition

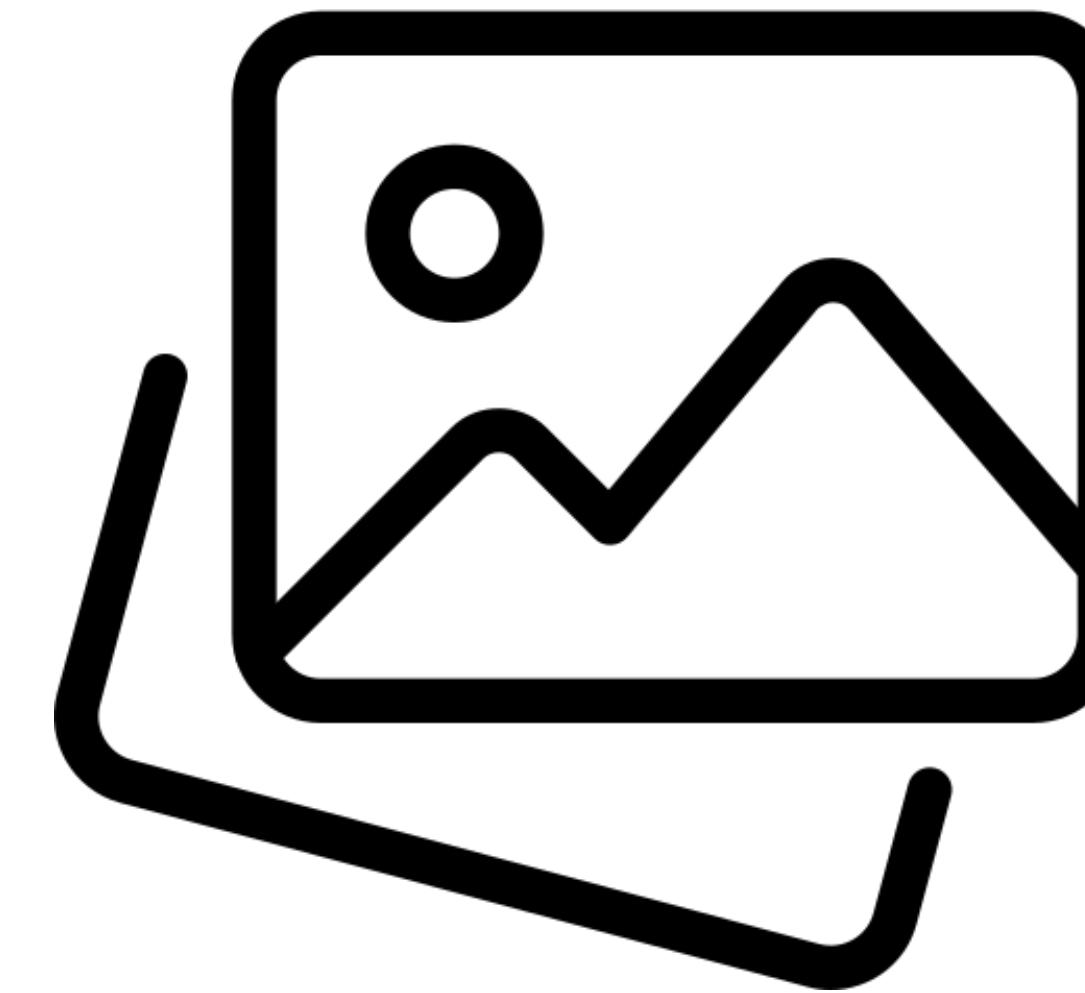


Image Recognition

Dataset

- UCI-HAR (primary dataset)
 - Smartphone (50 Hz)
 - “walking”, “walking upstairs”, “walking downstairs”, “sitting”, “standing”, and “lying”
 - 9 signals (3-axis body acceleration, 3-axis gyroscope, and 3-axis gravity)
 - Windows of 128 (2.56 seconds)
 - 10,299 total labeled samples
 - Expert features (561 values)

Dataset

Regime	Labeled Samples	Training Samples	Validation Samples
1	126	96	30
2	252	192	60
3	378	288	90
4	504	384	120
5	630	480	150
6	756	576	180
Full Dataset Regime	7352	5583	1769

Dataset

- STL10 (secondary dataset)
 - Images 96x96 from ImageNet
 - 100,000 unlabeled
 - 500 labeled
 - 800 test

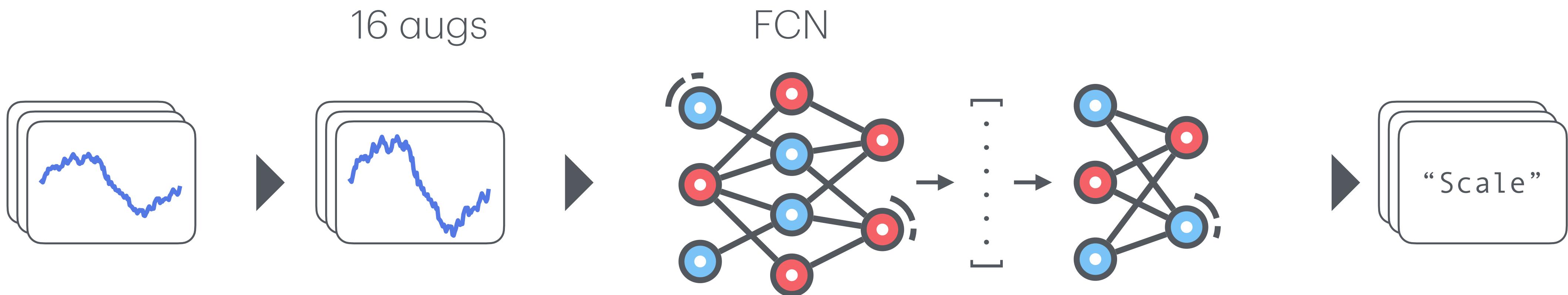
Dataset



SSL: Single Tasks

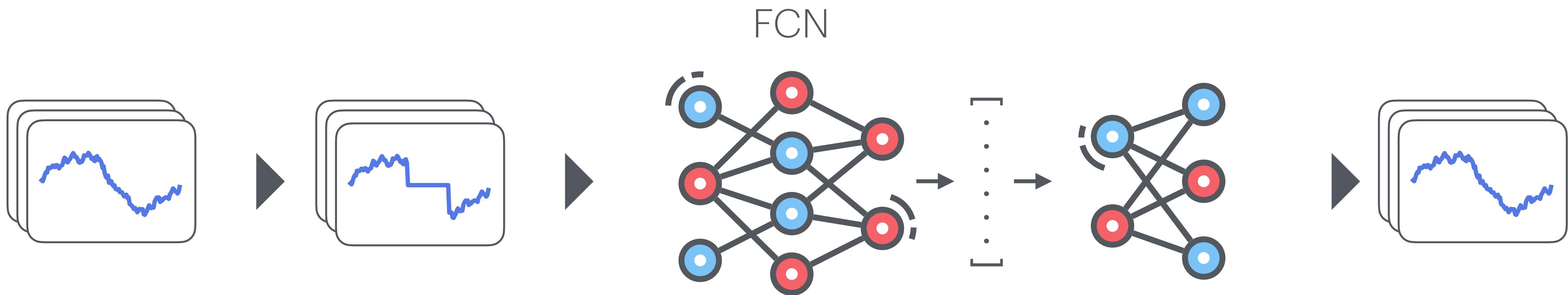
SSL

- Classifying Augmentation



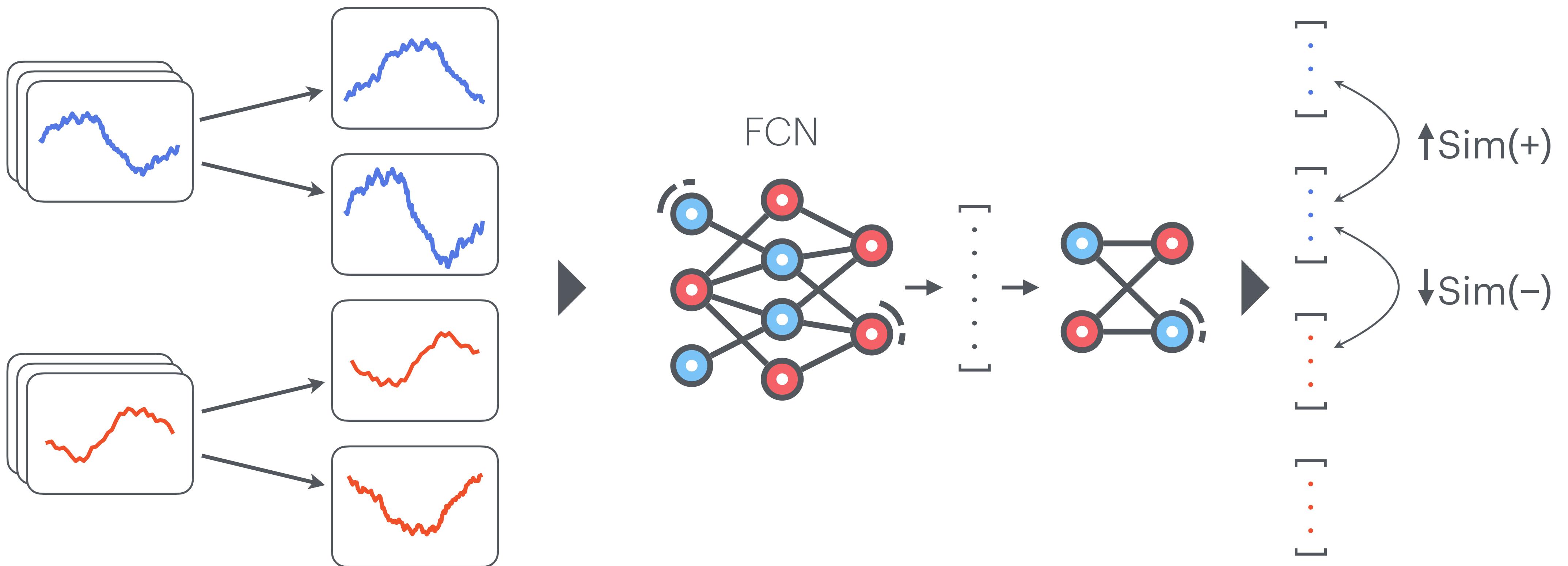
SSL

- Reconstruction



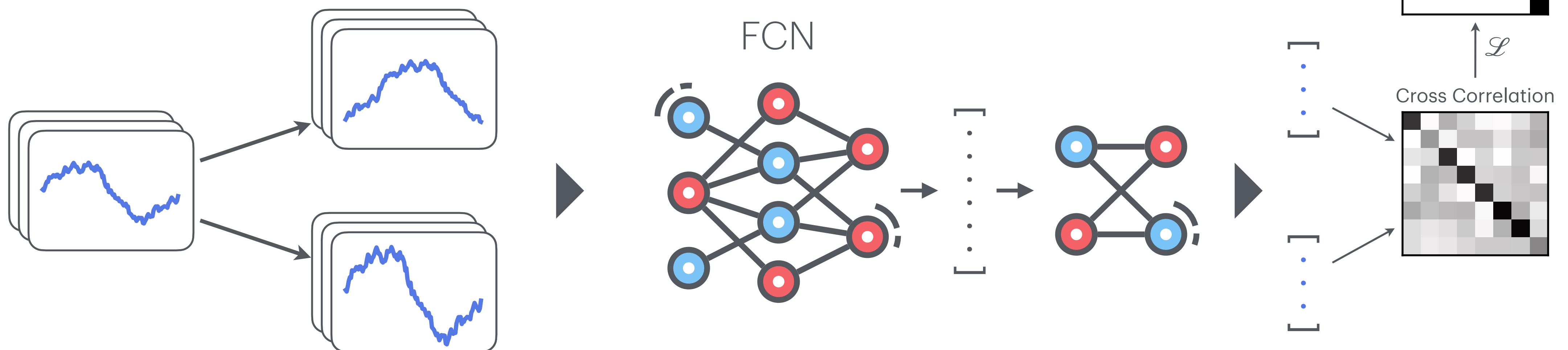
SSL

- Contrastive Learning (SimCLR)



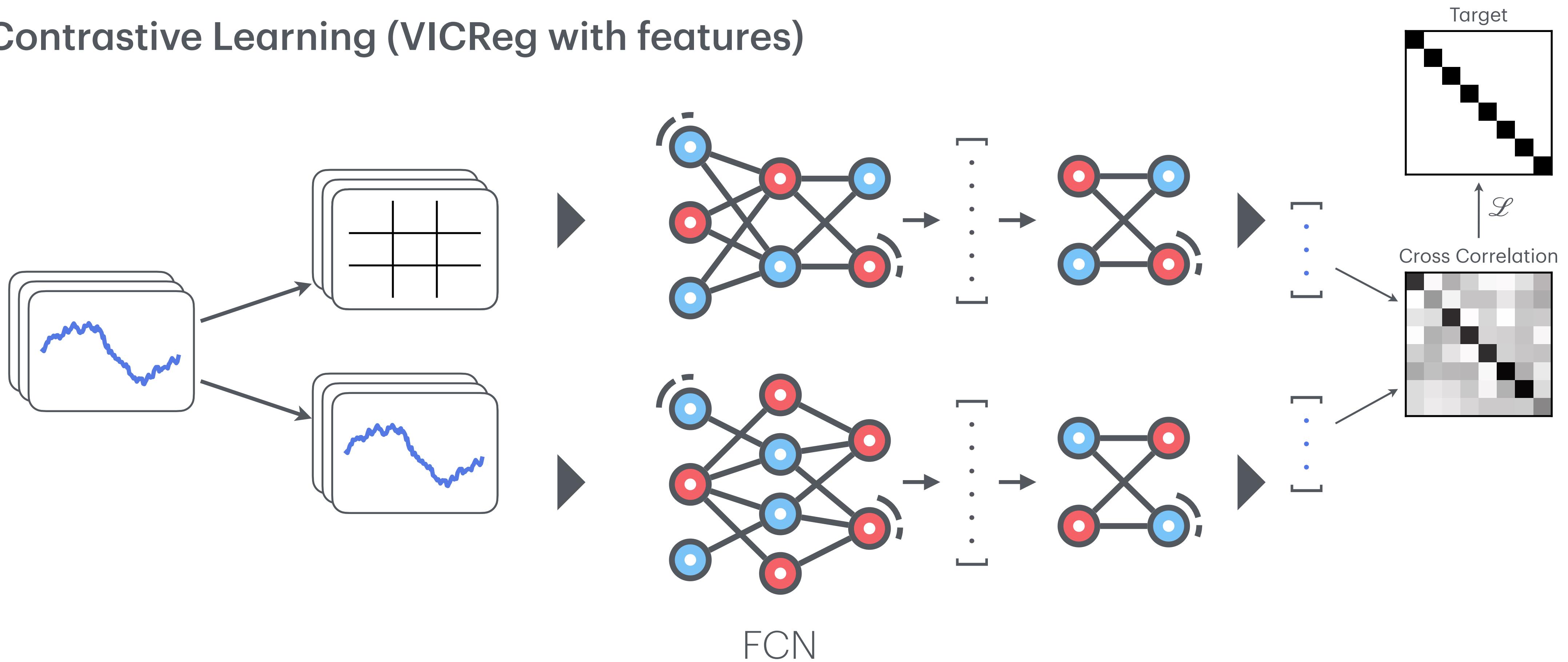
SSL

- Contrastive Learning (VICReg)

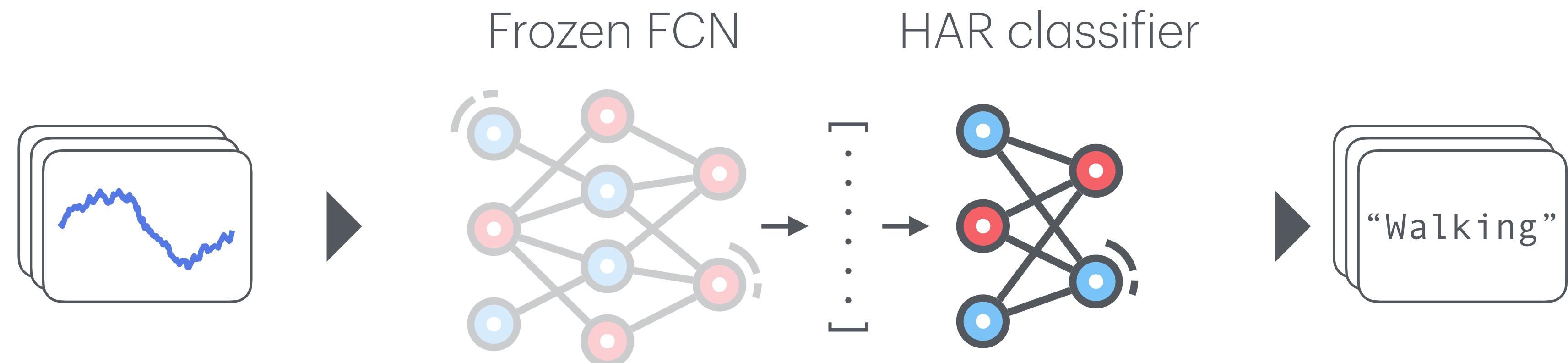


SSL

- Contrastive Learning (VICReg with features)

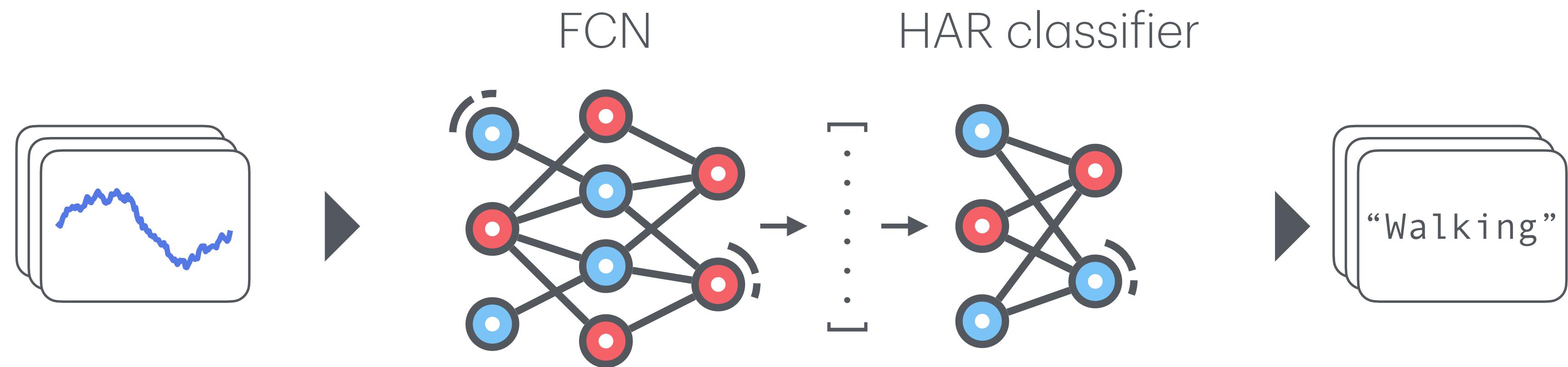


SSL

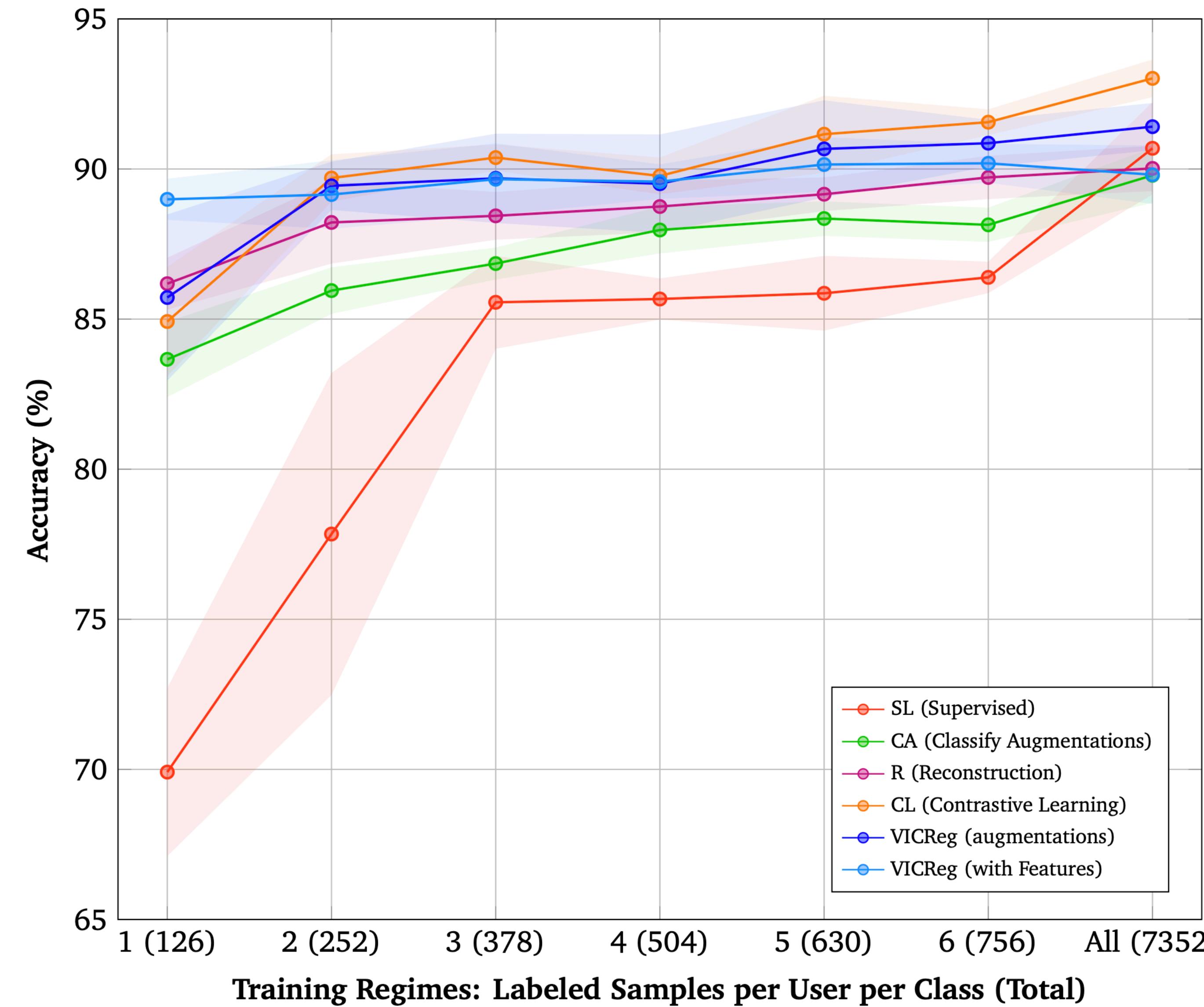


SSL

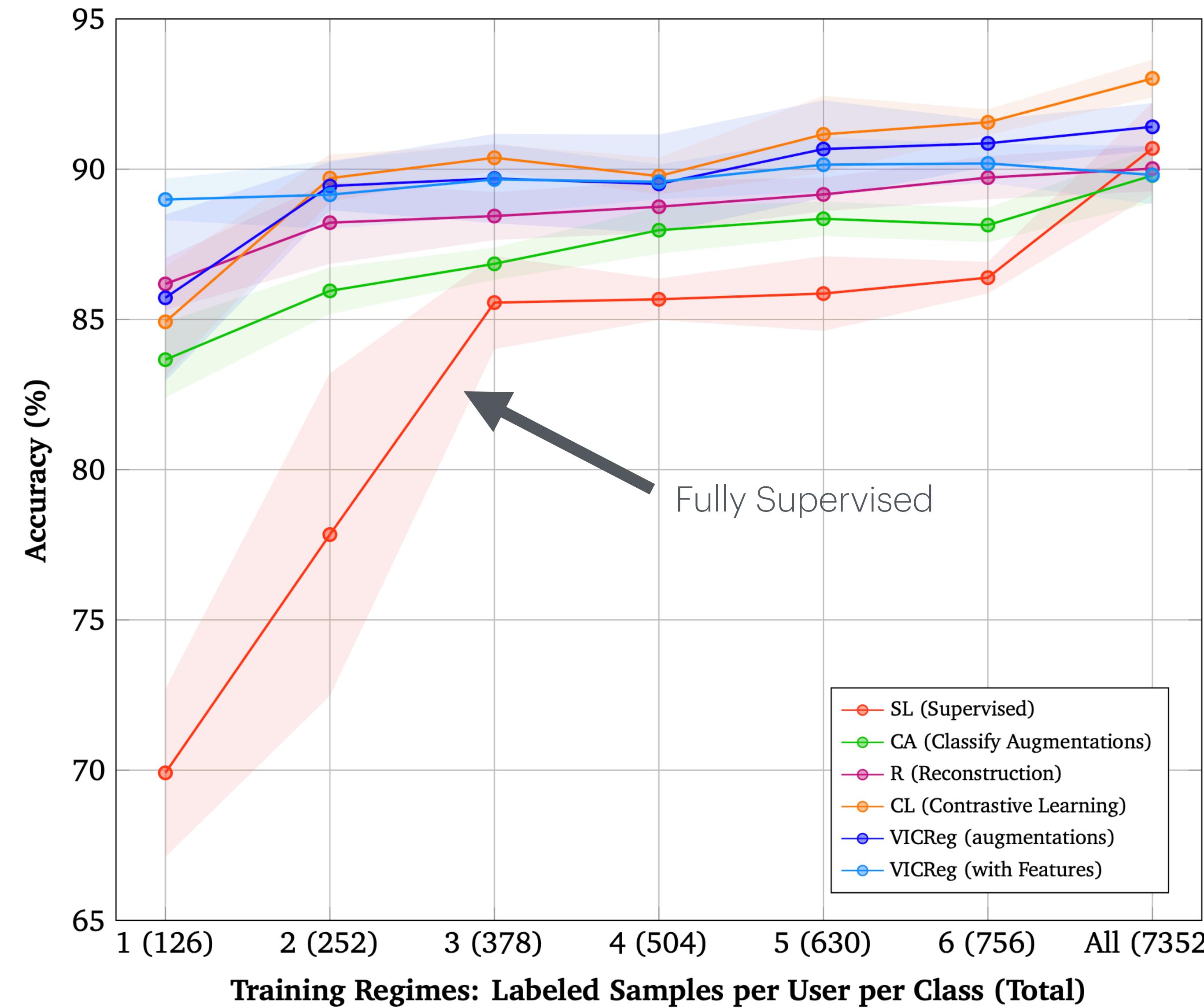
- Fully Supervised



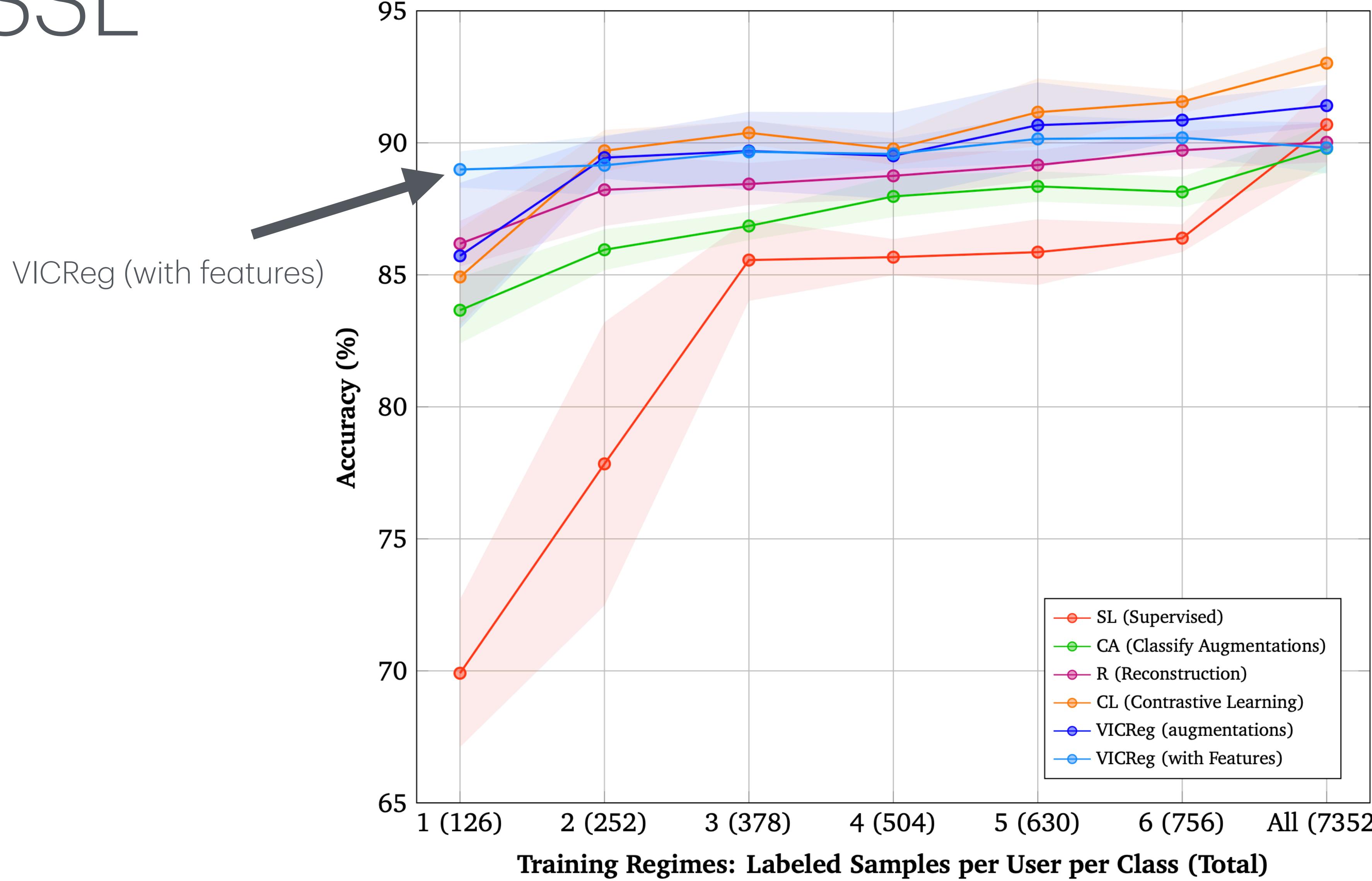
SSL



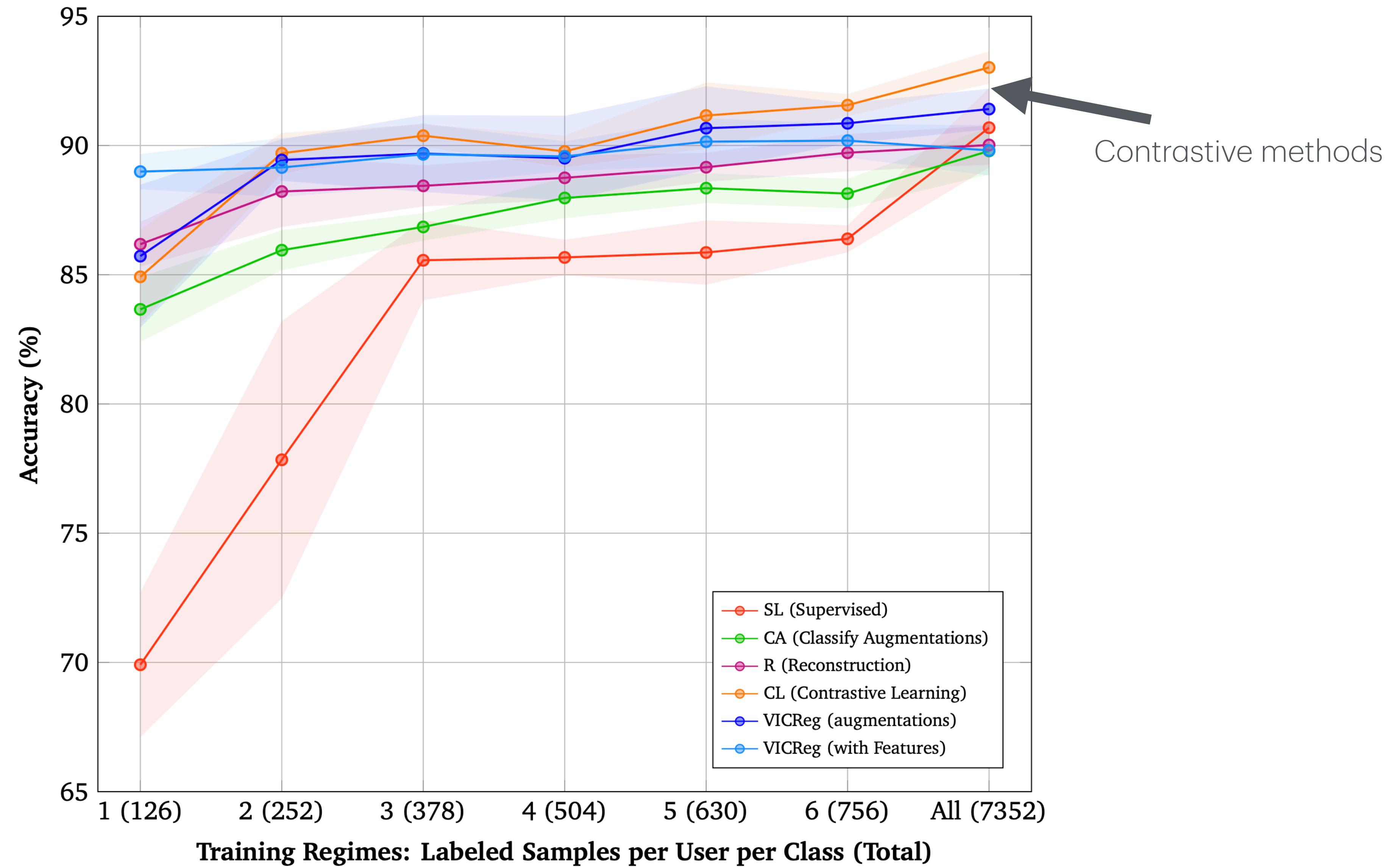
SSL



SSL

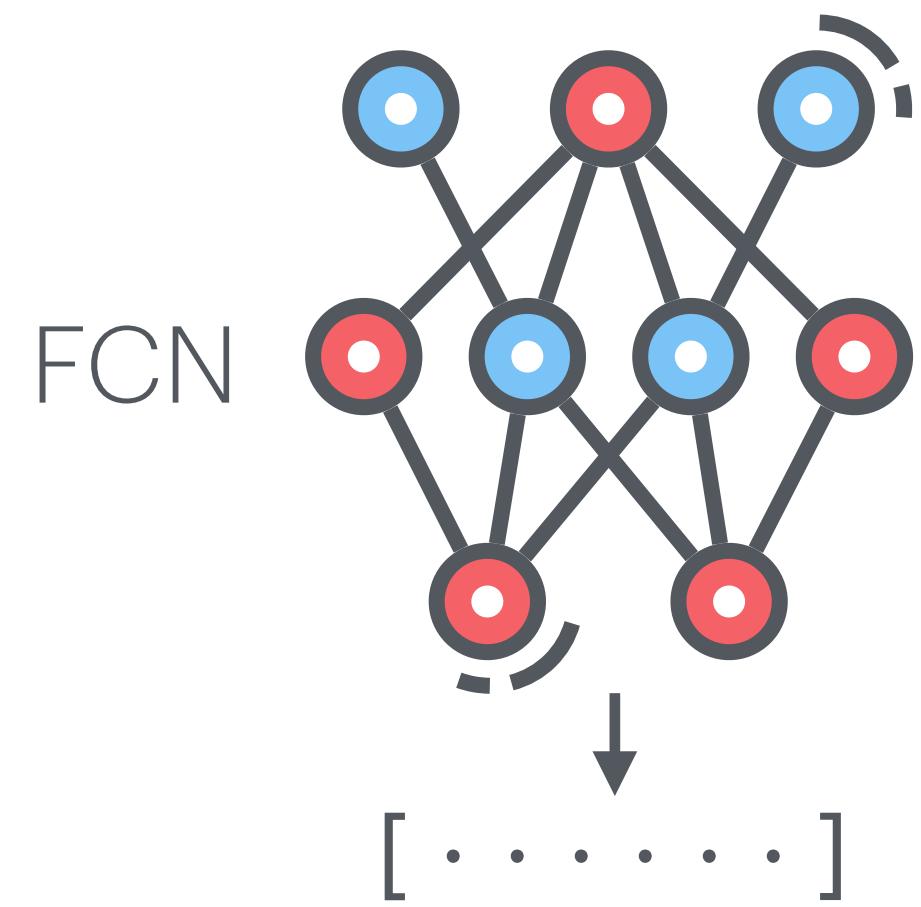
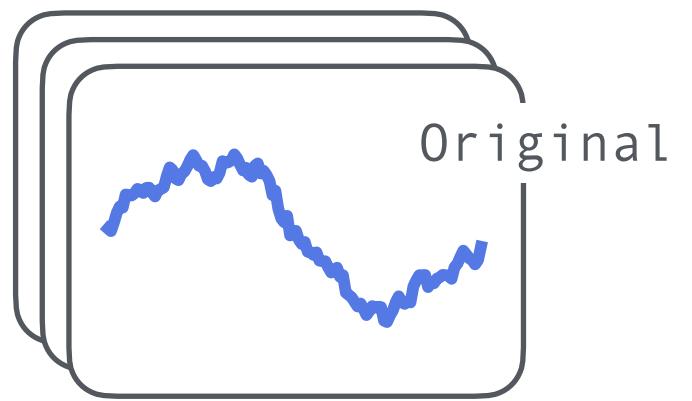


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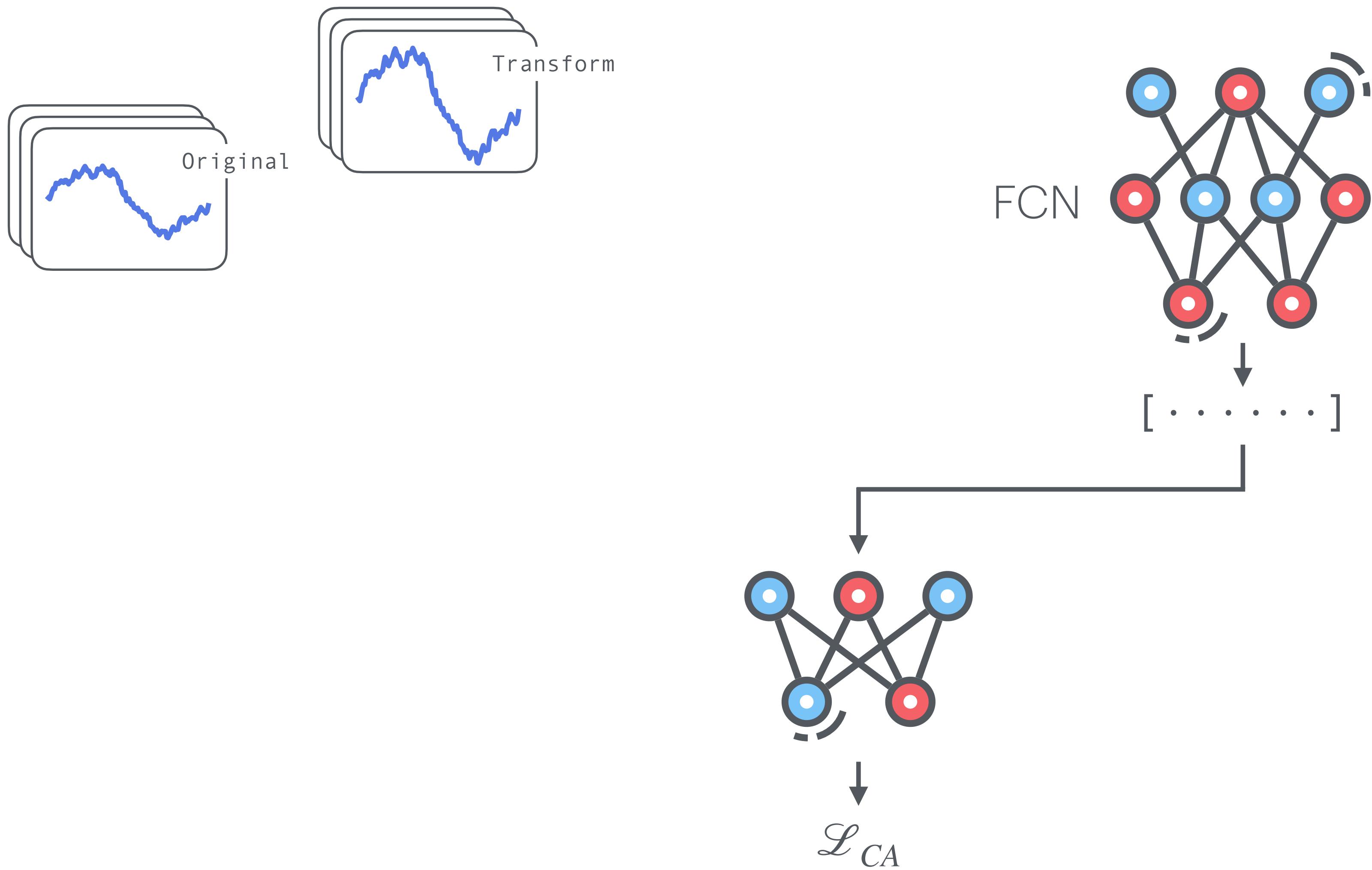


SSL: Multi-Task Learning

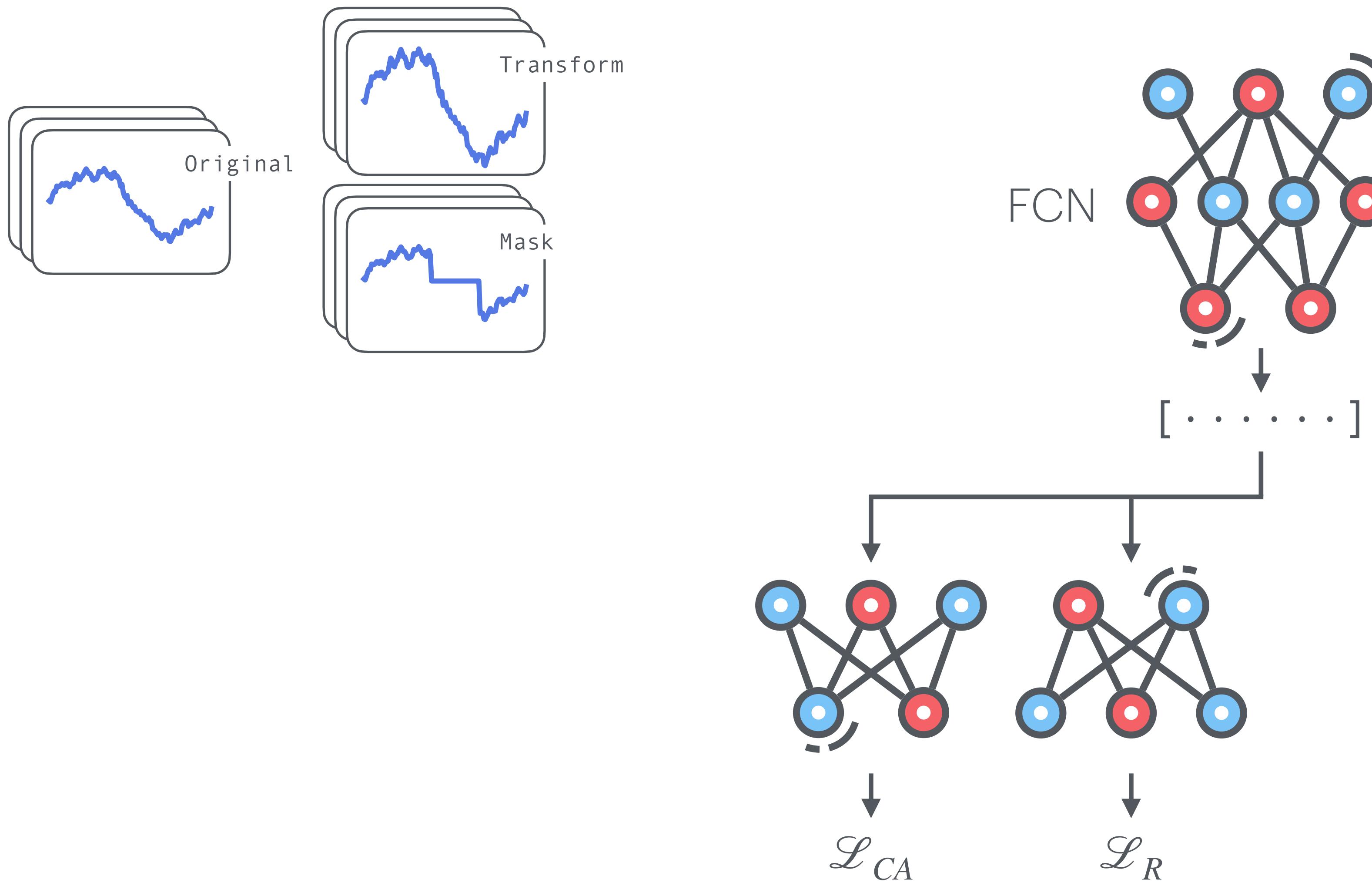
Architecture



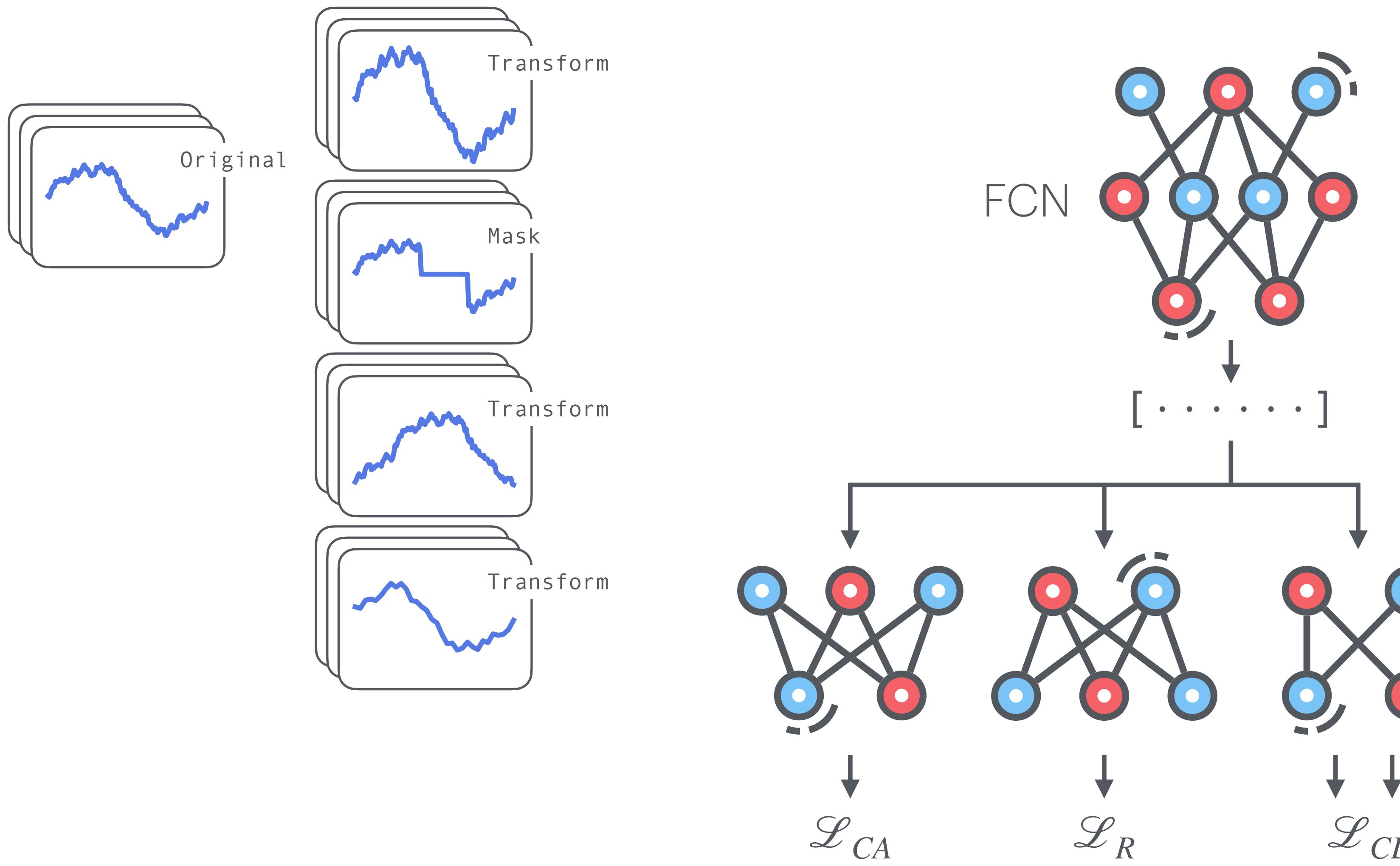
Architecture



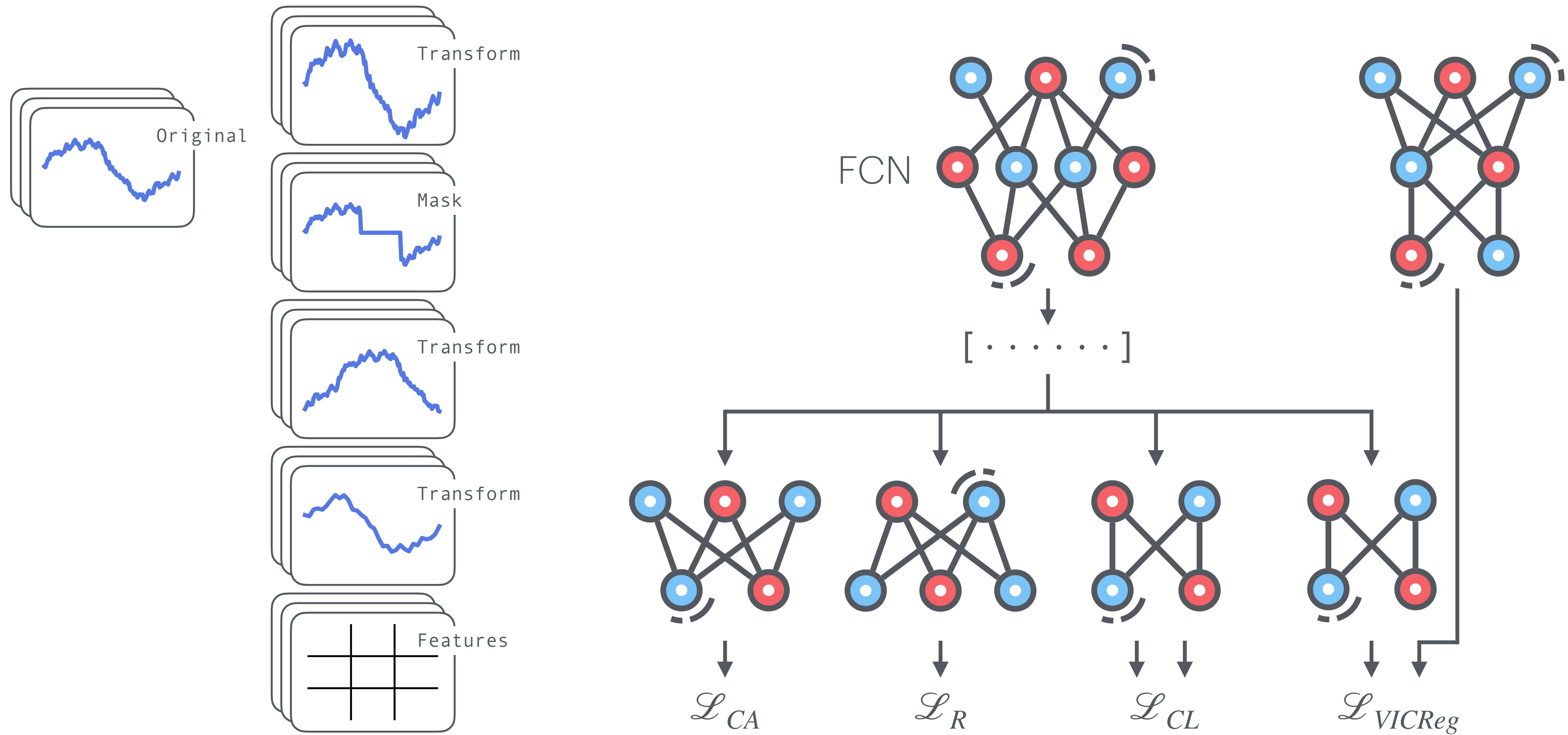
Architecture



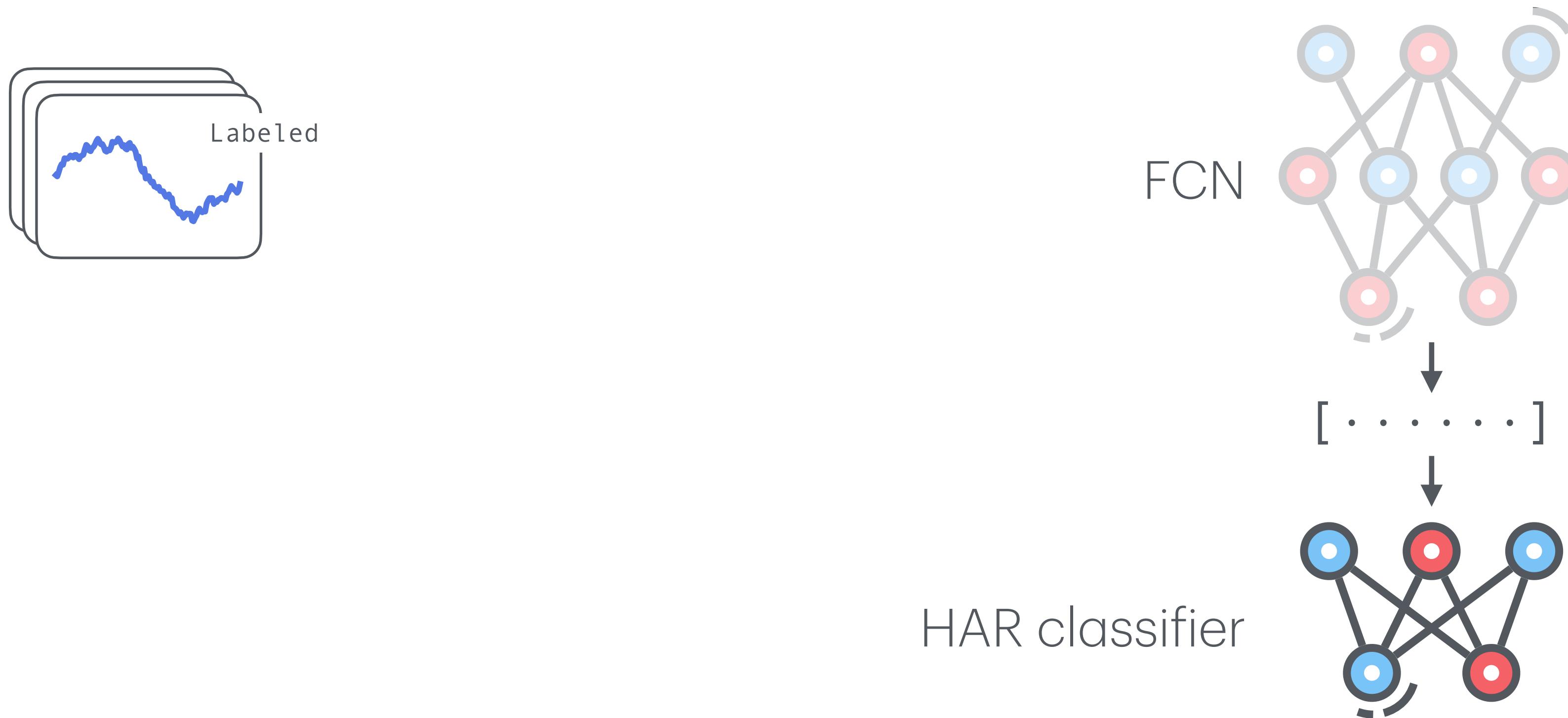
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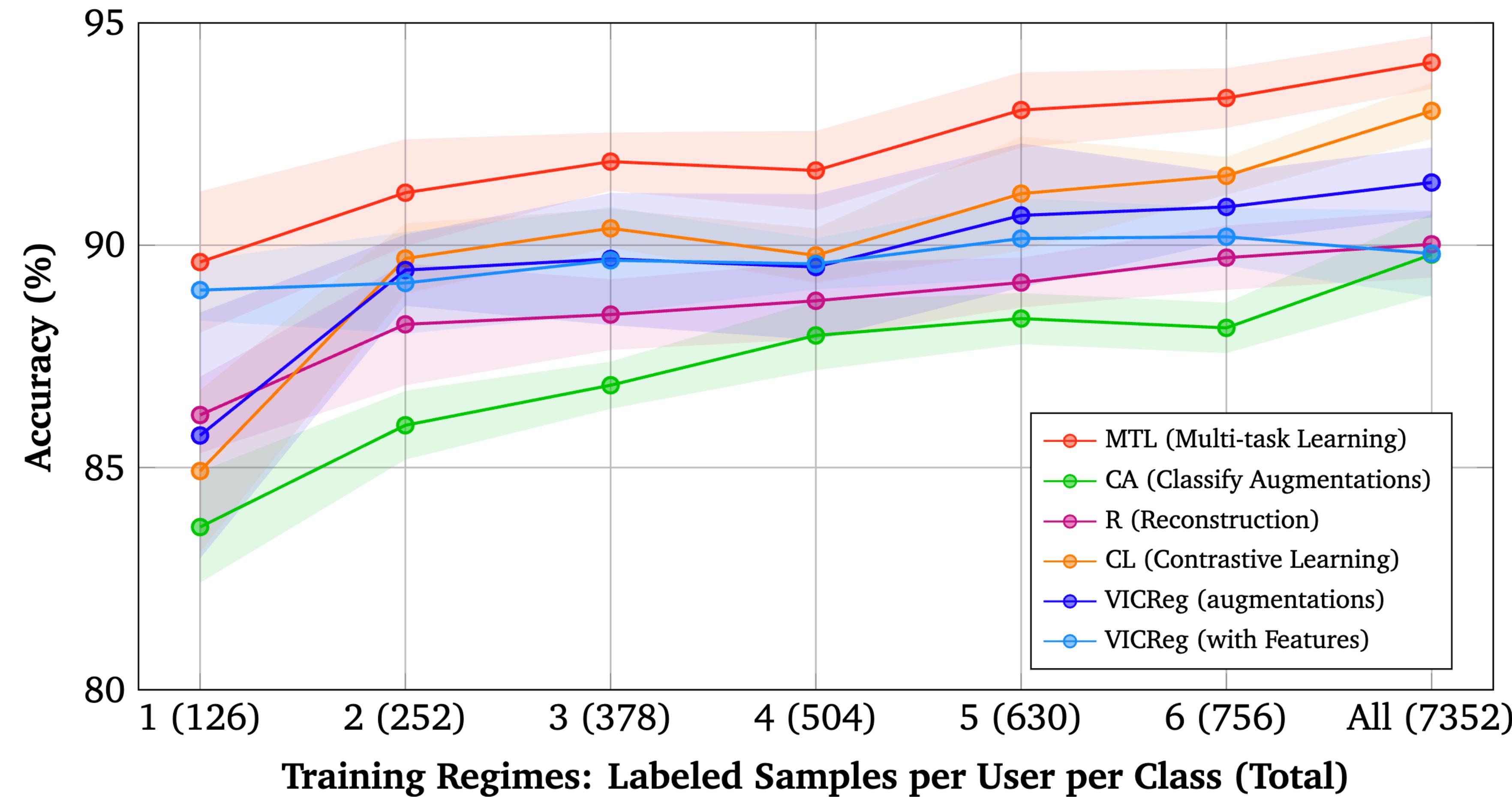
Architecture



Architecture

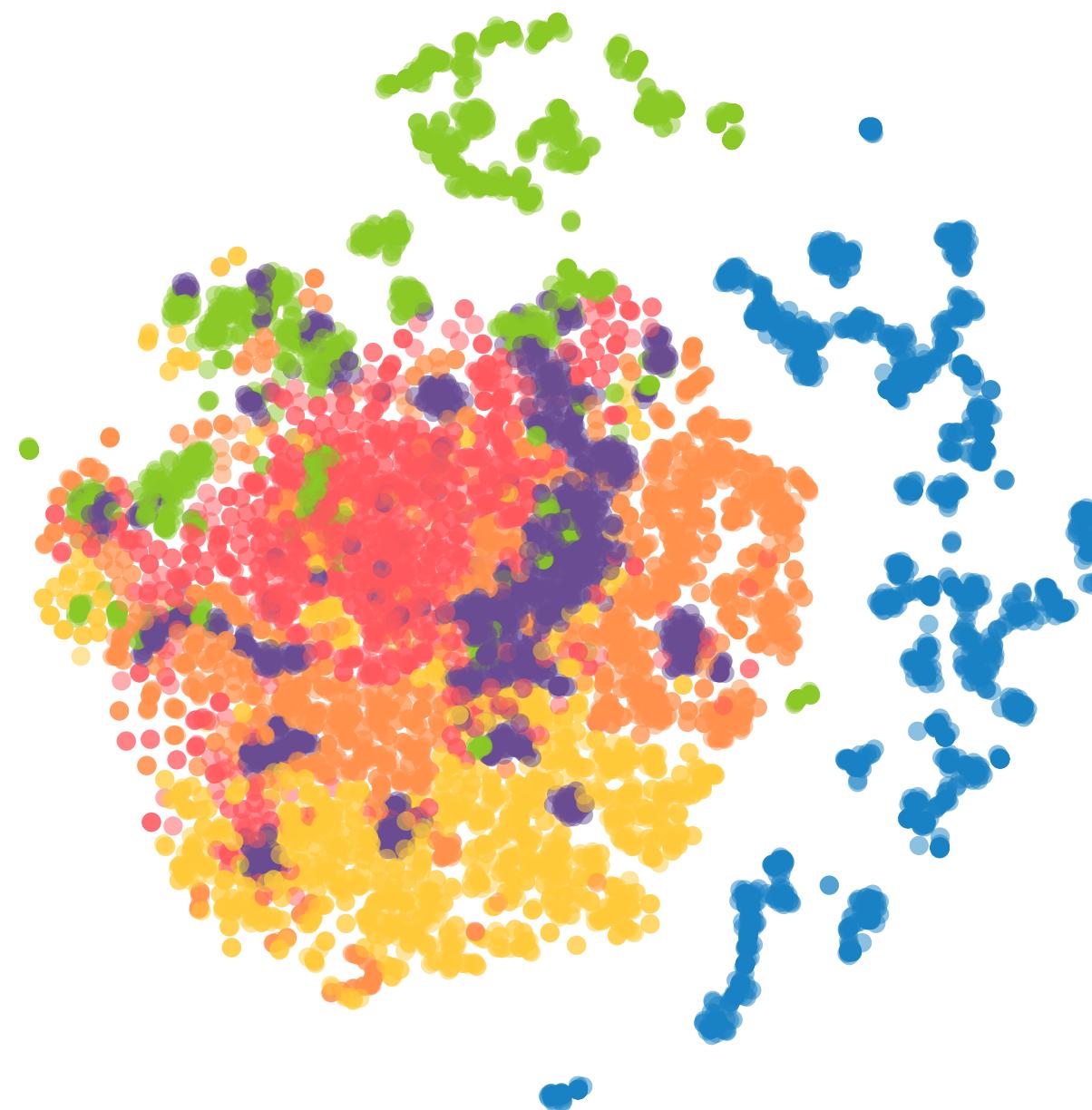


Multi-Task Learning



Visualizing Representations (t-SNE)

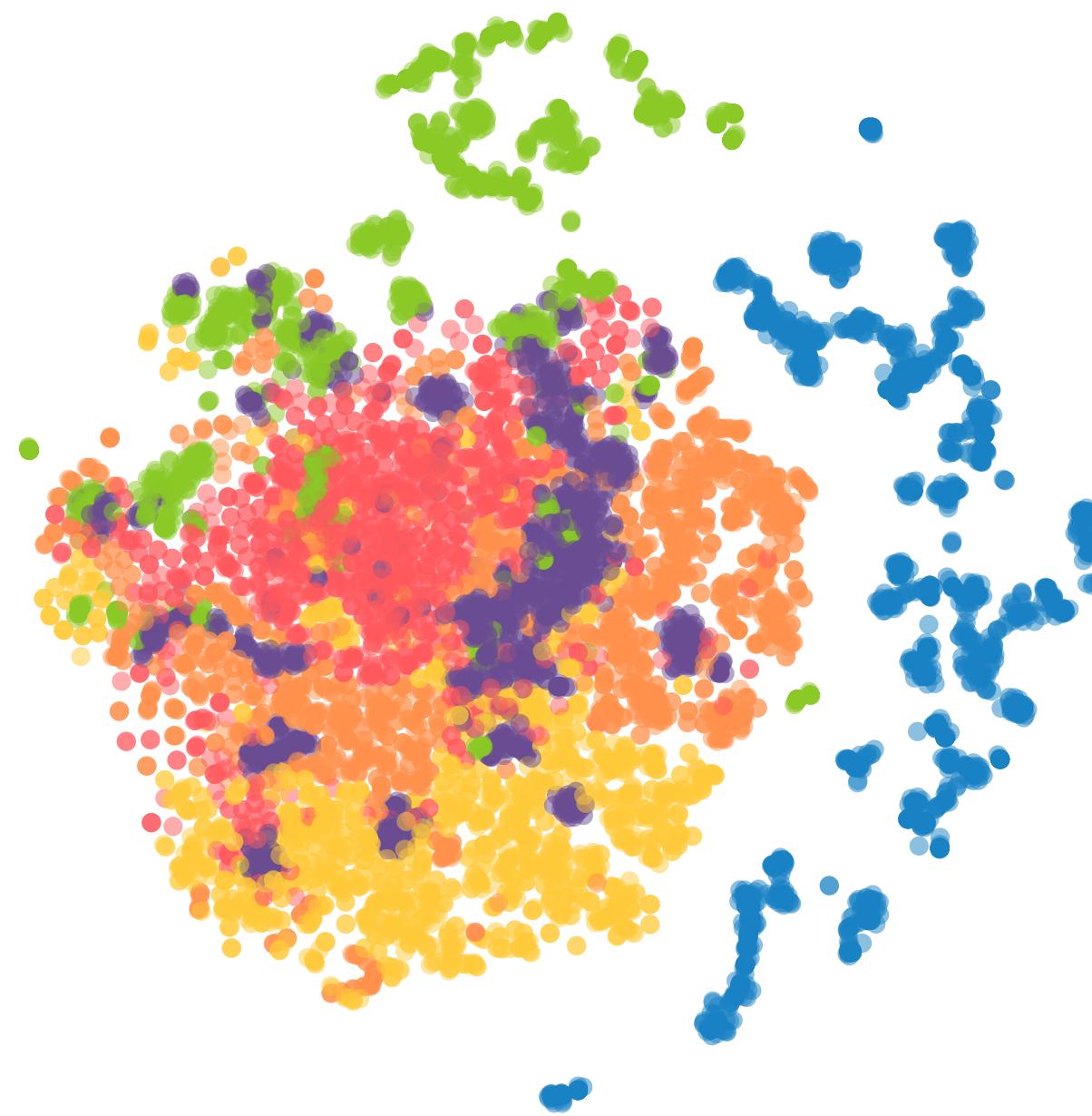
Activity
Walking
Walking upstairs
Walking downstairs
Sitting
Standing
Laying



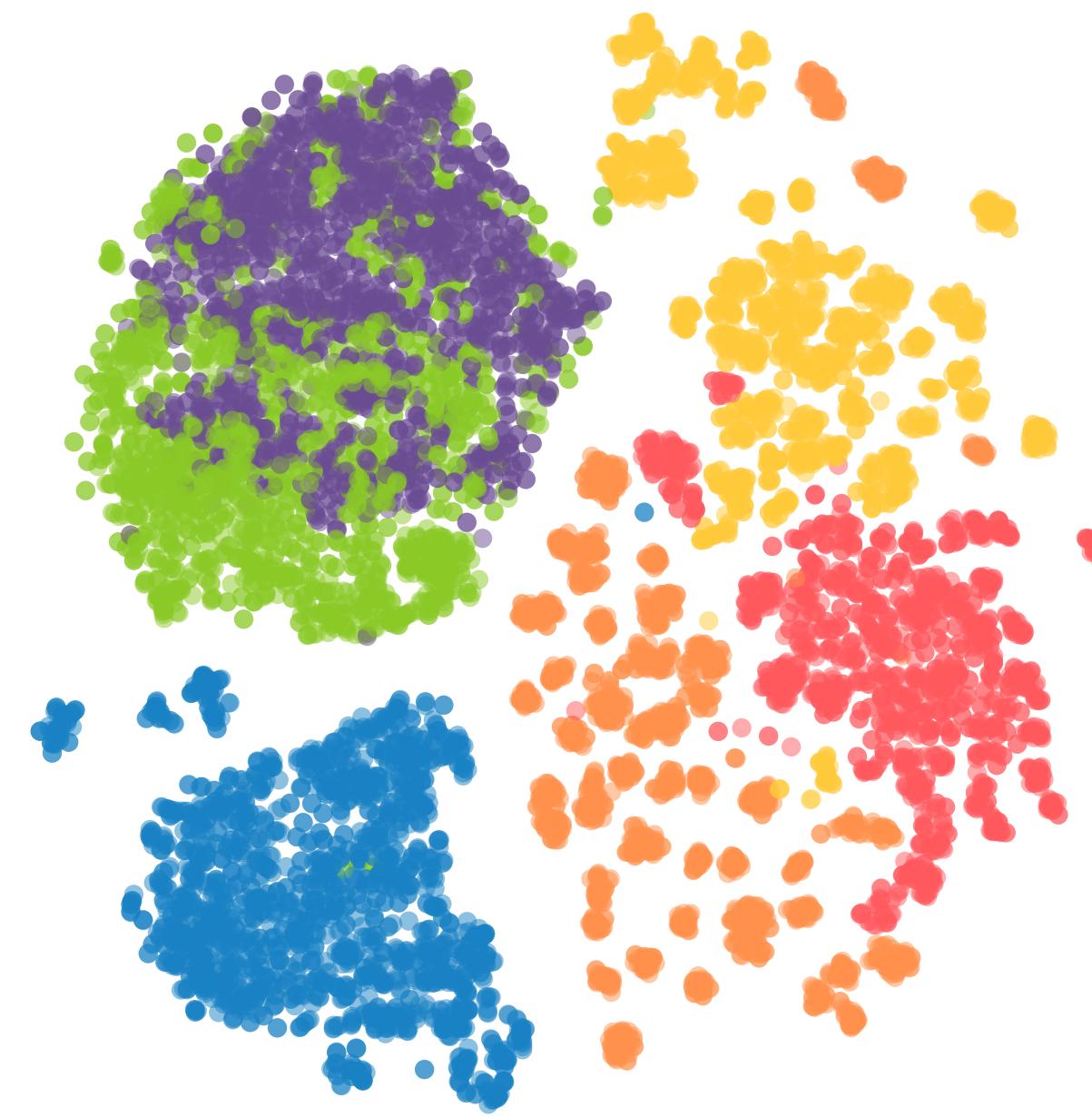
Raw Data (1,161)

Visualizing Representations (t-SNE)

Activity
Walking
Walking upstairs
Walking downstairs
Sitting
Standing
Laying



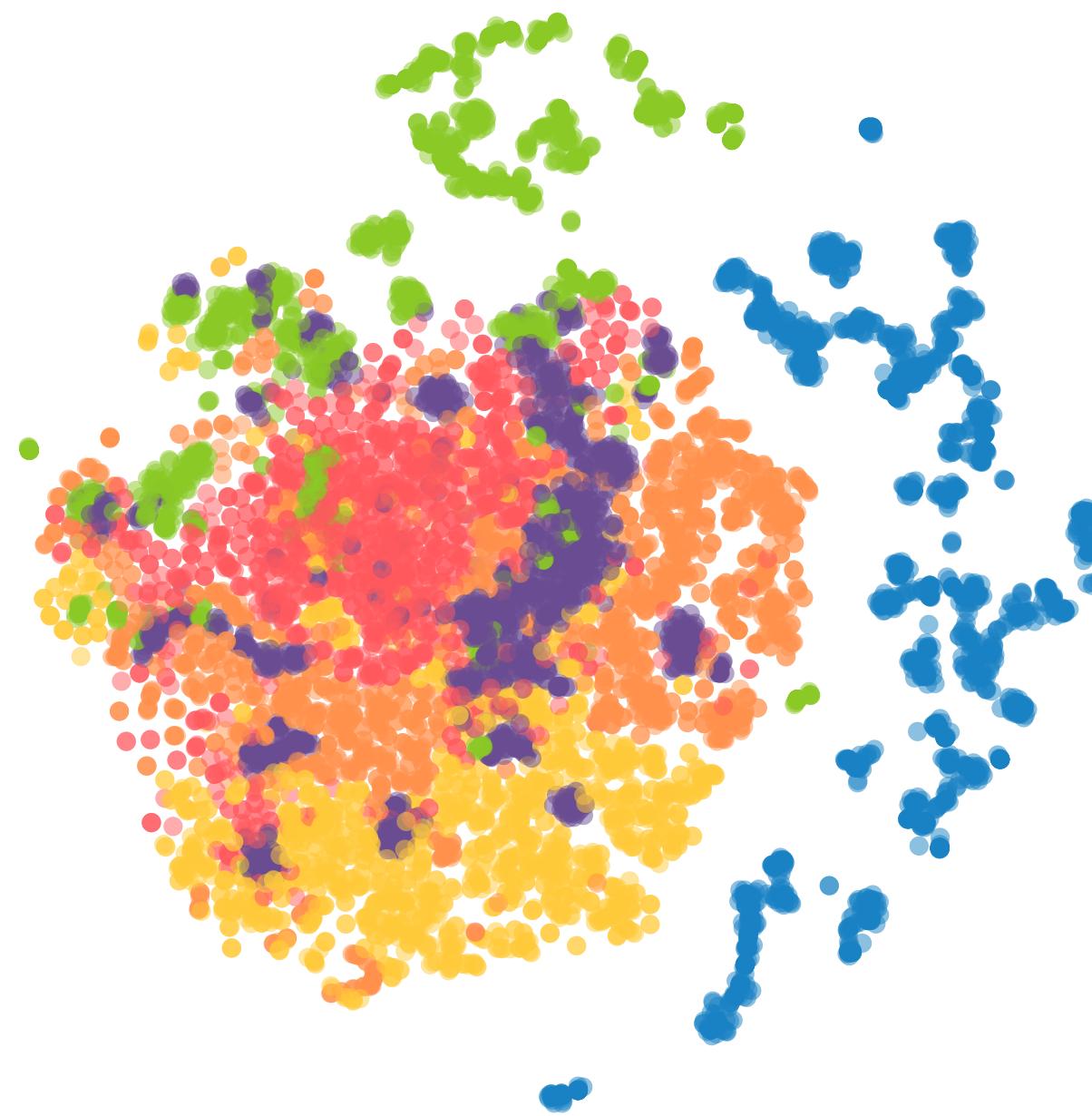
Raw Data (1,161)



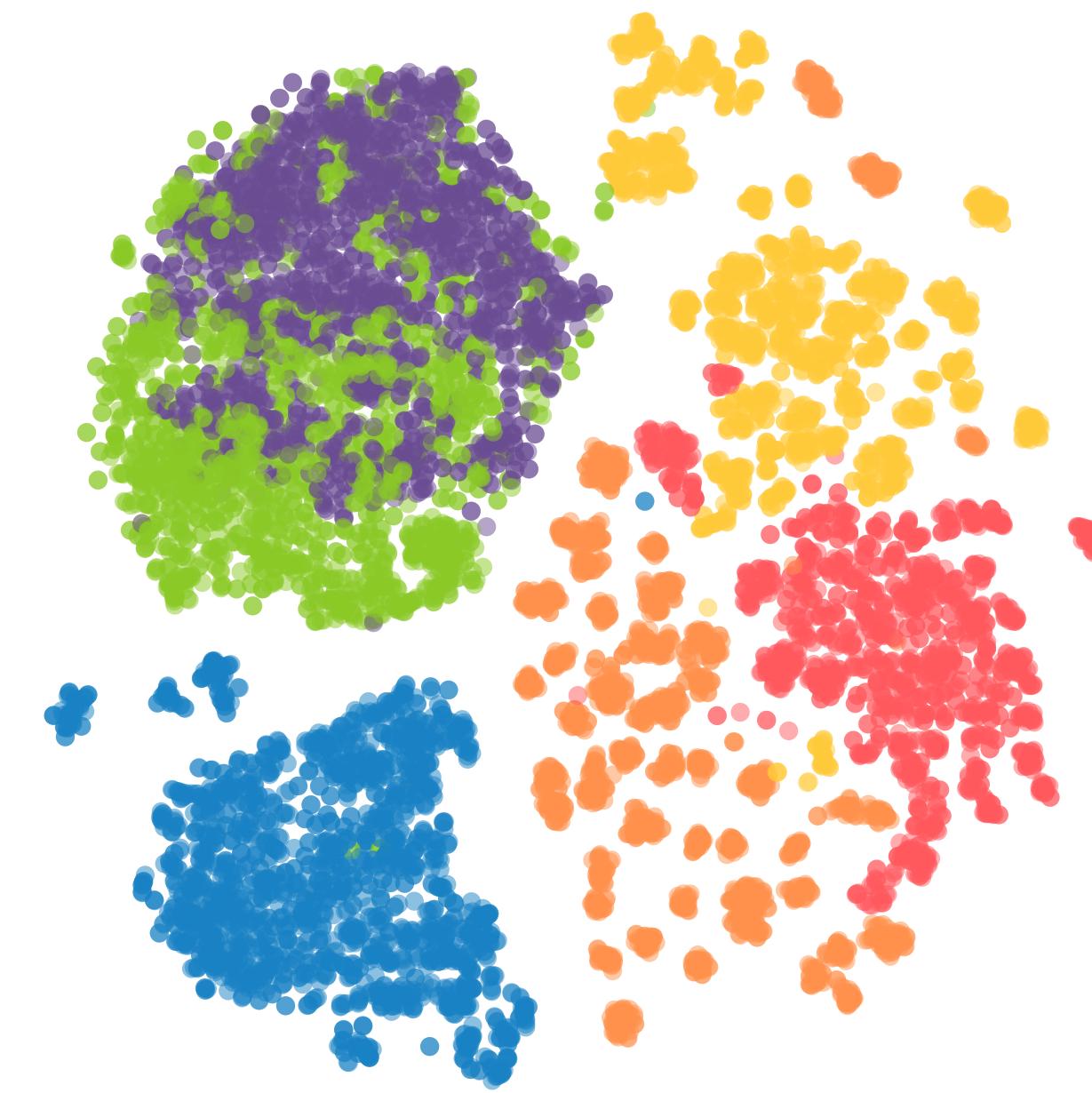
Expert Features (561)

Visualizing Representations (t-SNE)

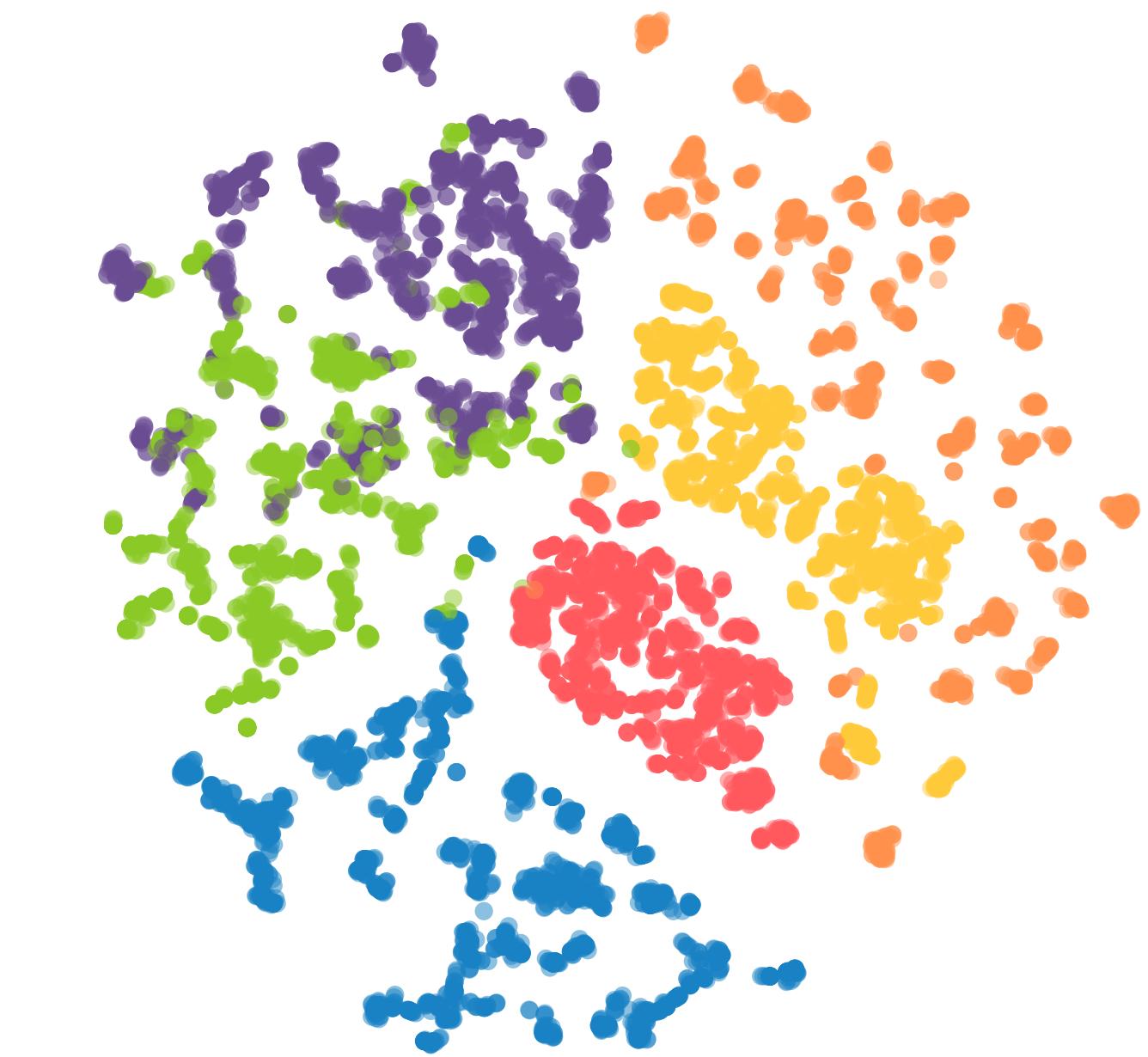
Activity
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Raw Data (1,161)



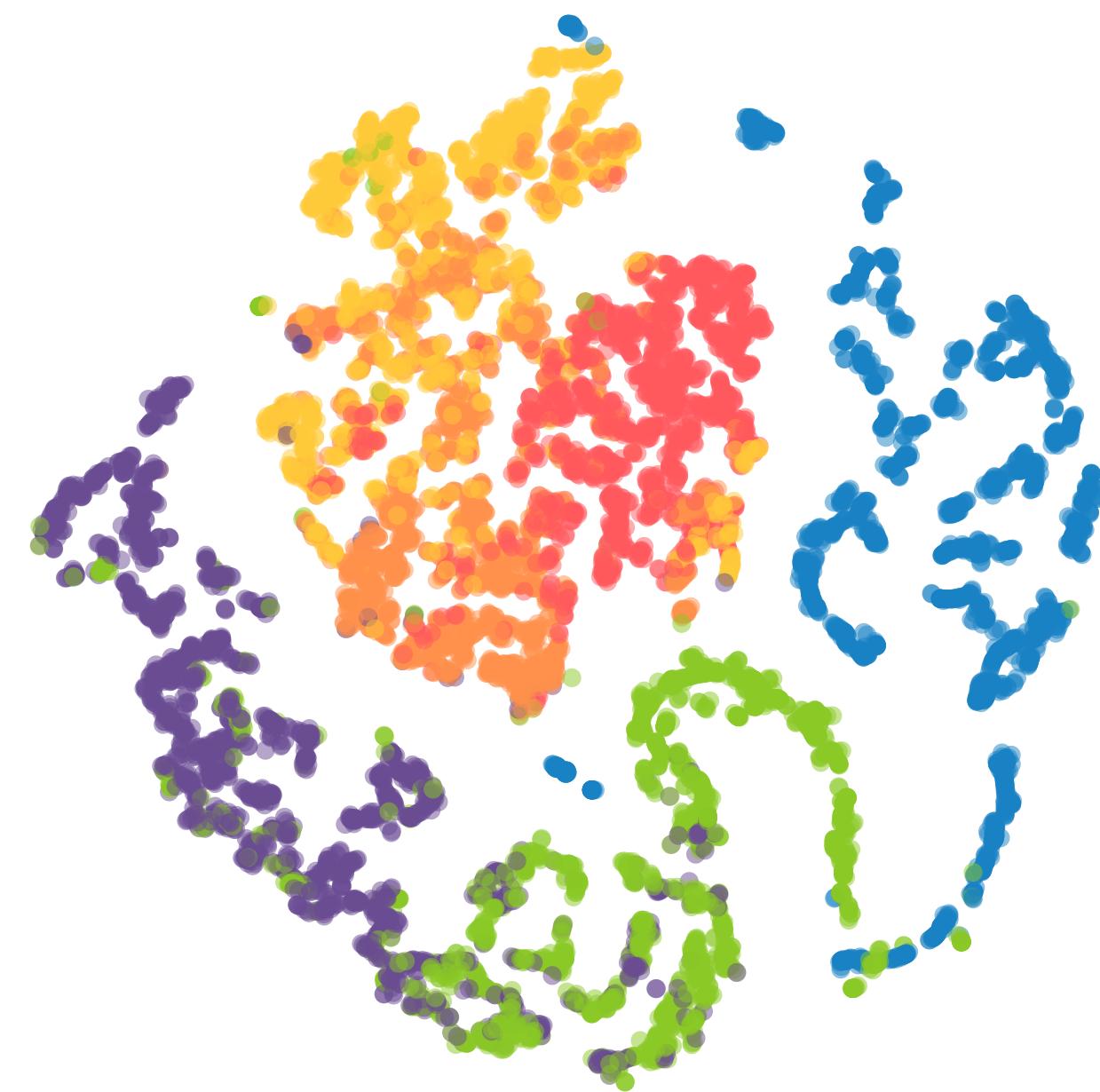
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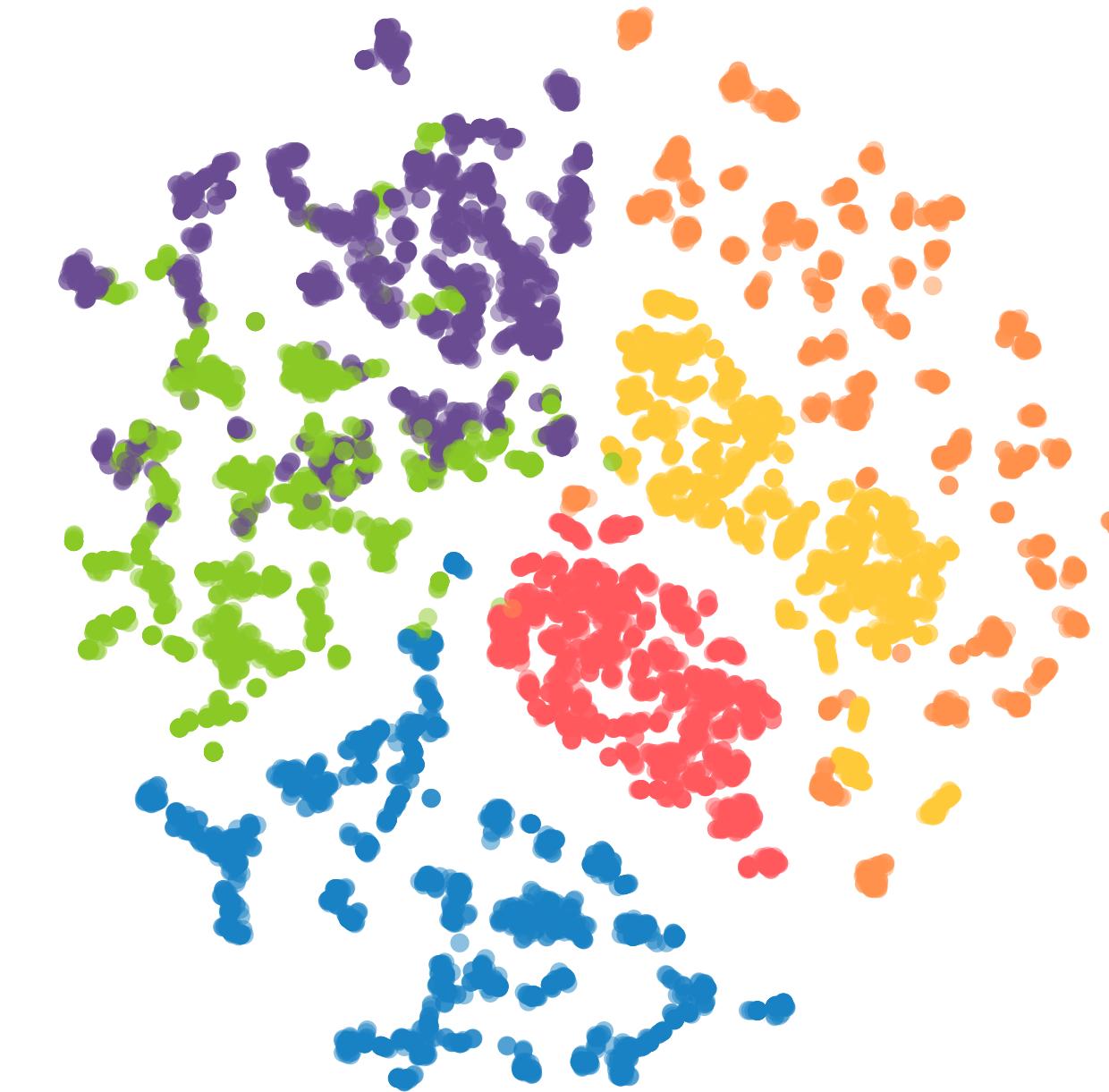
MTL Embeddings (128)

Visualizing Representations (t-SNE)

Activity
Walking
Walking upstairs
Walking downstairs
Sitting
Standing
Laying



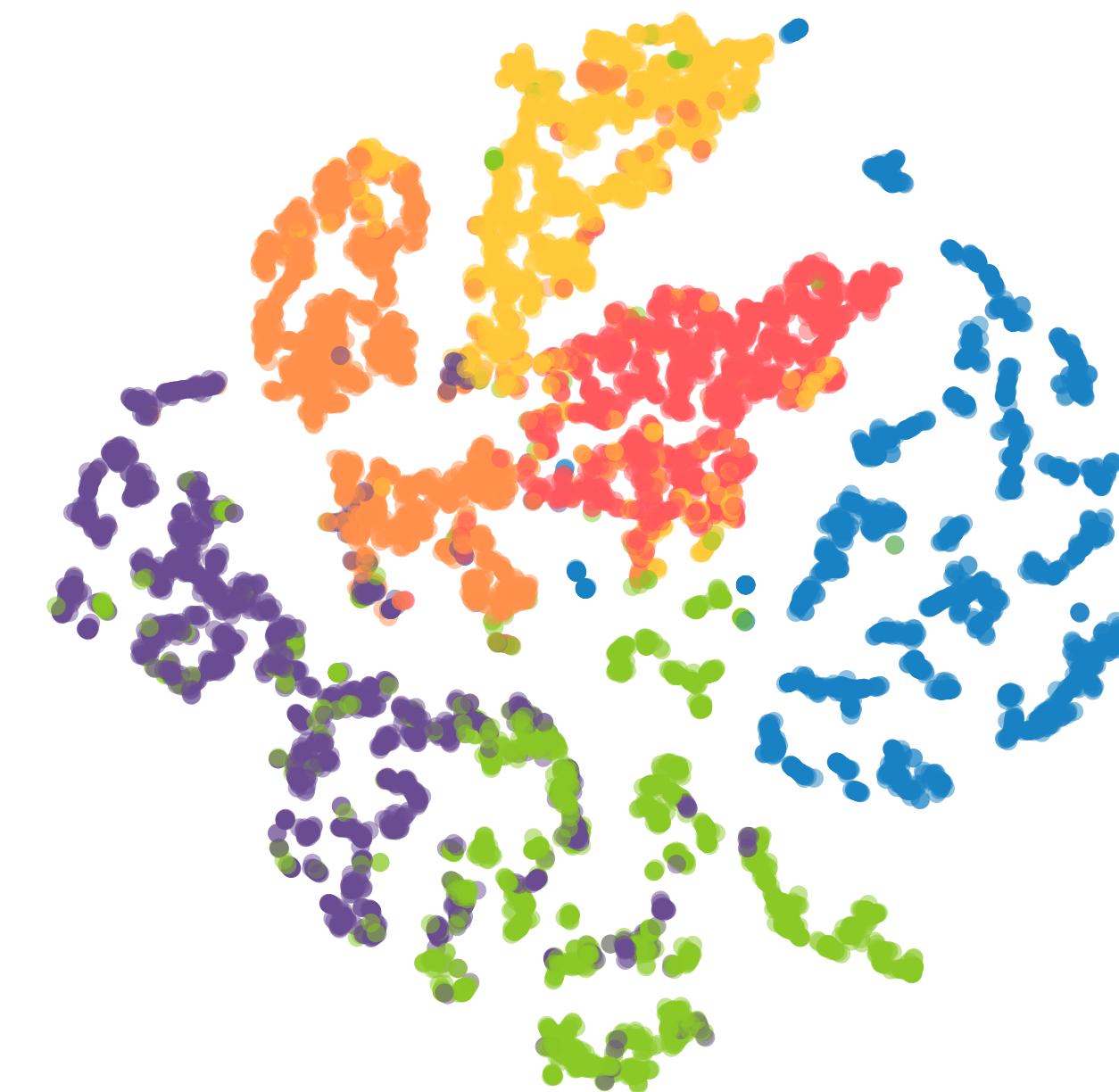
Fully Supervised: 1 | 126 (128)



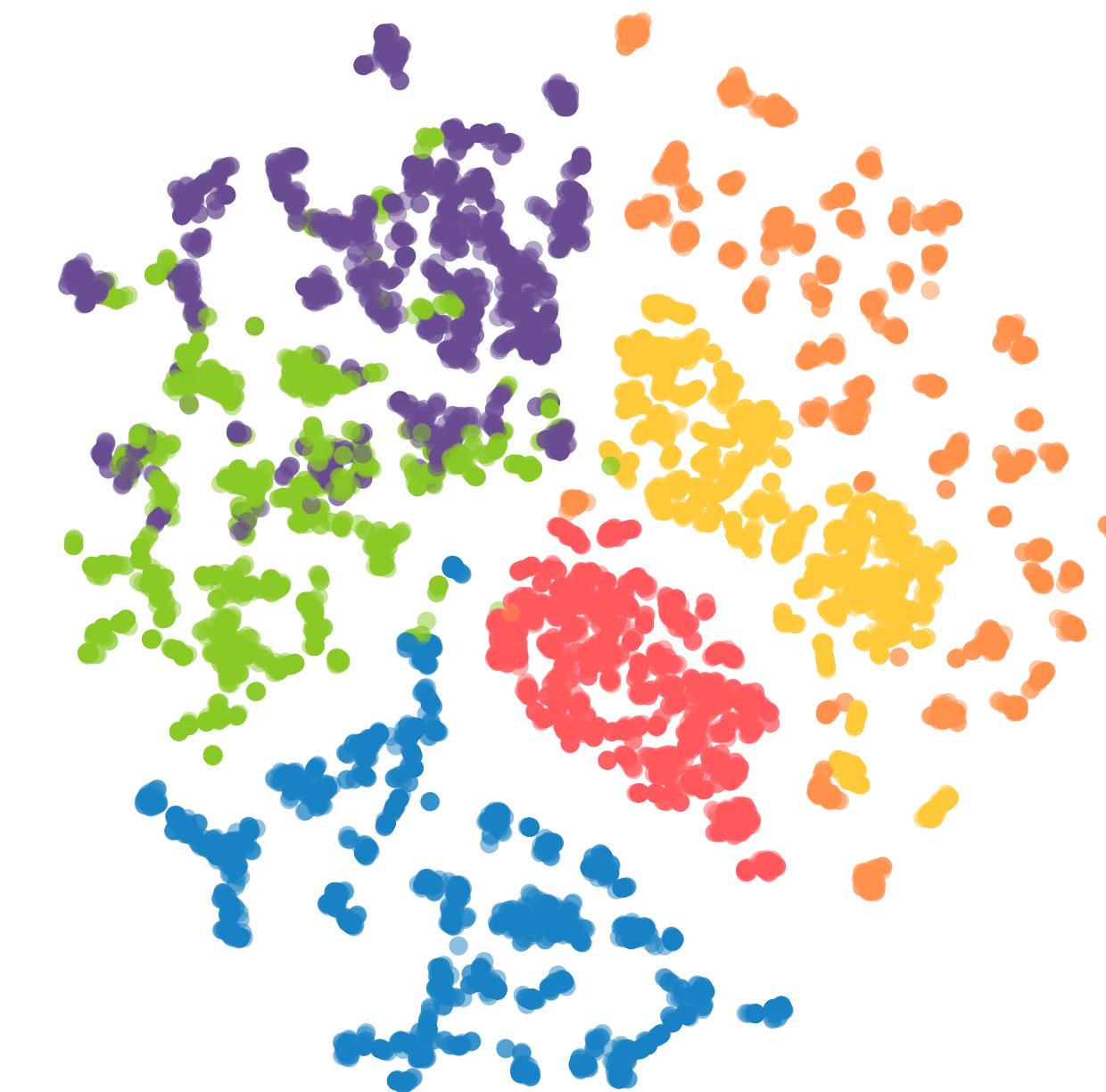
MTL Embeddings (128)

Visualizing Representations (t-SNE)

Activity
Walking
Walking upstairs
Walking downstairs
Sitting
Standing
Laying



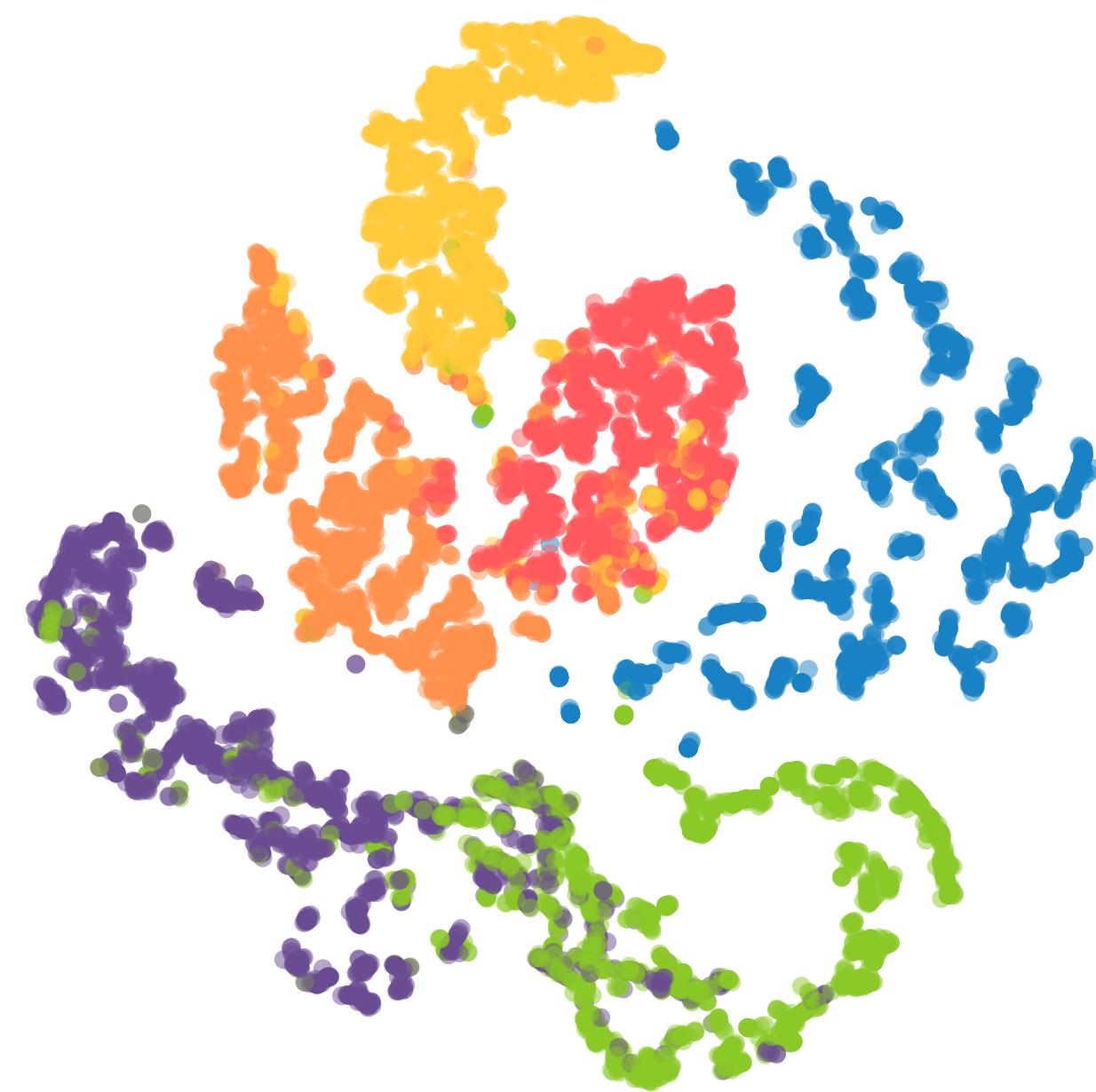
Fully Supervised: 2 | 252 (128)



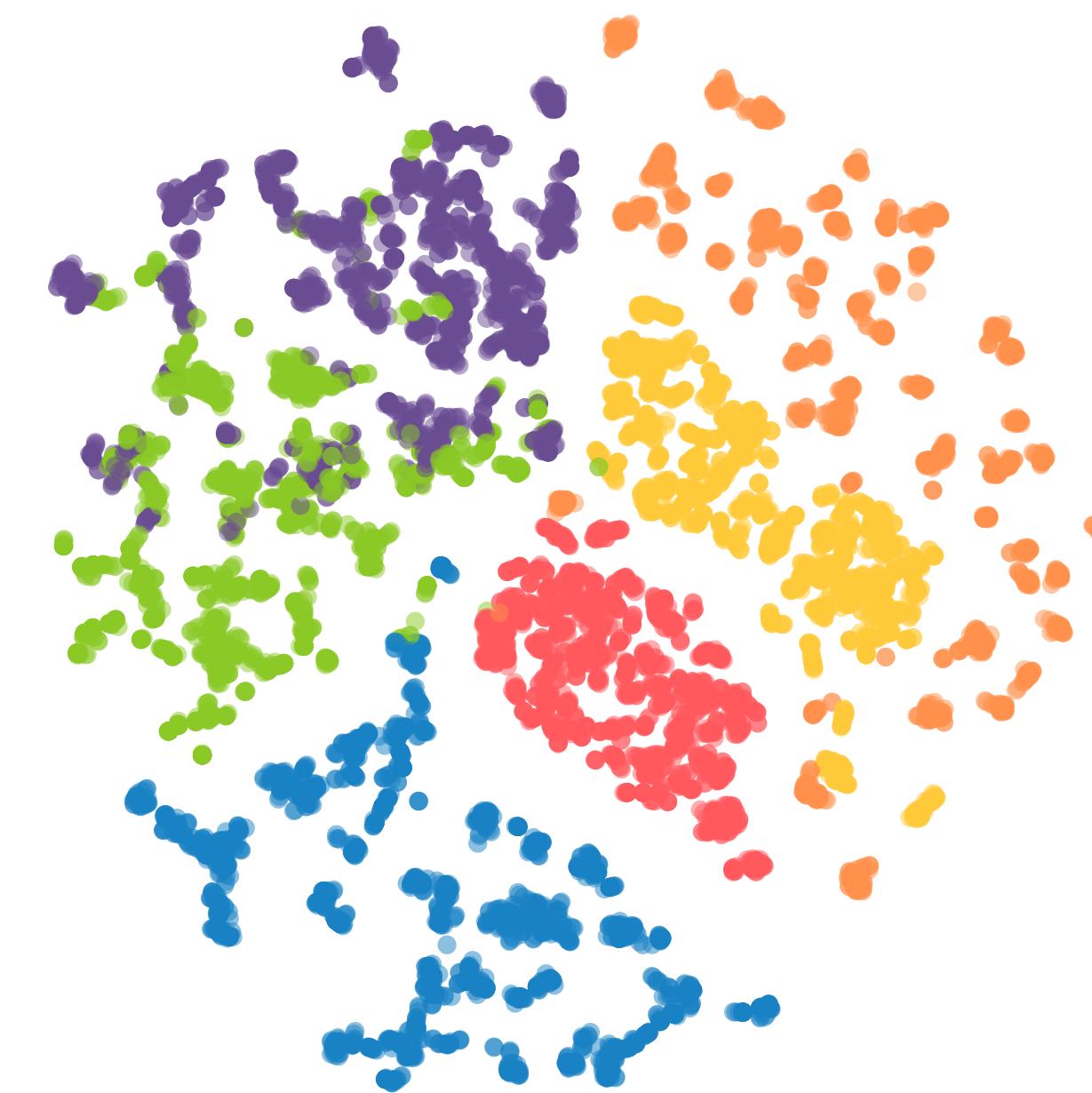
MTL Embeddings (128)

Visualizing Representations (t-SNE)

Activity
Walking
Walking upstairs
Walking downstairs
Sitting
Standing
Laying



Fully Supervised: 3 | 378 (128)



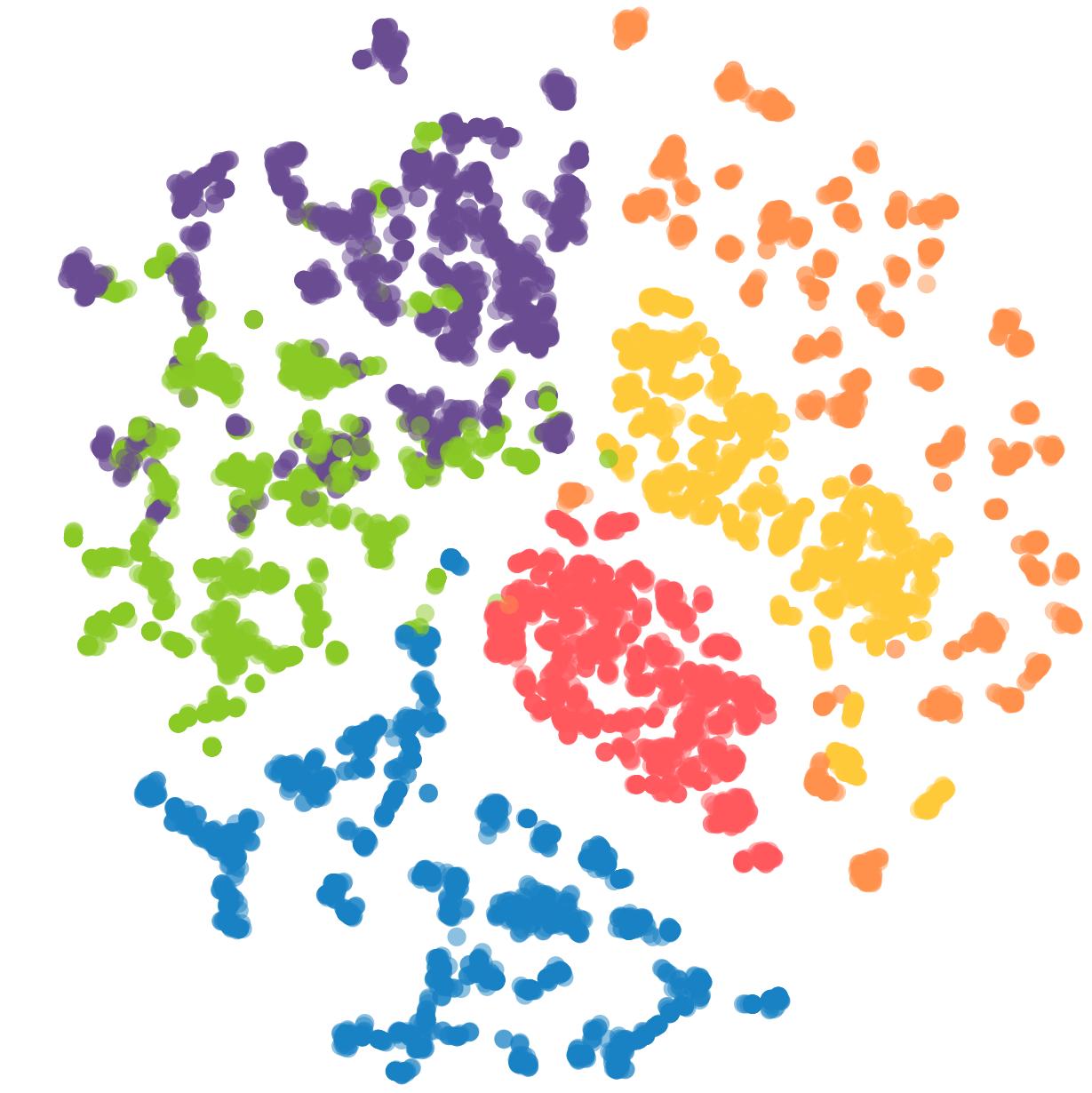
MTL Embeddings (128)

Visualizing Representations (t-SNE)

Activity
Walking
Walking upstairs
Walking downstairs
Sitting
Standing
Laying



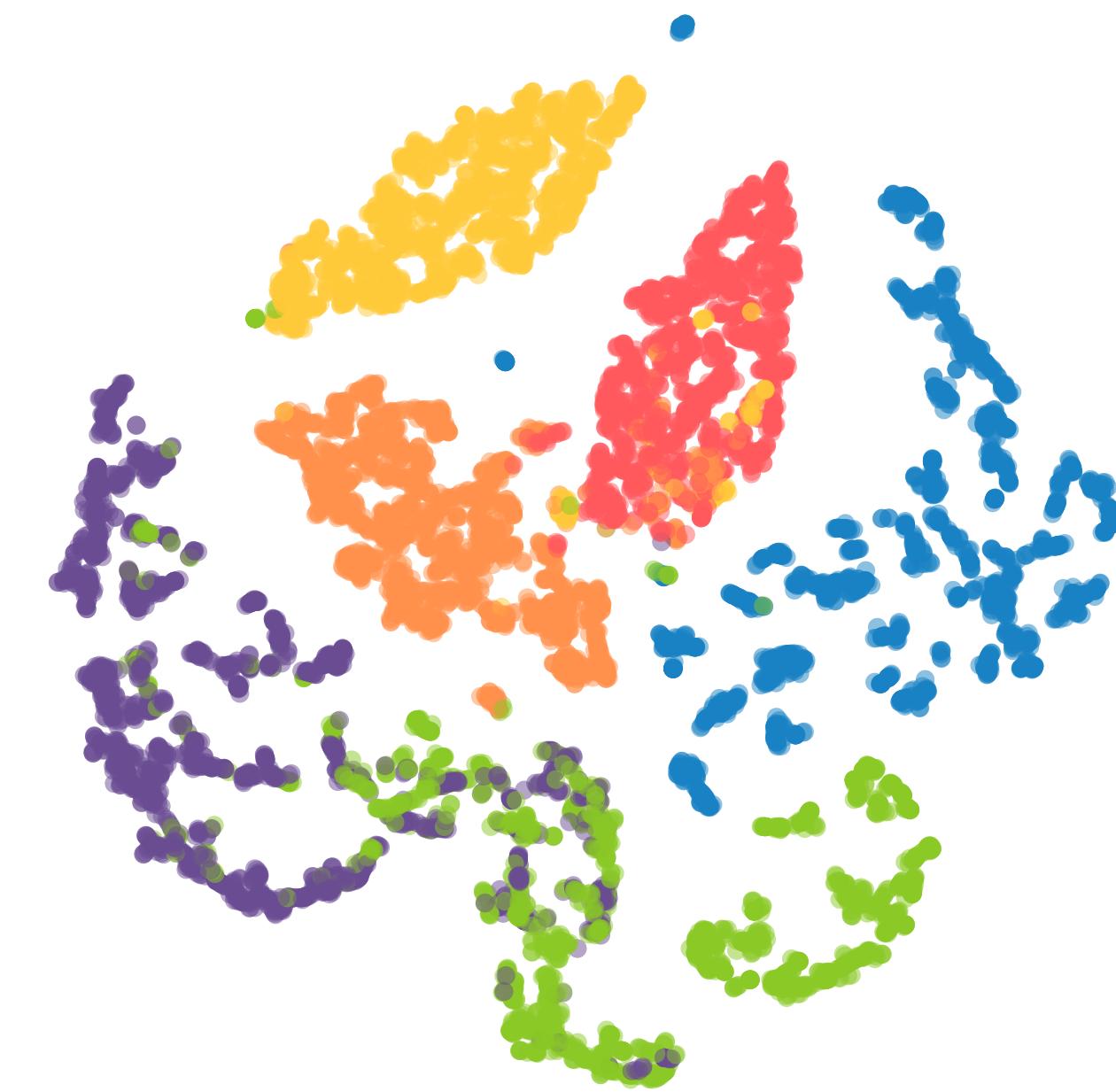
Fully Supervised: 4 | 504 (128)



MTL Embeddings (128)

Visualizing Representations (t-SNE)

Activity
Walking
Walking upstairs
Walking downstairs
Sitting
Standing
Laying



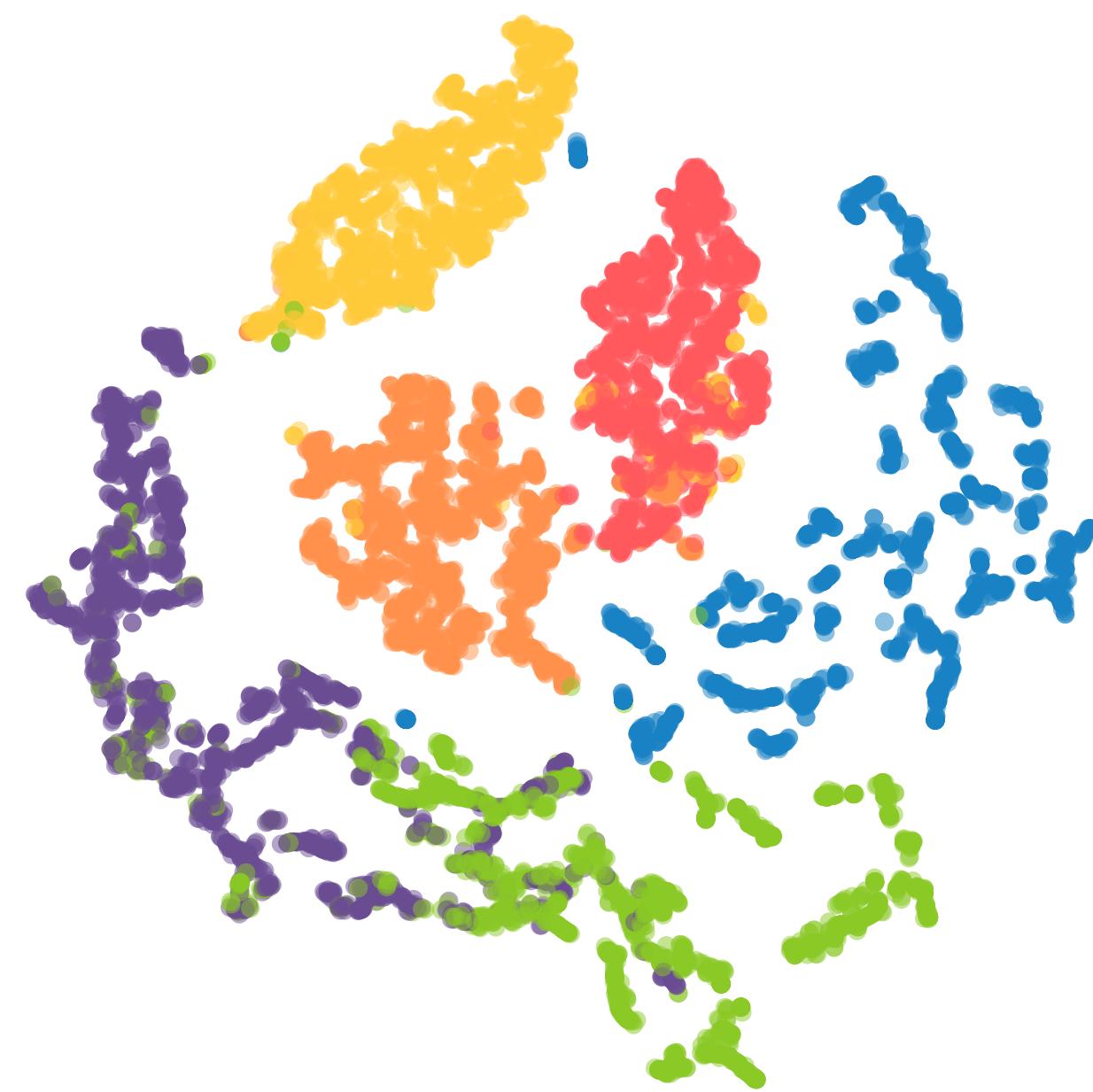
Fully Supervised: 5 | 630 (128)



MTL Embeddings (128)

Visualizing Representations (t-SNE)

Activity
Walking
Walking upstairs
Walking downstairs
Sitting
Standing
Laying



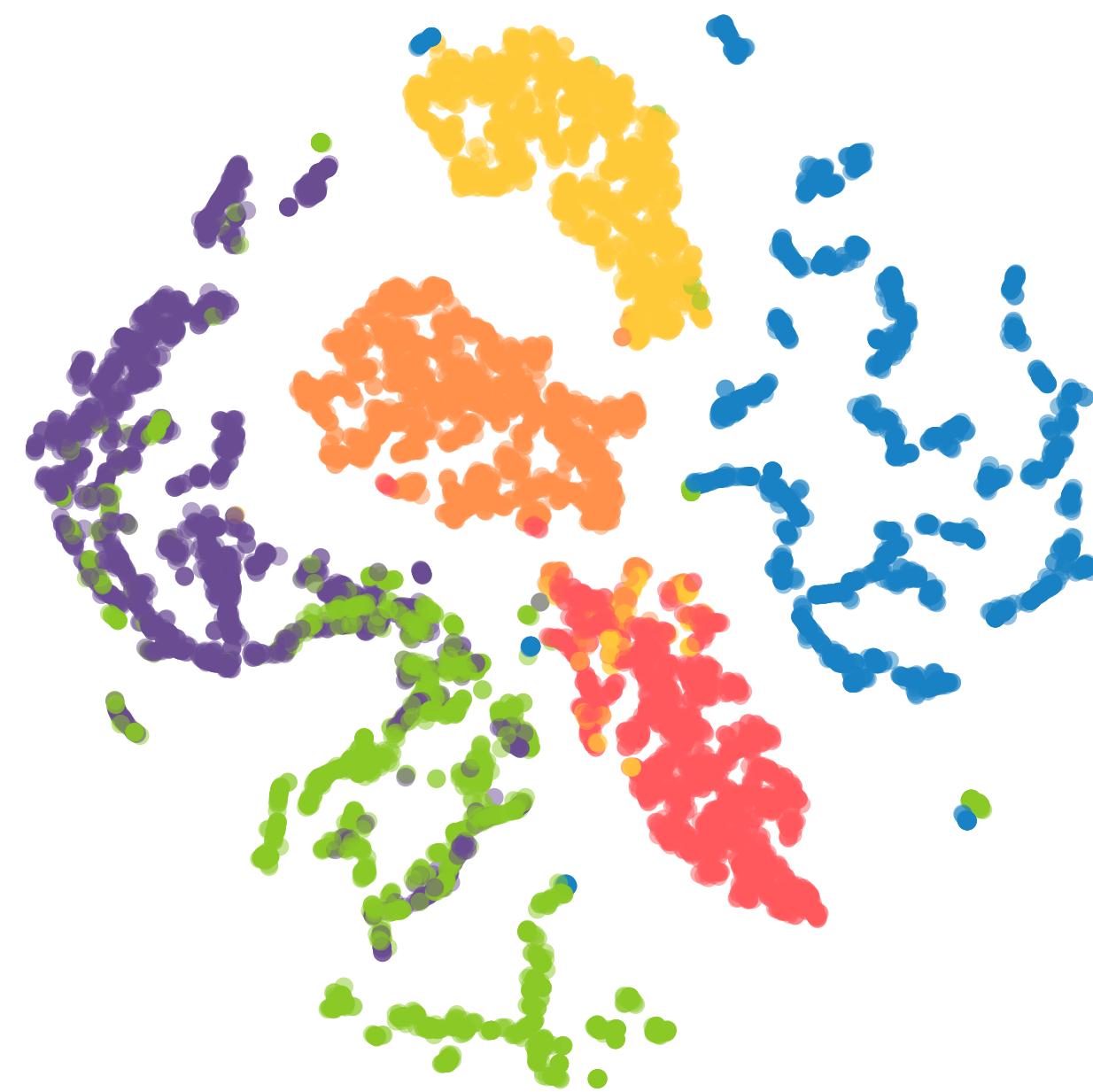
Fully Supervised: 6 | 756 (128)



MTL Embeddings (128)

Visualizing Representations (t-SNE)

Activity
Walking
Walking upstairs
Walking downstairs
Sitting
Standing
Laying

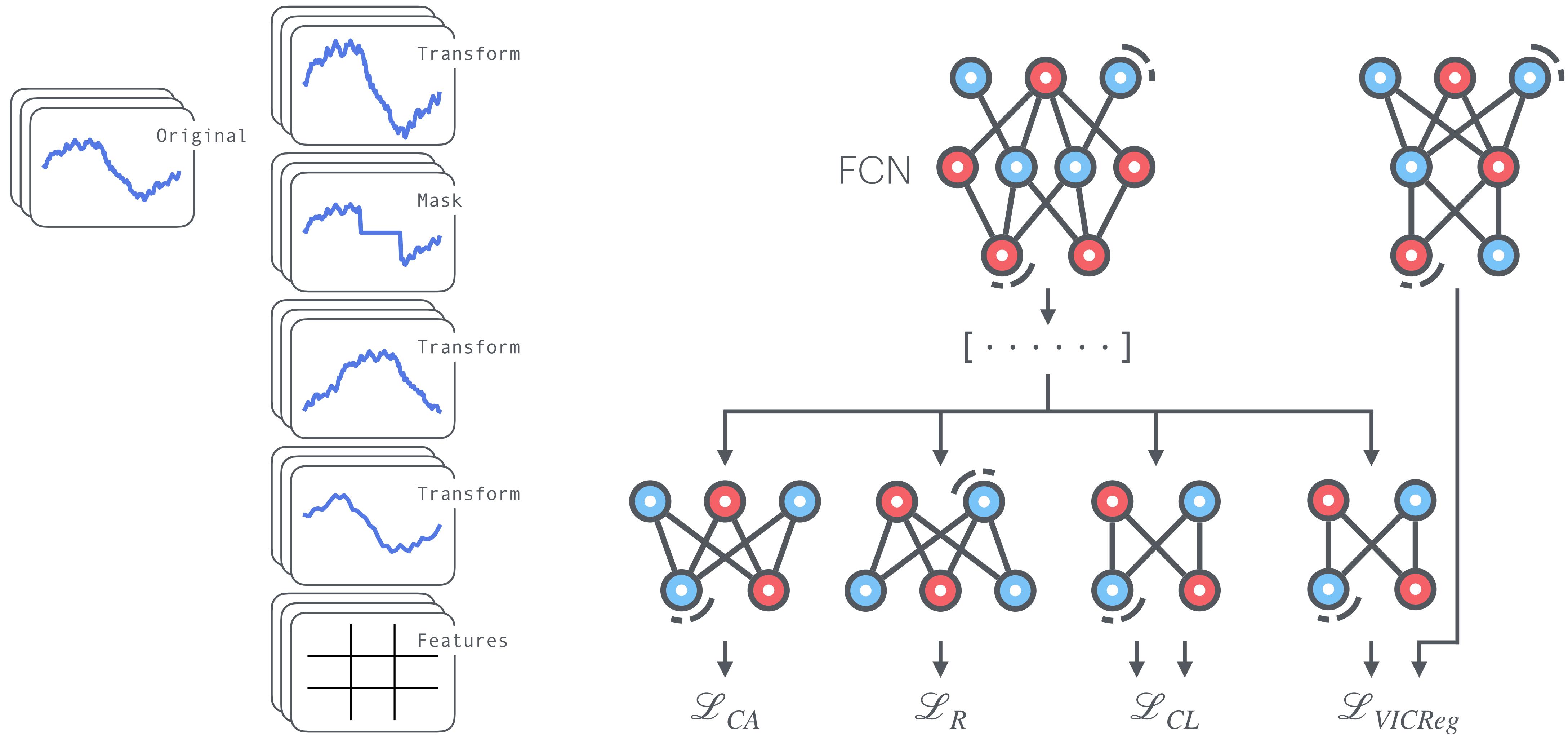


Fully Supervised: all | 7352 (128)

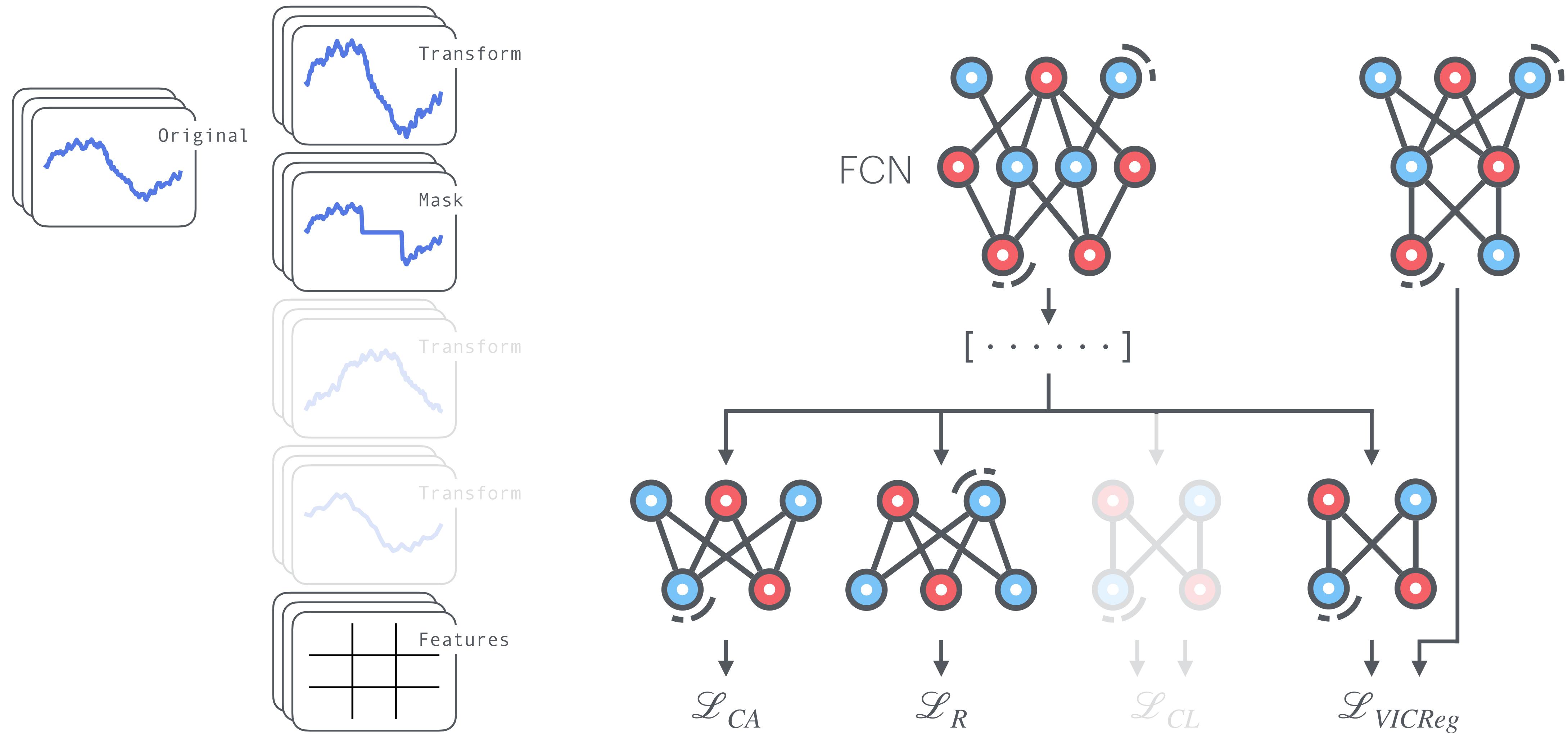


MTL Embeddings (128)

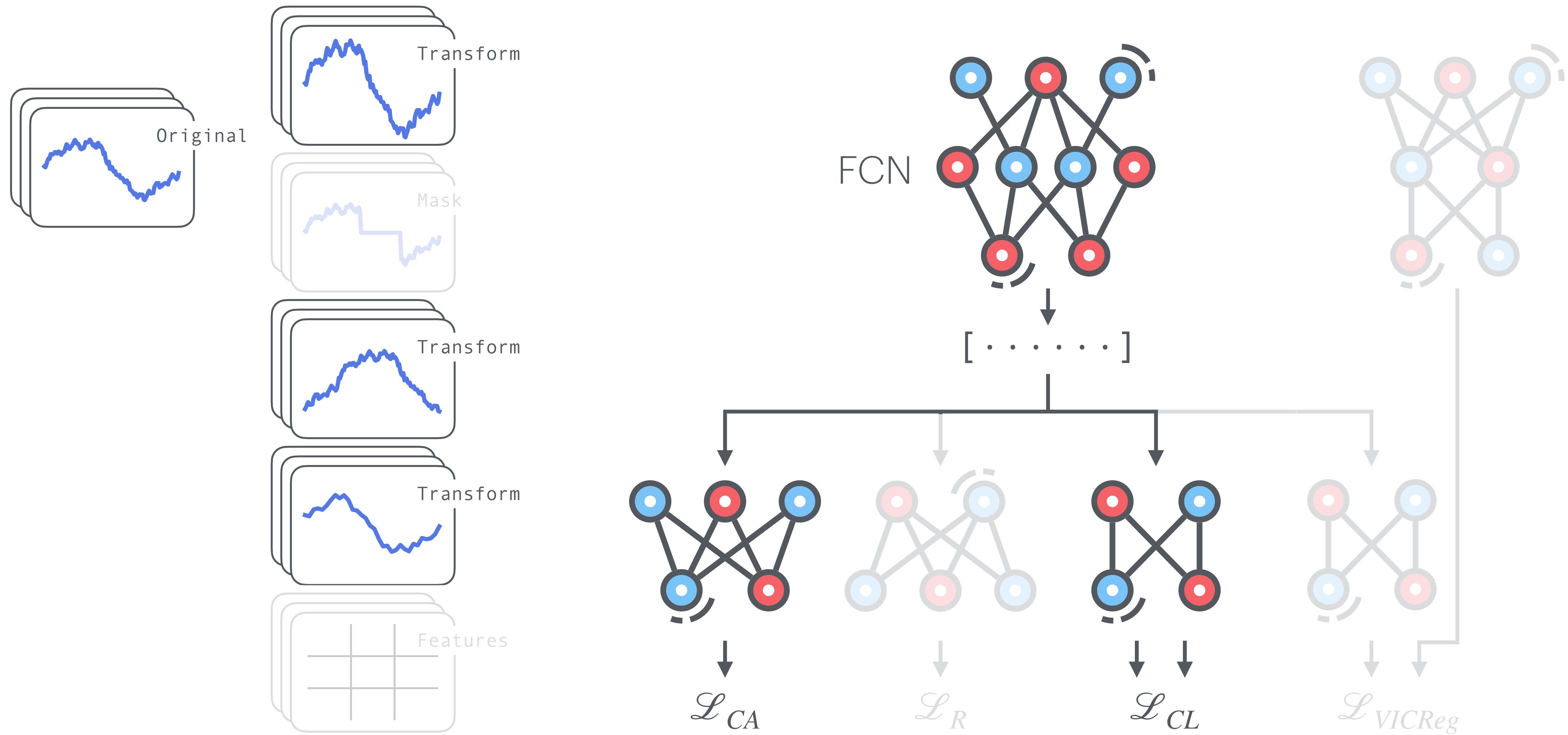
Multi-Task Combinations



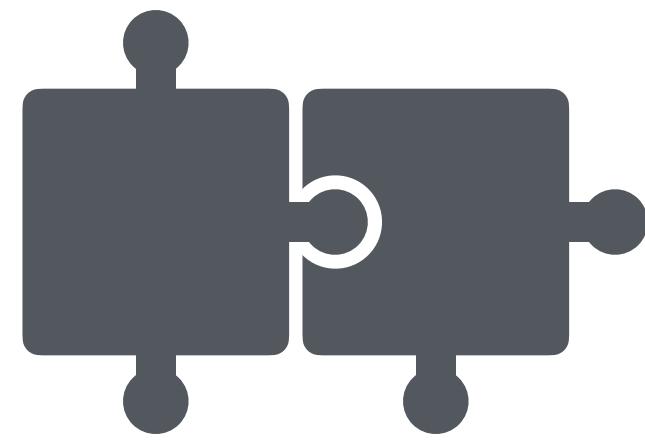
Multi-Task Combinations



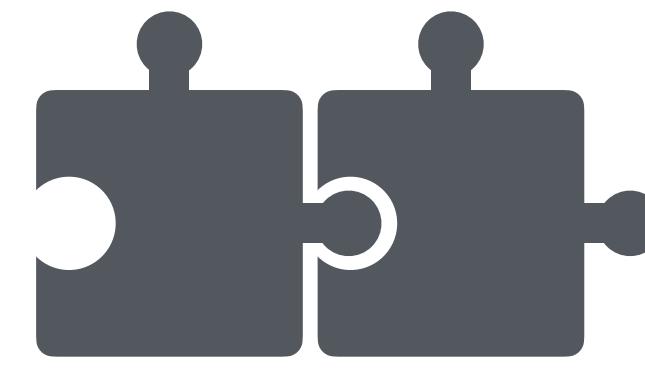
Multi-Task Combinations



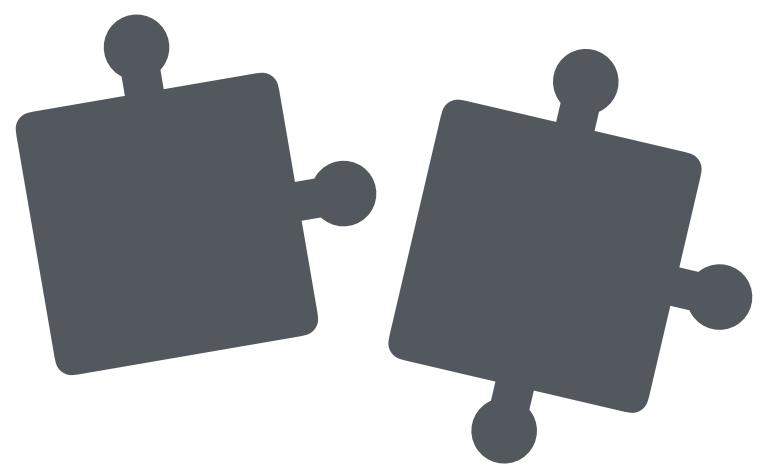
Multi-Task Combinations



Complementary



Redundant



Conflicting

Multi-Task Combinations

class rec CL VICReg	Accuracy (%)						
	1 (126)	2 (252)	3 (378)	4 (504)	5 (630)	6 (756)	all (7352)
✓ ✗ ✗ ✗	83.66 ± 1.70	85.95 ± 1.05	86.85 ± 0.72	87.97 ± 1.06	88.35 ± 0.78	88.14 ± 0.77	89.79 ± 1.24
✗ ✓ ✗ ✗	86.18 ± 1.17	88.22 ± 1.86	88.44 ± 1.08	88.75 ± 1.17	89.16 ± 0.76	89.72 ± 0.98	90.02 ± 1.02
✗ ✗ ✓ ✗	84.92 ± 2.47	89.70 ± 1.07	90.38 ± 0.59	89.77 ± 0.83	91.16 ± 1.74	91.56 ± 0.58	93.02 ± 0.85
✗ ✗ ✗ ✓	88.99 ± 0.93	89.15 ± 1.55	89.66 ± 1.62	89.58 ± 0.78	90.15 ± 1.23	90.19 ± 0.88	89.81 ± 1.32
✓ ✓ ✗ ✗	83.64 ± 1.90	87.85 ± 3.24	88.46 ± 1.73	88.27 ± 1.85	89.44 ± 1.89	88.94 ± 1.19	91.21 ± 2.02
✓ ✗ ✓ ✗	85.95 ± 2.87	89.93 ± 1.36	90.06 ± 1.36	90.36 ± 0.59	91.73 ± 0.79	91.58 ± 1.02	93.21 ± 0.99
✓ ✗ ✗ ✓	90.11 ± 1.36	91.03 ± 2.64	91.16 ± 1.84	90.46 ± 2.36	91.46 ± 1.85	91.17 ± 1.74	92.30 ± 1.29
✗ ✓ ✓ ✗	85.21 ± 3.26	89.74 ± 2.17	90.52 ± 1.77	90.20 ± 1.21	91.70 ± 2.08	92.00 ± 1.09	93.53 ± 1.02
✗ ✓ ✗ ✓	85.59 ± 2.17	87.82 ± 3.58	87.86 ± 3.05	88.86 ± 2.35	89.10 ± 2.25	89.39 ± 2.46	89.54 ± 1.88
✗ ✗ ✓ ✓	89.30 ± 2.80	91.23 ± 1.62	91.59 ± 1.34	91.30 ± 0.99	92.33 ± 1.25	92.50 ± 0.95	93.18 ± 0.60
✓ ✓ ✓ ✗	86.13 ± 2.59	89.72 ± 2.39	91.06 ± 1.35	90.95 ± 0.85	92.20 ± 1.70	92.12 ± 1.24	94.07 ± 0.97
✓ ✗ ✓ ✓	89.69 ± 0.79	91.80 ± 1.43	91.94 ± 0.76	91.77 ± 0.94	93.00 ± 0.87	92.94 ± 0.27	94.33 ± 0.63
✓ ✓ ✗ ✓	90.00 ± 1.29	91.53 ± 2.13	90.89 ± 2.02	91.19 ± 1.69	91.61 ± 1.78	91.12 ± 1.18	91.88 ± 0.96
✗ ✓ ✓ ✓	89.11 ± 2.06	91.60 ± 1.57	91.54 ± 0.86	91.69 ± 0.76	92.29 ± 1.19	92.62 ± 0.48	93.33 ± 0.91
✓ ✓ ✓ ✓	89.64 ± 2.02	91.40 ± 1.57	91.76 ± 0.83	91.97 ± 1.20	92.69 ± 1.80	93.28 ± 0.93	94.12 ± 1.14

Multi-Task Combinations

VICReg

-3.7 to -6.4

class rec CL VICReg	Accuracy (%)						
	1 (126)	2 (252)	3 (378)	4 (504)	5 (630)	6 (756)	all (7352)
✓ ✗ ✗ ✗	83.66 ± 1.70	85.95 ± 1.05	86.85 ± 0.72	87.97 ± 1.06	88.35 ± 0.78	88.14 ± 0.77	89.79 ± 1.24
✗ ✓ ✗ ✗	86.18 ± 1.17	88.22 ± 1.86	88.44 ± 1.08	88.75 ± 1.17	89.16 ± 0.76	89.72 ± 0.98	90.02 ± 1.02
✗ ✗ ✓ ✗	84.92 ± 2.47	89.70 ± 1.07	90.38 ± 0.59	89.77 ± 0.83	91.16 ± 1.74	91.56 ± 0.58	93.02 ± 0.85
✗ ✗ ✗ ✓	88.99 ± 0.93	89.15 ± 1.55	89.66 ± 1.62	89.58 ± 0.78	90.15 ± 1.23	90.19 ± 0.88	89.81 ± 1.32
✓ ✓ ✗ ✗	83.64 ± 1.90	87.85 ± 3.24	88.46 ± 1.73	88.27 ± 1.85	89.44 ± 1.89	88.94 ± 1.19	91.21 ± 2.02
✓ ✗ ✓ ✗	85.95 ± 2.87	89.93 ± 1.36	90.06 ± 1.36	90.36 ± 0.59	91.73 ± 0.79	91.58 ± 1.02	93.21 ± 0.99
✓ ✗ ✗ ✓	90.11 ± 1.36	91.03 ± 2.64	91.16 ± 1.84	90.46 ± 2.36	91.46 ± 1.85	91.17 ± 1.74	92.30 ± 1.29
✗ ✓ ✓ ✗	85.21 ± 3.26	89.74 ± 2.17	90.52 ± 1.77	90.20 ± 1.21	91.70 ± 2.08	92.00 ± 1.09	93.53 ± 1.02
✗ ✓ ✗ ✓	85.59 ± 2.17	87.82 ± 3.58	87.86 ± 3.05	88.86 ± 2.35	89.10 ± 2.25	89.39 ± 2.46	89.54 ± 1.88
✗ ✗ ✓ ✓	89.30 ± 2.80	91.23 ± 1.62	91.59 ± 1.34	91.30 ± 0.99	92.33 ± 1.25	92.50 ± 0.95	93.18 ± 0.60
✓ ✓ ✓ ✗	86.13 ± 2.59	89.72 ± 2.39	91.06 ± 1.35	90.95 ± 0.85	92.20 ± 1.70	92.12 ± 1.24	94.07 ± 0.97
✓ ✗ ✓ ✓	89.69 ± 0.79	91.80 ± 1.43	91.94 ± 0.76	91.77 ± 0.94	93.00 ± 0.87	92.94 ± 0.27	94.33 ± 0.63
✓ ✓ ✗ ✓	90.00 ± 1.29	91.53 ± 2.13	90.89 ± 2.02	91.19 ± 1.69	91.61 ± 1.78	91.12 ± 1.18	91.88 ± 0.96
✗ ✓ ✓ ✓	89.11 ± 2.06	91.60 ± 1.57	91.54 ± 0.86	91.69 ± 0.76	92.29 ± 1.19	92.62 ± 0.48	93.33 ± 0.91
✓ ✓ ✓ ✓	89.64 ± 2.02	91.40 ± 1.57	91.76 ± 0.83	91.97 ± 1.20	92.69 ± 1.80	93.28 ± 0.93	94.12 ± 1.14

Multi-Task Combinations

VICReg

class rec CL VICReg	Accuracy (%)						
	1 (126)	2 (252)	3 (378)	4 (504)	5 (630)	6 (756)	all (7352)
✓ ✗ ✗ ✗	83.66 ± 1.70	85.95 ± 1.05	86.85 ± 0.72	87.97 ± 1.06	88.35 ± 0.78	88.14 ± 0.77	89.79 ± 1.24
✗ ✓ ✗ ✗	86.18 ± 1.17	88.22 ± 1.86	88.44 ± 1.08	88.75 ± 1.17	89.16 ± 0.76	89.72 ± 0.98	90.02 ± 1.02
✗ ✗ ✓ ✗	84.92 ± 2.47	89.70 ± 1.07	90.38 ± 0.59	89.77 ± 0.83	91.16 ± 1.74	91.56 ± 0.58	93.02 ± 0.85
✗ ✗ ✗ ✓	88.99 ± 0.93	89.15 ± 1.55	89.66 ± 1.62	89.58 ± 0.78	90.15 ± 1.23	90.19 ± 0.88	89.81 ± 1.32
✓ ✓ ✗ ✗	83.64 ± 1.90	87.85 ± 3.24	88.46 ± 1.73	88.27 ± 1.85	89.44 ± 1.89	88.94 ± 1.19	91.21 ± 2.02
✓ ✗ ✓ ✗	85.95 ± 2.87	89.93 ± 1.36	90.06 ± 1.36	90.36 ± 0.59	91.73 ± 0.79	91.58 ± 1.02	93.21 ± 0.99
✓ ✗ ✗ ✓	90.11 ± 1.36	91.03 ± 2.64	91.16 ± 1.84	90.46 ± 2.36	91.46 ± 1.85	91.17 ± 1.74	92.30 ± 1.29
✗ ✓ ✓ ✗	85.21 ± 3.26	89.74 ± 2.17	90.52 ± 1.77	90.20 ± 1.21	91.70 ± 2.08	92.00 ± 1.09	93.53 ± 1.02
✗ ✓ ✗ ✓	85.59 ± 2.17	87.82 ± 3.58	87.86 ± 3.05	88.86 ± 2.35	89.10 ± 2.25	89.39 ± 2.46	89.54 ± 1.88
✗ ✗ ✓ ✓	89.30 ± 2.80	91.23 ± 1.62	91.59 ± 1.34	91.30 ± 0.99	92.33 ± 1.25	92.50 ± 0.95	93.18 ± 0.60
✓ ✓ ✓ ✗	86.13 ± 2.59	89.72 ± 2.39	91.06 ± 1.35	90.95 ± 0.85	92.20 ± 1.70	92.12 ± 1.24	94.07 ± 0.97
✓ ✗ ✓ ✓	89.69 ± 0.79	91.80 ± 1.43	91.94 ± 0.76	91.77 ± 0.94	93.00 ± 0.87	92.94 ± 0.27	94.33 ± 0.63
✓ ✓ ✗ ✓	90.00 ± 1.29	91.53 ± 2.13	90.89 ± 2.02	91.19 ± 1.69	91.61 ± 1.78	91.12 ± 1.18	91.88 ± 0.96
✗ ✓ ✓ ✓	89.11 ± 2.06	91.60 ± 1.57	91.54 ± 0.86	91.69 ± 0.76	92.29 ± 1.19	92.62 ± 0.48	93.33 ± 0.91
✓ ✓ ✓ ✓	89.64 ± 2.02	91.40 ± 1.57	91.76 ± 0.83	91.97 ± 1.20	92.69 ± 1.80	93.28 ± 0.93	94.12 ± 1.14

Multi-Task Combinations

CL (SimCLR)

class rec CL VICReg	Accuracy (%)						
	1 (126)	2 (252)	3 (378)	4 (504)	5 (630)	6 (756)	all (7352)
✓ ✗ ✗ ✗	83.66 ± 1.70	85.95 ± 1.05	86.85 ± 0.72	87.97 ± 1.06	88.35 ± 0.78	88.14 ± 0.77	89.79 ± 1.24
✗ ✓ ✗ ✗	86.18 ± 1.17	88.22 ± 1.86	88.44 ± 1.08	88.75 ± 1.17	89.16 ± 0.76	89.72 ± 0.98	90.02 ± 1.02
✗ ✗ ✓ ✗	84.92 ± 2.47	89.70 ± 1.07	90.38 ± 0.59	89.77 ± 0.83	91.16 ± 1.74	91.56 ± 0.58	93.02 ± 0.85
✗ ✗ ✗ ✓	88.99 ± 0.93	89.15 ± 1.55	89.66 ± 1.62	89.58 ± 0.78	90.15 ± 1.23	90.19 ± 0.88	89.81 ± 1.32
✓ ✓ ✗ ✗	83.64 ± 1.90	87.85 ± 3.24	88.46 ± 1.73	88.27 ± 1.85	89.44 ± 1.89	88.94 ± 1.19	91.21 ± 2.02
✓ ✗ ✓ ✗	85.95 ± 2.87	89.93 ± 1.36	90.06 ± 1.36	90.36 ± 0.59	91.73 ± 0.79	91.58 ± 1.02	93.21 ± 0.99
✓ ✗ ✗ ✓	90.11 ± 1.36	91.03 ± 2.64	91.16 ± 1.84	90.46 ± 2.36	91.46 ± 1.85	91.17 ± 1.74	92.30 ± 1.29
✗ ✓ ✓ ✗	85.21 ± 3.26	89.74 ± 2.17	90.52 ± 1.77	90.20 ± 1.21	91.70 ± 2.08	92.00 ± 1.09	93.53 ± 1.02
✗ ✓ ✗ ✓	85.59 ± 2.17	87.82 ± 3.58	87.86 ± 3.05	88.86 ± 2.35	89.10 ± 2.25	89.39 ± 2.46	89.54 ± 1.88
✗ ✗ ✓ ✓	89.30 ± 2.80	91.23 ± 1.62	91.59 ± 1.34	91.30 ± 0.99	92.33 ± 1.25	92.50 ± 0.95	93.18 ± 0.60
✓ ✓ ✓ ✗	86.13 ± 2.59	89.72 ± 2.39	91.06 ± 1.35	90.95 ± 0.85	92.20 ± 1.70	92.12 ± 1.24	94.07 ± 0.97
✓ ✗ ✓ ✓	89.69 ± 0.79	91.80 ± 1.43	91.94 ± 0.76	91.77 ± 0.94	93.00 ± 0.87	92.94 ± 0.27	94.33 ± 0.63
✓ ✓ ✗ ✓	90.00 ± 1.29	91.53 ± 2.13	90.89 ± 2.02	91.19 ± 1.69	91.61 ± 1.78	91.12 ± 1.18	91.88 ± 0.96
✗ ✓ ✓ ✓	89.11 ± 2.06	91.60 ± 1.57	91.54 ± 0.86	91.69 ± 0.76	92.29 ± 1.19	92.62 ± 0.48	93.33 ± 0.91
✓ ✓ ✓ ✓	89.64 ± 2.02	91.40 ± 1.57	91.76 ± 0.83	91.97 ± 1.20	92.69 ± 1.80	93.28 ± 0.93	94.12 ± 1.14

Multi-Task Combinations

Reconstruction

class rec CL VICReg	Accuracy (%)						
	1 (126)	2 (252)	3 (378)	4 (504)	5 (630)	6 (756)	all (7352)
✓ ✗ ✗ ✗	83.66 ± 1.70	85.95 ± 1.05	86.85 ± 0.72	87.97 ± 1.06	88.35 ± 0.78	88.14 ± 0.77	89.79 ± 1.24
✗ ✓ ✗ ✗	86.18 ± 1.17	88.22 ± 1.86	88.44 ± 1.08	88.75 ± 1.17	89.16 ± 0.76	89.72 ± 0.98	90.02 ± 1.02
✗ ✗ ✓ ✗	84.92 ± 2.47	89.70 ± 1.07	90.38 ± 0.59	89.77 ± 0.83	91.16 ± 1.74	91.56 ± 0.58	93.02 ± 0.85
✗ ✗ ✗ ✓	88.99 ± 0.93	89.15 ± 1.55	89.66 ± 1.62	89.58 ± 0.78	90.15 ± 1.23	90.19 ± 0.88	89.81 ± 1.32
✓ ✓ ✗ ✗	83.64 ± 1.90	87.85 ± 3.24	88.46 ± 1.73	88.27 ± 1.85	89.44 ± 1.89	88.94 ± 1.19	91.21 ± 2.02
✓ ✗ ✓ ✗	85.95 ± 2.87	89.93 ± 1.36	90.06 ± 1.36	90.36 ± 0.59	91.73 ± 0.79	91.58 ± 1.02	93.21 ± 0.99
✓ ✗ ✗ ✓	90.11 ± 1.36	91.03 ± 2.64	91.16 ± 1.84	90.46 ± 2.36	91.46 ± 1.85	91.17 ± 1.74	92.30 ± 1.29
✗ ✓ ✓ ✗	85.21 ± 3.26	89.74 ± 2.17	90.52 ± 1.77	90.20 ± 1.21	91.70 ± 2.08	92.00 ± 1.09	93.53 ± 1.02
✗ ✓ ✗ ✓	85.59 ± 2.17	87.82 ± 3.58	87.86 ± 3.05	88.86 ± 2.35	89.10 ± 2.25	89.39 ± 2.46	89.54 ± 1.88
✗ ✗ ✓ ✓	89.30 ± 2.80	91.23 ± 1.62	91.59 ± 1.34	91.30 ± 0.99	92.33 ± 1.25	92.50 ± 0.95	93.18 ± 0.60
✓ ✓ ✓ ✗	86.13 ± 2.59	89.72 ± 2.39	91.06 ± 1.35	90.95 ± 0.85	92.20 ± 1.70	92.12 ± 1.24	94.07 ± 0.97
✓ ✗ ✓ ✓	89.69 ± 0.79	91.80 ± 1.43	91.94 ± 0.76	91.77 ± 0.94	93.00 ± 0.87	92.94 ± 0.27	94.33 ± 0.63
✓ ✓ ✗ ✓	90.00 ± 1.29	91.53 ± 2.13	90.89 ± 2.02	91.19 ± 1.69	91.61 ± 1.78	91.12 ± 1.18	91.88 ± 0.96
✗ ✓ ✓ ✓	89.11 ± 2.06	91.60 ± 1.57	91.54 ± 0.86	91.69 ± 0.76	92.29 ± 1.19	92.62 ± 0.48	93.33 ± 0.91
✓ ✓ ✓ ✓	89.64 ± 2.02	91.40 ± 1.57	91.76 ± 0.83	91.97 ± 1.20	92.69 ± 1.80	93.28 ± 0.93	94.12 ± 1.14

Multi-Task Combinations

Reconstruction

class rec CL VICReg	Accuracy (%)						
	1 (126)	2 (252)	3 (378)	4 (504)	5 (630)	6 (756)	all (7352)
✓ ✗ ✗ ✗	83.66 ± 1.70	85.95 ± 1.05	86.85 ± 0.72	87.97 ± 1.06	88.35 ± 0.78	88.14 ± 0.77	89.79 ± 1.24
✗ ✓ ✗ ✗	86.18 ± 1.17	88.22 ± 1.86	88.44 ± 1.08	88.75 ± 1.17	89.16 ± 0.76	89.72 ± 0.98	90.02 ± 1.02
✗ ✗ ✓ ✗	84.92 ± 2.47	89.70 ± 1.07	90.38 ± 0.59	89.77 ± 0.83	91.16 ± 1.74	91.56 ± 0.58	93.02 ± 0.85
✗ ✗ ✗ ✓	88.99 ± 0.93	89.15 ± 1.55	89.66 ± 1.62	89.58 ± 0.78	90.15 ± 1.23	90.19 ± 0.88	89.81 ± 1.32
✓ ✓ ✗ ✗	83.64 ± 1.90	87.85 ± 3.24	88.46 ± 1.73	88.27 ± 1.85	89.44 ± 1.89	88.94 ± 1.19	91.21 ± 2.02
✓ ✗ ✓ ✗	85.95 ± 2.87	89.93 ± 1.36	90.06 ± 1.36	90.36 ± 0.59	91.73 ± 0.79	91.58 ± 1.02	93.21 ± 0.99
✓ ✗ ✗ ✓	90.11 ± 1.36	91.03 ± 2.64	91.16 ± 1.84	90.46 ± 2.36	91.46 ± 1.85	91.17 ± 1.74	92.30 ± 1.29
✗ ✓ ✓ ✗	85.21 ± 3.26	89.74 ± 2.17	90.52 ± 1.77	90.20 ± 1.21	91.70 ± 2.08	92.00 ± 1.09	93.53 ± 1.02
✗ ✓ ✗ ✓	85.59 ± 2.17	87.82 ± 3.58	87.86 ± 3.05	88.86 ± 2.35	89.10 ± 2.25	89.39 ± 2.46	89.54 ± 1.88
✗ ✗ ✓ ✓	89.30 ± 2.80	91.23 ± 1.62	91.59 ± 1.34	91.30 ± 0.99	92.33 ± 1.25	92.50 ± 0.95	93.18 ± 0.60
✓ ✓ ✓ ✗	86.13 ± 2.59	89.72 ± 2.39	91.06 ± 1.35	90.95 ± 0.85	92.20 ± 1.70	92.12 ± 1.24	94.07 ± 0.97
✓ ✗ ✓ ✓	89.69 ± 0.79	91.80 ± 1.43	91.94 ± 0.76	91.77 ± 0.94	93.00 ± 0.87	92.94 ± 0.27	94.33 ± 0.63
✓ ✓ ✗ ✓	90.00 ± 1.29	91.53 ± 2.13	90.89 ± 2.02	91.19 ± 1.69	91.61 ± 1.78	91.12 ± 1.18	91.88 ± 0.96
✗ ✓ ✓ ✓	89.11 ± 2.06	91.60 ± 1.57	91.54 ± 0.86	91.69 ± 0.76	92.29 ± 1.19	92.62 ± 0.48	93.33 ± 0.91
✓ ✓ ✓ ✓	89.64 ± 2.02	91.40 ± 1.57	91.76 ± 0.83	91.97 ± 1.20	92.69 ± 1.80	93.28 ± 0.93	94.12 ± 1.14

Multi-Task Combinations

Reconstruction

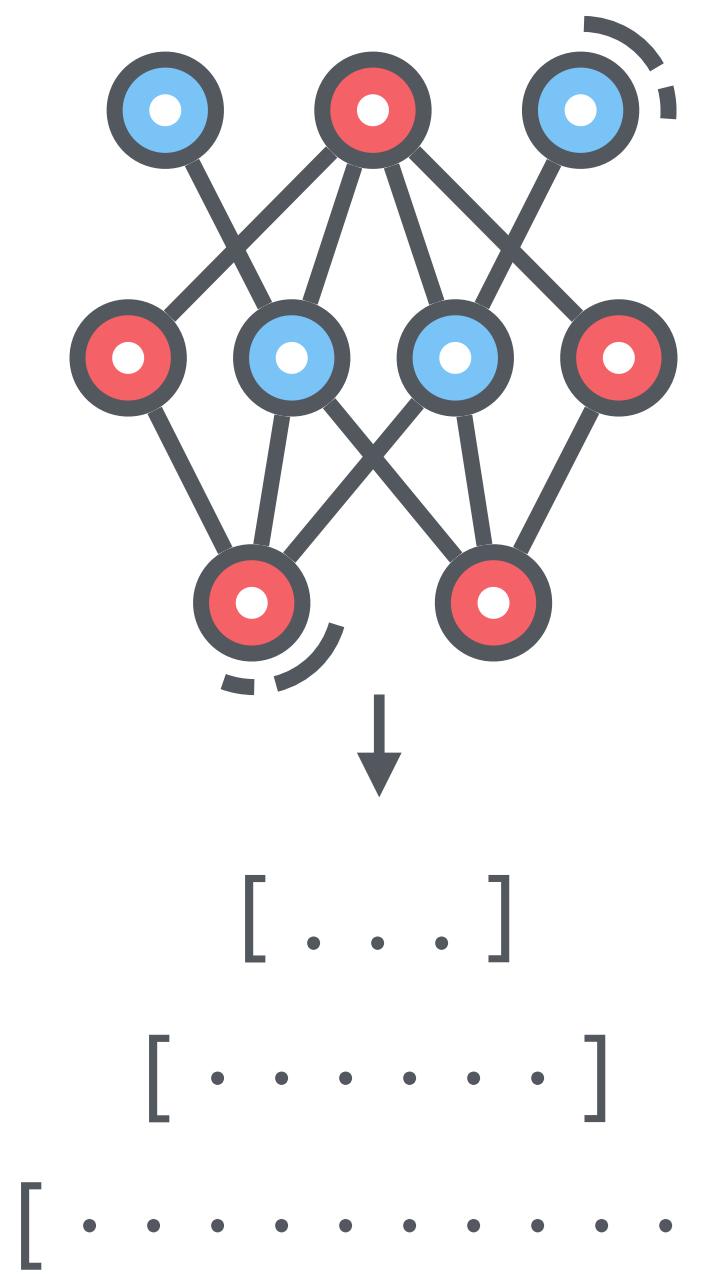
CA + CL + VICReg $\stackrel{?}{=}$ R

class rec CL VICReg	Accuracy (%)						
	1 (126)	2 (252)	3 (378)	4 (504)	5 (630)	6 (756)	all (7352)
✓ ✗ ✗ ✗	83.66 \pm 1.70	85.95 \pm 1.05	86.85 \pm 0.72	87.97 \pm 1.06	88.35 \pm 0.78	88.14 \pm 0.77	89.79 \pm 1.24
✗ ✓ ✗ ✗	86.18 \pm 1.17	88.22 \pm 1.86	88.44 \pm 1.08	88.75 \pm 1.17	89.16 \pm 0.76	89.72 \pm 0.98	90.02 \pm 1.02
✗ ✗ ✓ ✗	84.92 \pm 2.47	89.70 \pm 1.07	90.38 \pm 0.59	89.77 \pm 0.83	91.16 \pm 1.74	91.56 \pm 0.58	93.02 \pm 0.85
✗ ✗ ✗ ✓	88.99 \pm 0.93	89.15 \pm 1.55	89.66 \pm 1.62	89.58 \pm 0.78	90.15 \pm 1.23	90.19 \pm 0.88	89.81 \pm 1.32
✓ ✓ ✗ ✗	83.64 \pm 1.90	87.85 \pm 3.24	88.46 \pm 1.73	88.27 \pm 1.85	89.44 \pm 1.89	88.94 \pm 1.19	91.21 \pm 2.02
✓ ✗ ✓ ✗	85.95 \pm 2.87	89.93 \pm 1.36	90.06 \pm 1.36	90.36 \pm 0.59	91.73 \pm 0.79	91.58 \pm 1.02	93.21 \pm 0.99
✓ ✗ ✗ ✓	90.11 \pm 1.36	91.03 \pm 2.64	91.16 \pm 1.84	90.46 \pm 2.36	91.46 \pm 1.85	91.17 \pm 1.74	92.30 \pm 1.29
✗ ✓ ✓ ✗	85.21 \pm 3.26	89.74 \pm 2.17	90.52 \pm 1.77	90.20 \pm 1.21	91.70 \pm 2.08	92.00 \pm 1.09	93.53 \pm 1.02
✗ ✓ ✗ ✓	85.59 \pm 2.17	87.82 \pm 3.58	87.86 \pm 3.05	88.86 \pm 2.35	89.10 \pm 2.25	89.39 \pm 2.46	89.54 \pm 1.88
✗ ✗ ✓ ✓	89.30 \pm 2.80	91.23 \pm 1.62	91.59 \pm 1.34	91.30 \pm 0.99	92.33 \pm 1.25	92.50 \pm 0.95	93.18 \pm 0.60
✓ ✓ ✓ ✗	86.13 \pm 2.59	89.72 \pm 2.39	91.06 \pm 1.35	90.95 \pm 0.85	92.20 \pm 1.70	92.12 \pm 1.24	94.07 \pm 0.97
✓ ✗ ✓ ✓	89.69 \pm 0.79	91.80 \pm 1.43	91.94 \pm 0.76	91.77 \pm 0.94	93.00 \pm 0.87	92.94 \pm 0.27	94.33 \pm 0.63
✓ ✓ ✗ ✓	90.00 \pm 1.29	91.53 \pm 2.13	90.89 \pm 2.02	91.19 \pm 1.69	91.61 \pm 1.78	91.12 \pm 1.18	91.88 \pm 0.96
✗ ✓ ✓ ✓	89.11 \pm 2.06	91.60 \pm 1.57	91.54 \pm 0.86	91.69 \pm 0.76	92.29 \pm 1.19	92.62 \pm 0.48	93.33 \pm 0.91
✓ ✓ ✓ ✓	89.64 \pm 2.02	91.40 \pm 1.57	91.76 \pm 0.83	91.97 \pm 1.20	92.69 \pm 1.80	93.28 \pm 0.93	94.12 \pm 1.14

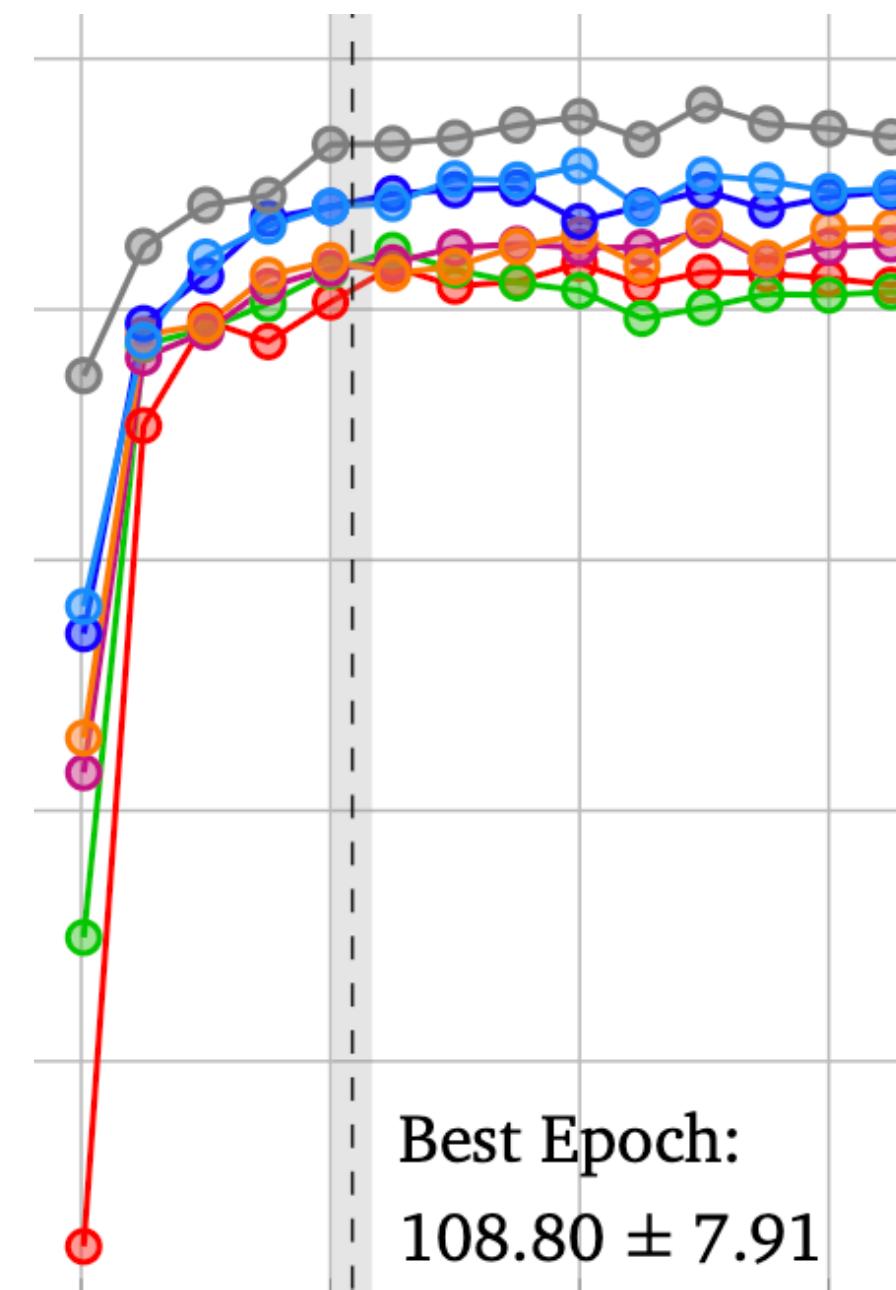
Multi-Task Combinations

class rec CL VICReg	Accuracy (%)						
	1 (126)	2 (252)	3 (378)	4 (504)	5 (630)	6 (756)	all (7352)
✓ ✗ ✗ ✗	83.66 ± 1.70	85.95 ± 1.05	86.85 ± 0.72	87.97 ± 1.06	88.35 ± 0.78	88.14 ± 0.77	89.79 ± 1.24
✗ ✓ ✗ ✗	86.18 ± 1.17	88.22 ± 1.86	88.44 ± 1.08	88.75 ± 1.17	89.16 ± 0.76	89.72 ± 0.98	90.02 ± 1.02
✗ ✗ ✓ ✗	84.92 ± 2.47	89.70 ± 1.07	90.38 ± 0.59	89.77 ± 0.83	91.16 ± 1.74	91.56 ± 0.58	93.02 ± 0.85
✗ ✗ ✗ ✓	88.99 ± 0.93	89.15 ± 1.55	89.66 ± 1.62	89.58 ± 0.78	90.15 ± 1.23	90.19 ± 0.88	89.81 ± 1.32
✓ ✓ ✗ ✗	83.64 ± 1.90	87.85 ± 3.24	88.46 ± 1.73	88.27 ± 1.85	89.44 ± 1.89	88.94 ± 1.19	91.21 ± 2.02
✓ ✗ ✓ ✗	85.95 ± 2.87	89.93 ± 1.36	90.06 ± 1.36	90.36 ± 0.59	91.73 ± 0.79	91.58 ± 1.02	93.21 ± 0.99
✓ ✗ ✗ ✓	90.11 ± 1.36	91.03 ± 2.64	91.16 ± 1.84	90.46 ± 2.36	91.46 ± 1.85	91.17 ± 1.74	92.30 ± 1.29
✗ ✓ ✓ ✗	85.21 ± 3.26	89.74 ± 2.17	90.52 ± 1.77	90.20 ± 1.21	91.70 ± 2.08	92.00 ± 1.09	93.53 ± 1.02
✗ ✓ ✗ ✓	85.59 ± 2.17	87.82 ± 3.58	87.86 ± 3.05	88.86 ± 2.35	89.10 ± 2.25	89.39 ± 2.46	89.54 ± 1.88
✗ ✗ ✓ ✓	89.30 ± 2.80	91.23 ± 1.62	91.59 ± 1.34	91.30 ± 0.99	92.33 ± 1.25	92.50 ± 0.95	93.18 ± 0.60
✓ ✓ ✓ ✗	86.13 ± 2.59	89.72 ± 2.39	91.06 ± 1.35	90.95 ± 0.85	92.20 ± 1.70	92.12 ± 1.24	94.07 ± 0.97
✓ ✗ ✓ ✓	89.69 ± 0.79	91.80 ± 1.43	91.94 ± 0.76	91.77 ± 0.94	93.00 ± 0.87	92.94 ± 0.27	94.33 ± 0.63
✓ ✓ ✗ ✓	90.00 ± 1.29	91.53 ± 2.13	90.89 ± 2.02	91.19 ± 1.69	91.61 ± 1.78	91.12 ± 1.18	91.88 ± 0.96
✗ ✓ ✓ ✓	89.11 ± 2.06	91.60 ± 1.57	91.54 ± 0.86	91.69 ± 0.76	92.29 ± 1.19	92.62 ± 0.48	93.33 ± 0.91
✓ ✓ ✓ ✓	89.64 ± 2.02	91.40 ± 1.57	91.76 ± 0.83	91.97 ± 1.20	92.69 ± 1.80	93.28 ± 0.93	94.12 ± 1.14

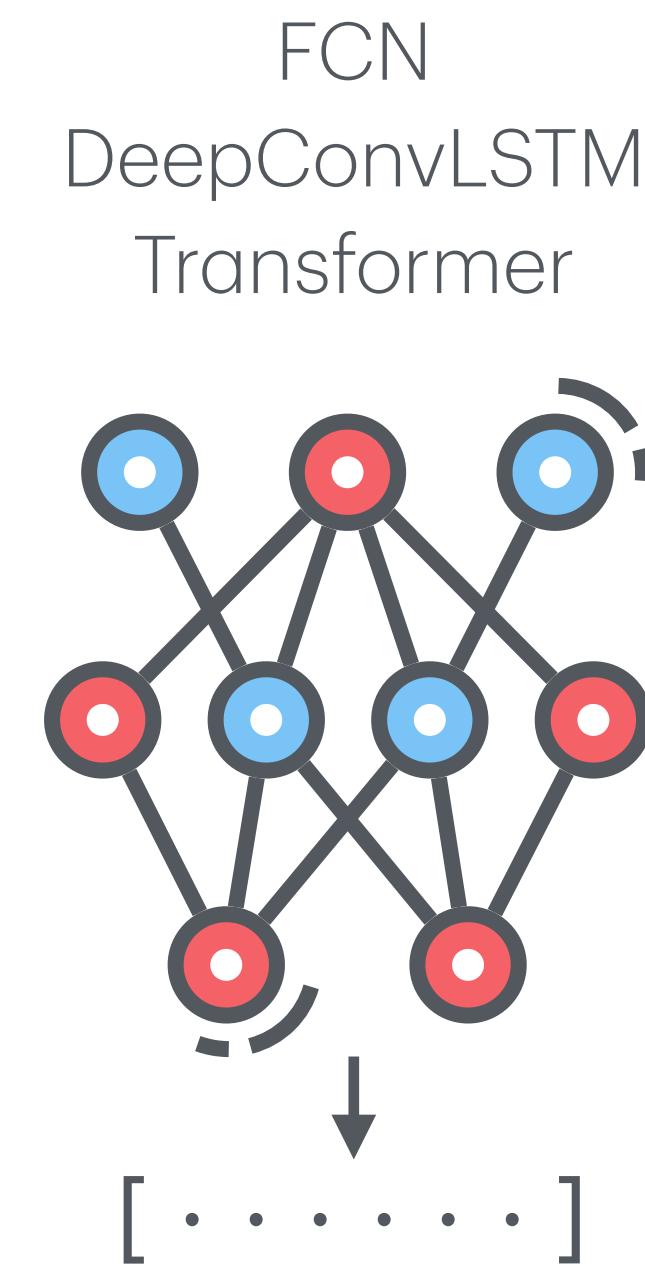
Other Multi-Task SSL Experiments



Embedding size

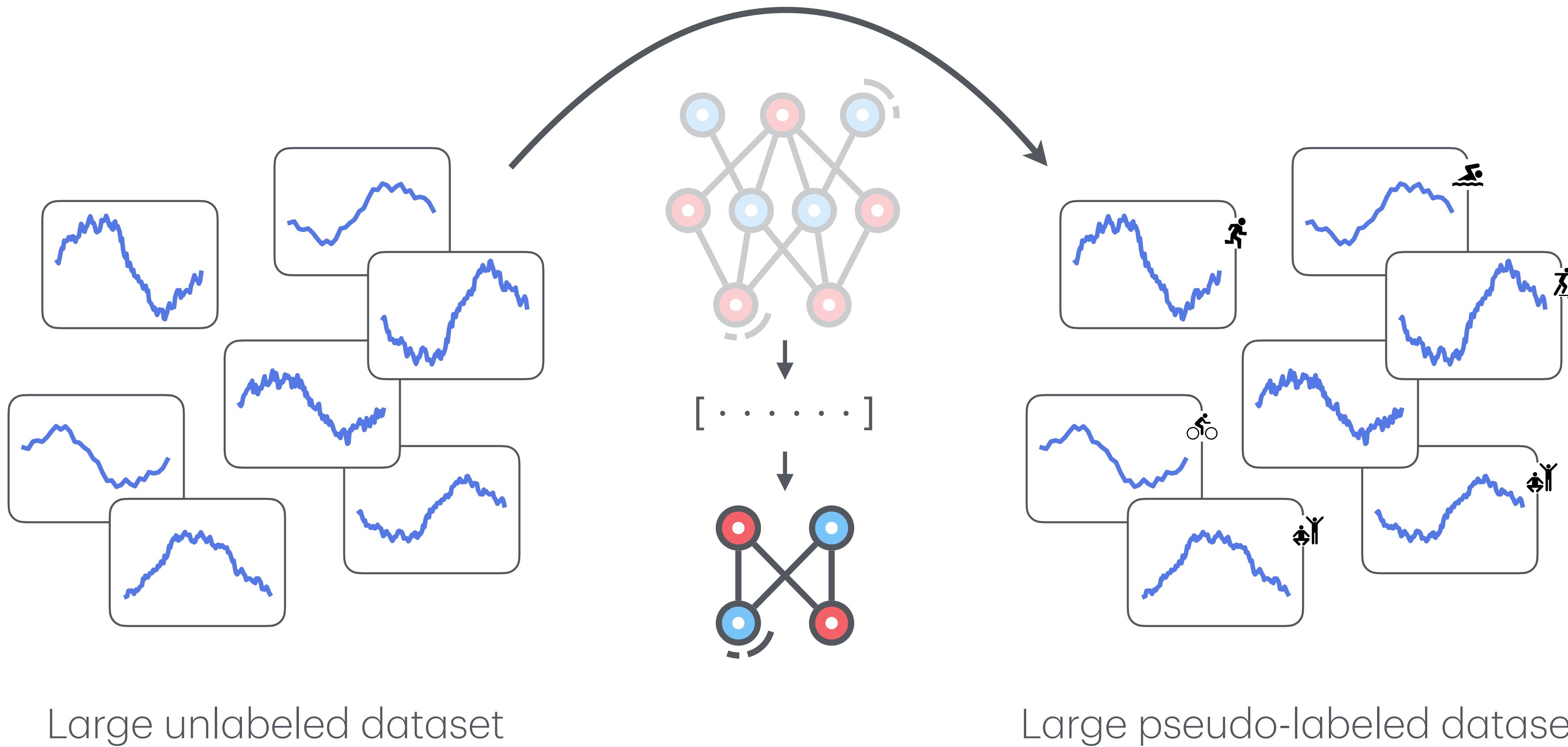


When to stop pretraining?



Encoder architecture

Further Improvements

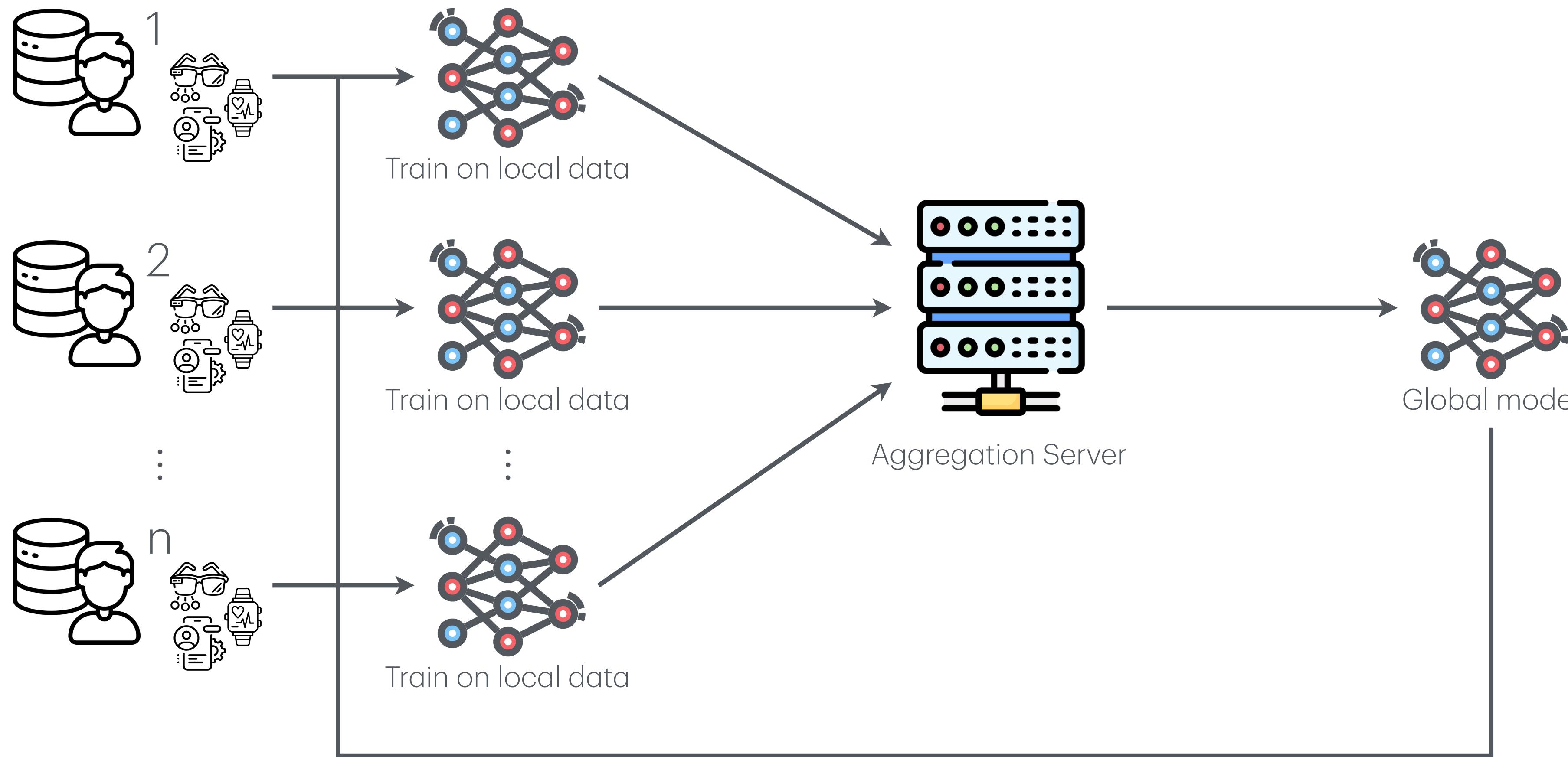


Preserving Privacy & Security

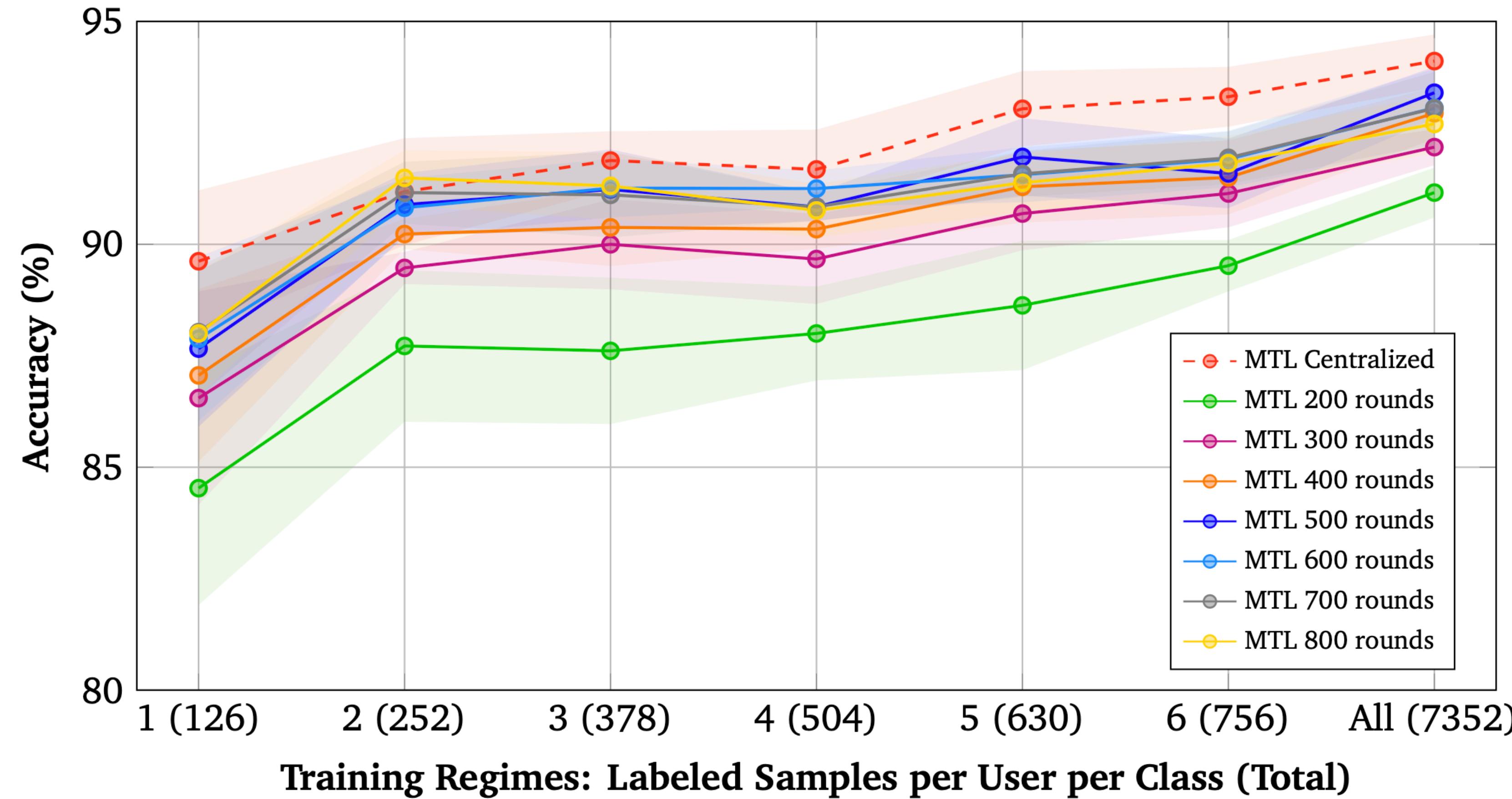
Preserving Privacy & Security



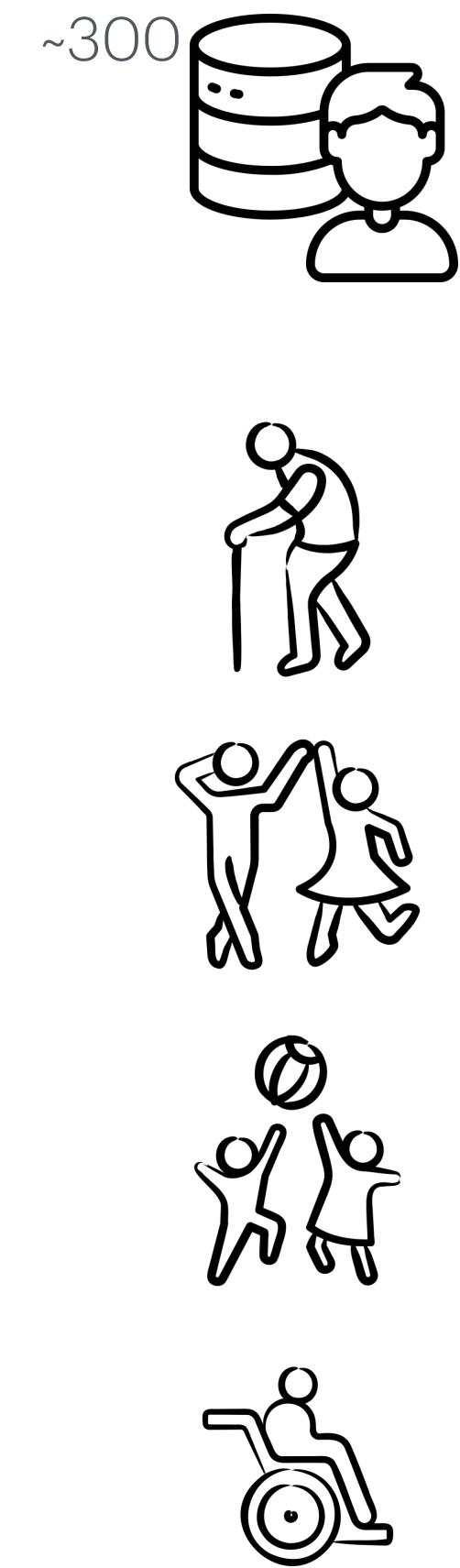
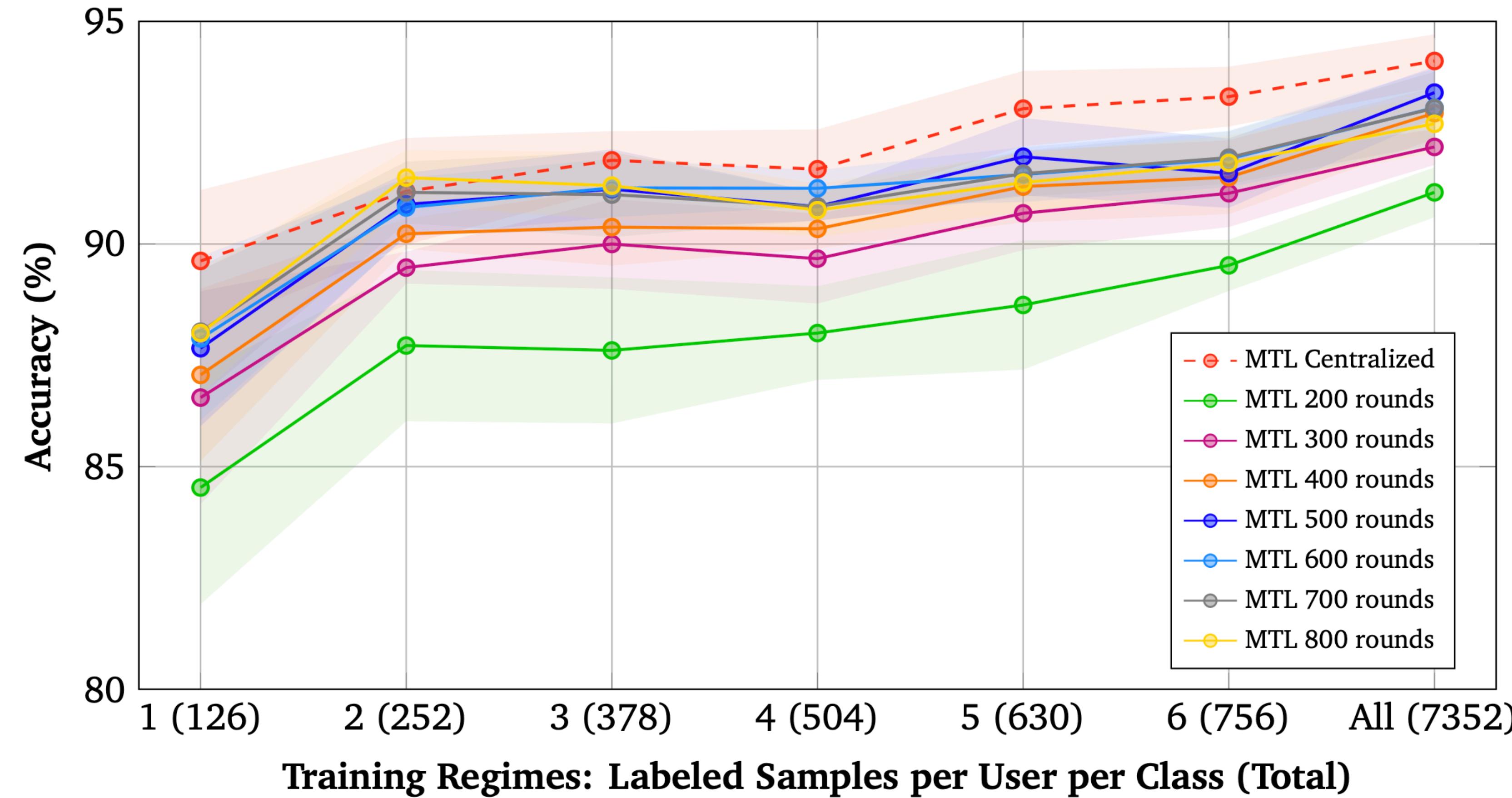
Federated Learning



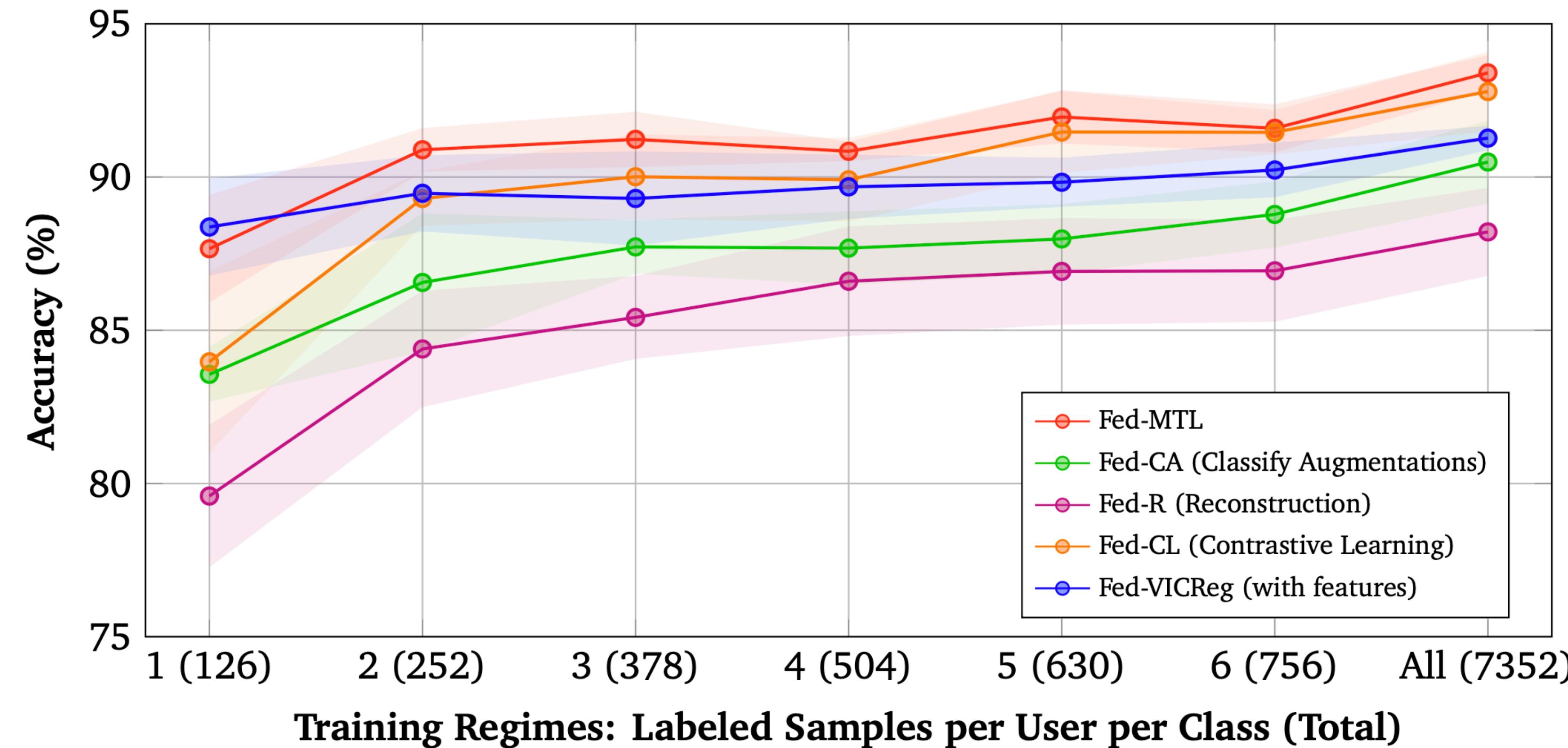
Federated Learning



Federated Learning



Federated Learning



Generalization to Other Domains

Objectives



Human Activity Recognition

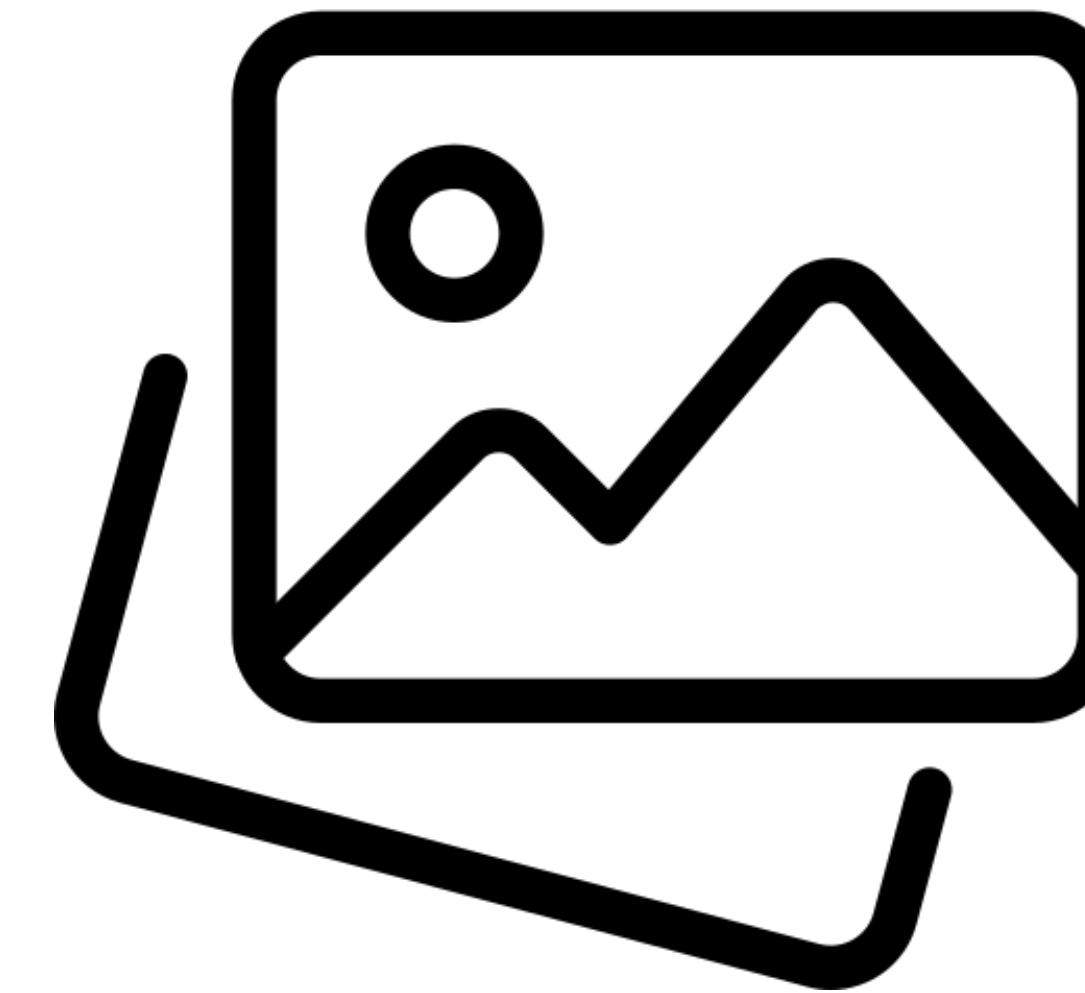
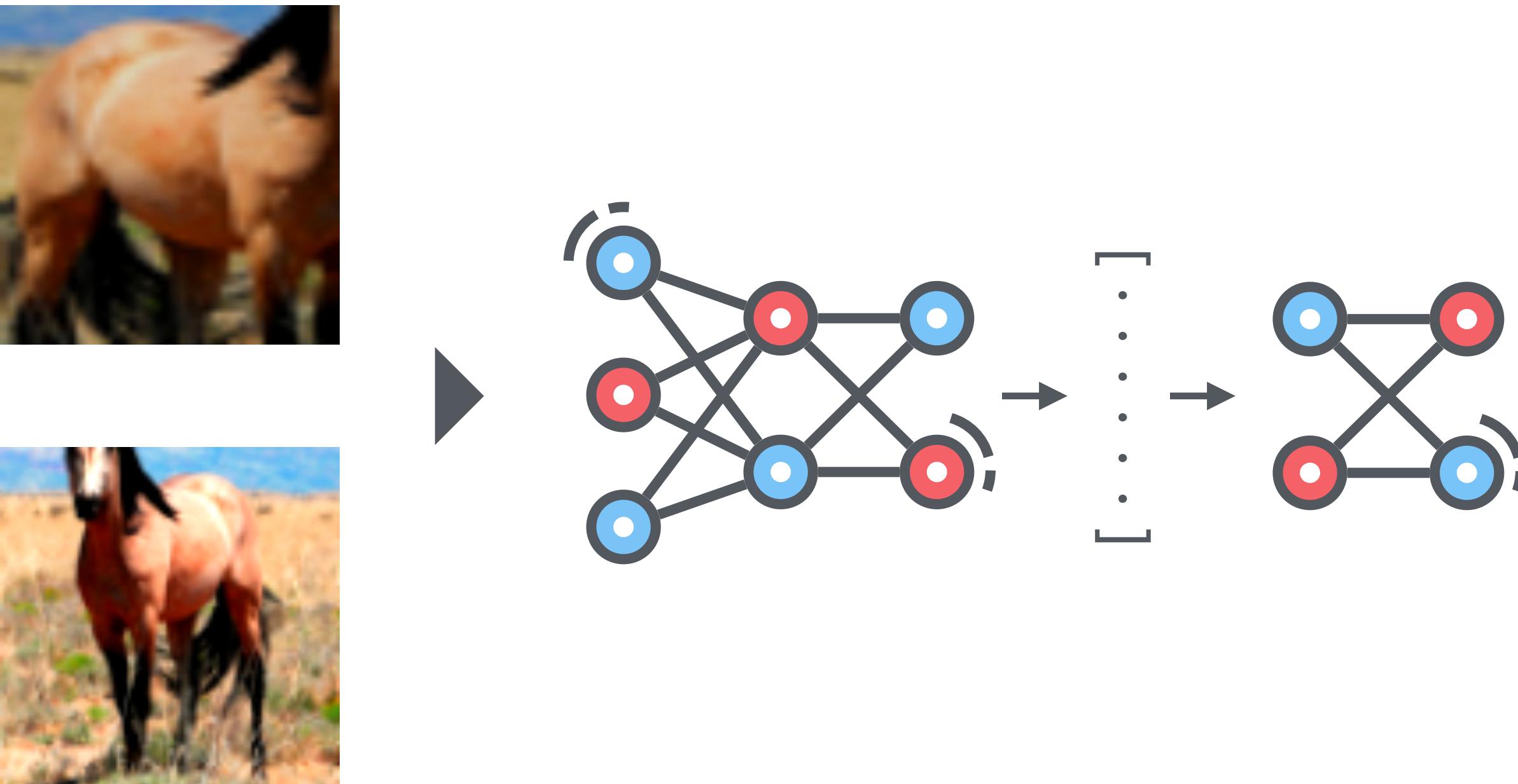


Image Recognition

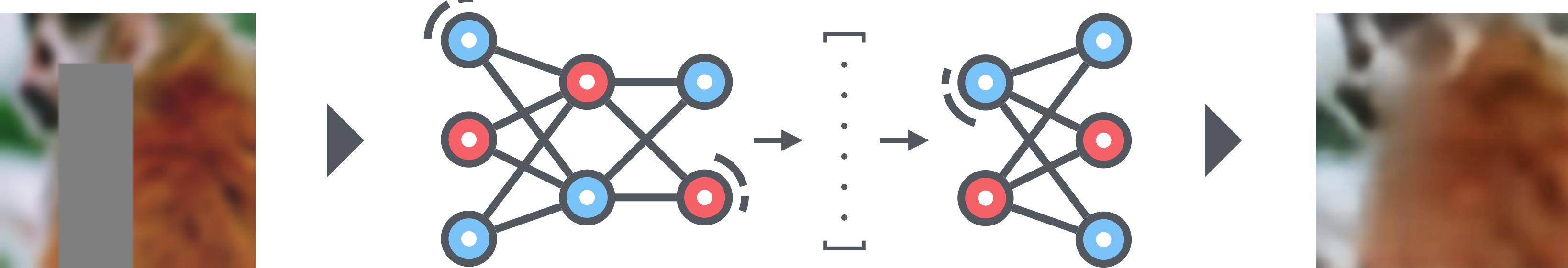
Tasks

- Contrastive Learning (SimCLR)



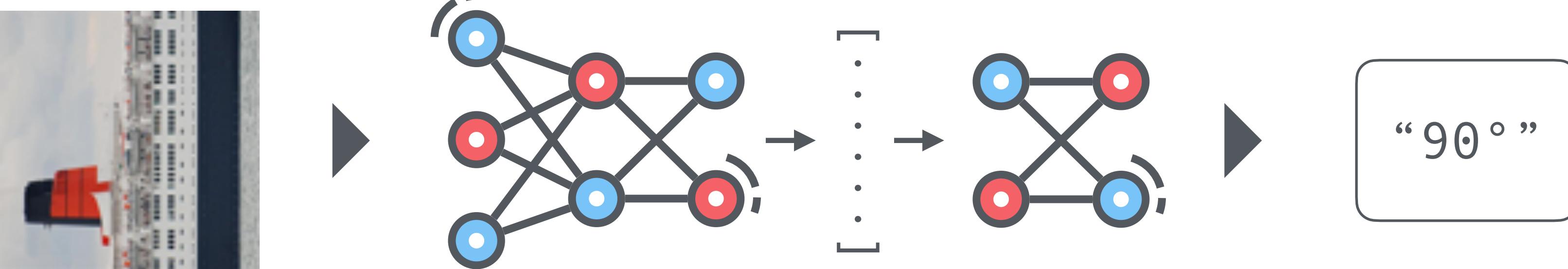
Tasks

- Masked Reconstruction

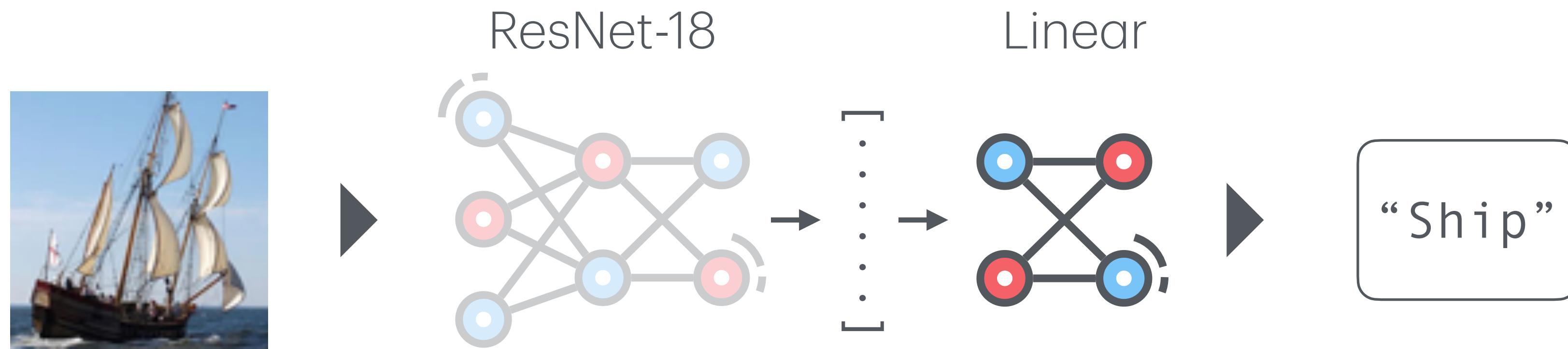


Tasks

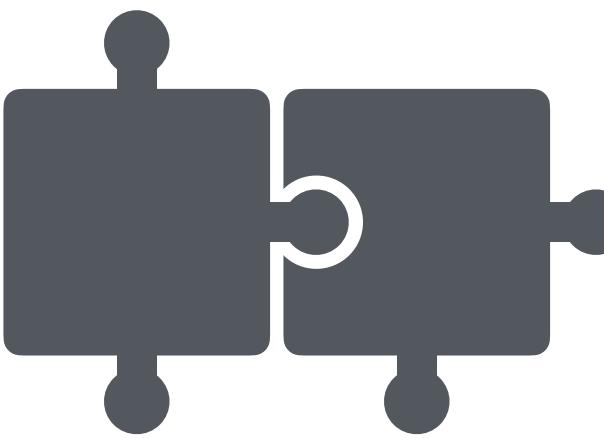
- Rotation Prediction



Downstream Training



Objective



Complementarity

Results

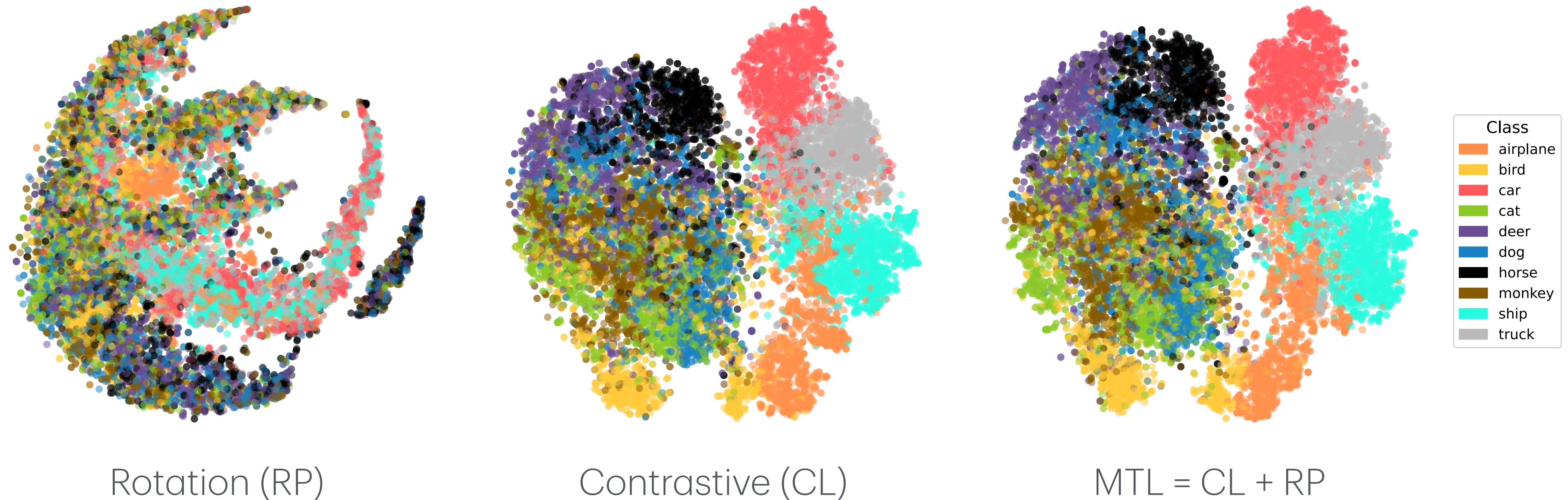
Method	100 (80 + 20)	250 (200 + 50)	500 (400 + 100)
Supervised (no pretrain)	46.92	58.48	66.59
Masked Autoencoder (MAE)	42.60	46.96	49.79
Rotation Prediction (RP)	52.50	56.19	59.41
Contrastive Learning (CL)	73.65	76.65	78.51
MTL: CL + MAE	74.01	76.75	77.91
MTL: CL + RP	74.59	78.22	80.17

Results

+0.94 to +1.66

Method	100 (80 + 20)	250 (200 + 50)	500 (400 + 100)
Supervised (no pretrain)	46.92	58.48	66.59
Masked Autoencoder (MAE)	42.60	46.96	49.79
Rotation Prediction (RP)	52.50	56.19	59.41
Contrastive Learning (CL)	73.65	76.65	78.51
MTL: CL + MAE	74.01	76.75	77.91
MTL: CL + RP	74.59	78.22	80.17

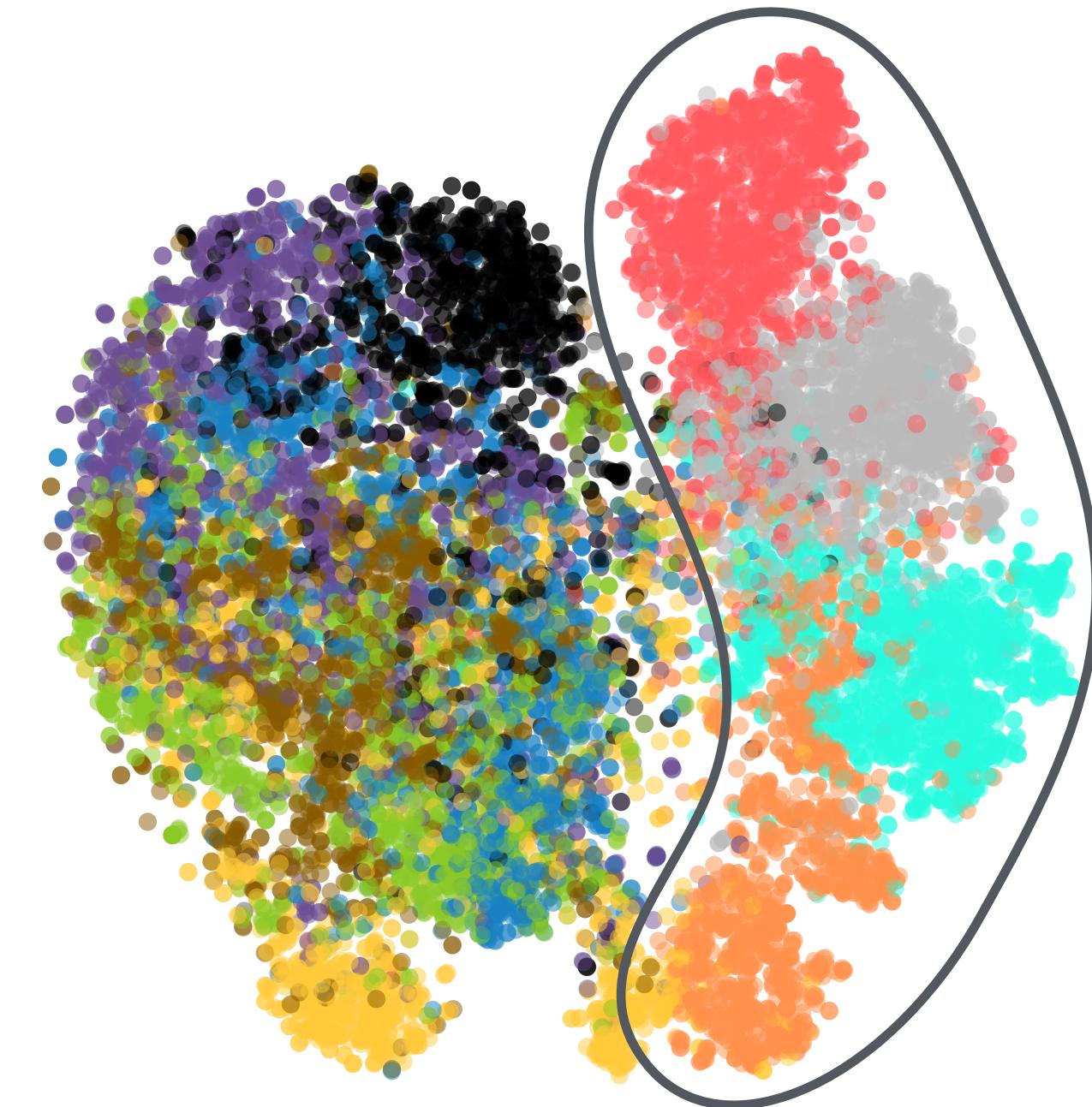
Visualizing Representations (t-SNE)



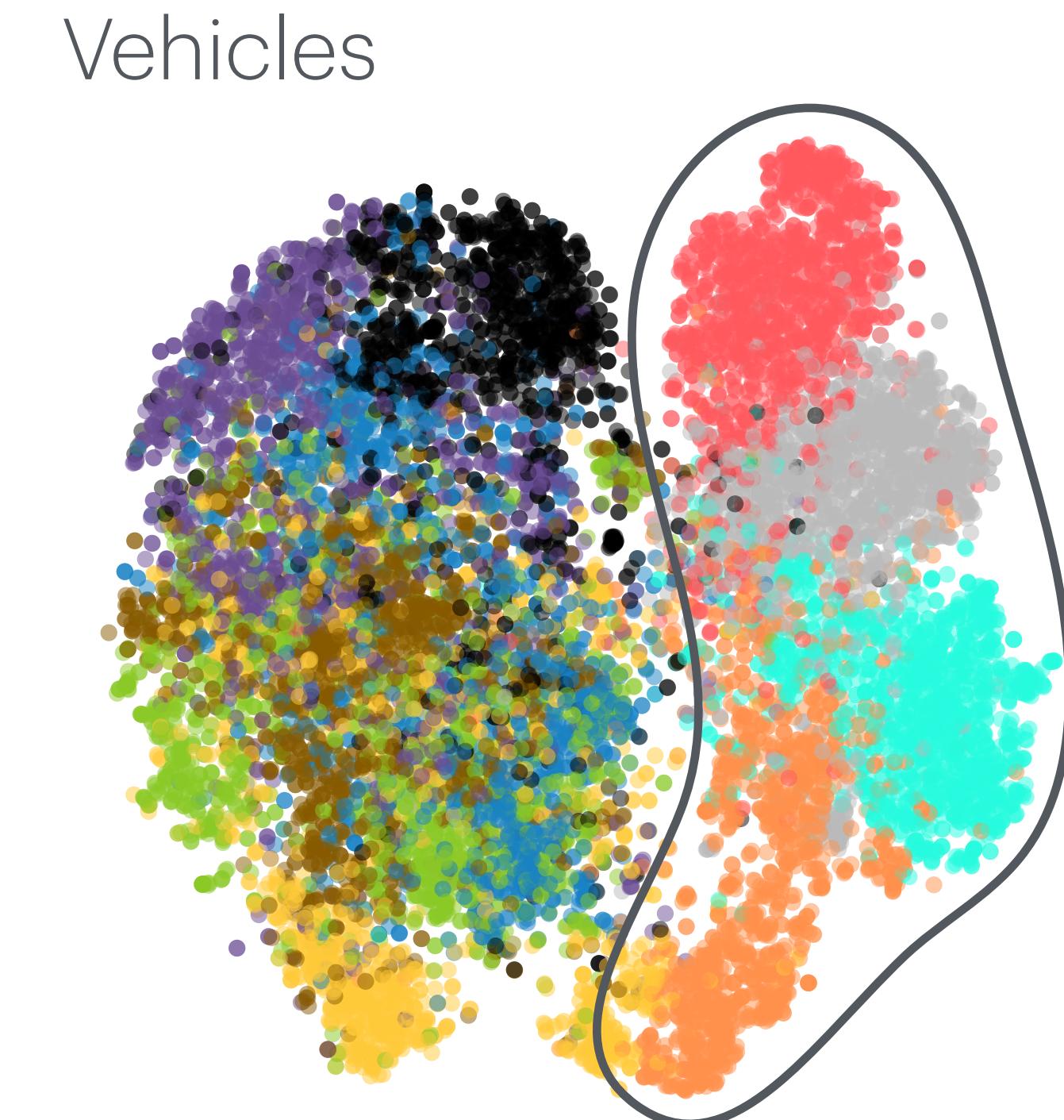
Visualizing Representations (t-SNE)



Rotation (RP)



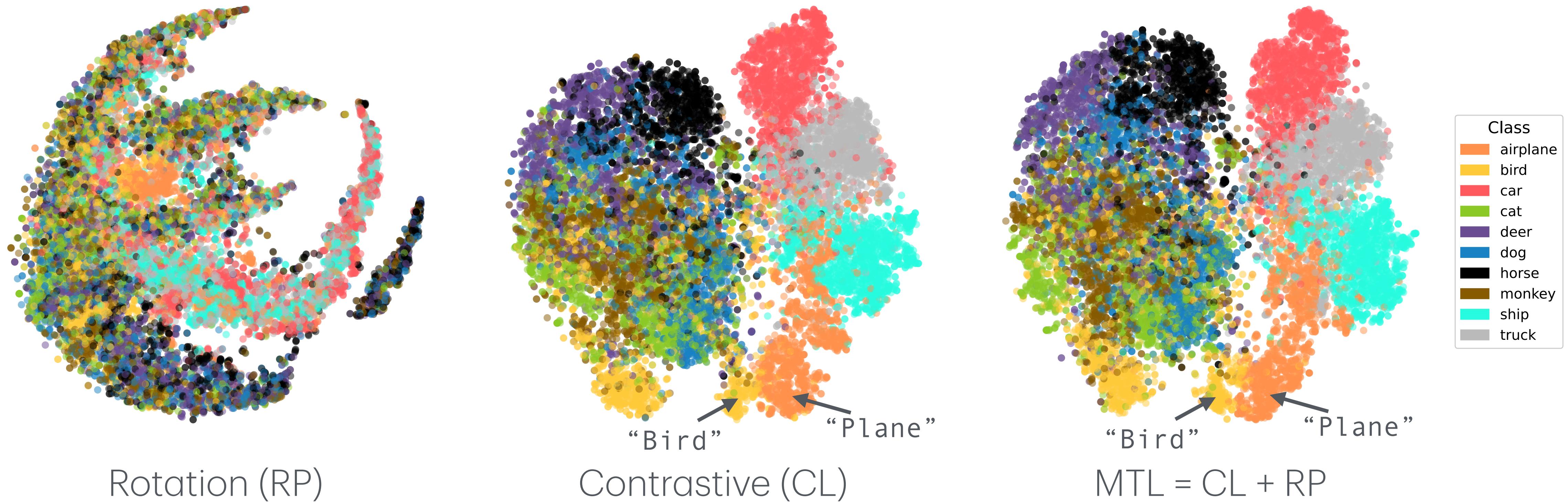
Contrastive (CL)



MTL = CL + RP

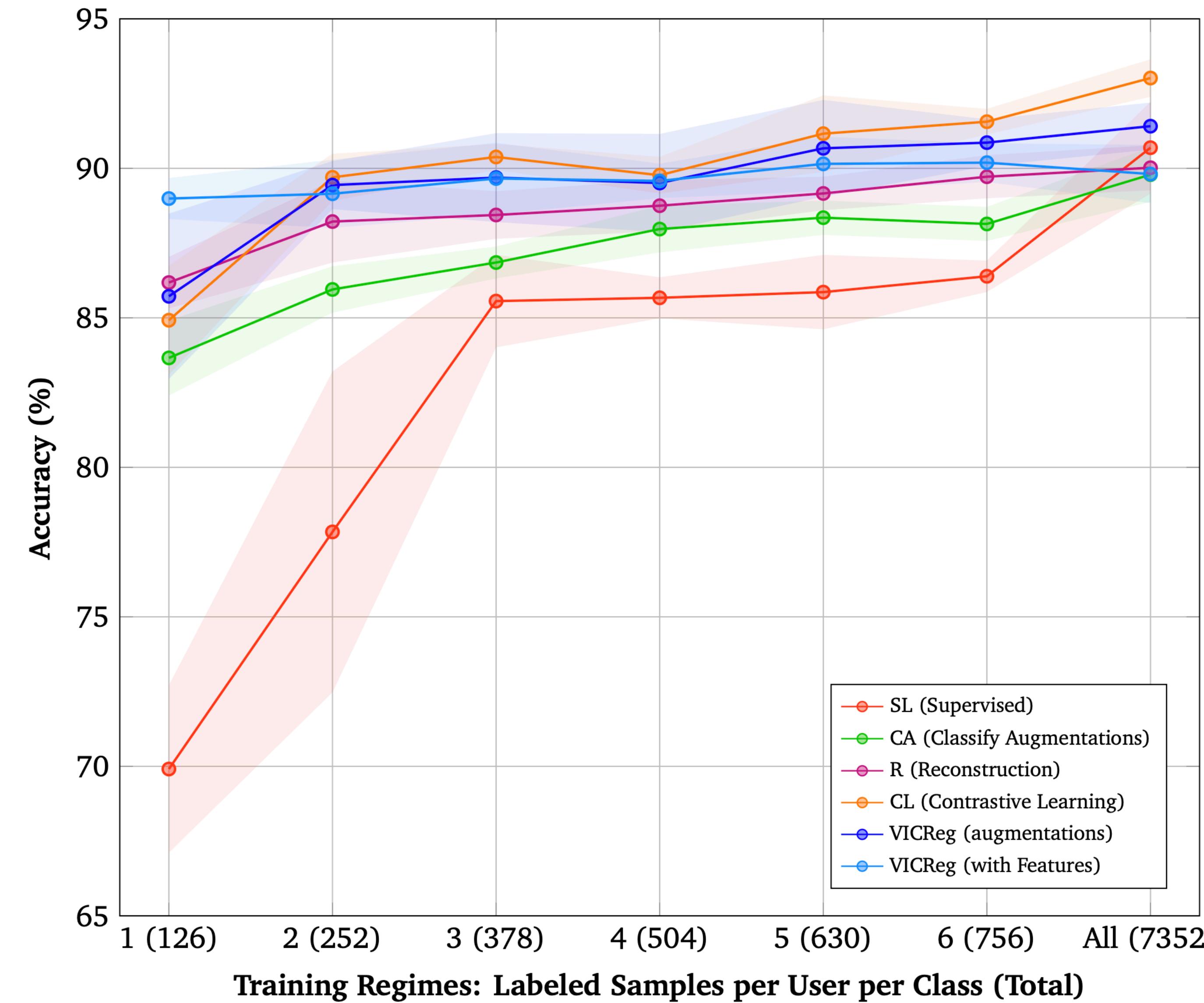
Class
airplane
bird
car
cat
deer
dog
horse
monkey
ship
truck

Visualizing Representations (t-SNE)

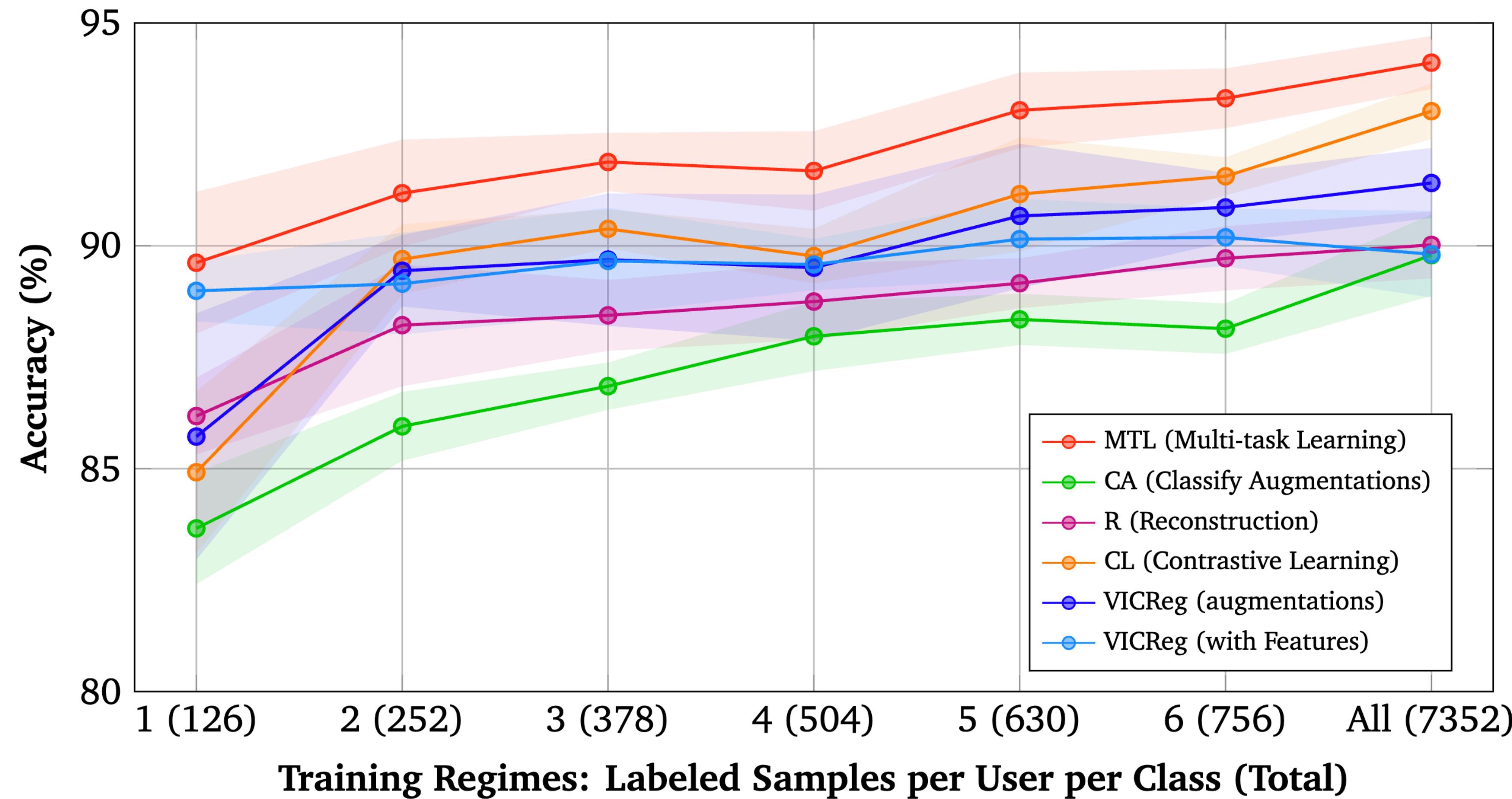


Conclusion

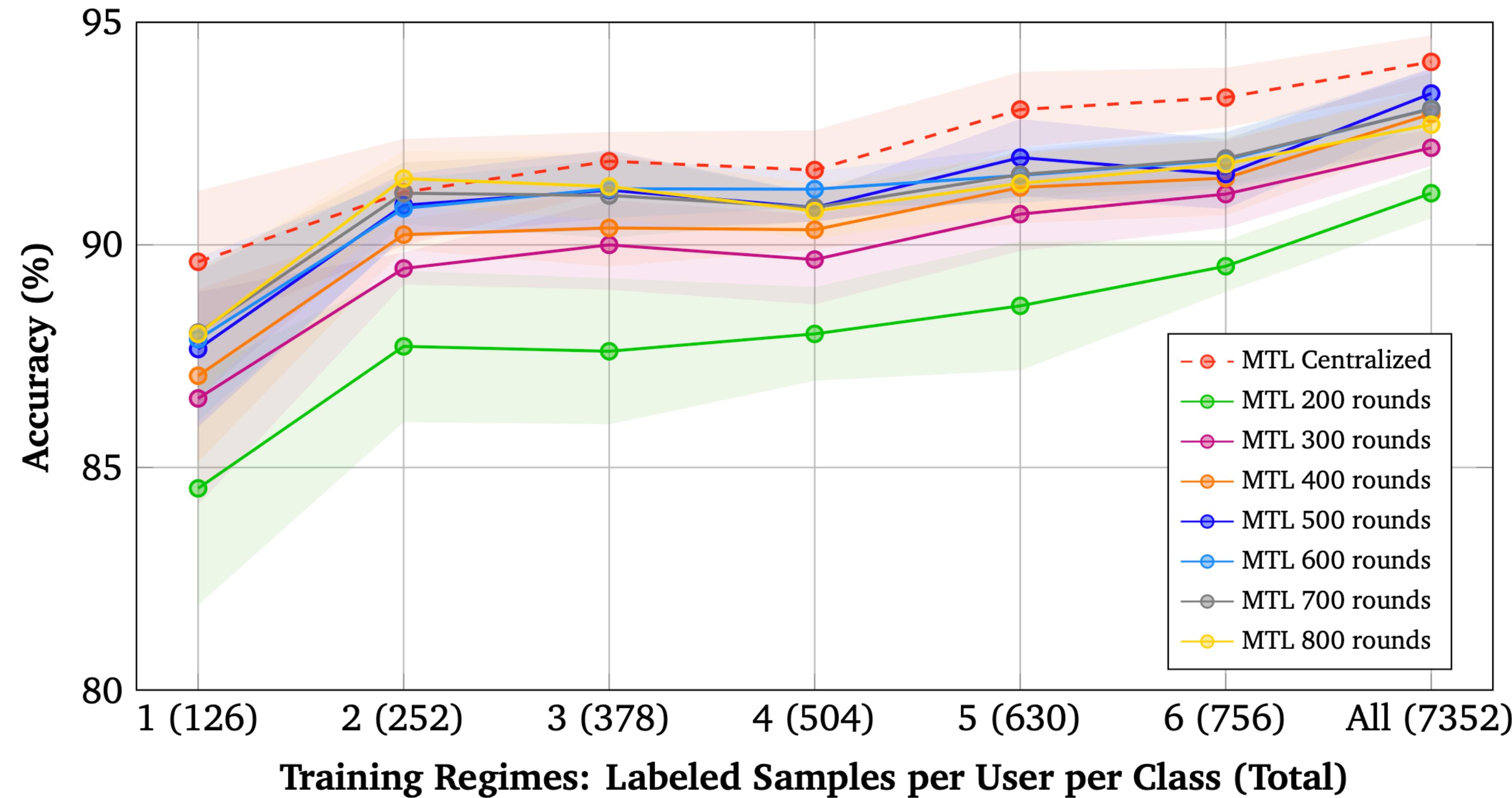
SSL



Multi-Task Learning



Federated Learning



Not Domain Specific!



Human Activity Recognition

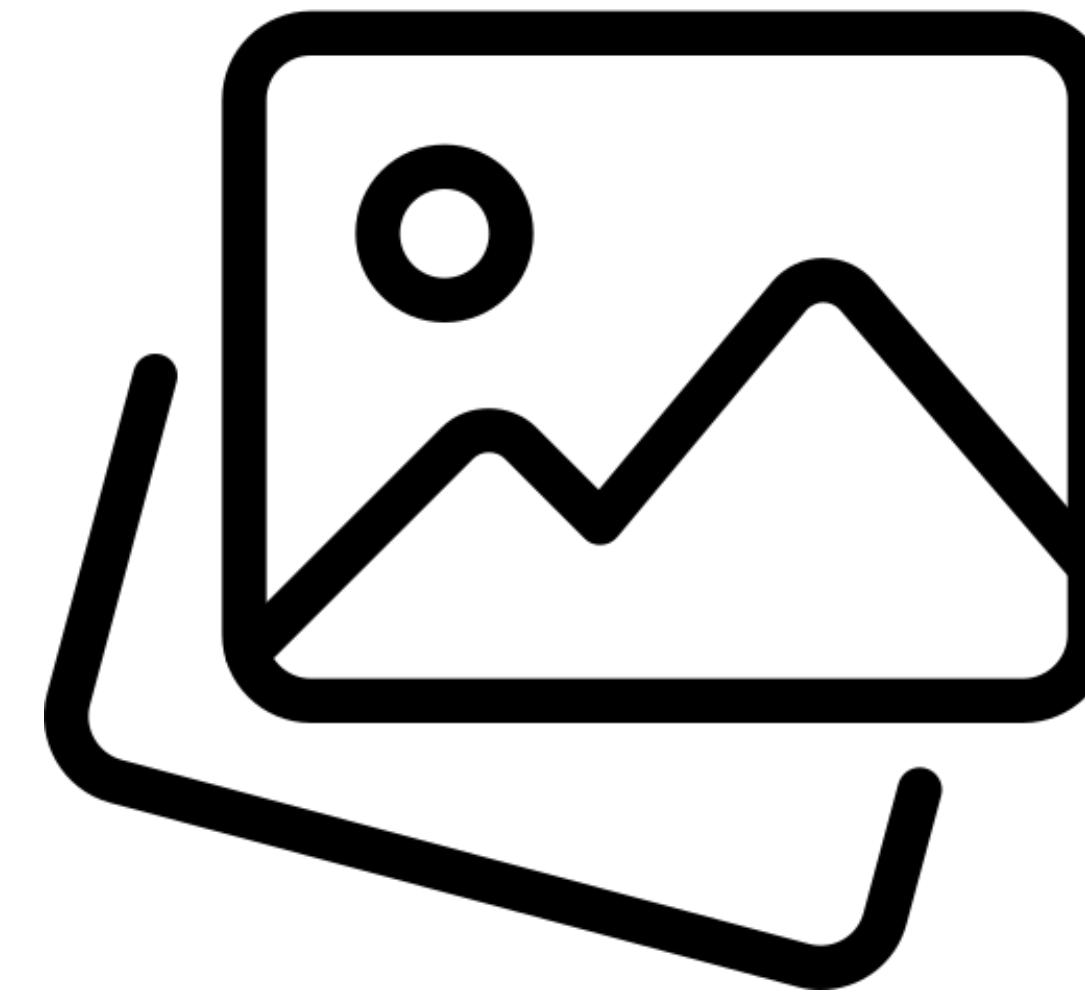
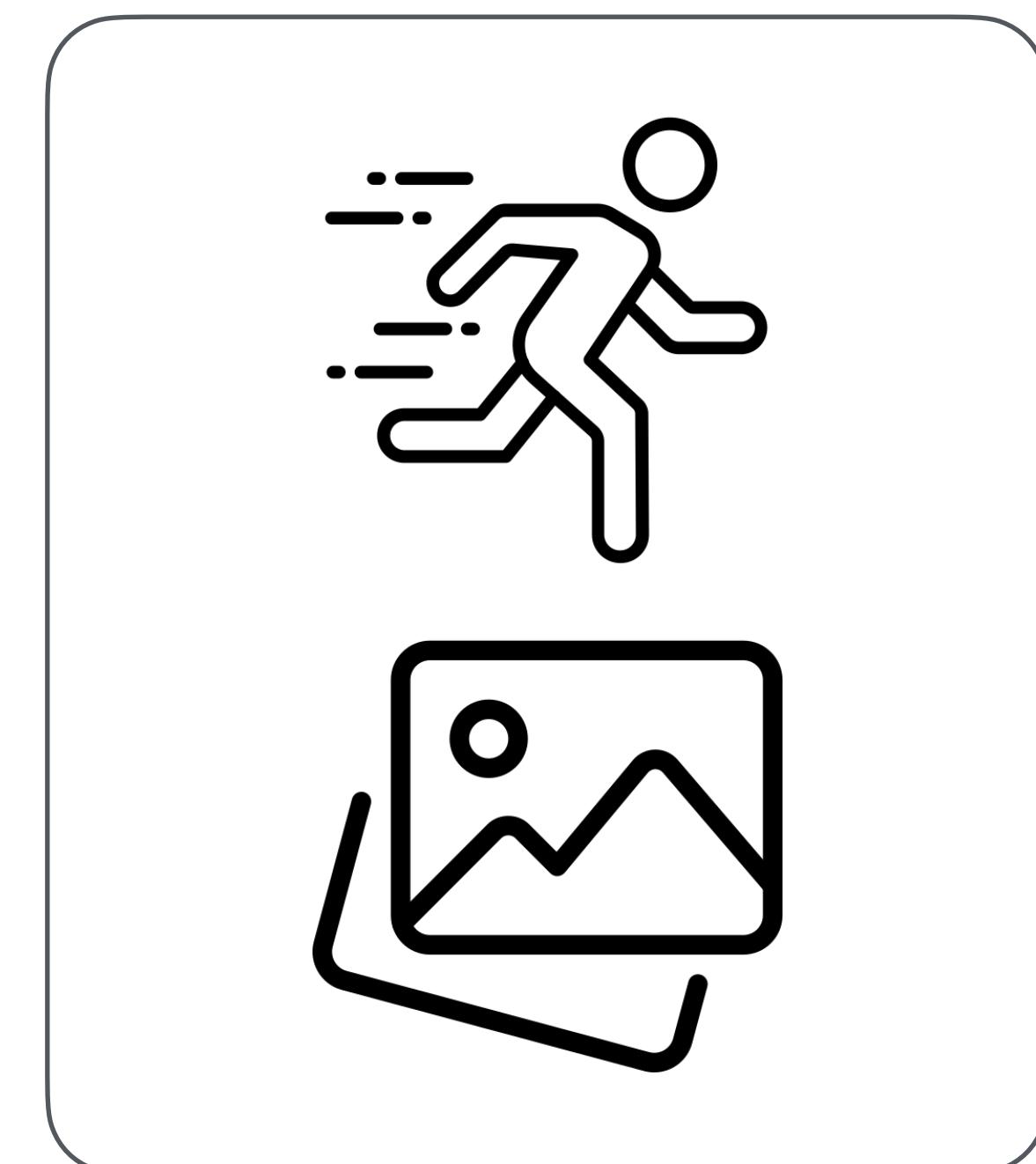
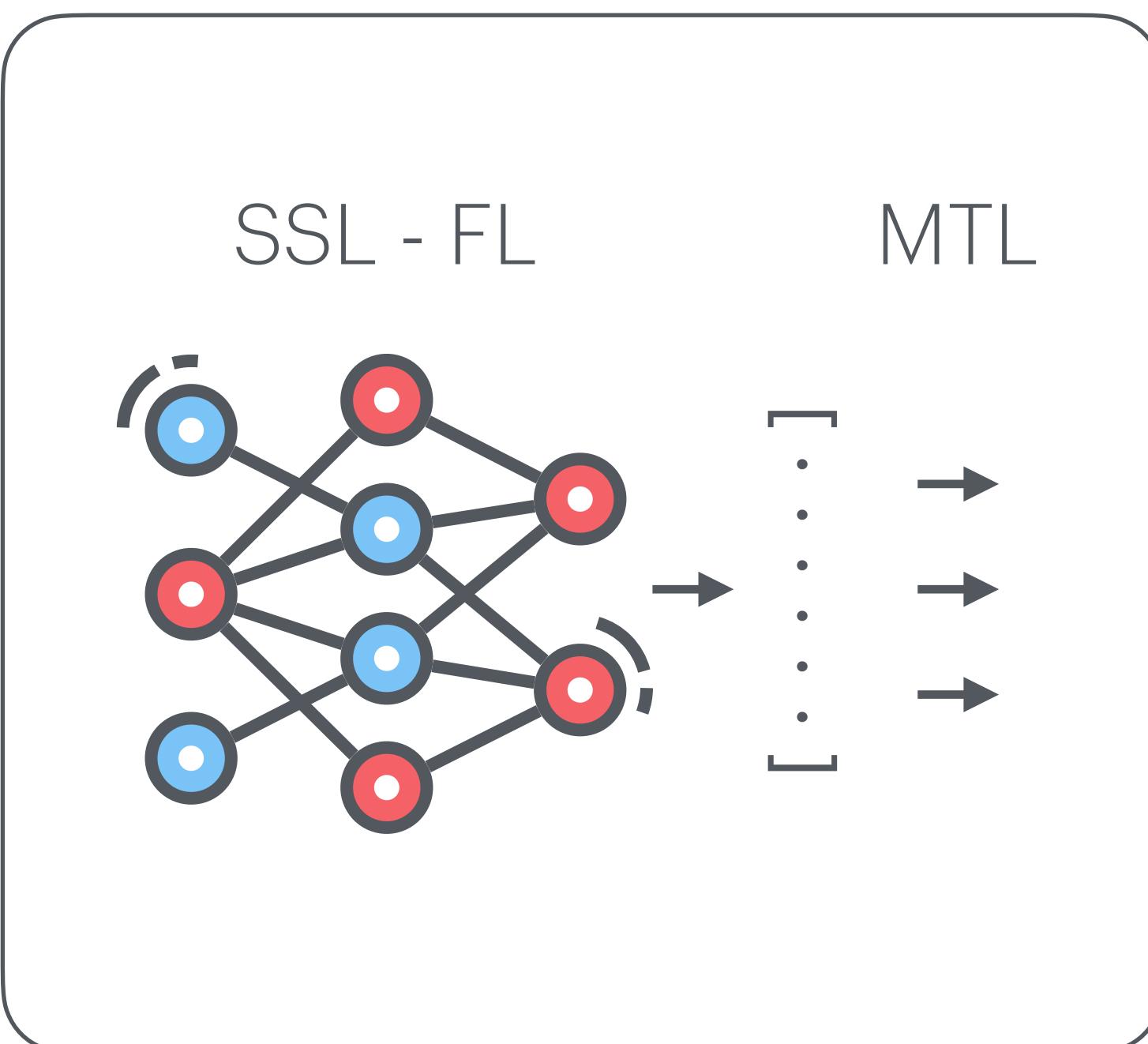
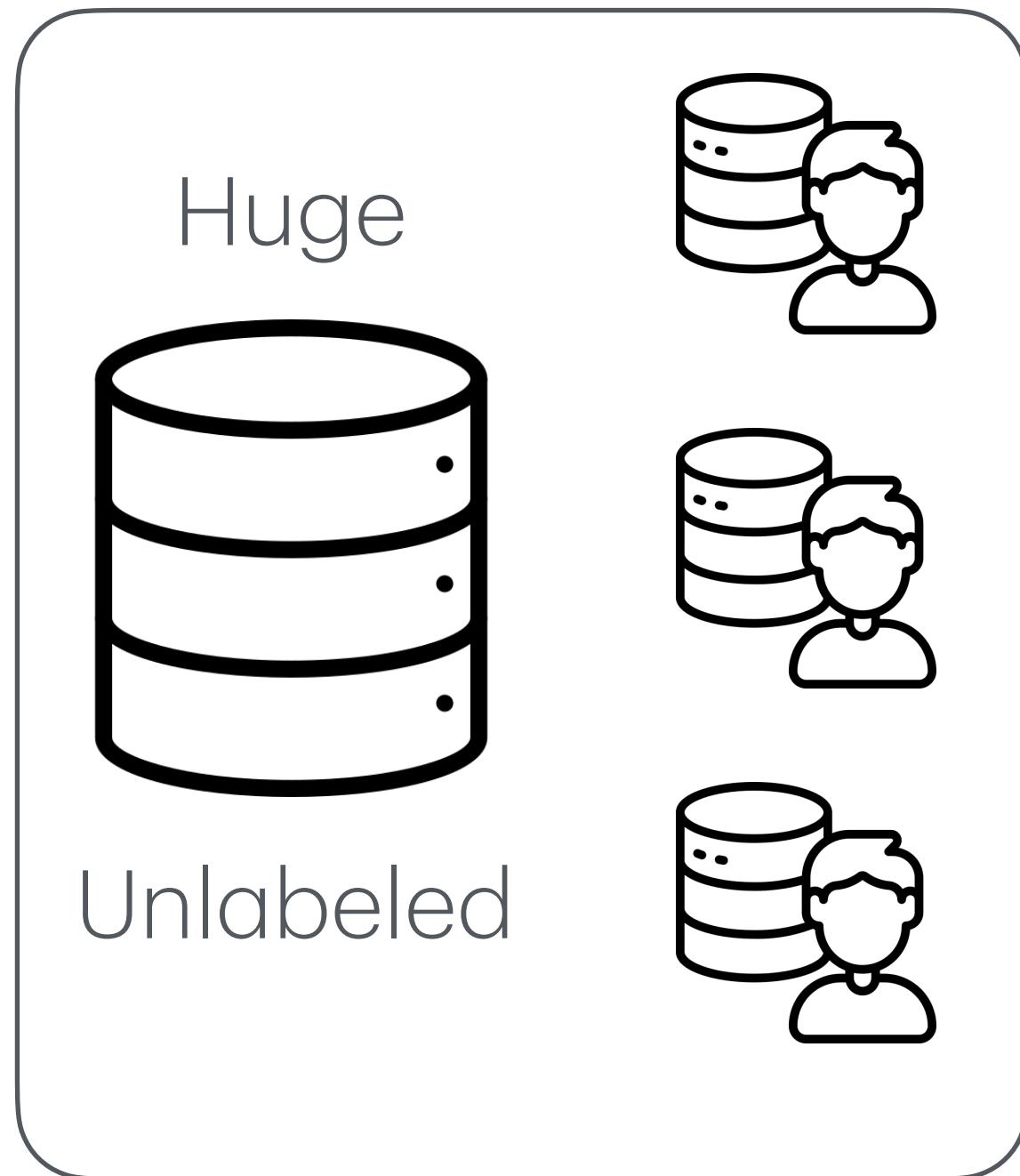
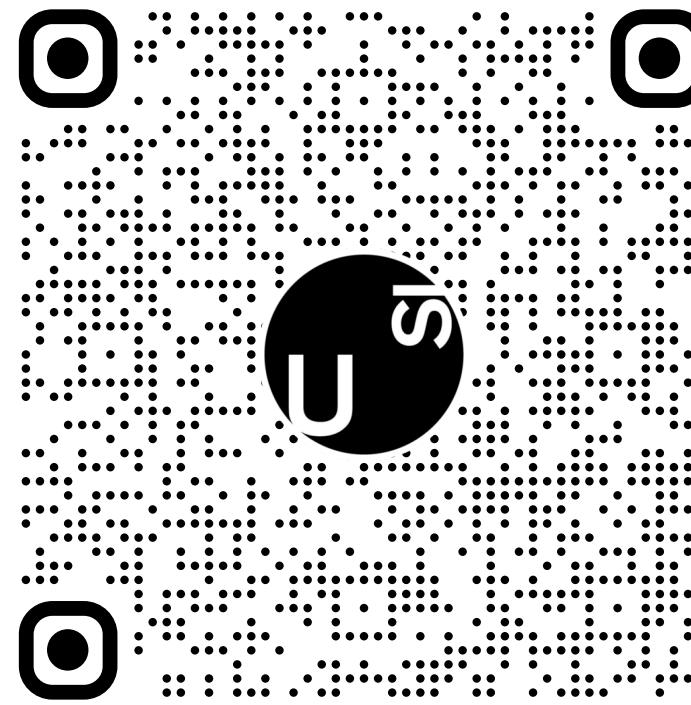


Image Recognition

Conclusion



Thank you for your time!



Code and Data available on  GitHub

https://github.com/Alessandro-Gobbetti/MTSSL_for_Label-Efficient_Learning

UCI-HAR Dataset: courtesy of Anguita et al.

STL-10 Dataset: courtesy of Coates et al.

Icons: courtesy of Flaticon (deemakdaksina, DinosoftLabs, Freepik, Futuer, gravisio, Hexagon075, ionicnut, Kalashnyk, Kharisma, Pixel perfect, PLANBSTUDIO, RaftelDesign, Roundicons Premium, rukanicon, Vectors Tank, Vitaly Gorbachev)

Extras

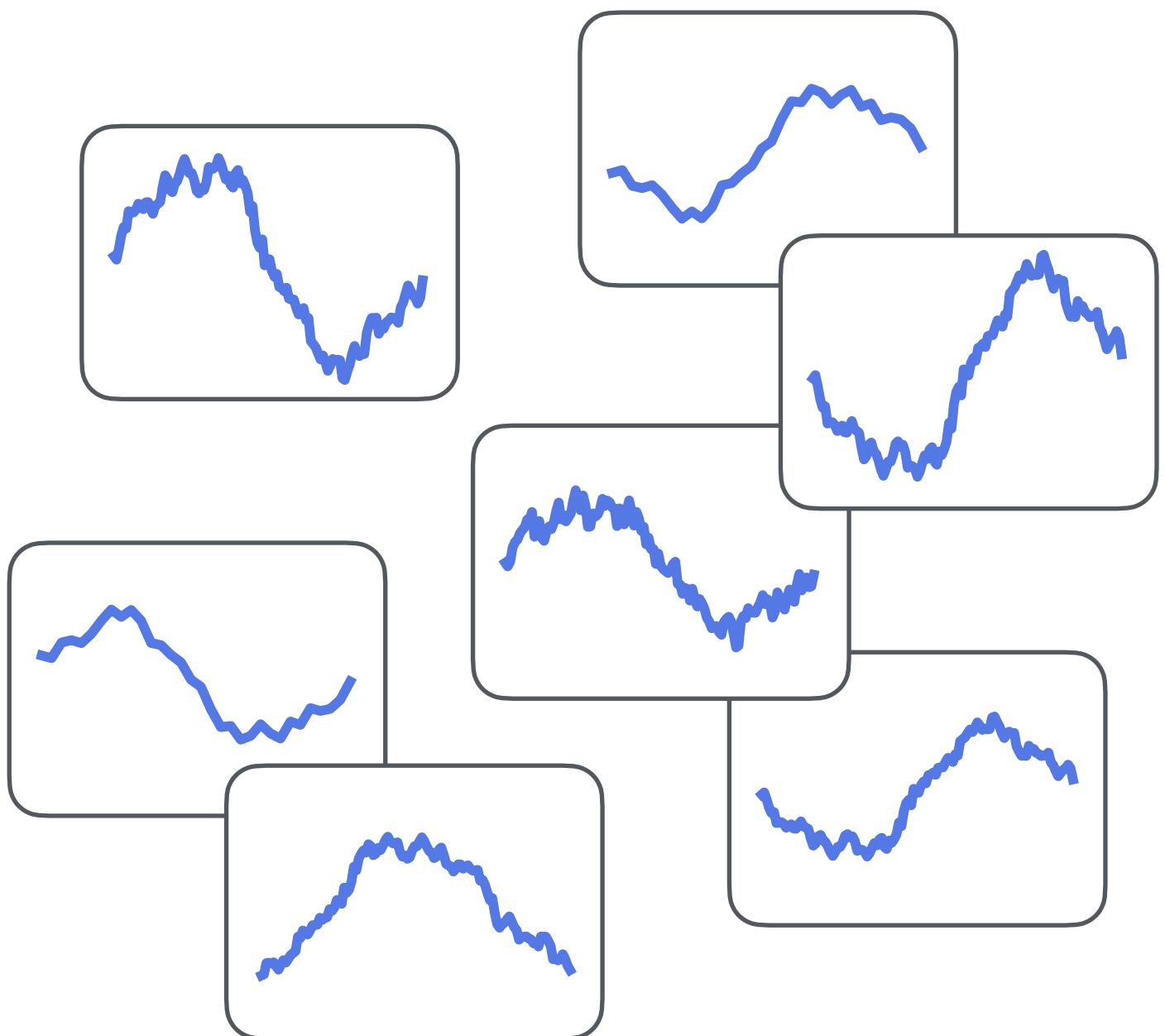
Pseudo-Labeling

Limitations & Future Work

Further Improving Performance

Self-Supervised Learning

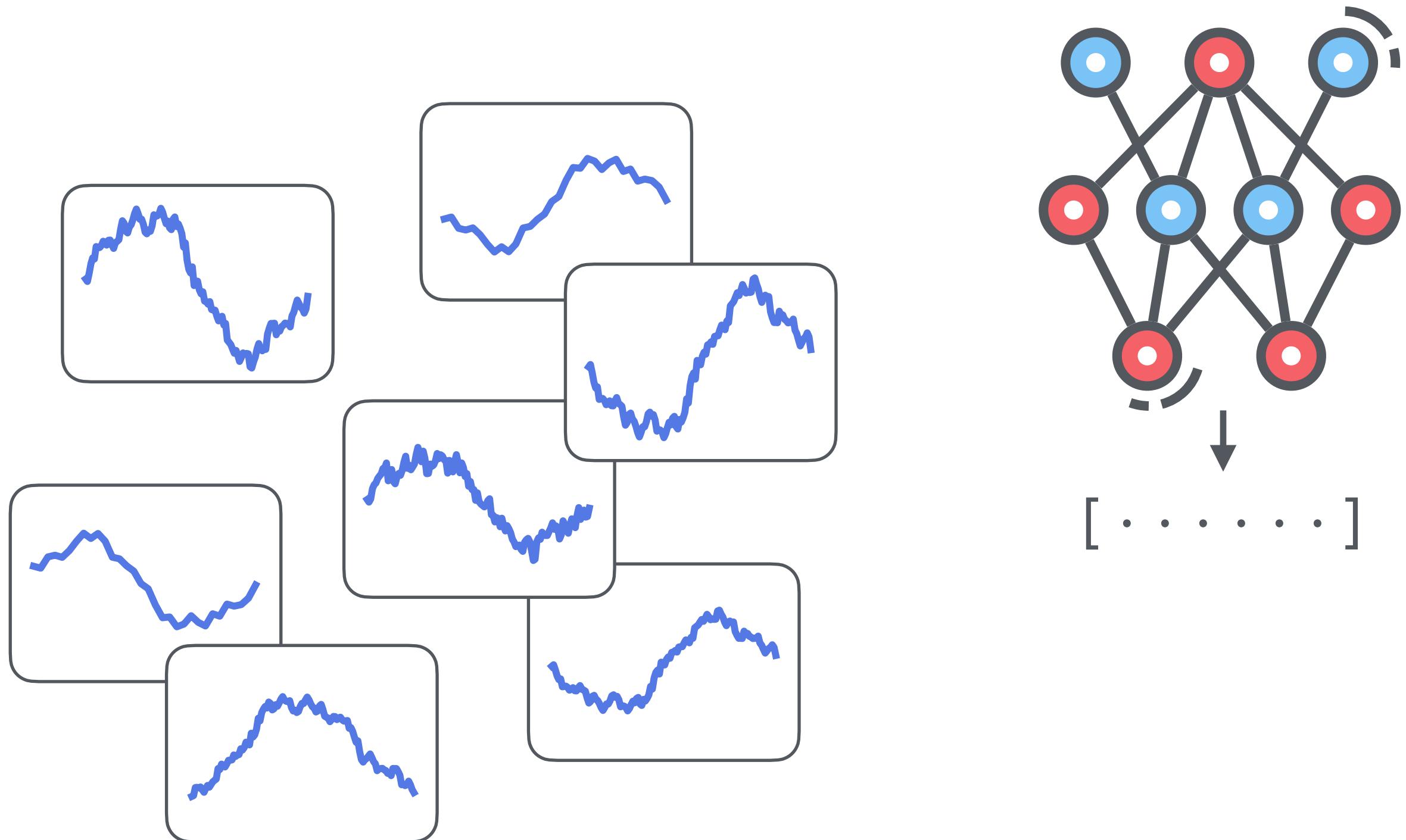
1. Pretraining Phase



Large unlabeled dataset

Self-Supervised Learning

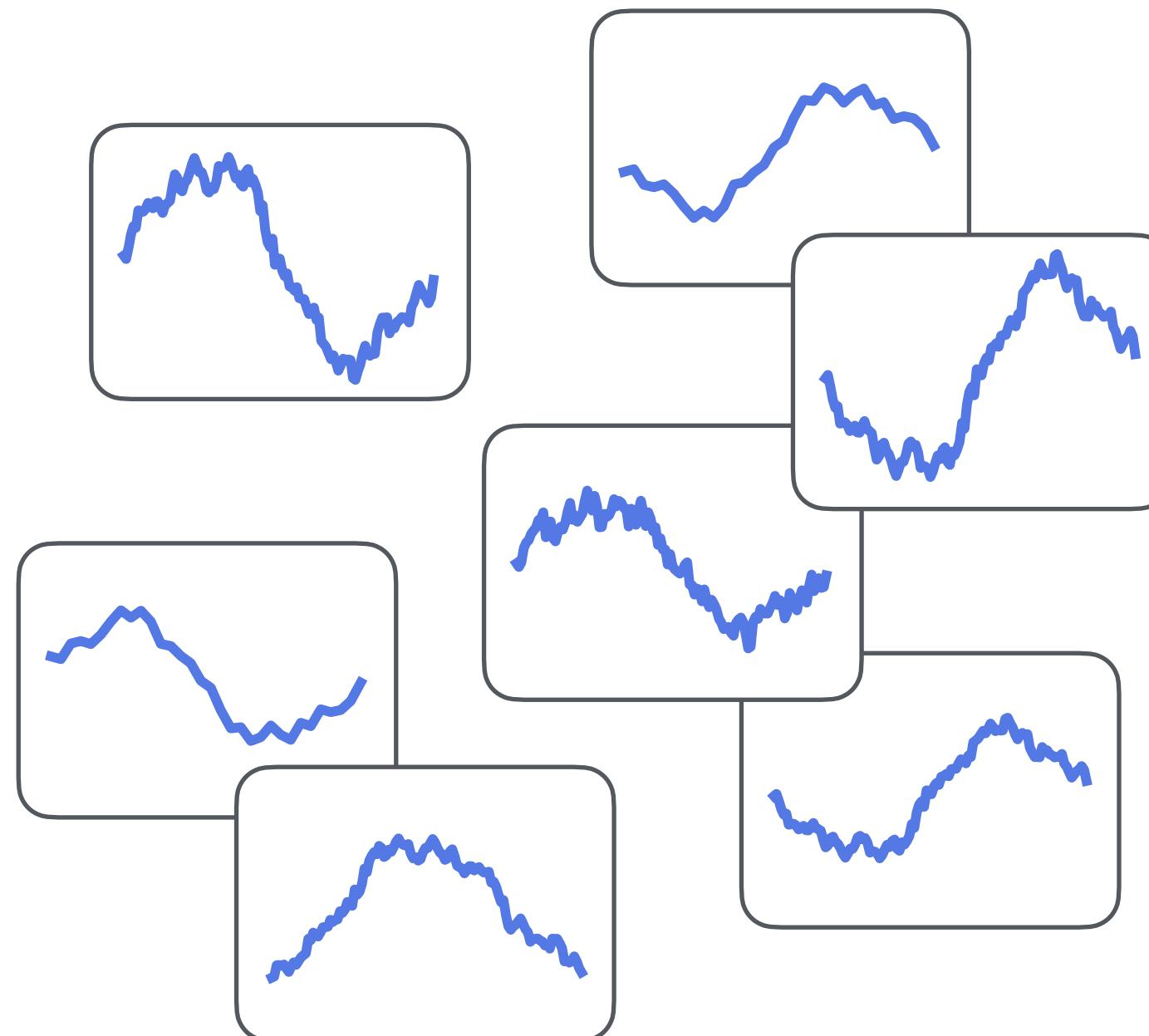
1. Pretraining Phase



Large unlabeled dataset

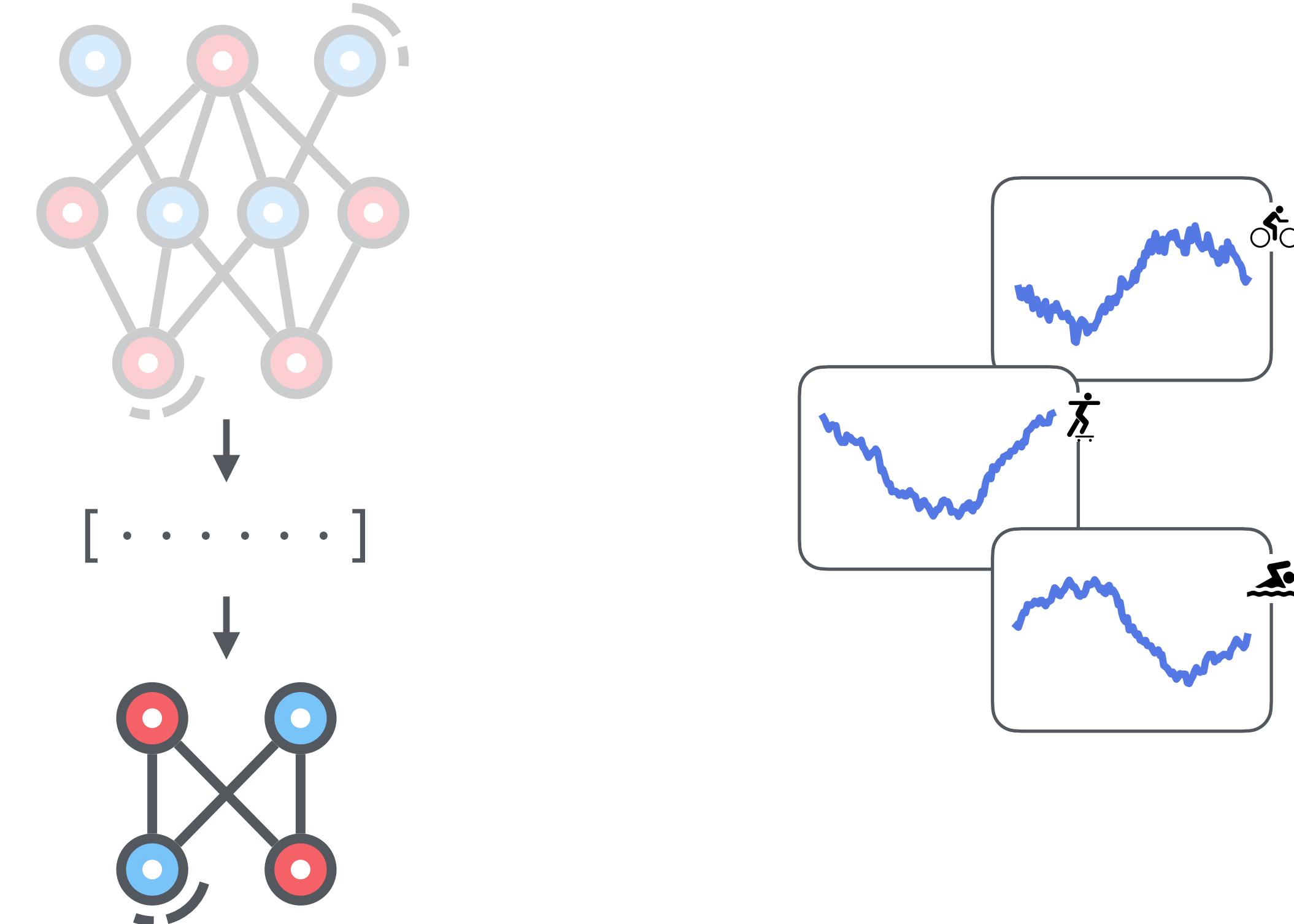
Self-Supervised Learning

1. Pretraining Phase



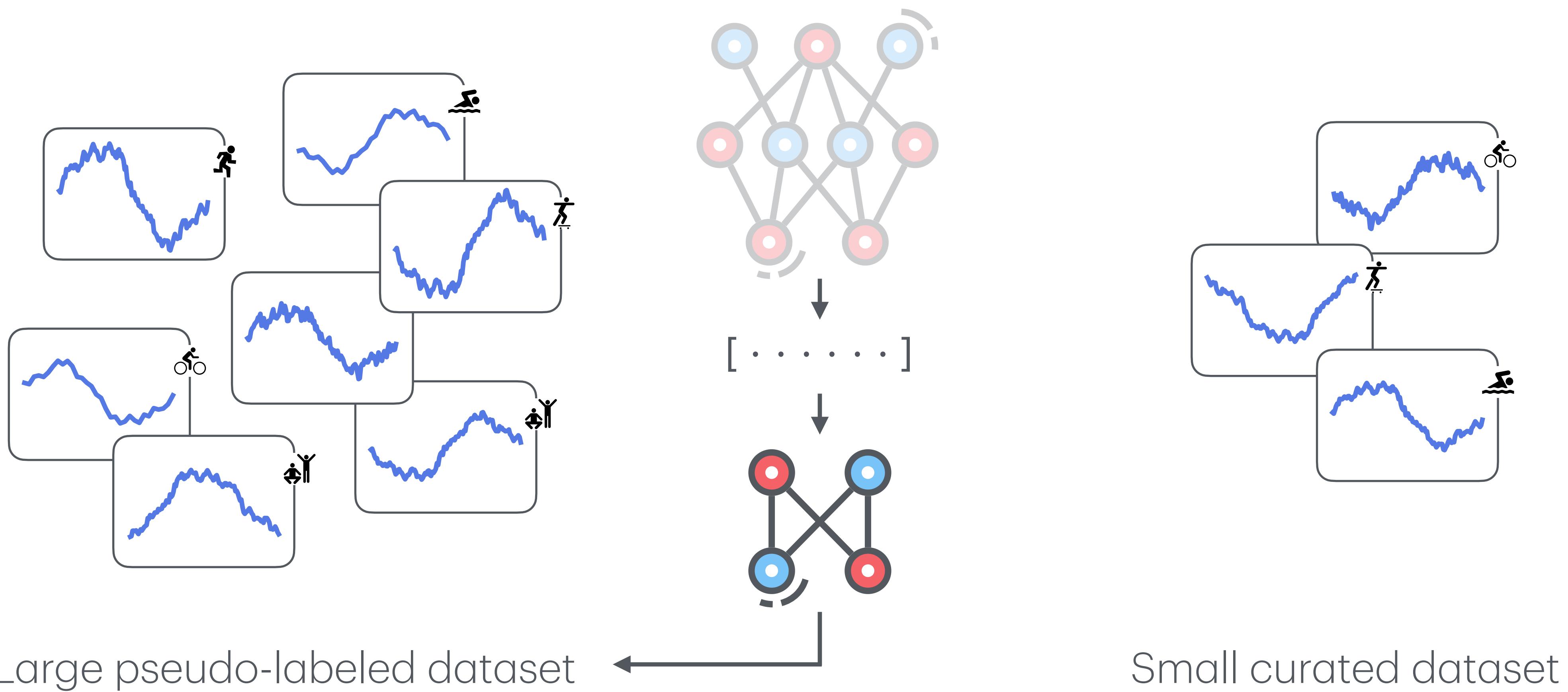
Large unlabeled dataset

2. Downstream Phase

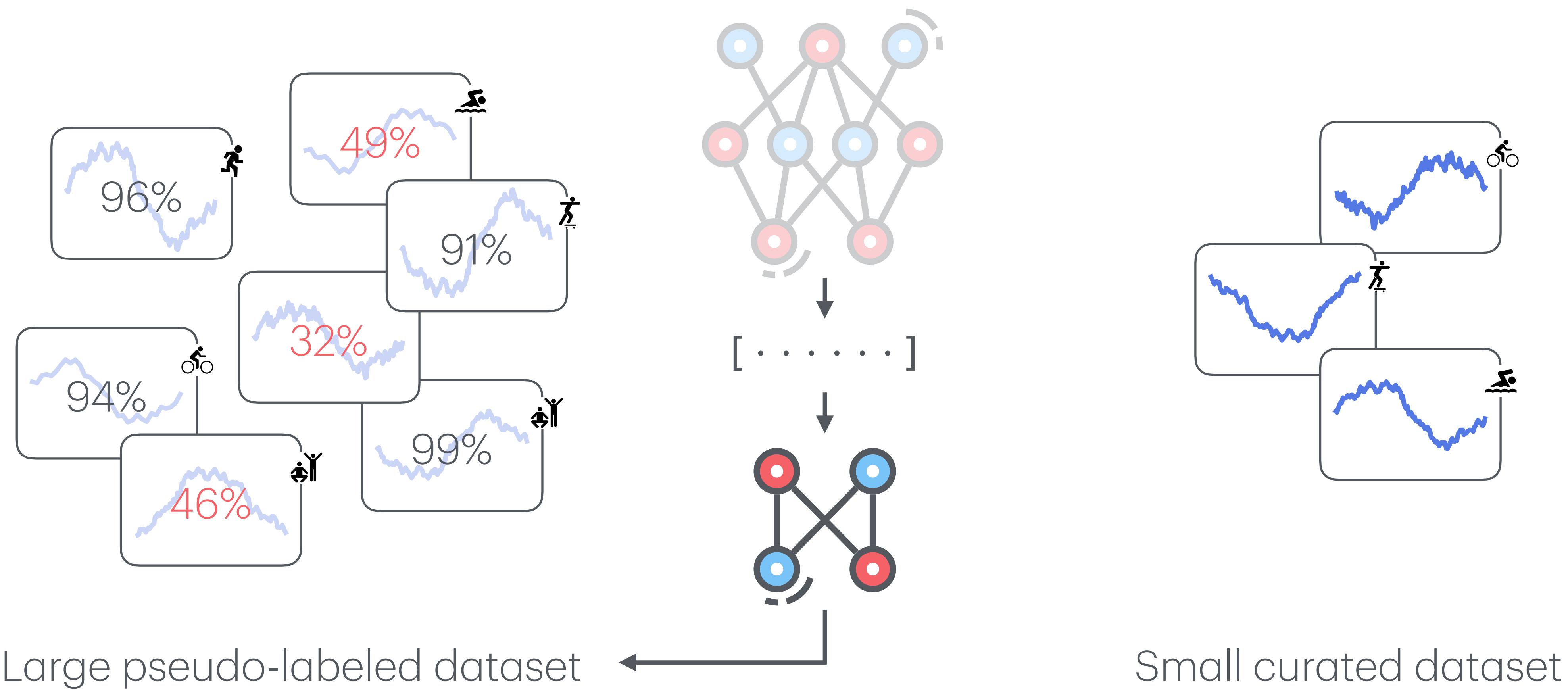


Small curated dataset

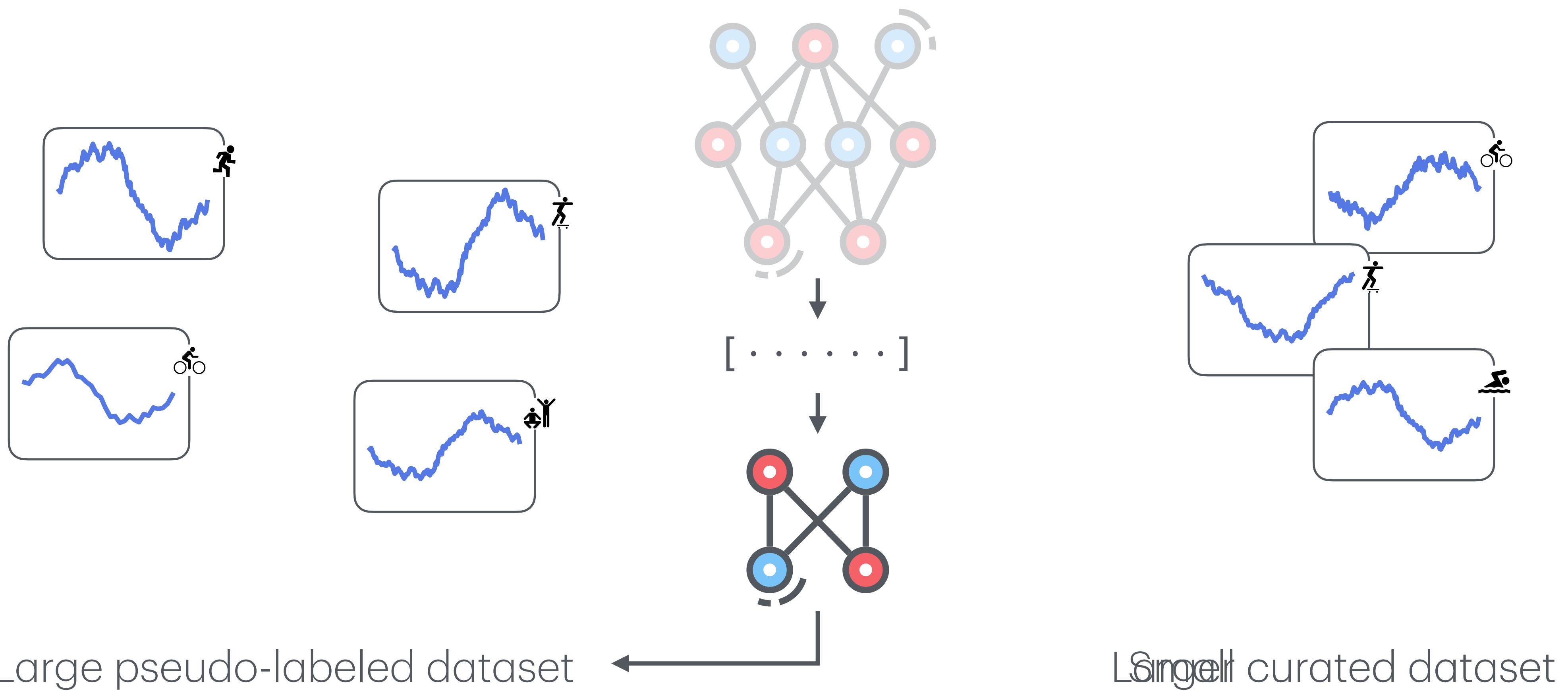
Pseudo-Labeling



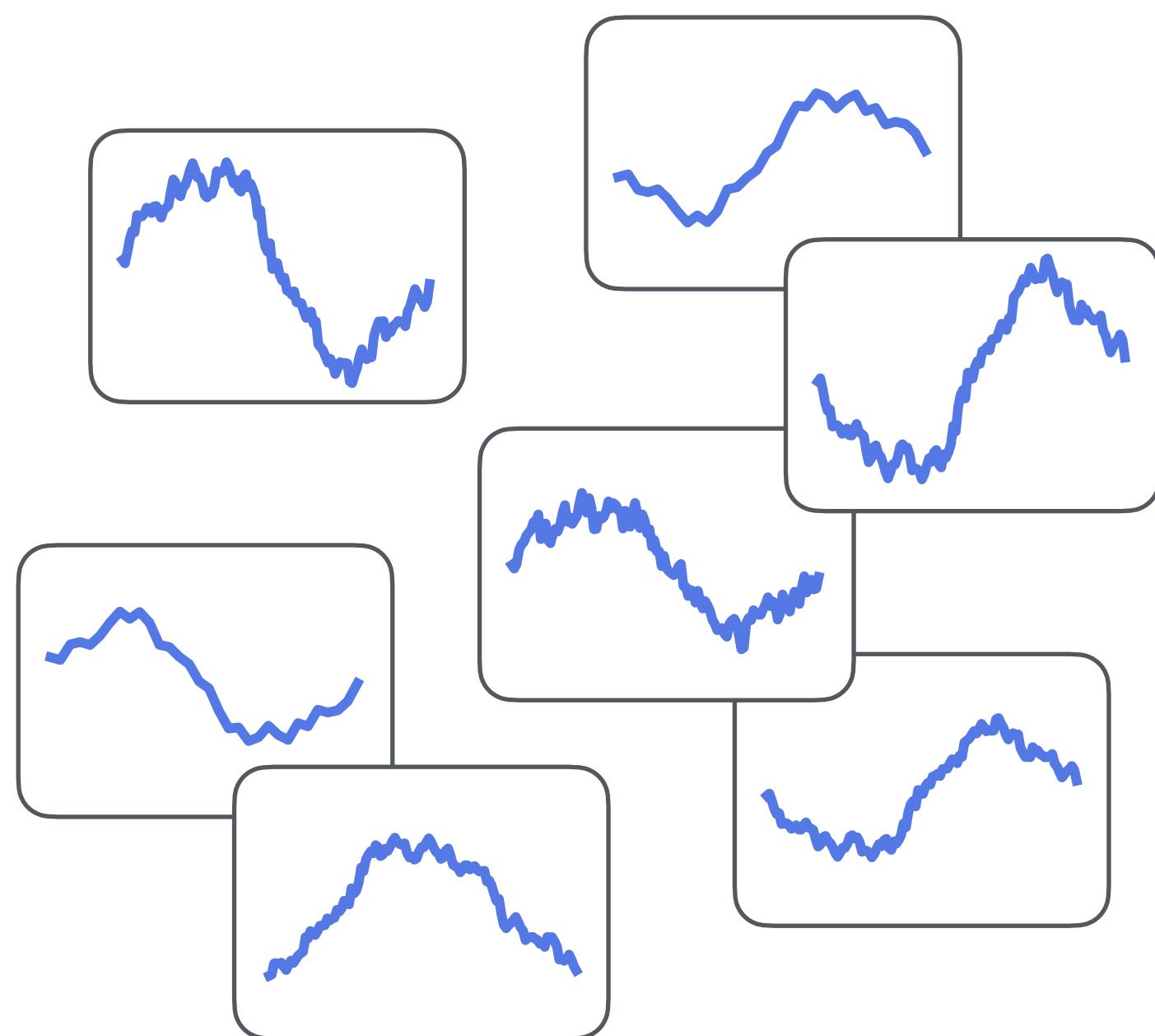
Pseudo-Labeling



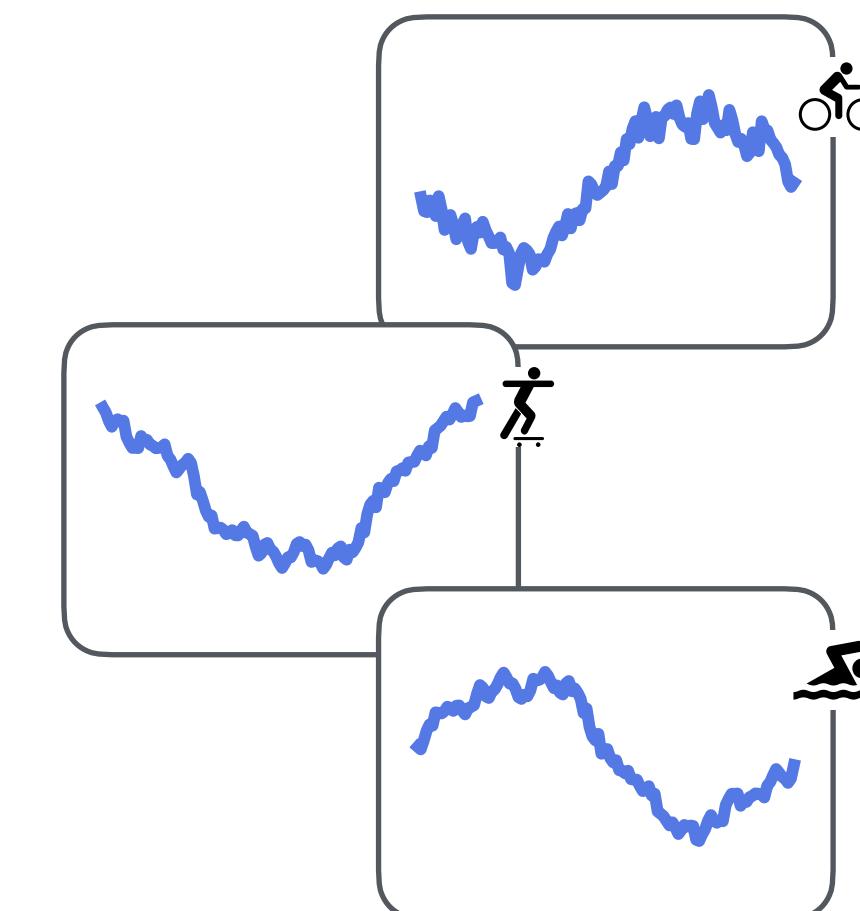
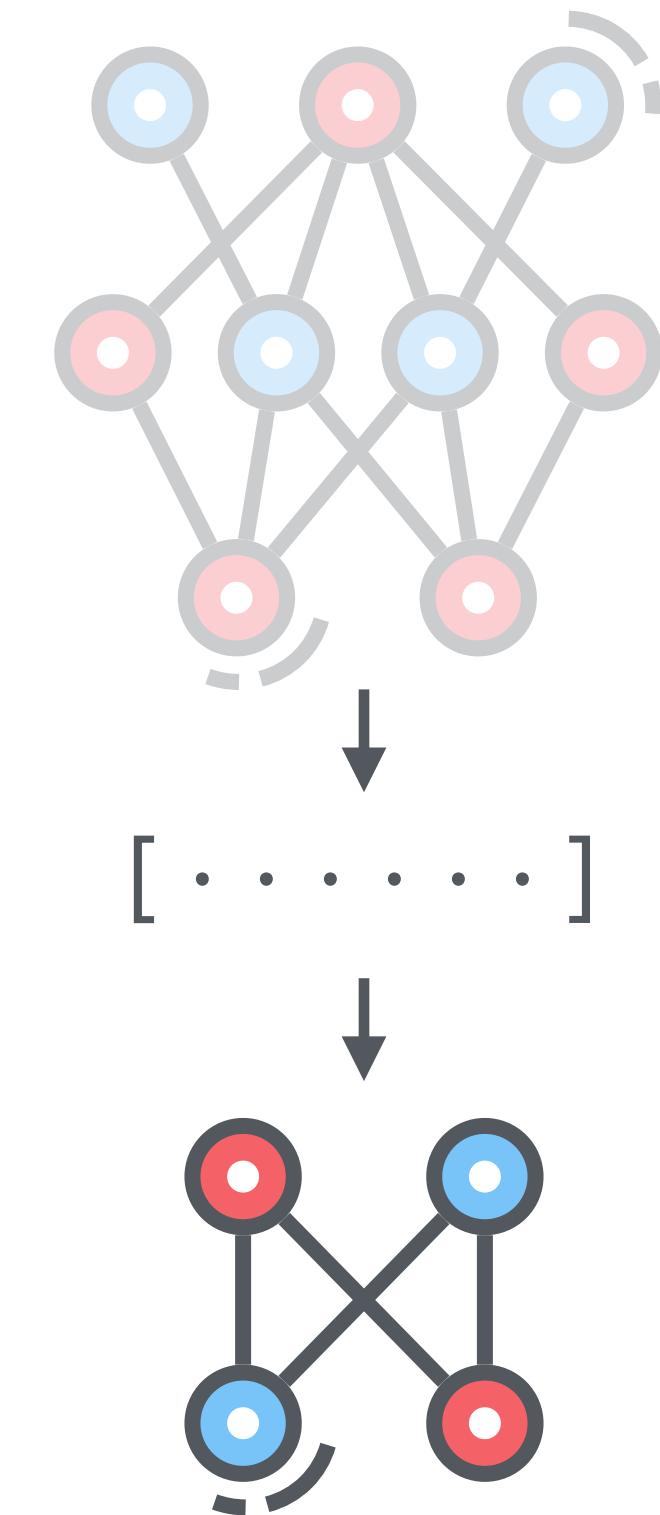
Pseudo-Labeling



Pseudo-Labeling



Large unlabeled dataset



Small curated dataset

Pseudo-Labeling

Size	Method	1 (126)	2 (252)	3 (378)	4 (504)	5 (630)	6 (756)
128	Base model	89.62 ± 2.16	92.26 ± 2.15	91.41 ± 0.55	91.82 ± 1.08	92.93 ± 0.80	93.15 ± 0.66
	Pseudo-labels	90.47 ± 1.73	92.36 ± 1.23	91.24 ± 0.80	92.47 ± 1.44	92.62 ± 1.48	92.60 ± 0.90
384	Improvement	+0.85	+0.10	-0.17	+0.65	-0.31	-0.55
	Base model	86.72 ± 2.40	91.31 ± 1.59	91.80 ± 1.00	91.65 ± 0.53	92.20 ± 1.13	92.72 ± 0.46
	Pseudo-labels	89.74 ± 2.62	92.47 ± 1.94	92.32 ± 1.31	92.01 ± 0.59	93.06 ± 1.15	93.16 ± 1.23
	Improvement	+3.02	+1.16	+0.52	+0.36	+0.86	+0.44

Limitations & Future Work

Limitations & Future Work

Data & Scaling

- Mainly UCI HAR (small, domain-specific)
- Preliminary STL-10 evaluation
- Broader datasets & transfer learning
- Larger unlabeled data → stronger embeddings [Yuan et al., NPJ Digit. Med. 2024]

Domains & Architectures

- Focused on HAR, limited vision test
- Extend to other domains
- Adapt architectures for new data

Limitations & Future Work

Optimization & Tasks

- No extensive tuning of models/hyperparameters
- Already close to supervised state-of-the-art [Bozkurt, AJSE 2021]
- Future: select other pretraining tasks, tune models, loss terms, hyperparameters
- Tasks contribute unevenly → refine cross-task interactions

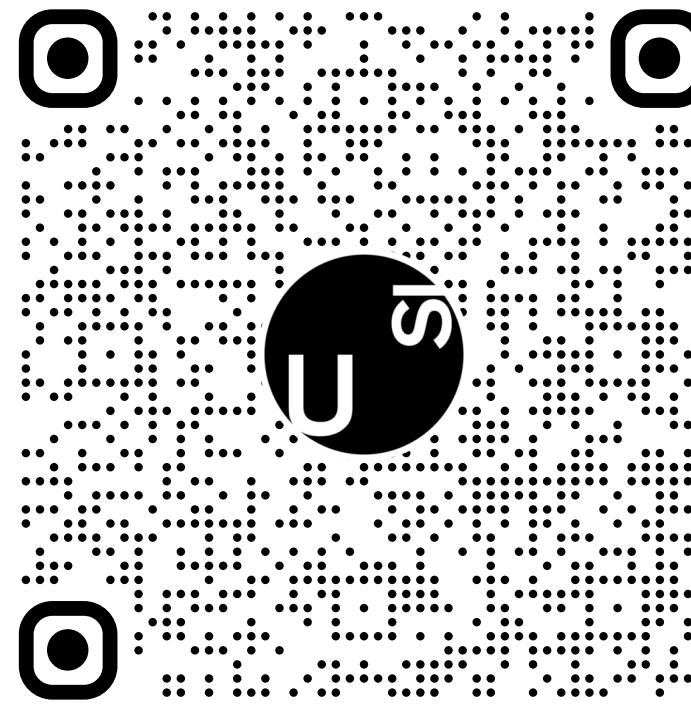
Task Weighting

- Dynamic weighting worked well
- Explore gradient-based methods (e.g., PCGrad [Yu et al., NeurIPS 2020])

Federated Learning

- Current FL only in pretraining
- Extend to downstream → full privacy-preserving pipeline
- Integrate FL for heterogeneous/unbalanced data (e.g., Orchestra [Lubana et al., ICML 2022])

Thank you for your time!



Code and Data available on  **GitHub**

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