Comparison of Supervised and Unsupervised Spiking Neural Networks for MNIST Classification

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Project-1
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Project Objectives

- Implement and study two SNN paradigms:
  - **Unsupervised STDP** (Diehl & Cook 2015)
  - **Supervised BPTT** (snnTorch)
- Compare:
  - Computational sequence
  - Resource usage
  - Learning dynamics
  - Accuracy & scalability

Dataset and Common Setup

- **Dataset:** MNIST (28×28 grayscale)
- **Encoding:** Rate coding, 35 time steps
- **Neuron model:** Leaky Integrate–and–Fire (LIF)
- **Training samples:**
  - Unsupervised: 10,000
  - Supervised (parity): 10,000
  - Supervised (full): 60,000

Unsupervised SNN with STDP

Reference implemented: Diehl & Cook, Frontiers 2015

- Framework: **Brian2**
- 784 $\rightarrow$ 400 excitatory + 400 inhibitory
- Lateral inhibition $\rightarrow$ specialization
- No labels used during learning
- Classification via neuron activity statistics

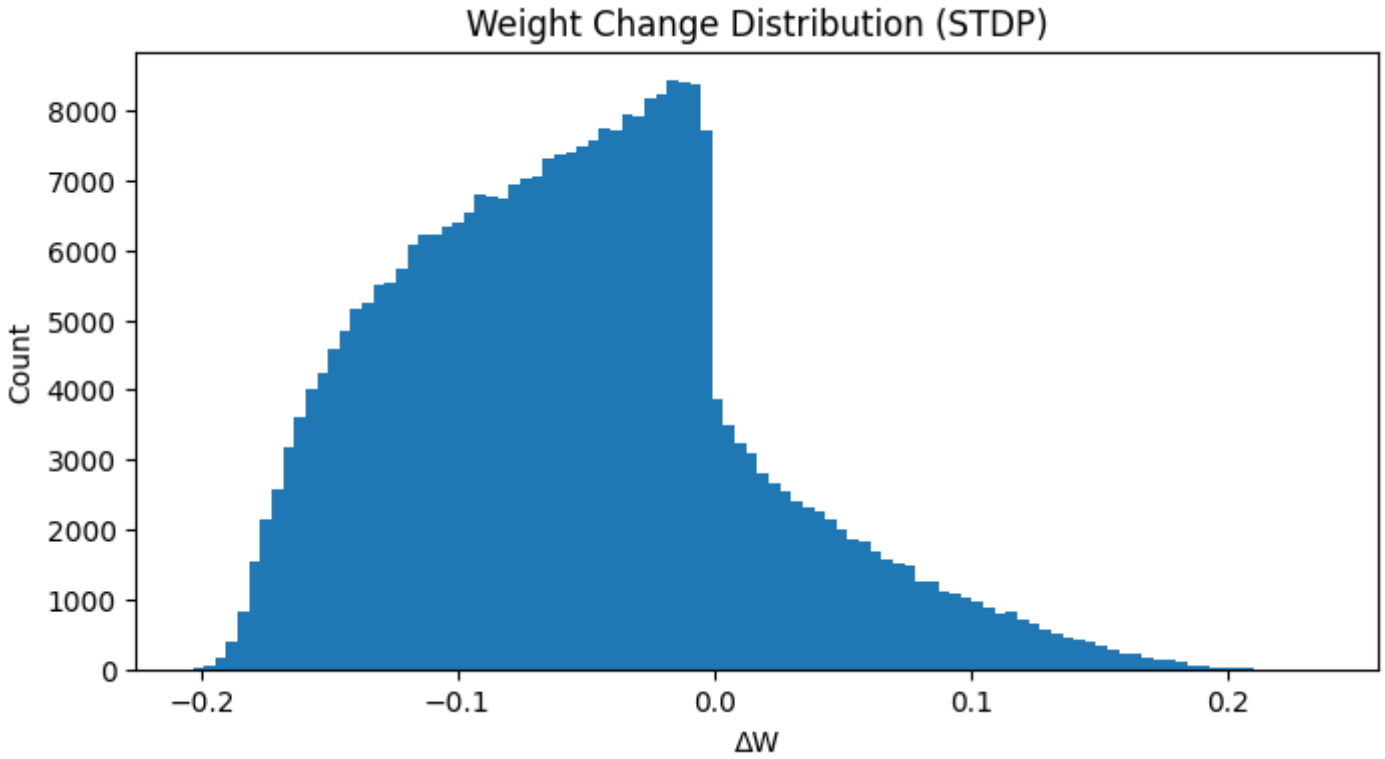
STDP Learning Rule

$$\Delta w = \begin{cases} A_+ e^{-(t_{\text{post}} - t_{\text{pre}})/\tau_+}, & t_{\text{pre}} < t_{\text{post}} \\ -A_- e^{-(t_{\text{pre}} - t_{\text{post}})/\tau_-}, & t_{\text{post}} < t_{\text{pre}} \end{cases}$$

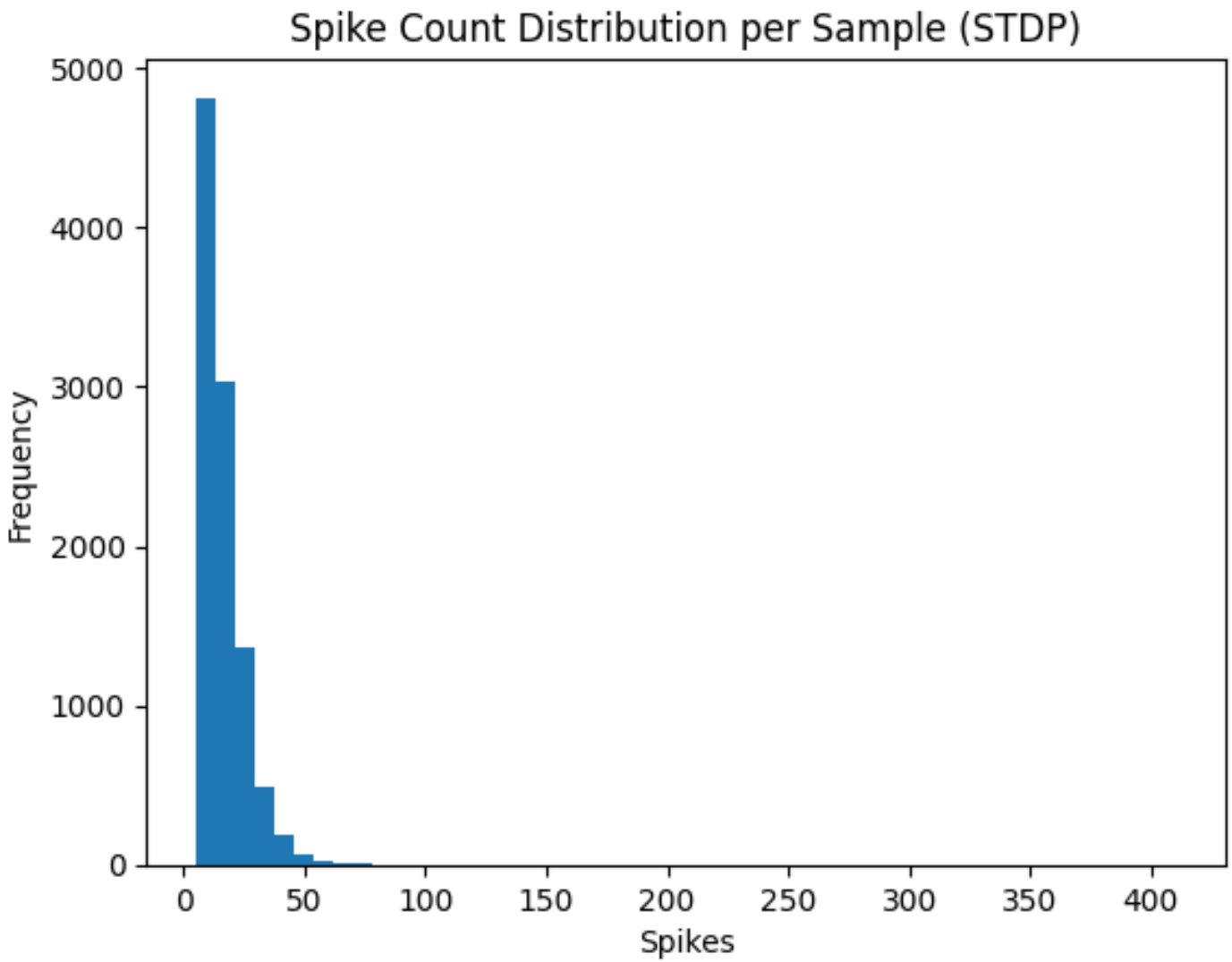
- Purely spike-timing-based plasticity
- Encourages emergent selectivity
- Biologically plausible

Receptive Fields Learned via STDP

Weight Evolution During STDP

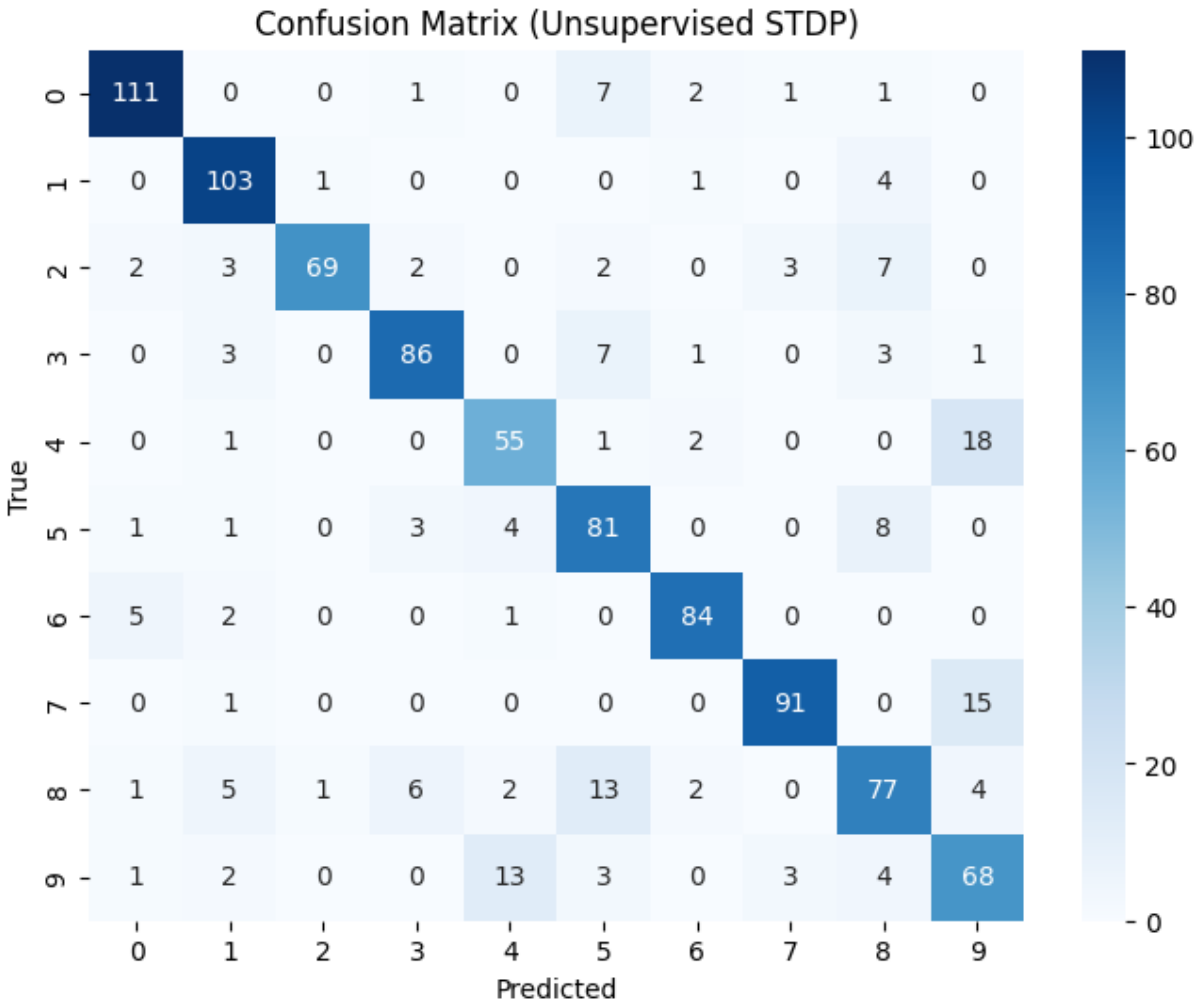


STDP Spike Statistics



- Mean spikes/sample: **16.1**
- Efficient, event–driven computation

STDP Confusion Matrix (1000 Samples)

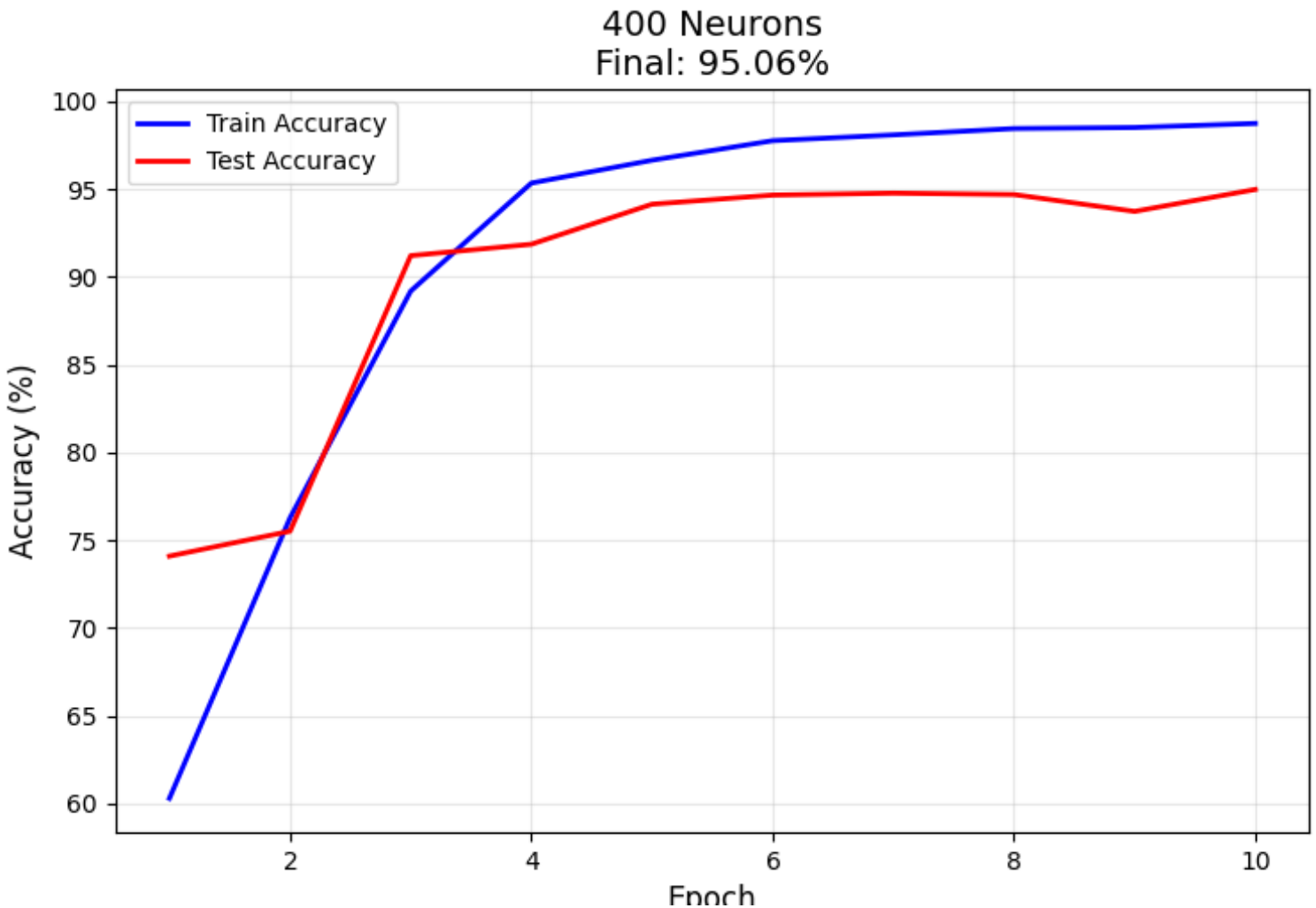


- Final Accuracy: **82.5%**

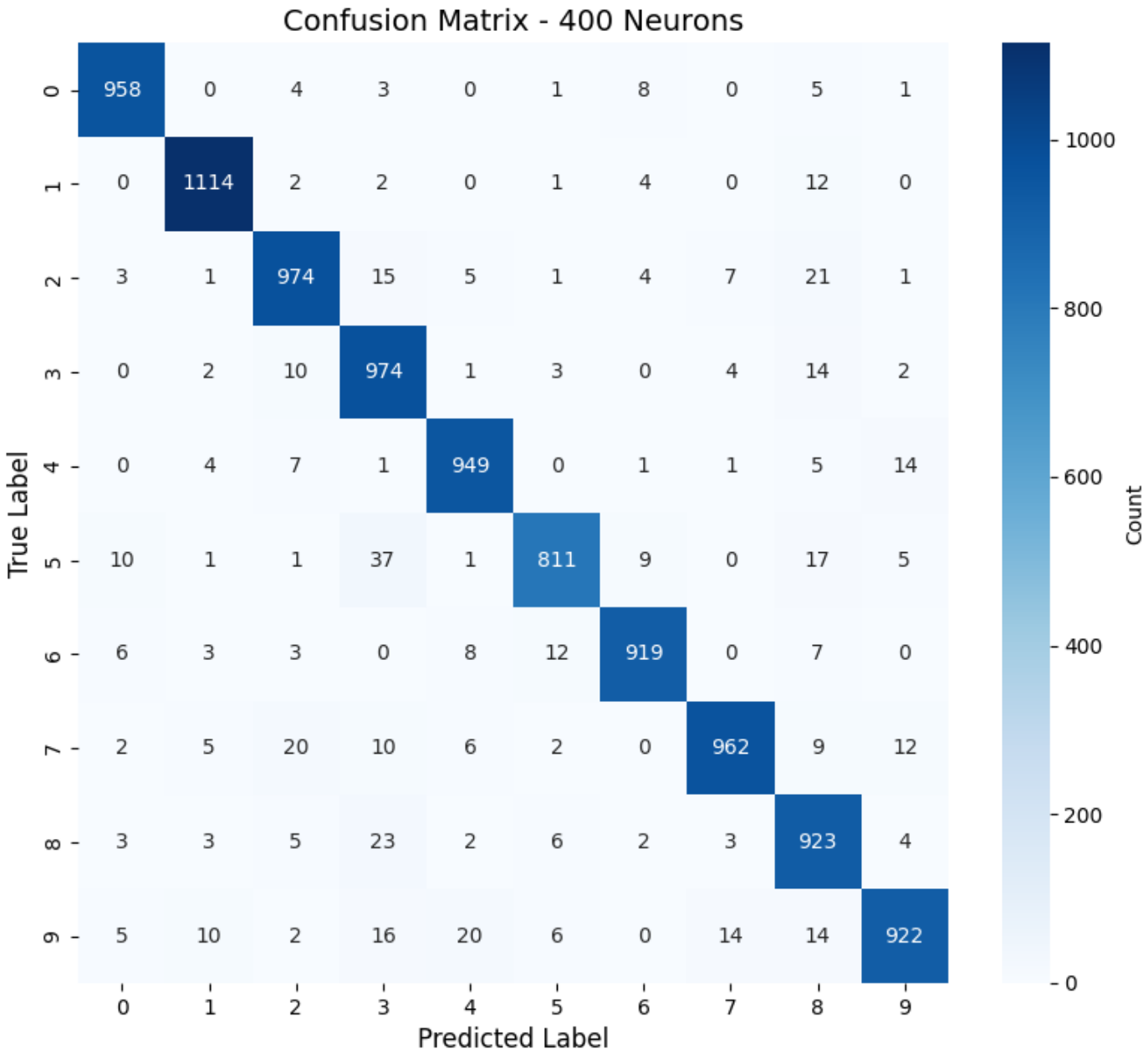
Supervised SNN with BPTT

- Framework: **snnTorch + PyTorch**
- Learning: **Backpropagation Through Time**
- Surrogate gradient: `fast_sigmoid`
- Architecture: $784 \rightarrow 400$ LIF $\rightarrow 10$
- GPU-friendly, fully differentiable

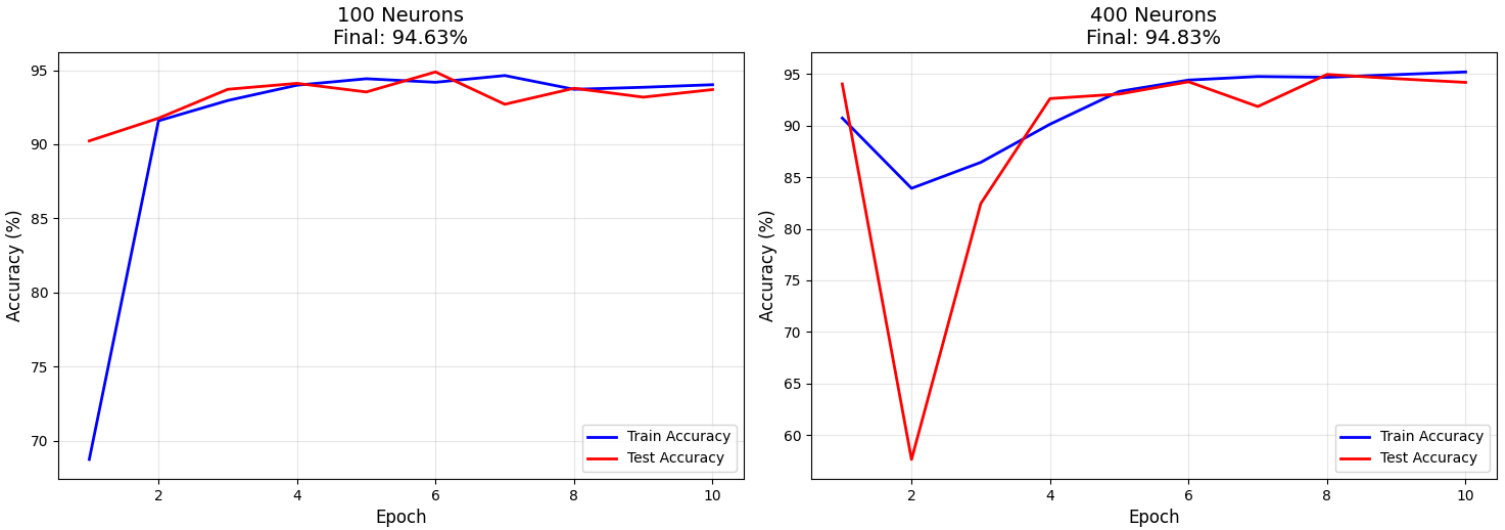
Supervised (10k): Accuracy Curve



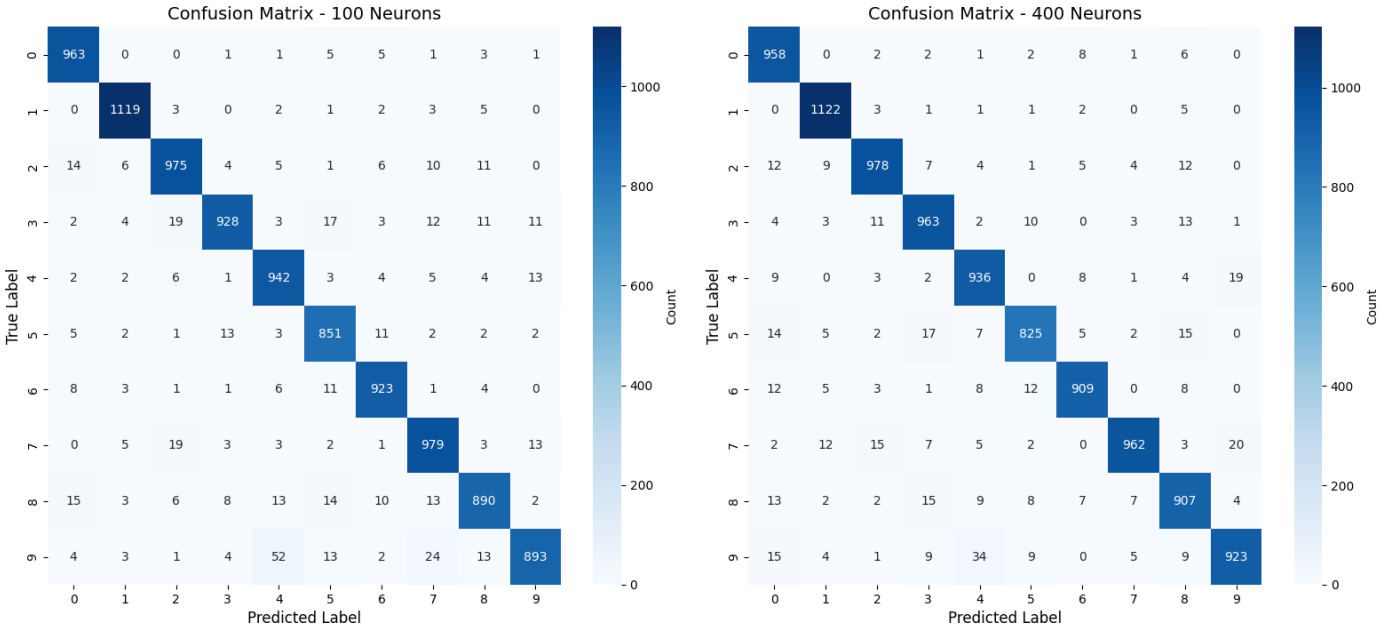
Supervised (10k): Confusion Matrix



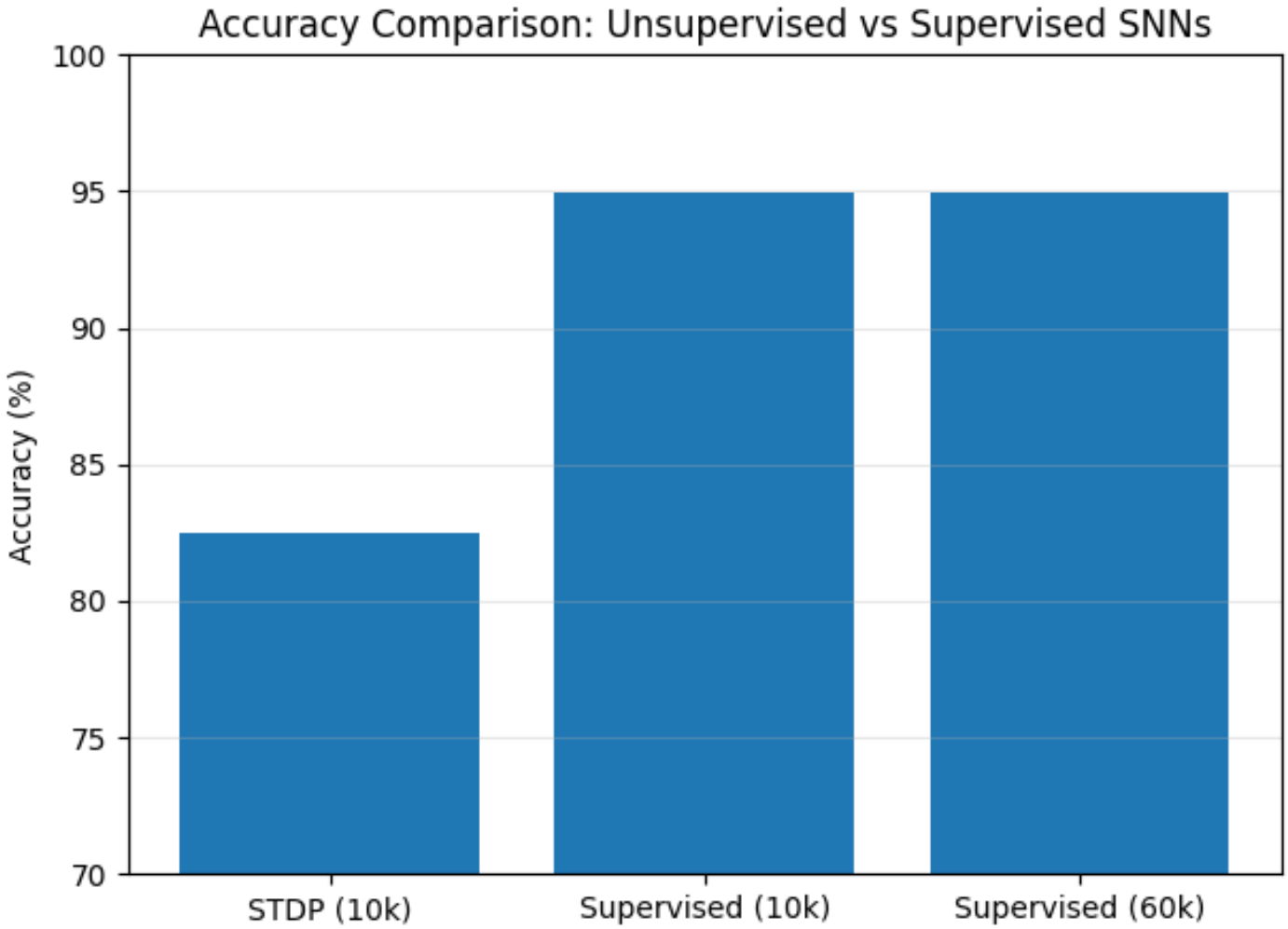
Supervised (60k): Accuracy Curve



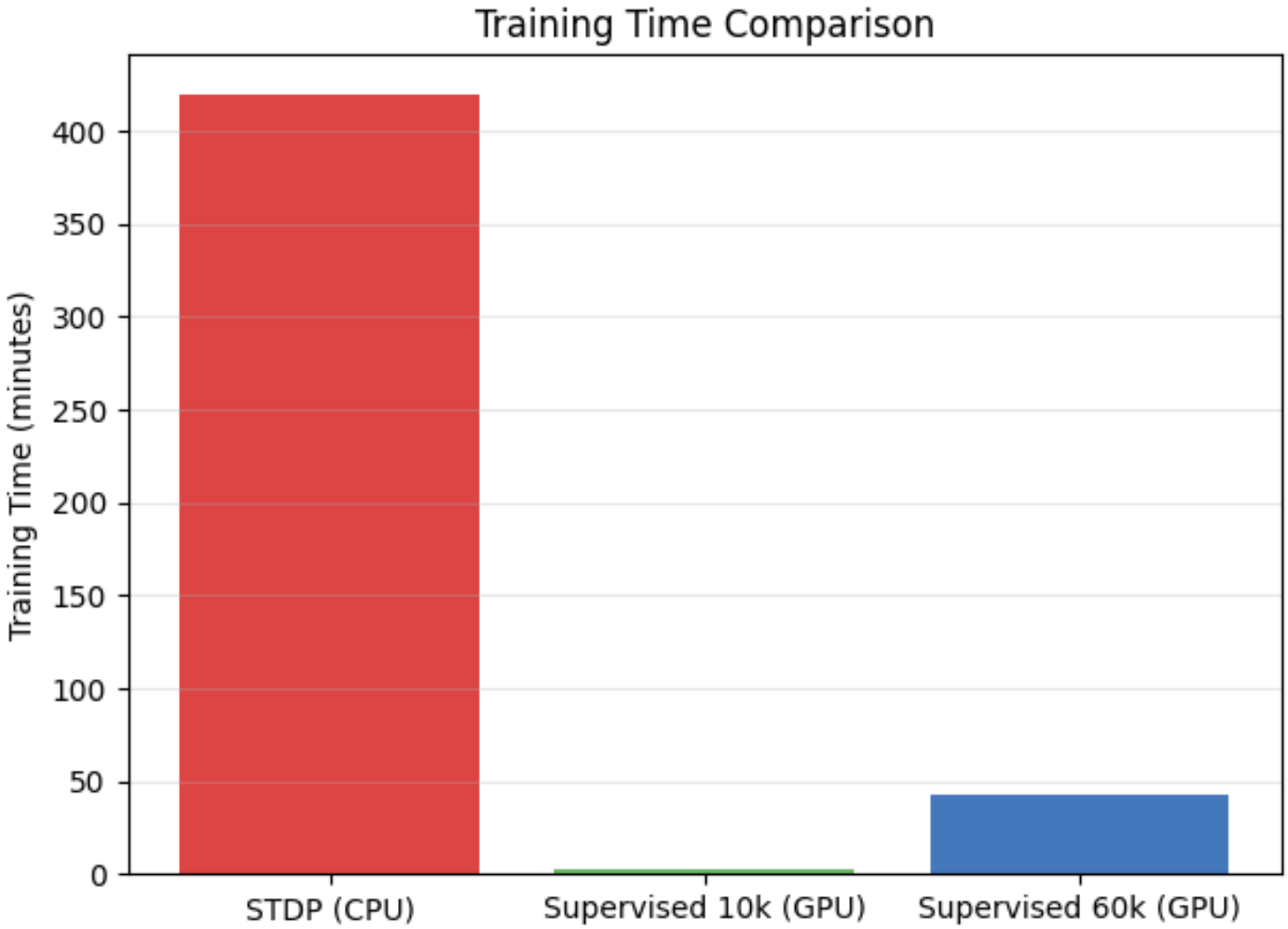
Supervised (60k): Confusion Matrix



Accuracy Comparison



Training Time Comparison



Quantitative Comparison

Metric	**STDP (10k)**	**Sup. (10k)**	**Sup. (60k)**
Accuracy	82.5%	94.97%	94.96%
Spikes/sample	16.1	37.5	37.5
Training Time	7 hr (CPU)	140.6s (CPU)	2561.9 (CPU)
Biological plausibility	High	Low	Low
Compute model	Event-driven	Dense BPTT	Dense BPTT

Limitations

STDP

- Slow (hours on CPU)
- Accuracy saturates around 82–85%

Supervised BPTT

- High memory usage (unrolled time)
- Requires labels
- Surrogate gradients biologically implausible

Recommendation

For engineering tasks (accuracy + efficiency):

- Supervised BPTT $\rightarrow$ **97% accuracy**, fast, scalable

For neuromorphic hardware / biological plausibility:

- STDP $\rightarrow$ spike-driven, local, low-power

Thank You!