



ICML
International Conference
On Machine Learning

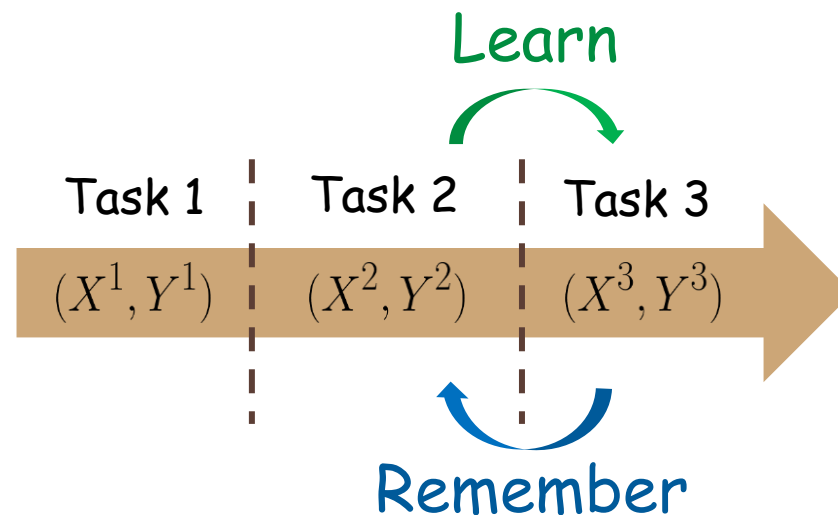
NISPA: Neuro-Inspired Stability-Plasticity Adaptation for Continual Learning in Sparse Networks

M. Burak Gurbuz and Constantine Dovrolis



Continual Learning and Catastrophic Forgetting

- Standard Neural Network Training
 - Shuffled inputs satisfy i.i.d assumption
- Continual Learning
 - Tasks encountered sequentially
 - Catastrophic Forgetting: overwrite information from past task(s)



From Neuroscience to Deep Learning

- Five facts about brain's structure and function.



From Neuroscience to Deep Learning

- Five facts about brain's structure and function.



- ❖ Babadi & Sompolinsky, Sparseness and expansion in sensory representations, Neuron 2014
- ❖ Holmgren et. al., Pyramidal cell communication within local networks in layer 2/3 of rat neocortex, The Journal of Physiology, 2003

From Neuroscience to Deep Learning

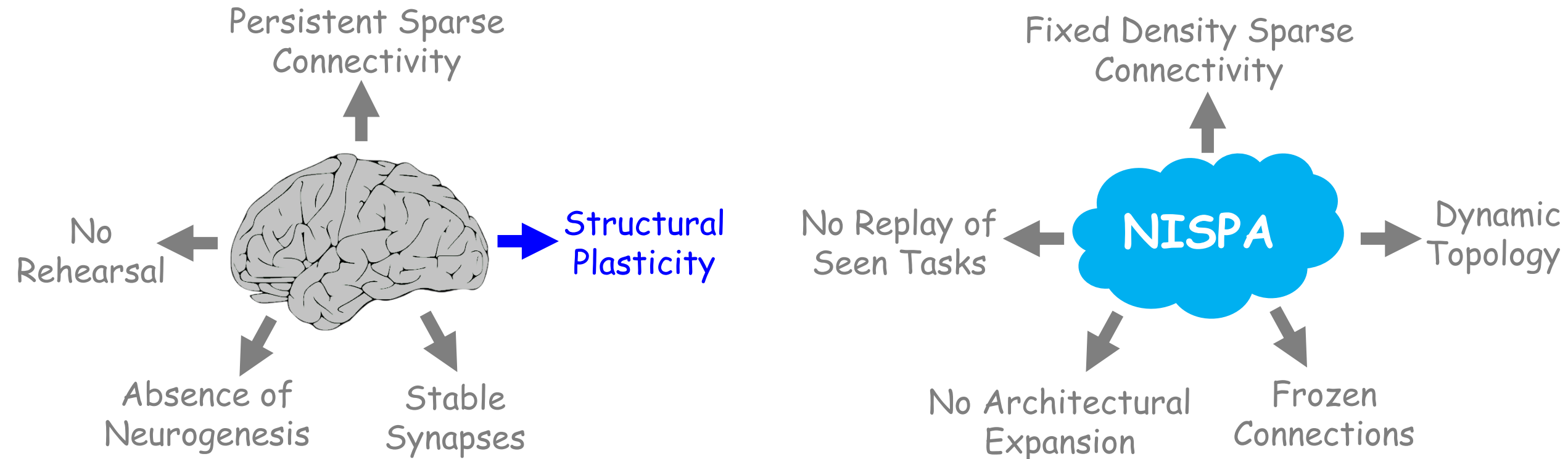
- Five facts about brain's structure and function.



- ❖ Babadi & Sompolinsky, Sparseness and expansion in sensory representations, Neuron 2014
- ❖ Holmgren et. al., Pyramidal cell communication within local networks in layer 2/3 of rat neocortex, The Journal of Physiology, 2003

From Neuroscience to Deep Learning

- Five facts about brain's structure and function.



- ❖ Fu & Zuo, Experience-dependent structural plasticity in the cortex, Trends in Neurosciences 2011
- ❖ Kasai et al. Structural dynamics of dendritic spines in memory and cognition, Trends in Neurosciences, 2010

From Neuroscience to Deep Learning

- Five facts about brain's structure and function.



- ❖ Fu & Zuo, Experience-dependent structural plasticity in the cortex, Trends in Neurosciences 2011
- ❖ Kasai et al. Structural dynamics of dendritic spines in memory and cognition, Trends in Neurosciences, 2010

From Neuroscience to Deep Learning

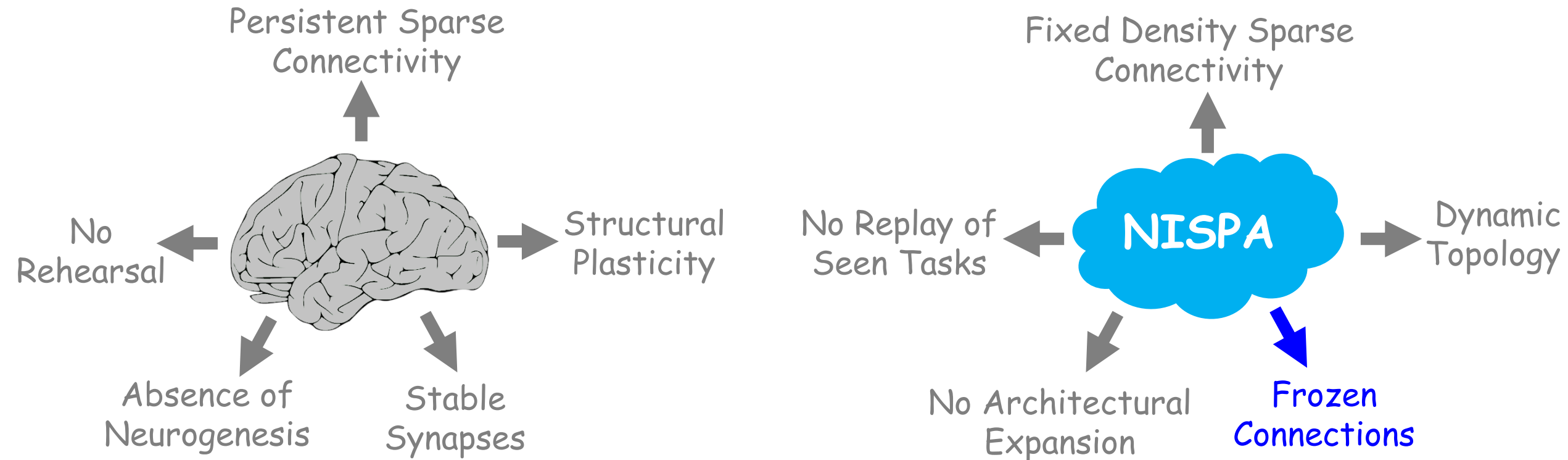
- Five facts about brain's structure and function.



- ❖ Yang et al. Stably maintained dendritic spines are associated with lifelong memories, *Nature*, 2009
- ❖ Grutzendler et al. Long-term dendritic spine stability in the adult cortex, *Nature*, 2002

From Neuroscience to Deep Learning

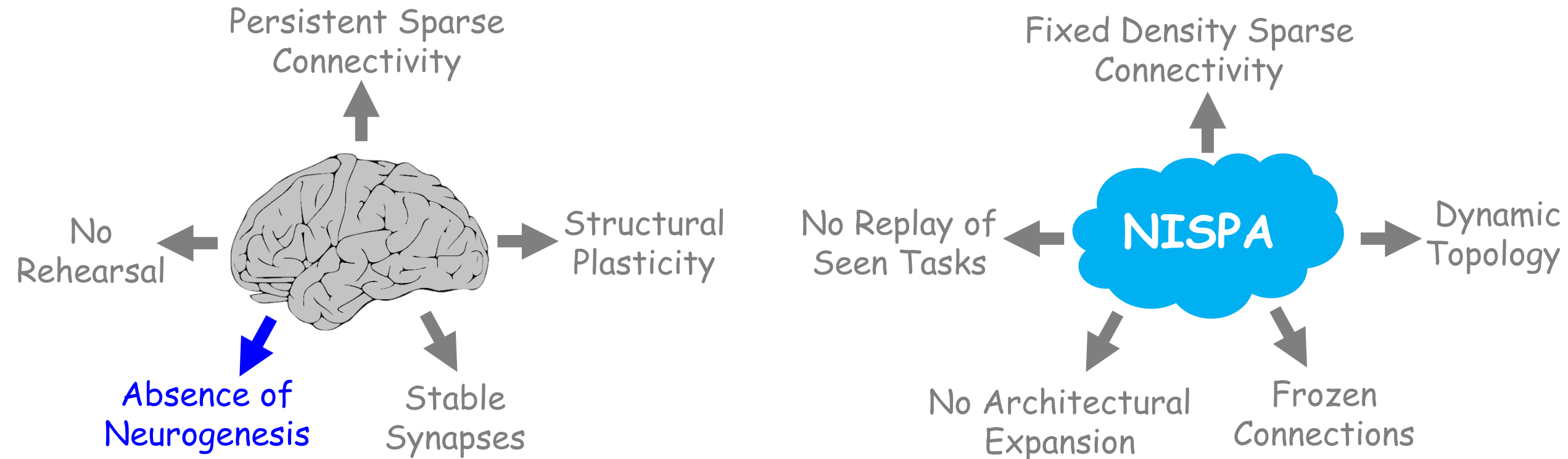
- Five facts about brain's structure and function.



- ❖ Yang et al. Stably maintained dendritic spines are associated with lifelong memories, *Nature*, 2009
- ❖ Grutzendler et al. Long-term dendritic spine stability in the adult cortex, *Nature*, 2002

From Neuroscience to Deep Learning

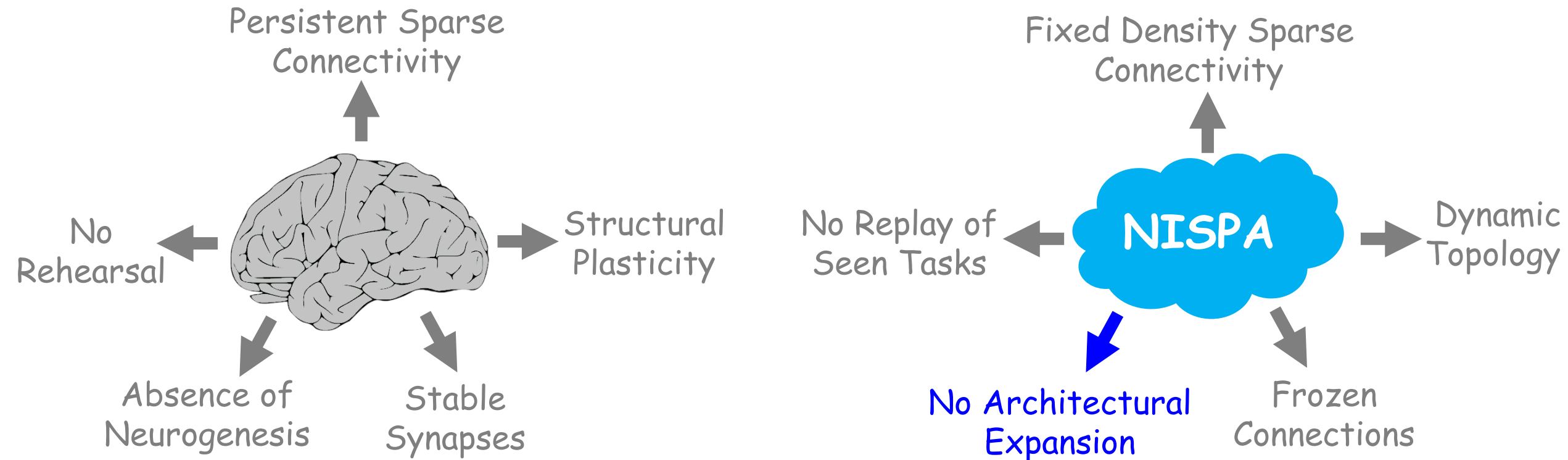
- Five facts about brain's structure and function.



- ❖ Leuner et al. *Is There A Link Between Adult Neurogenesis and Learning?*, Hippocampus, 2006
- ❖ Ming and Song, *Adult Neurogenesis in the Mammalian Brain: Significant Answers and Significant Questions*, Neuron, 2011

From Neuroscience to Deep Learning

- Five facts about brain's structure and function.



- ❖ Leuner et al. Is There A Link Between Adult Neurogenesis and Learning?, Hippocampus, 2006
- ❖ Ming and Song, Adult Neurogenesis in the Mammalian Brain: Significant Answers and Significant Questions, Neuron, 2011

From Neuroscience to Deep Learning

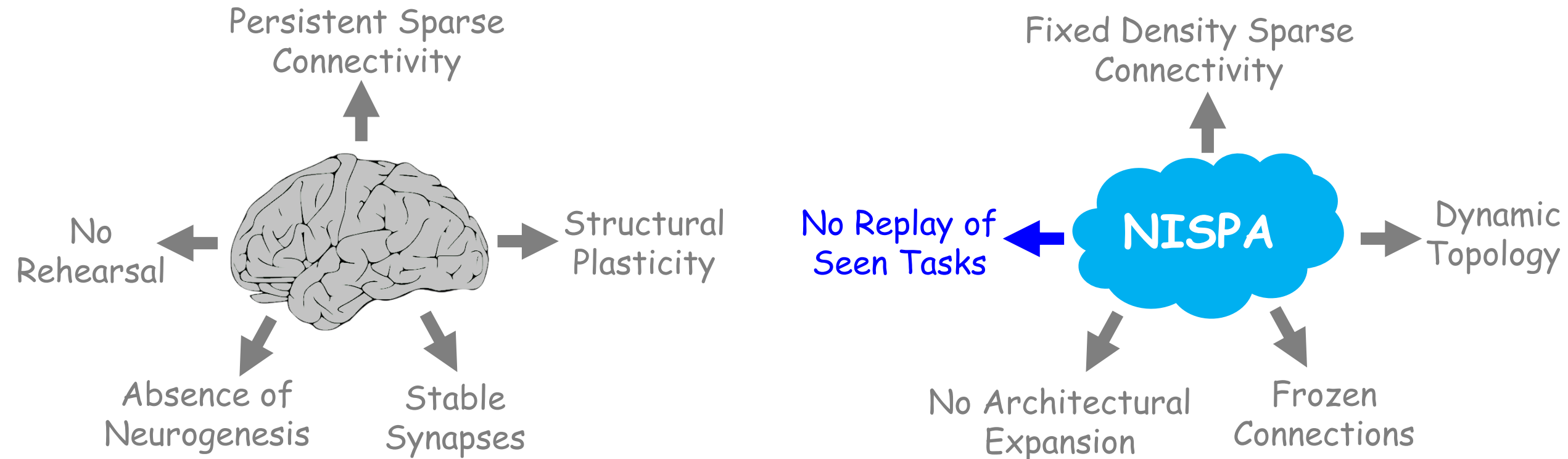
- Five facts about brain's structure and function.



- ❖ Gupta et al. Hippocampal replay is not a simple function of experience, *Neuron*, 2010
- ❖ van de Ven et al. Brain-inspired replay for continual learning with artificial neural networks. *Nature Communications*, 2020


From Neuroscience to Deep Learning

- Five facts about brain's structure and function.



- ❖ Gupta et al. Hippocampal replay is not a simple function of experience, *Neuron*, 2010
- ❖ van de Ven et al. Brain-inspired replay for continual learning with artificial neural networks. *Nature Communications*, 2020

NISPA: Stable Unit Selection

 Plastic Units  Candidate Stable Units  Stable Units

NISPA: Stable Unit Selection

○ Plastic Units



Learn new
information

○ Candidate Stable Units



Transition
State

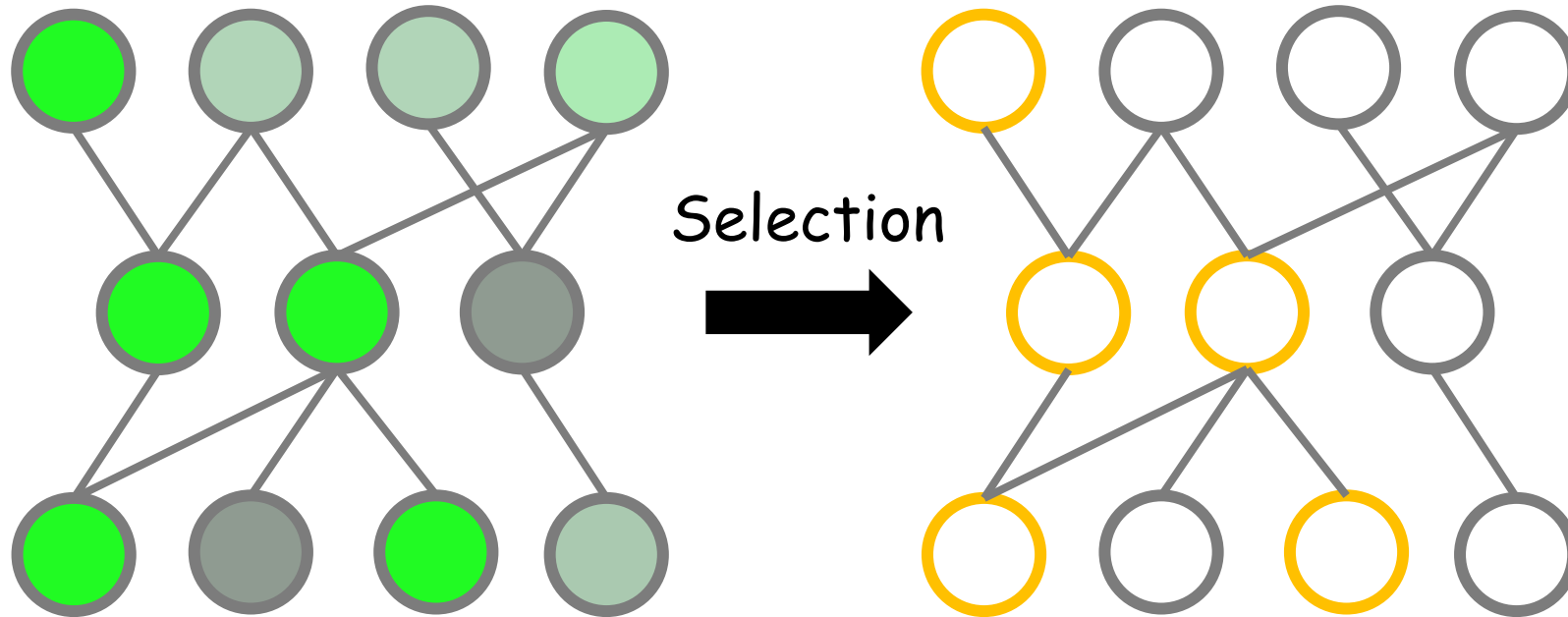
○ Stable Units



Preserve old
information

NISPA: Stable Unit Selection

○ Plastic Units ○ Candidate Stable Units ○ Stable Units



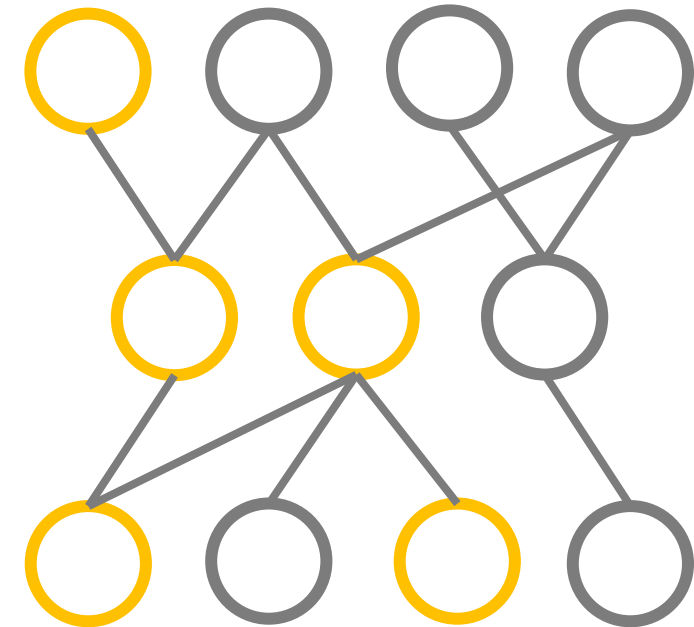
Less Activation  High Activation

NISPA: Rewiring

○ Plastic Units

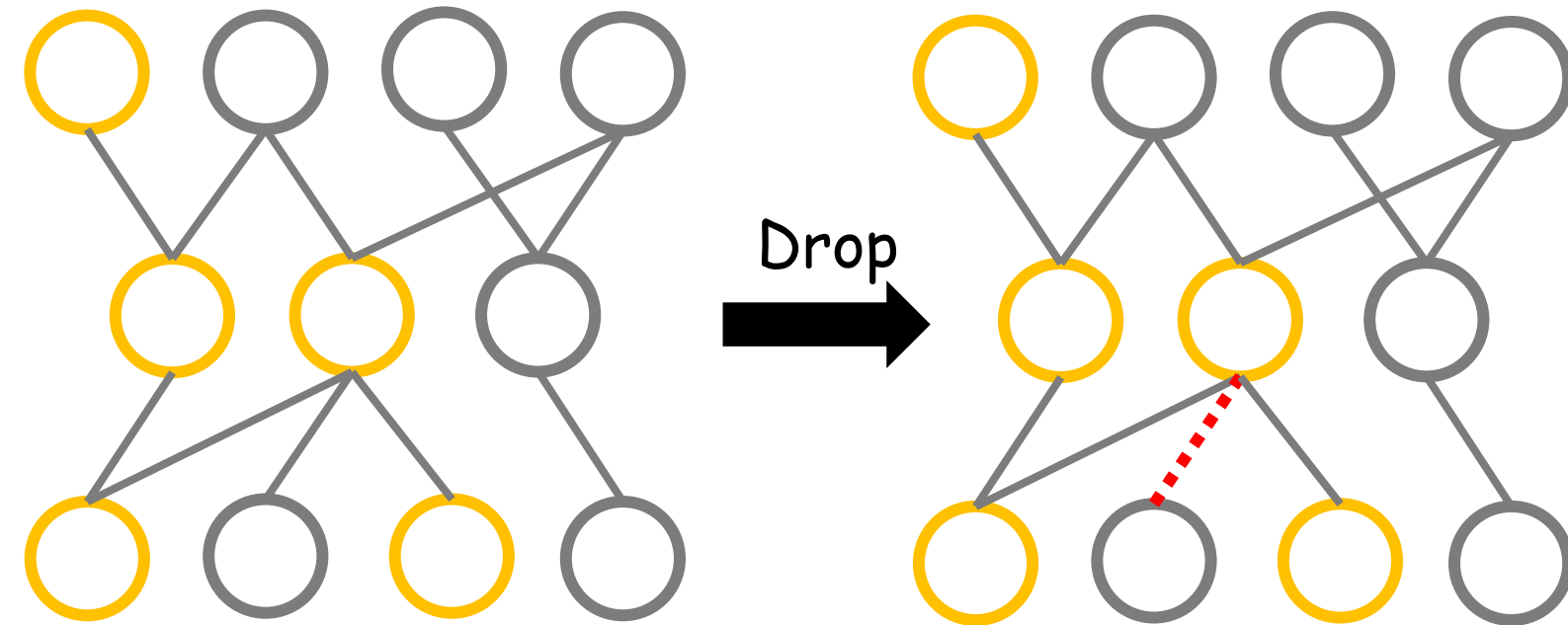
○ Candidate Stable Units

○ Stable Units



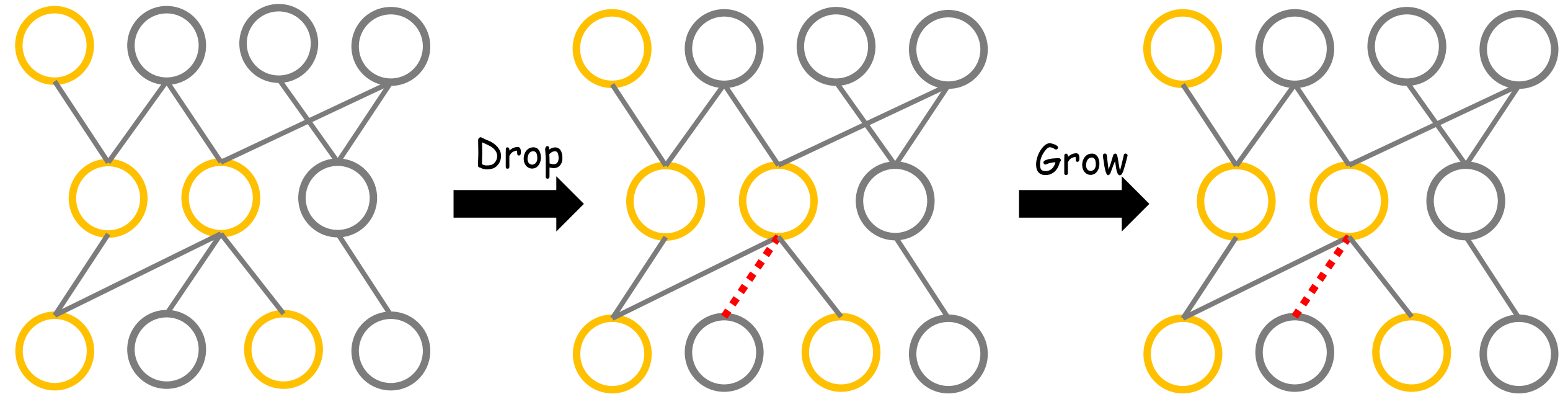
NISPA: Rewiring

○ Plastic Units ○ Candidate Stable Units ○ Stable Units



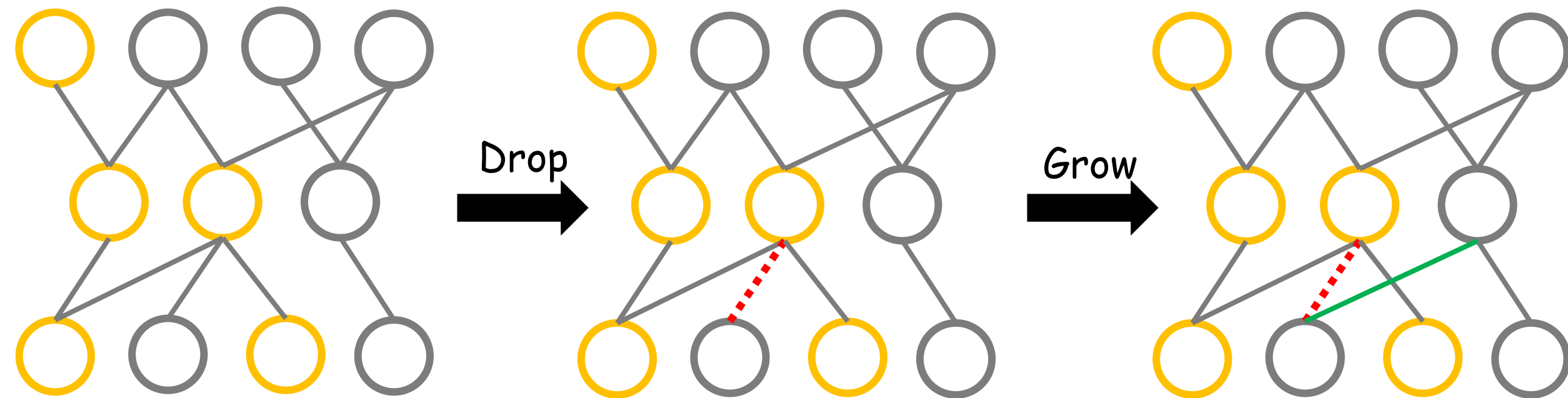
NISPA: Rewiring

○ Plastic Units ○ Candidate Stable Units ○ Stable Units



NISPA: Rewiring

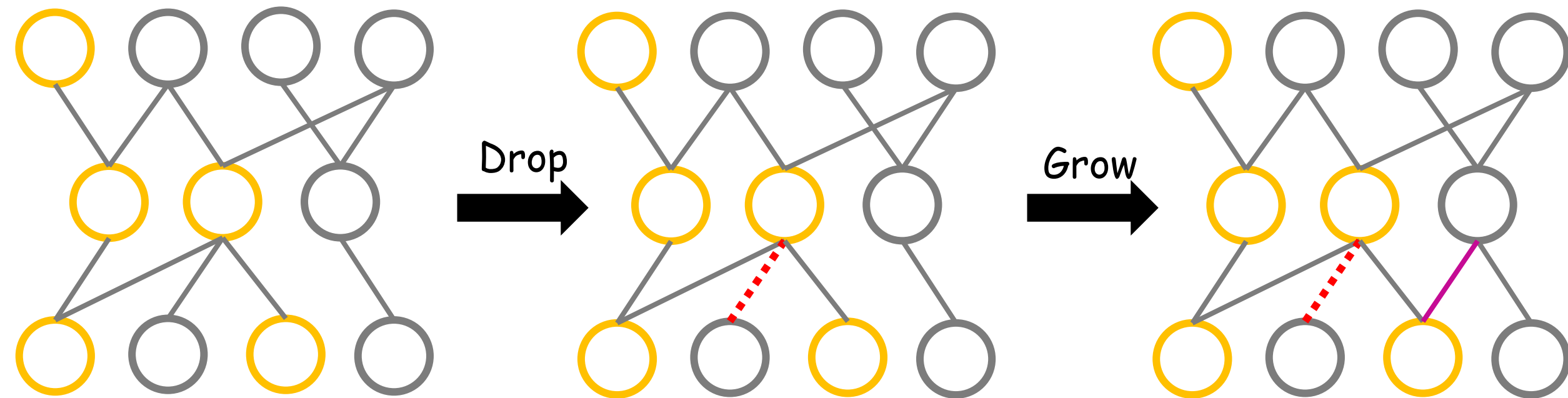
○ Plastic Units ○ Candidate Stable Units ○ Stable Units



Plastic → Plastic
(New Representation)

NISPA: Rewiring

○ Plastic Units ○ Candidate Stable Units ○ Stable Units



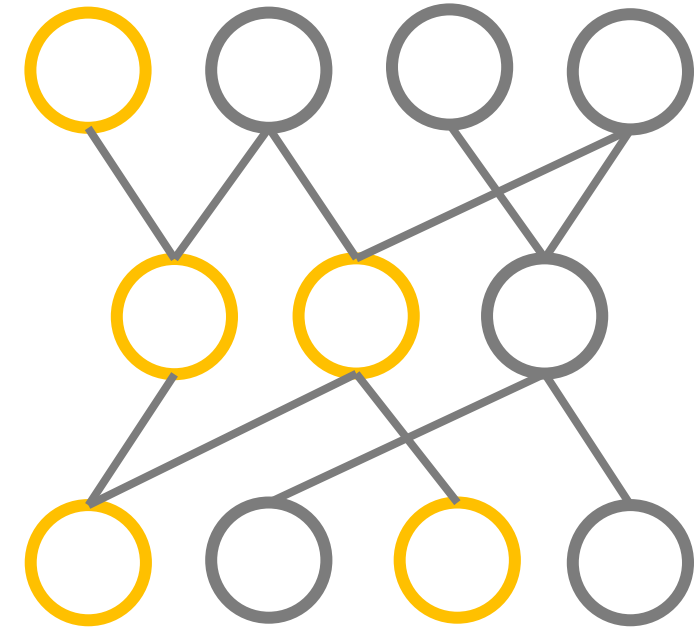
Stable → Plastic
(Transfer)

NISPA: Stabilizing a Unit

○ Plastic Units

○ Candidate Stable Units

○ Stable Units

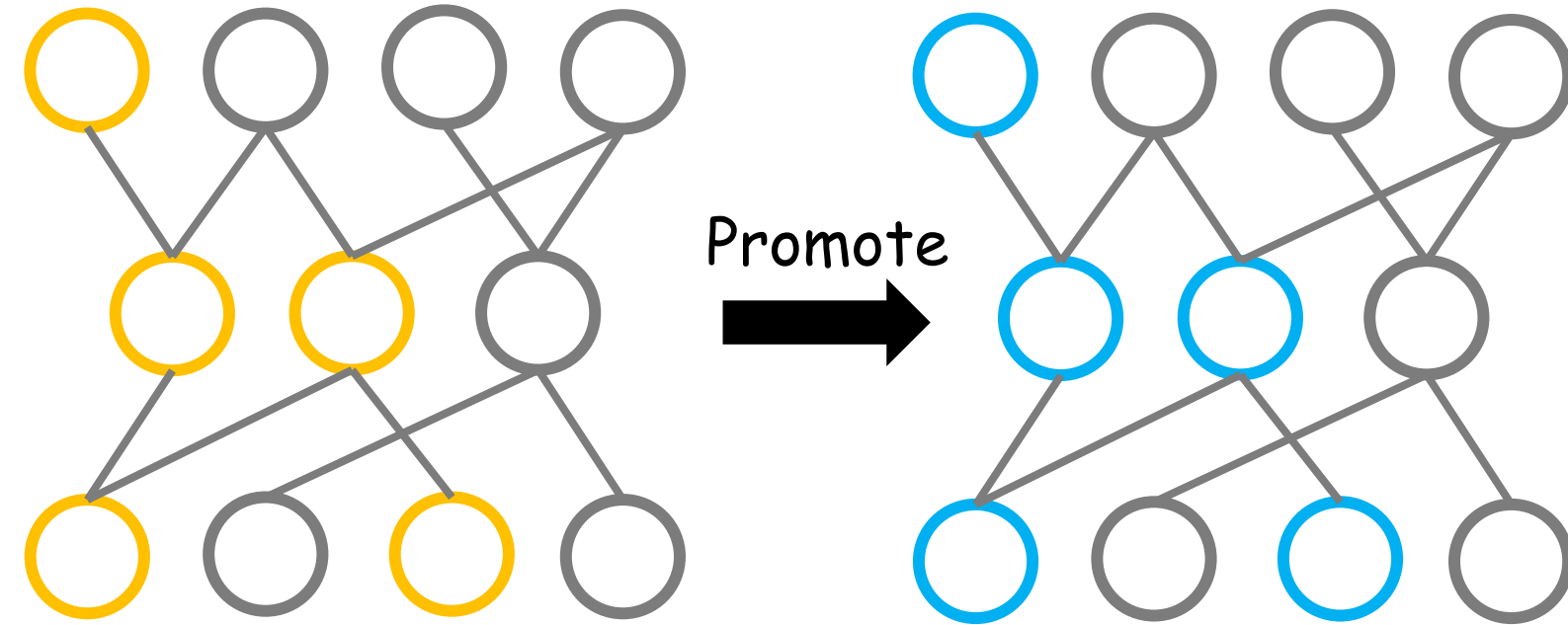


NISPA: Stabilizing a Unit

○ Plastic Units

○ Candidate Stable Units

○ Stable Units

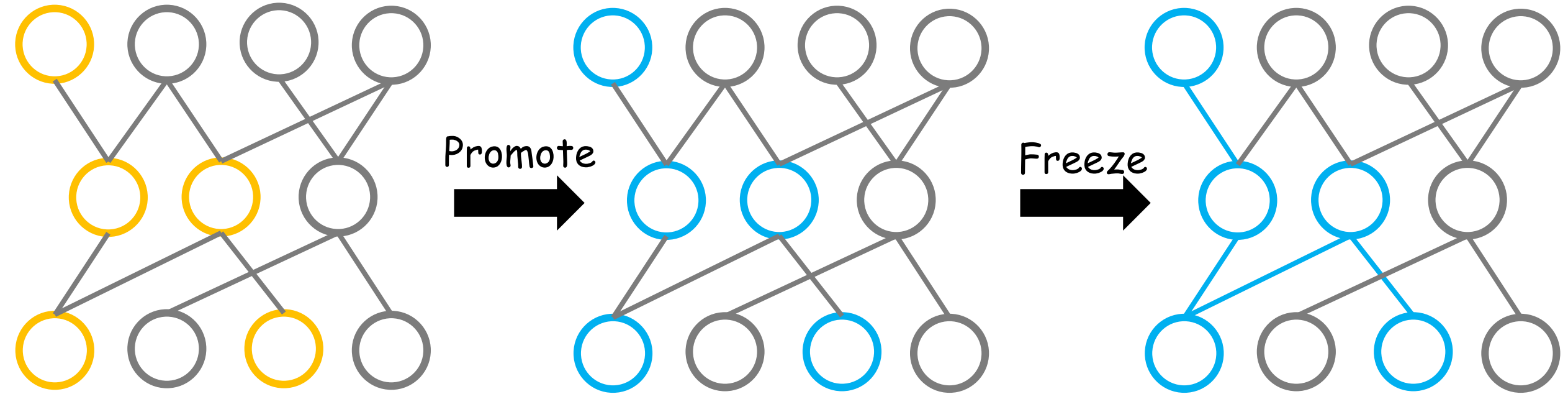


NISPA: Stabilizing a Unit

○ Plastic Units

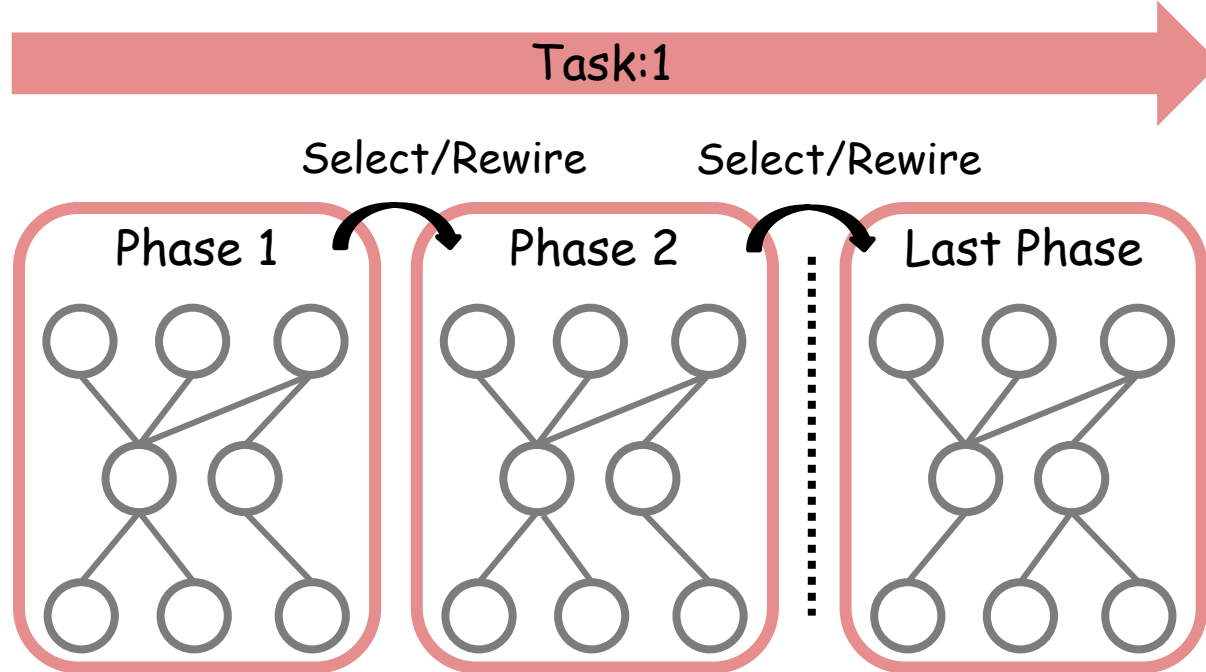
○ Candidate Stable Units

○ Stable Units



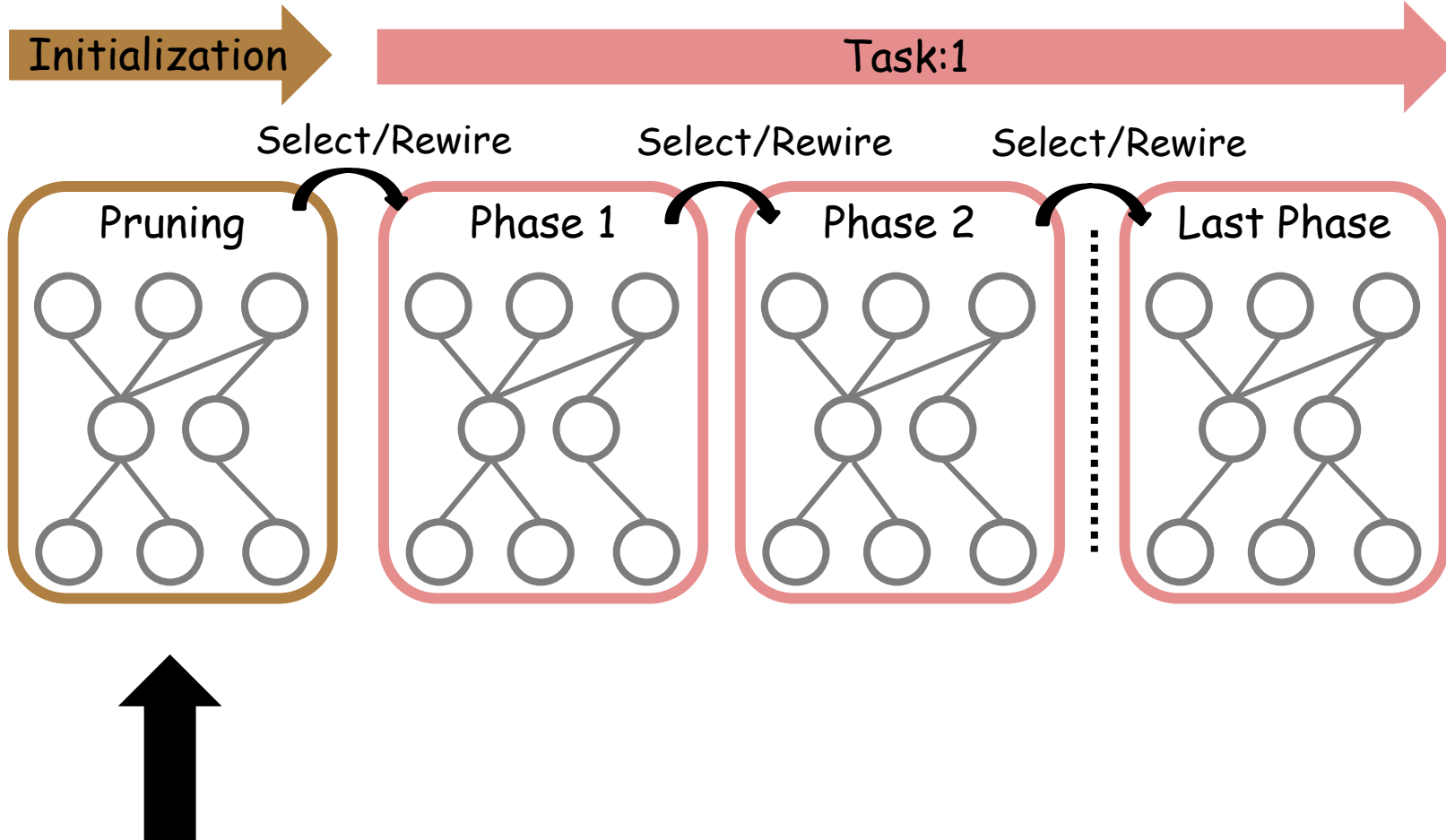
NISPA: Putting It All Together

○ Plastic Units ○ Candidate Stable Units ○ Stable Units



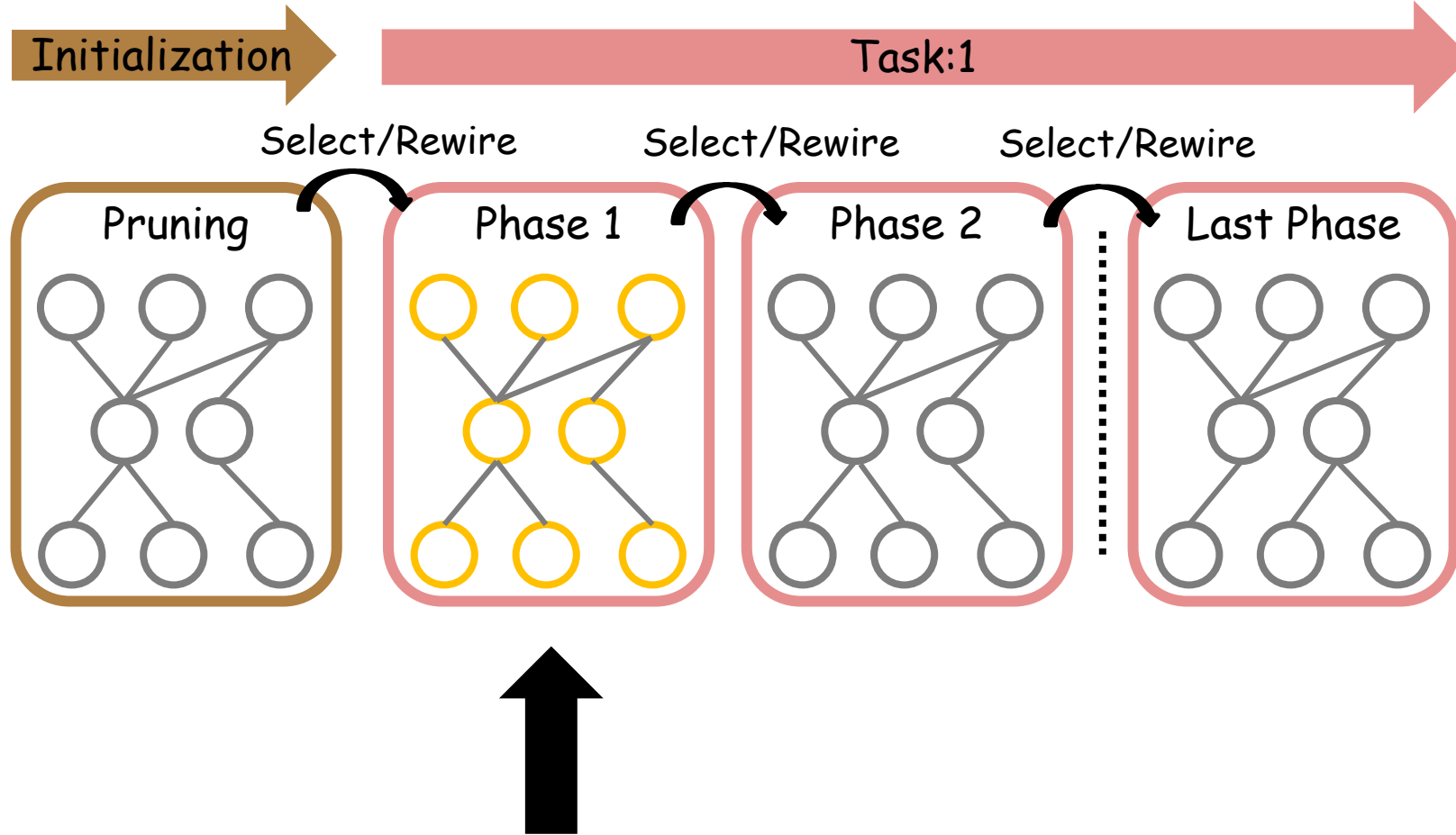
NISPA: Putting It All Together

○ Plastic Units ○ Candidate Stable Units ○ Stable Units



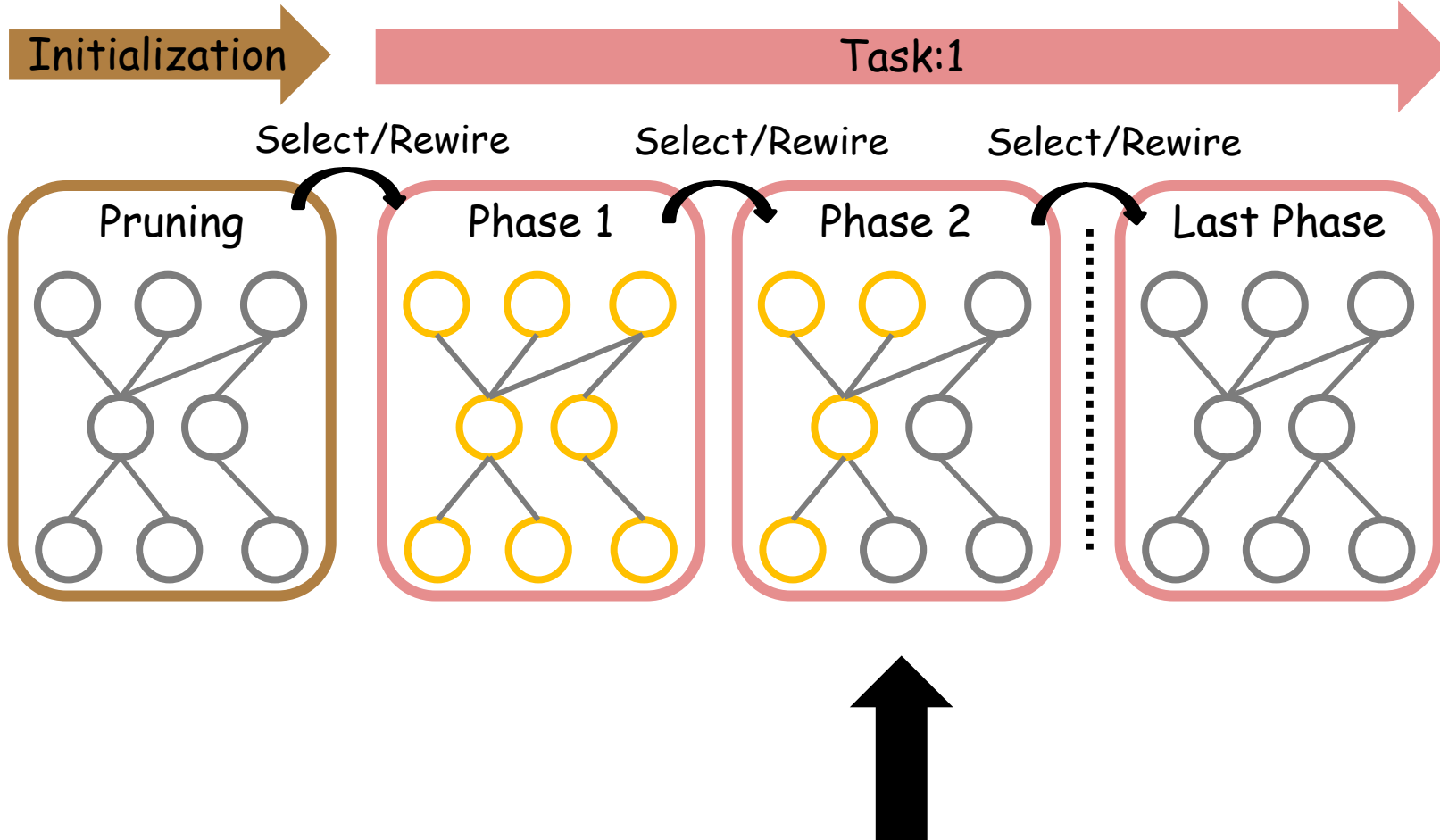
NISPA: Putting It All Together

○ Plastic Units ○ Candidate Stable Units ○ Stable Units



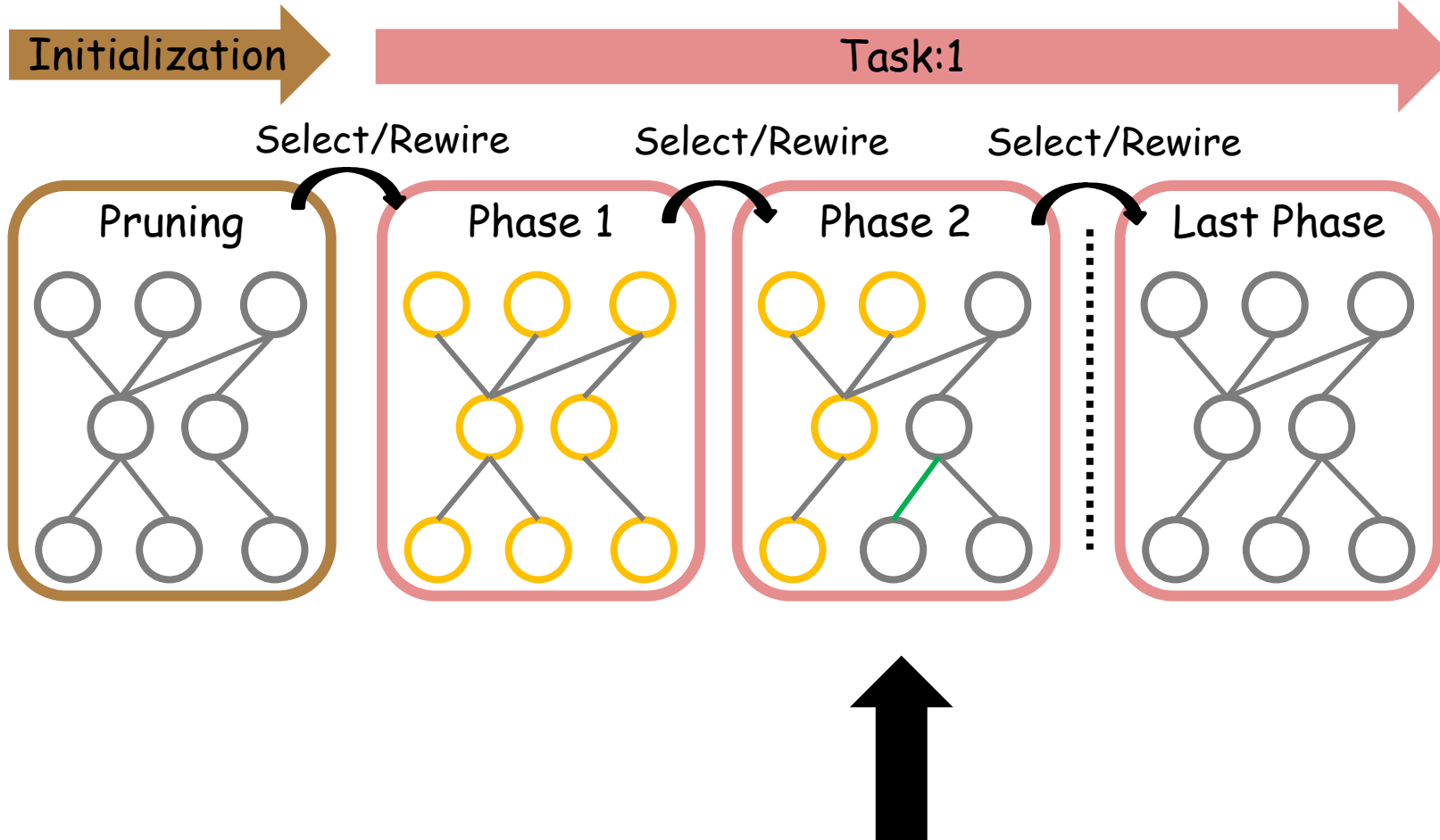
NISPA: Putting It All Together

○ Plastic Units ○ Candidate Stable Units ○ Stable Units



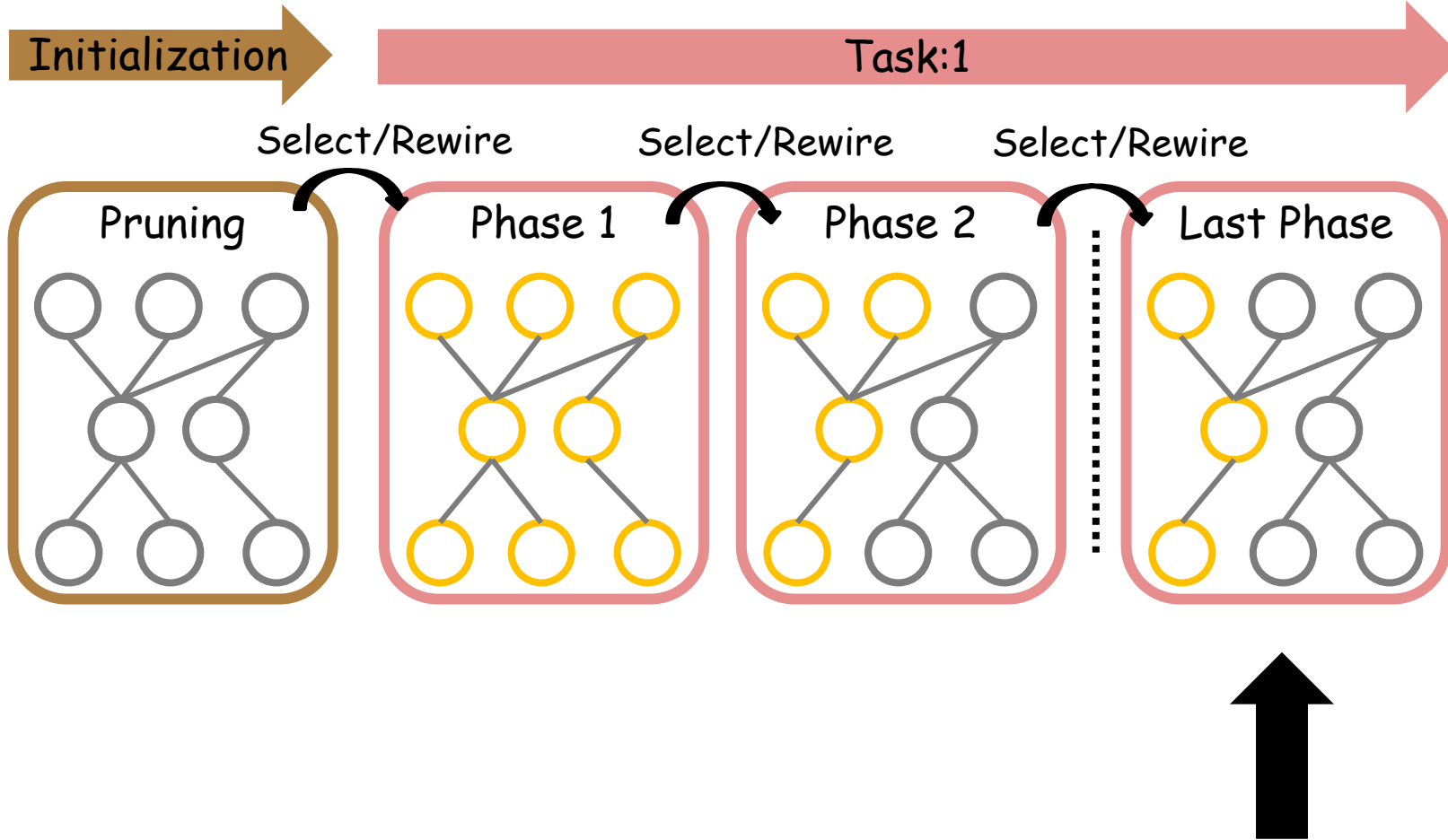
NISPA: Putting It All Together

○ Plastic Units ○ Candidate Stable Units ○ Stable Units

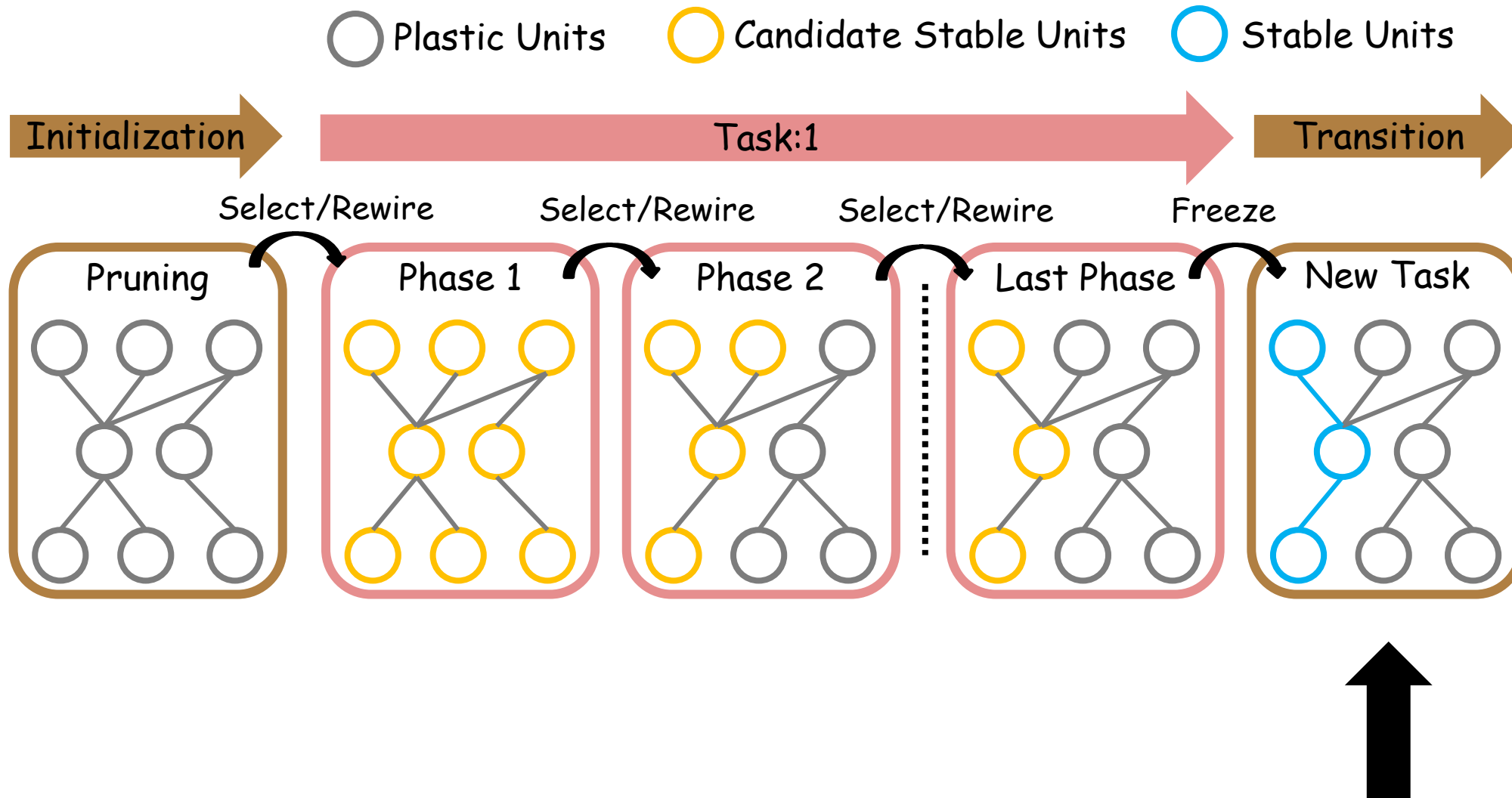


NISPA: Putting It All Together

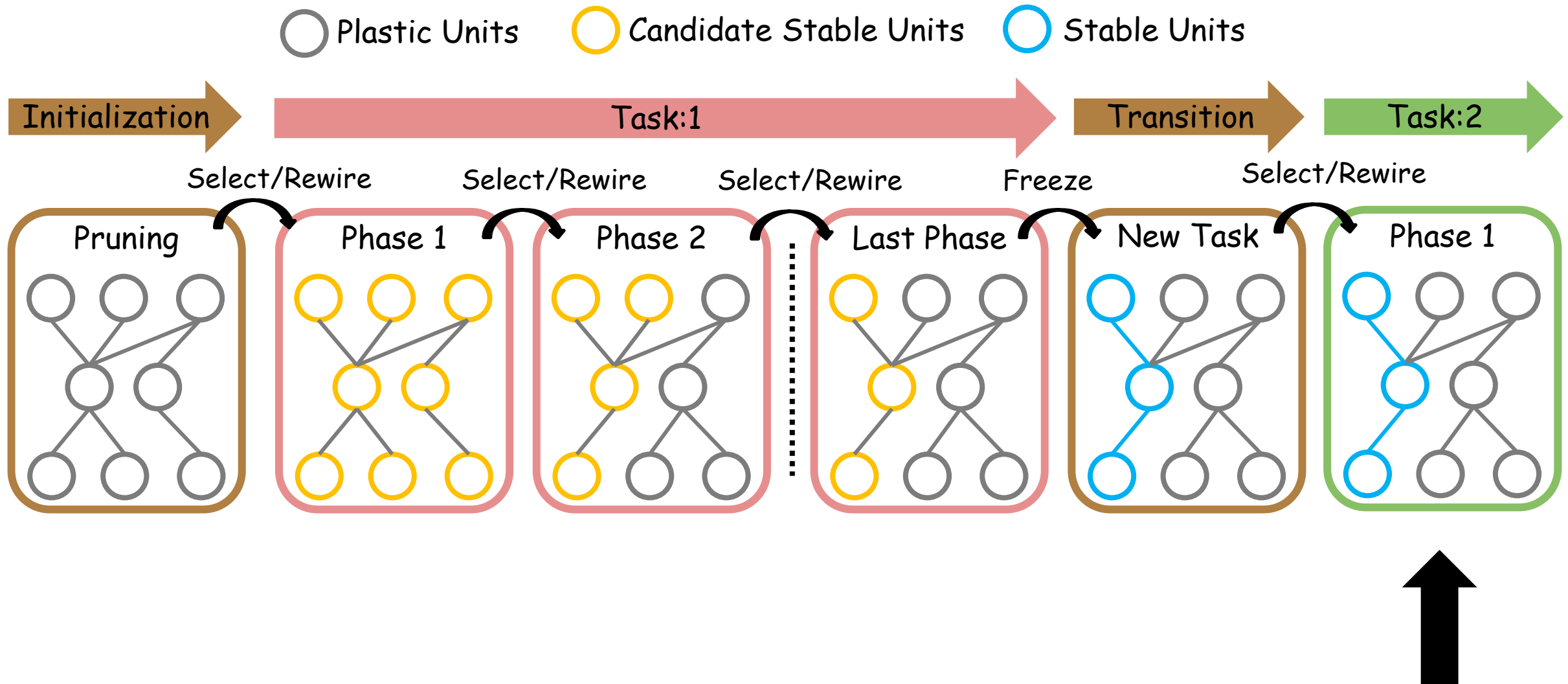
○ Plastic Units ○ Candidate Stable Units ○ Stable Units



NISPA: Putting It All Together

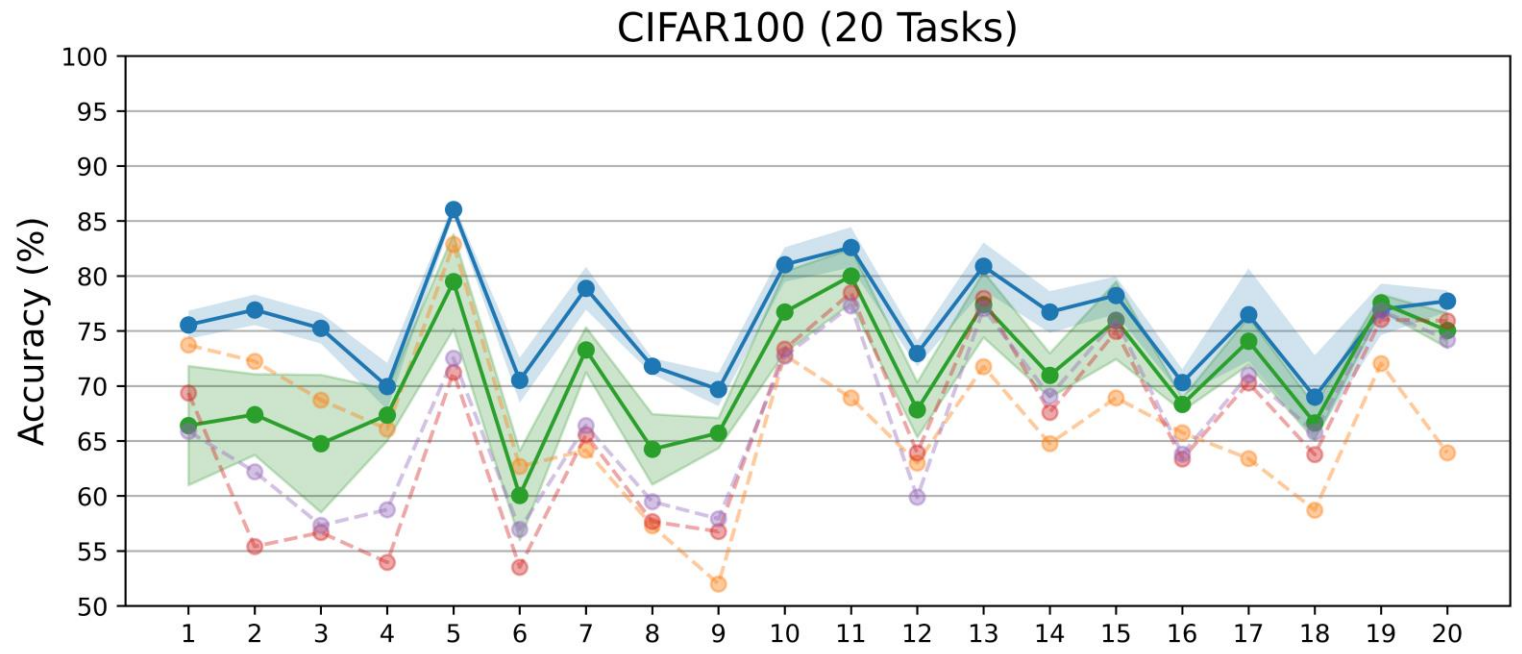
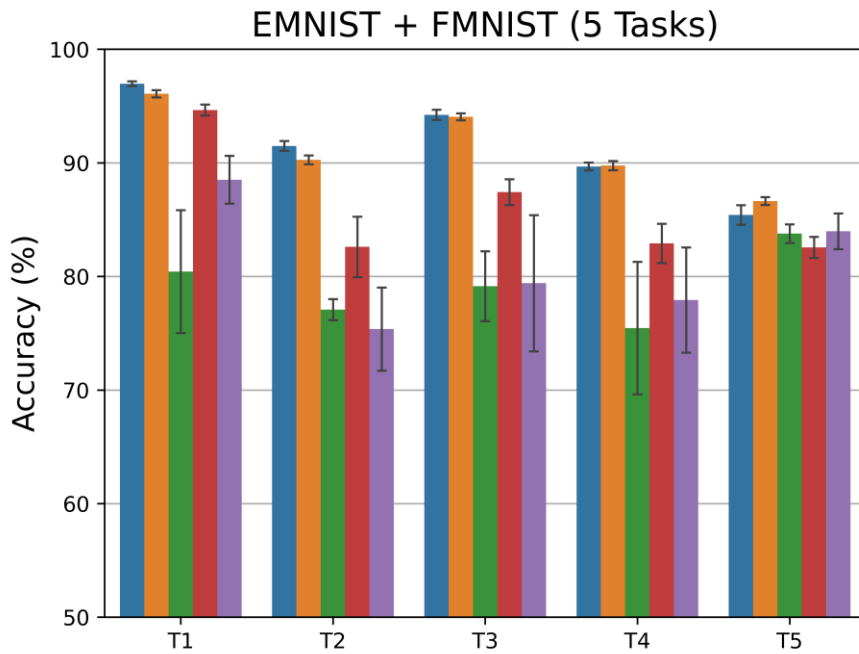


NISPA: Putting It All Together



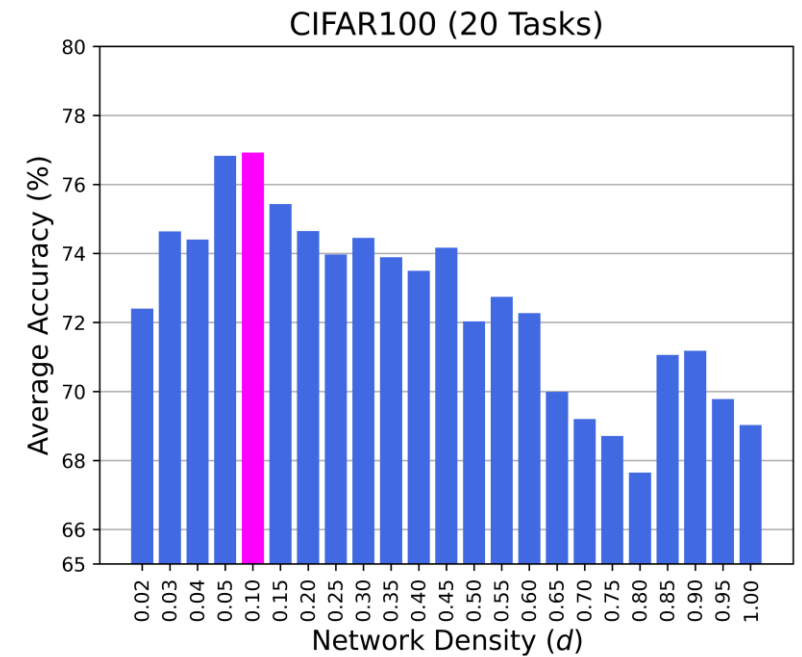
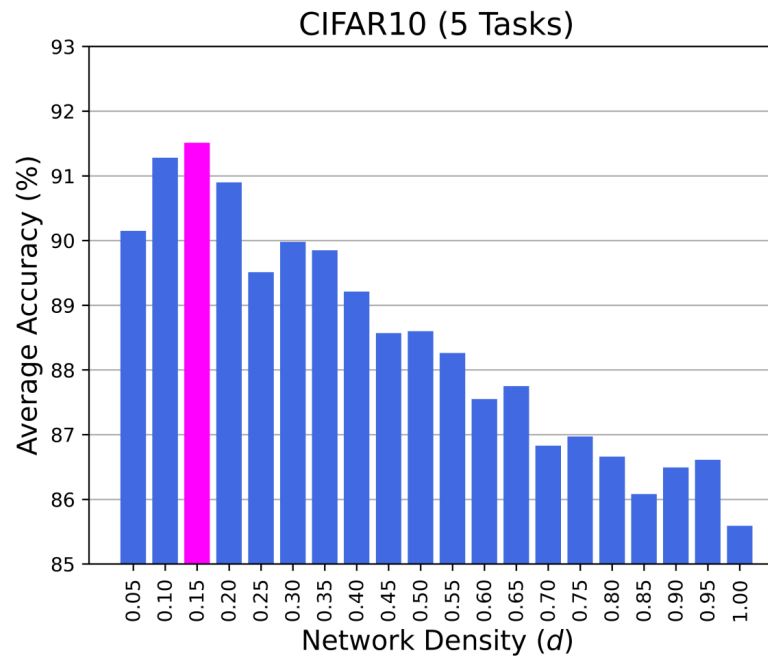
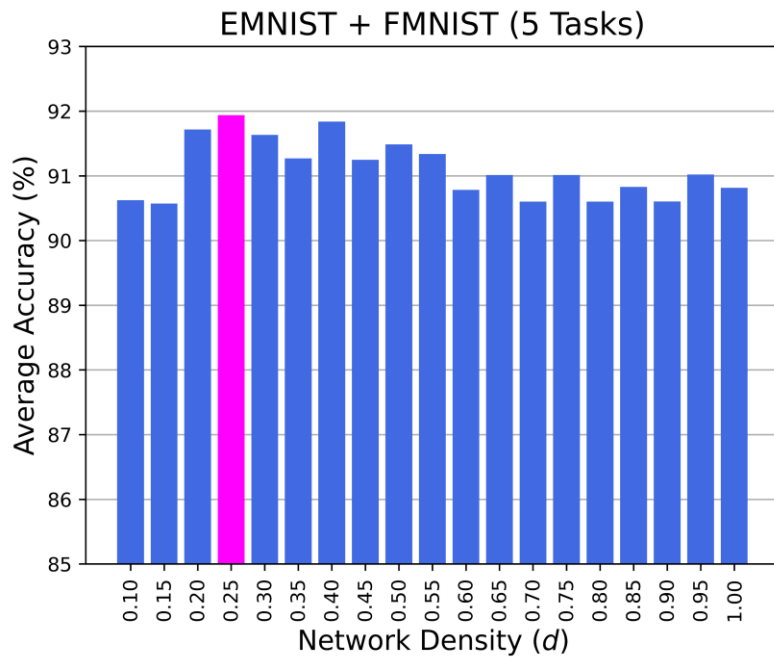
NISPA Outperforms State-of-the-Art Methods

- NISPA outperforms baselines, using up to ten times fewer parameters.



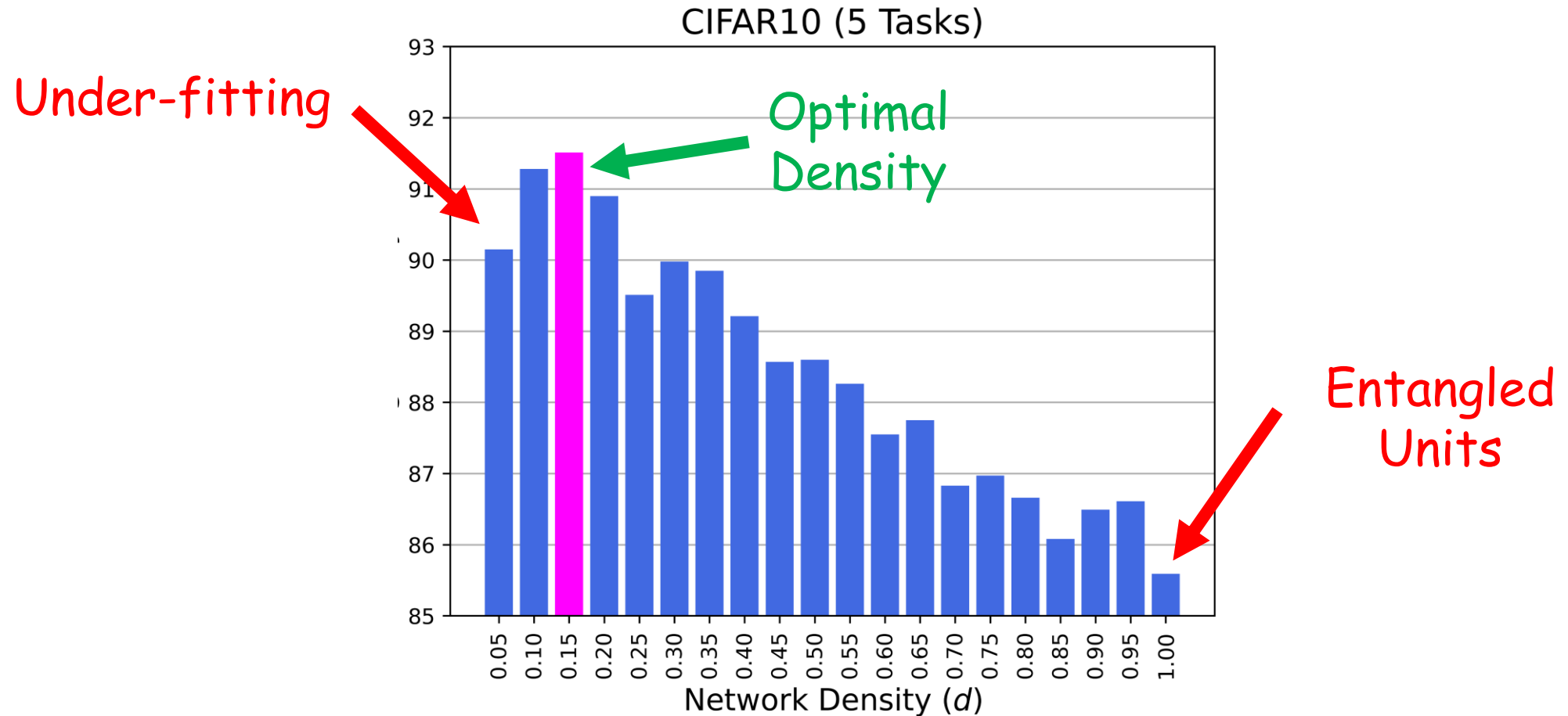
Sparsity is Necessary

- Sparsity is an essential ingredient for continual learning.



Sparsity is Necessary

- Sparsity is an essential ingredient for continual learning.



Conclusion and Future Work

- Conclusion
 - NISPA is a neuro-inspired continual learning approach.
 - It uses sparsity and dynamic connectivity to avoid catastrophic forgetting.
 - Outperforms baselines using up to ten times fewer parameters.
- Future Work
 - Selective unfreezing strategies
 - Using network-theoretic metrics for connection rewiring.