Gating cells as an emergent property of artificial neural networks

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Neuroethology

- Study of neural circuits that have evolved to solve problems in an animal's natural environment
- **Fixed action pattern**
  - swimming in a leech
  - egg-rolling in geese
- **Motor pattern generator**

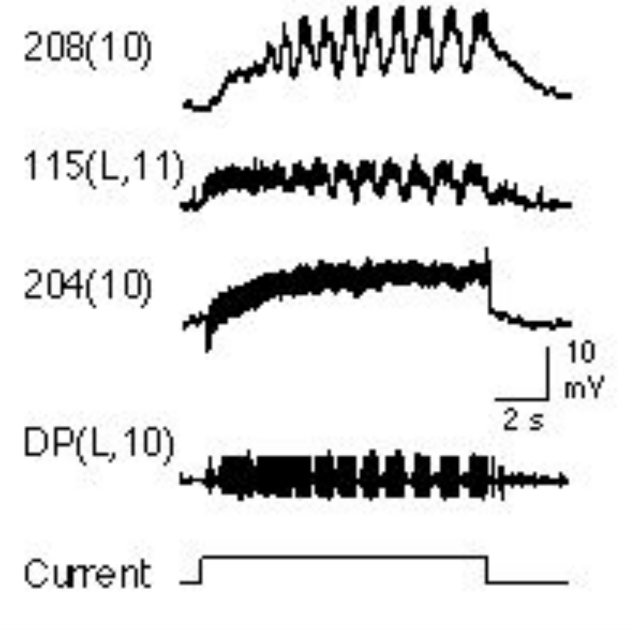
Idealized Gating Cells

- Neuronal switches
  - controls motor pattern generator (on / off)
  - continues to fire during motor pattern
- Necessary
- Sufficient

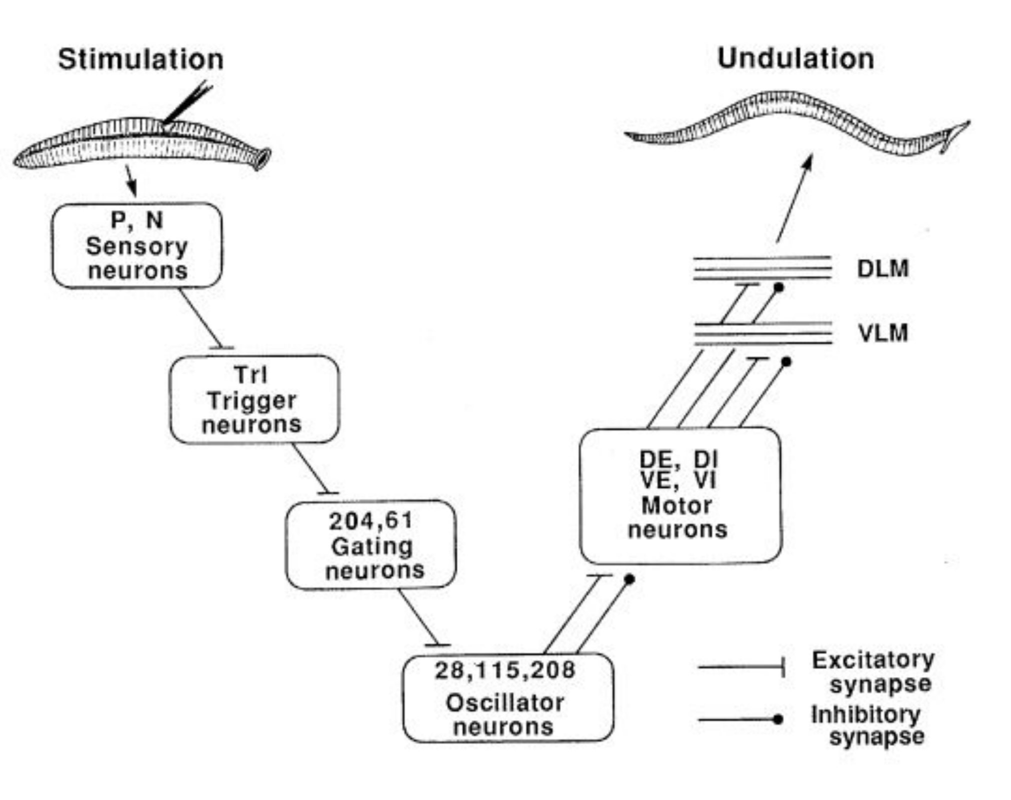
Cell 204, a real world gating cell

- activated by mechanoreceptors
- continues to fire after sensory event

  has ceased
- excites a central pattern generator
- produce swimming in the leech



Conceptual model



Linear

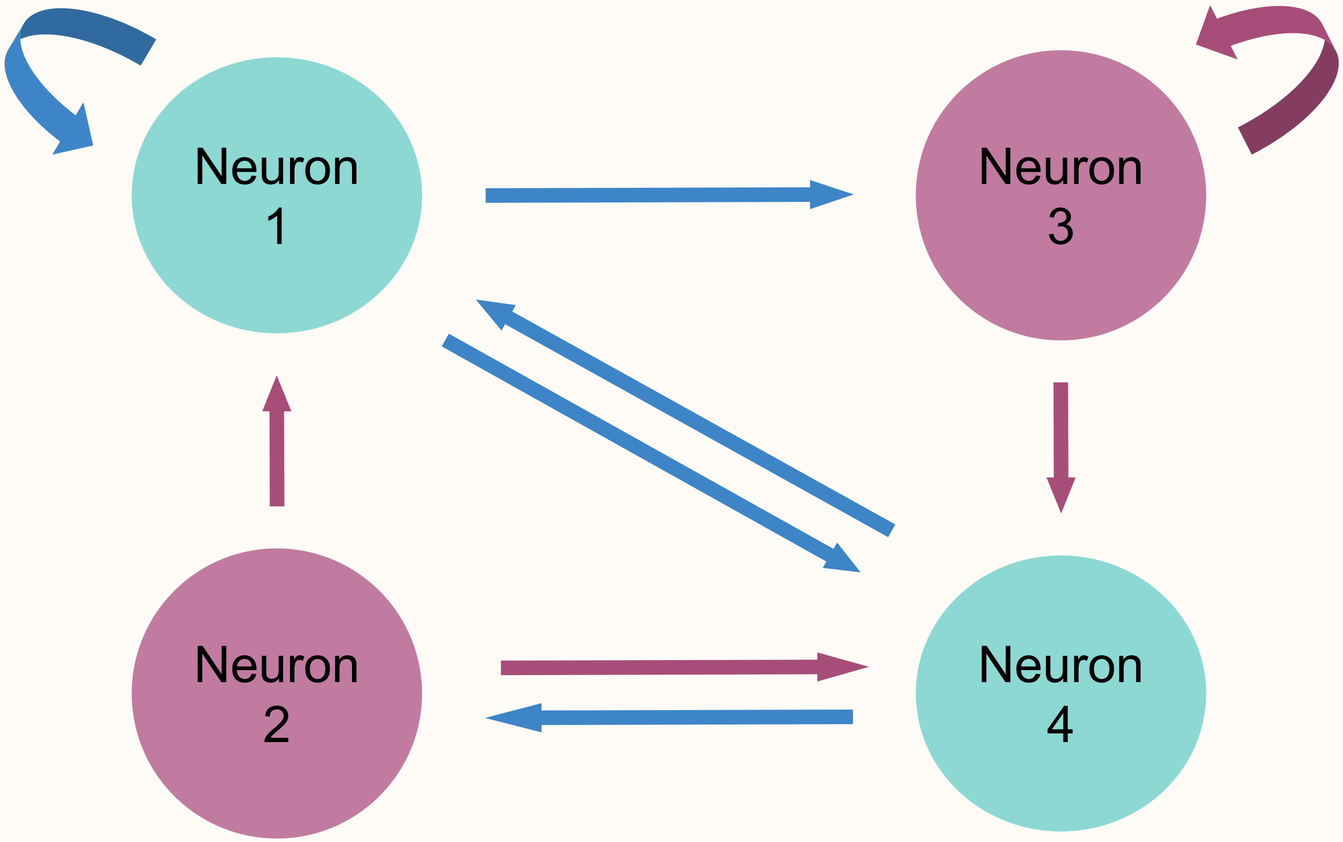
Hierarchical

Problem with the model

- Efficacy of cell 204 is 50 - 100% depending on the firing of other neurons in the network
- Cell 204 also fires rhythmically during crawling
    - a distinct behavior from swimming
    - governed by a separate motor pattern generator

Randomly-Connected ANNs

- ANN: artificial neural network
- Resemble real neural networks
  - produce spontaneous patterns of behavior
  - generate distinct patterns of activity based on starting conditions

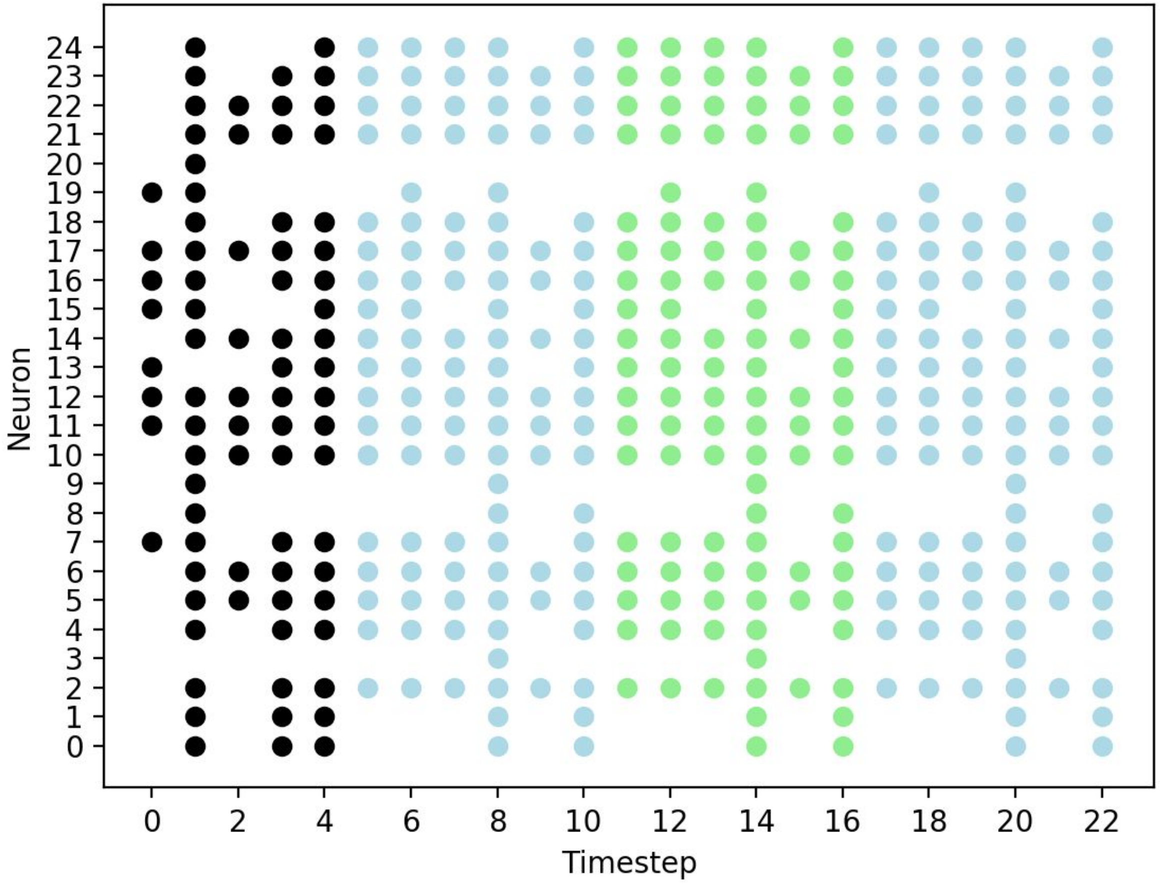

Neuron 1
Neuron 3
Neuron 2
Neuron 4

Our Research

- Can we find cells with gating characteristics in ANN?
- Can we show that such a cell is necessary and sufficient for particular patterns of activity?
- Could gating cells be an emergent property of recurrent, densely-connected networks?

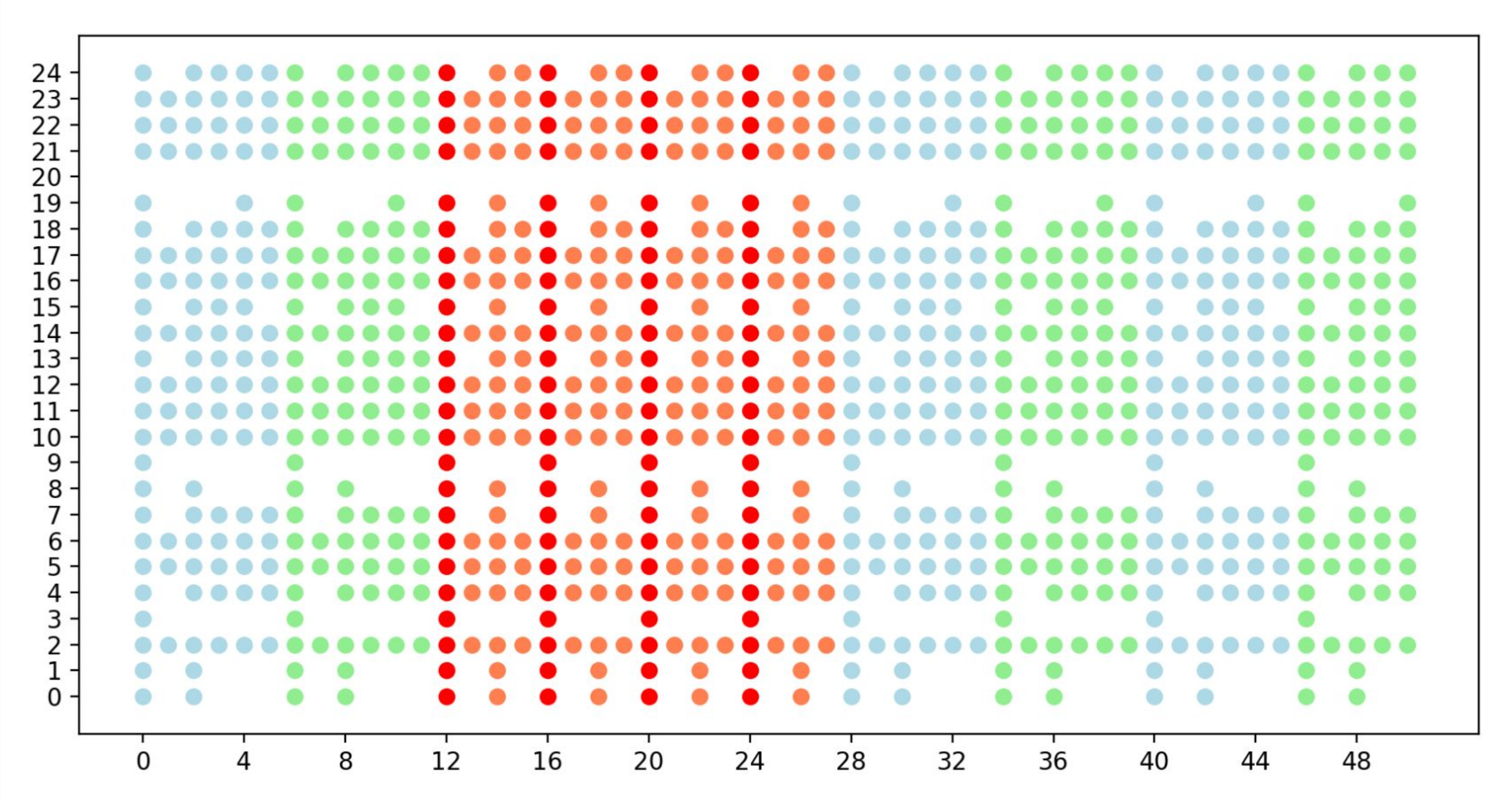
Model Setup

- 25 neurons
    - Excitatory or Inhibitory
    - Firing threshold = 0
- Random-directed edges (synapses) between neurons
    - Excitatory or Inhibitory



One run with a random starting condition

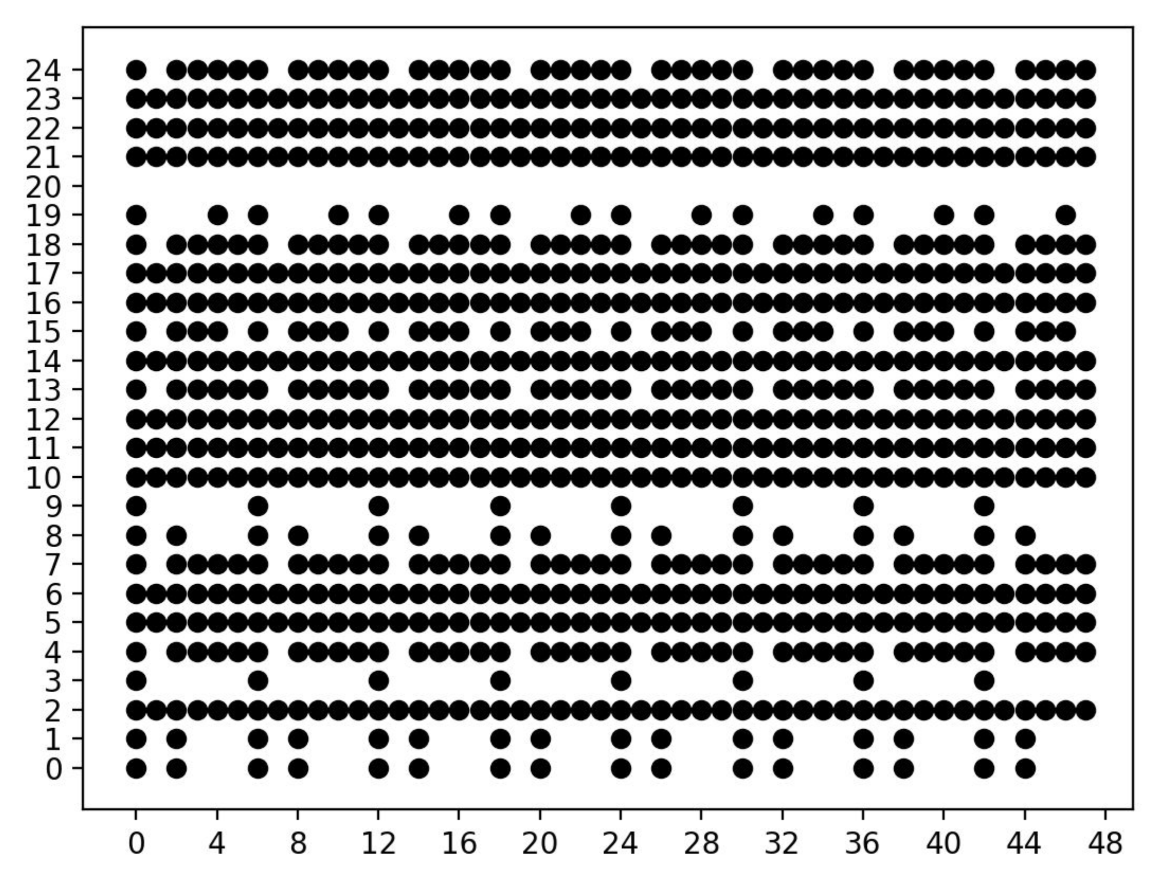
End up in stable cycles



Force neuron 4 on at time step 12 - 27

Is Neuron 4 a Gating Cell

- When Neuron 4 bursting, blue/green pattern
  - 57.3% of starting conditions end up in blue/green pattern
  - **0%** of starting conditions end up in red pattern (Necessary)
- When Neuron 4 forced on, red pattern (Necessary)
  - **95.7%** of starting conditions end up in red pattern (Sufficient)
  - Firing the whole time during the red pattern



Tonic: always firing

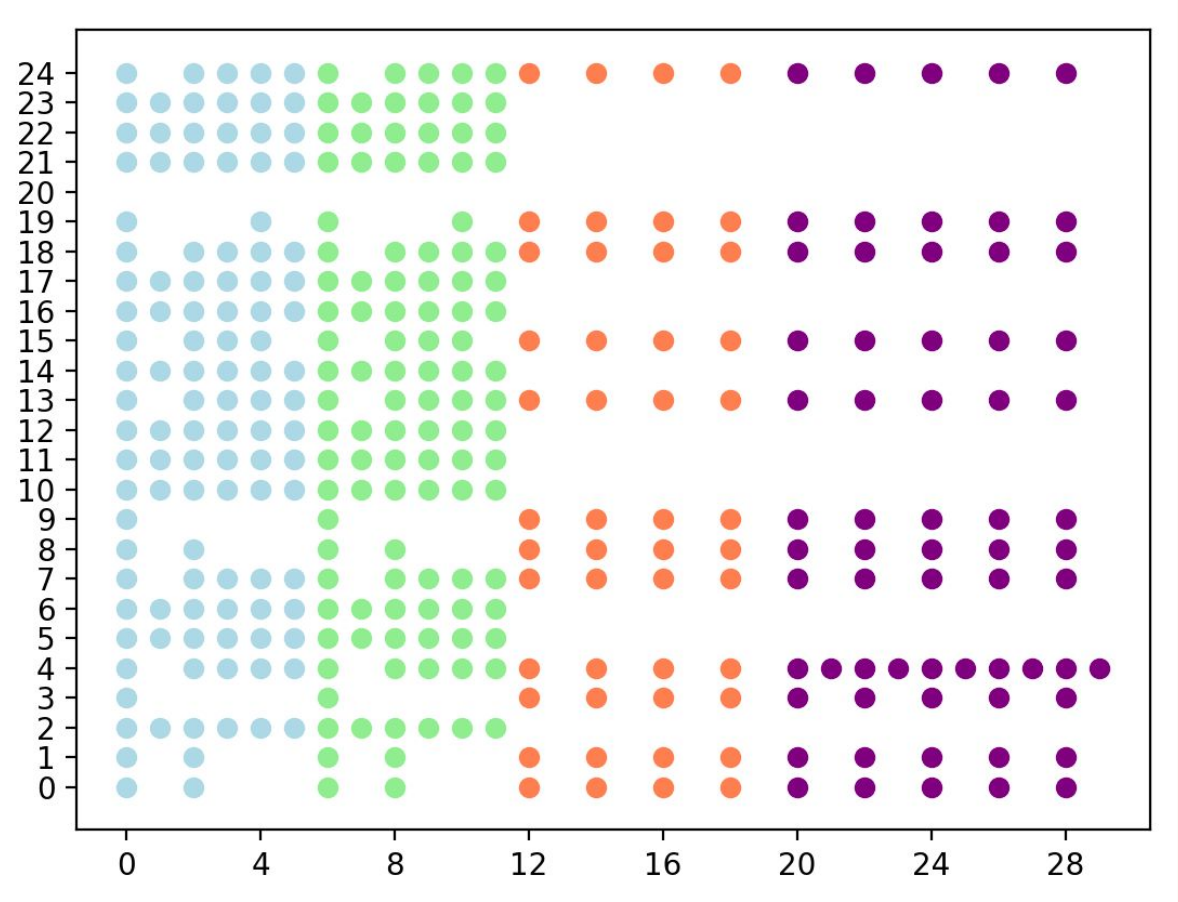
Ex: Neuron 21

Bursting: sometimes firing

Ex: Neuron 19

Quiescent: no firing

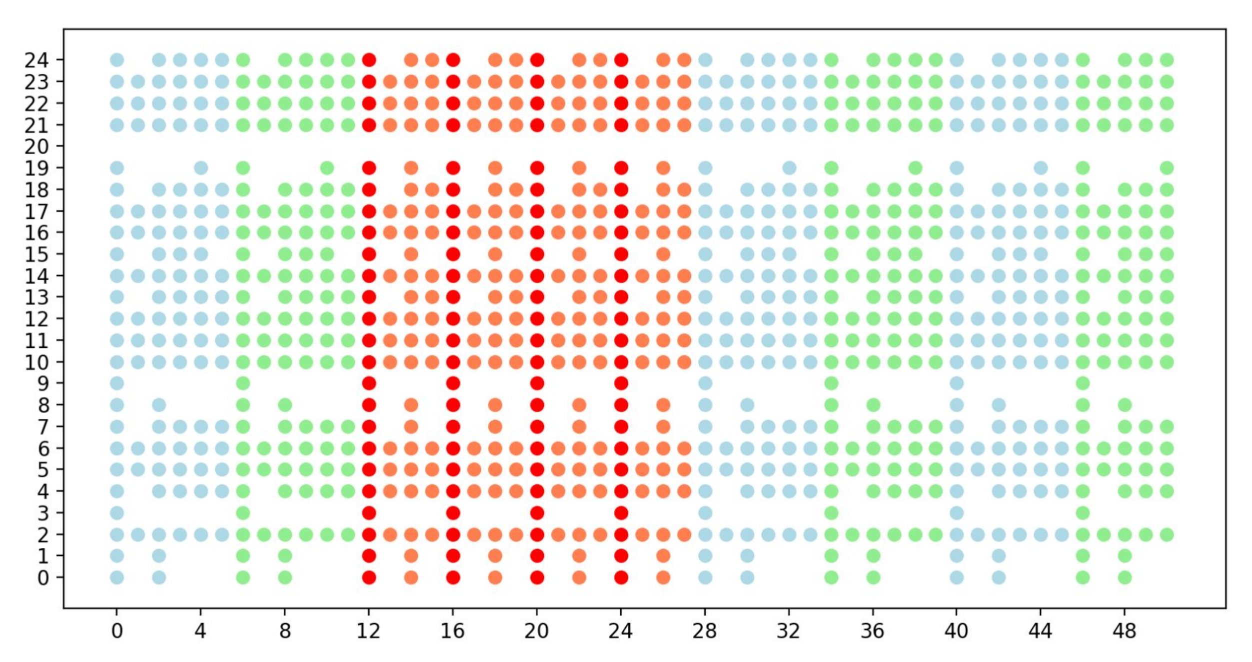
Ex: Neuron 20



At time step 12, inhibit all tonic neurons

At time step 20, force neuron 4 on

- Network “crashes”
- Neuron 4 does not cause pattern change



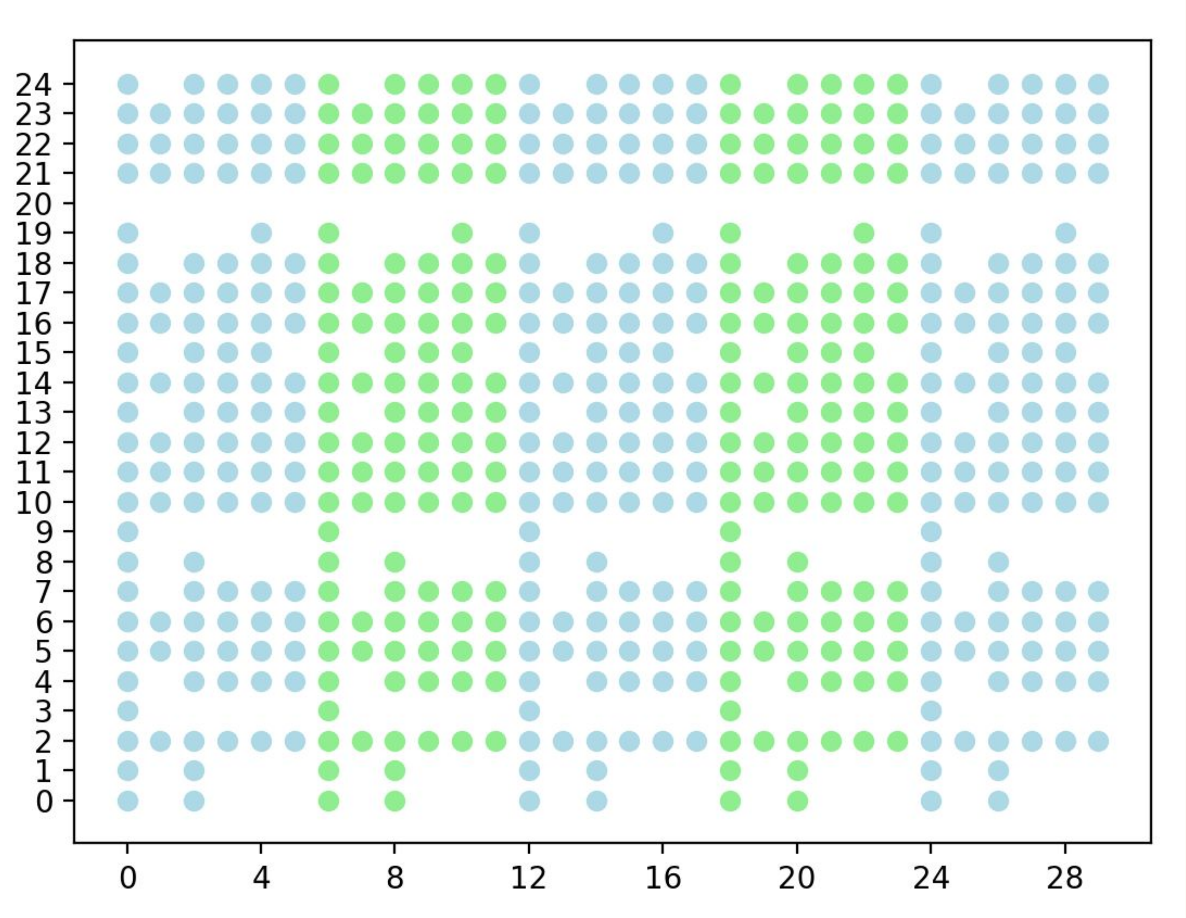
From time step 12 to 27, remove the connections from neuron 6 to 4 and from neuron 21 to 4

Neuron 6 and 21

Both tonic and inhibitory

Both inhibits Neuron 4

The exact same effect as forcing neuron 4 on



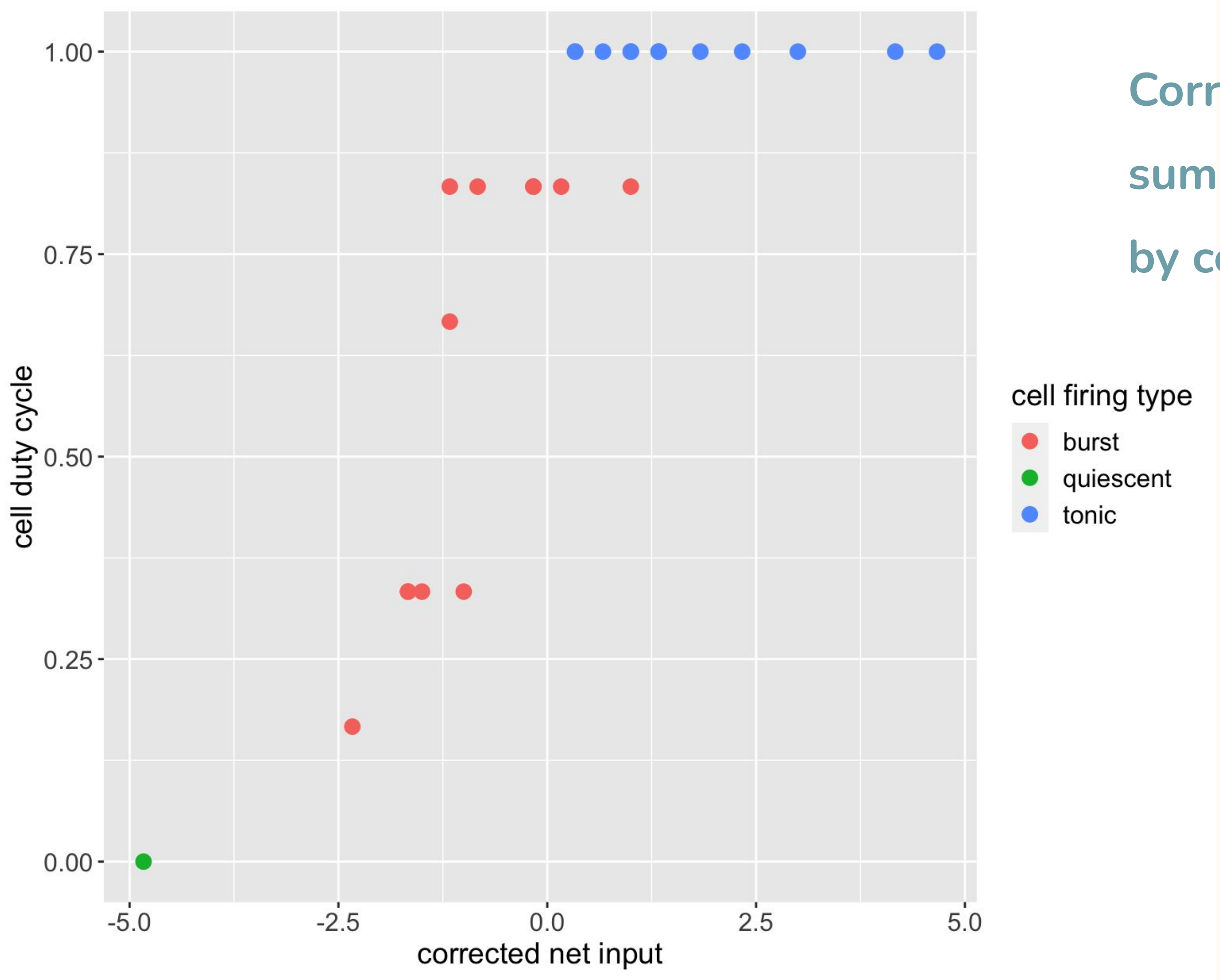
Cell Duty Cycle:

# of times a cell fired in one cycle / cycle length

Neuron 21: 6/6 = 1

Neuron 19: 2/6 = 1/3

Neuron 20: 0/6 = 0



Corrected net input:

sum of all inputs weighted

by cell duty cycle

Conclusion

- Identified cells with gating like characteristics in ANN
    - tend to fire phasically rather than tonically.
    - tend to be targets of more inhibitory than excitatory synapses
- Feedback from the oscillators onto gating cells; wiring not linear
- The efficacy of gating cells and the activity of the oscillatory subnetwork is highly dependent on the activity of tonically active neurons
    - set the threshold for firing on a neuron-by-neuron basis

Future Work

- More simulations and networks
    - better methods for analyzing networks
    - eigenvectors?
- Being able to identify gating cells based on network connections
    - input connections?
    - output?
    - cell type?
- Noise in the network

Questions?