Neuroscience Flythrough

Lukas Schott und Letita Parcalabescu

Content

- Raw Observations
  - What does the brain look like?
- Modeling
  - How can we model/replicate the behavior?
- Testing
  - Does our method make sense?

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- **Raw Observations**
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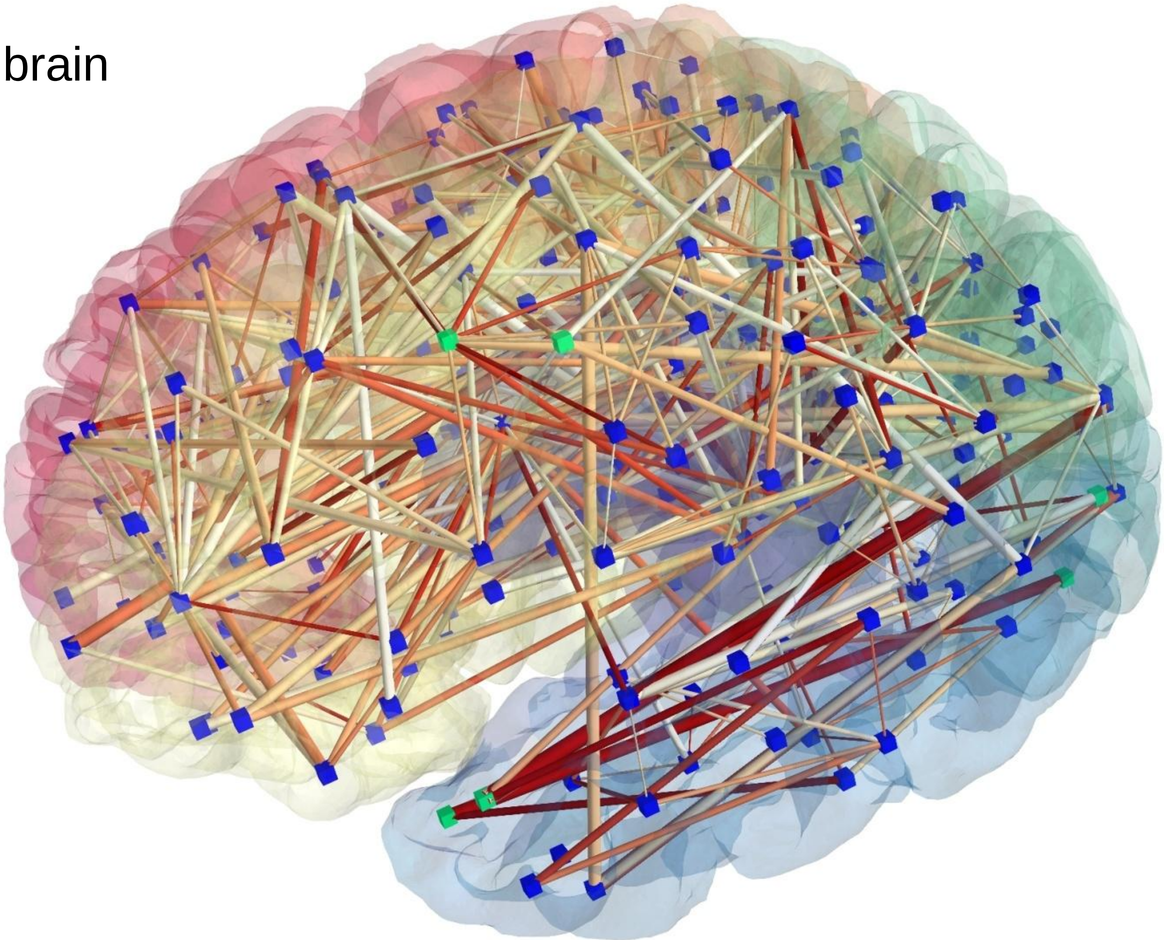
Connectomes

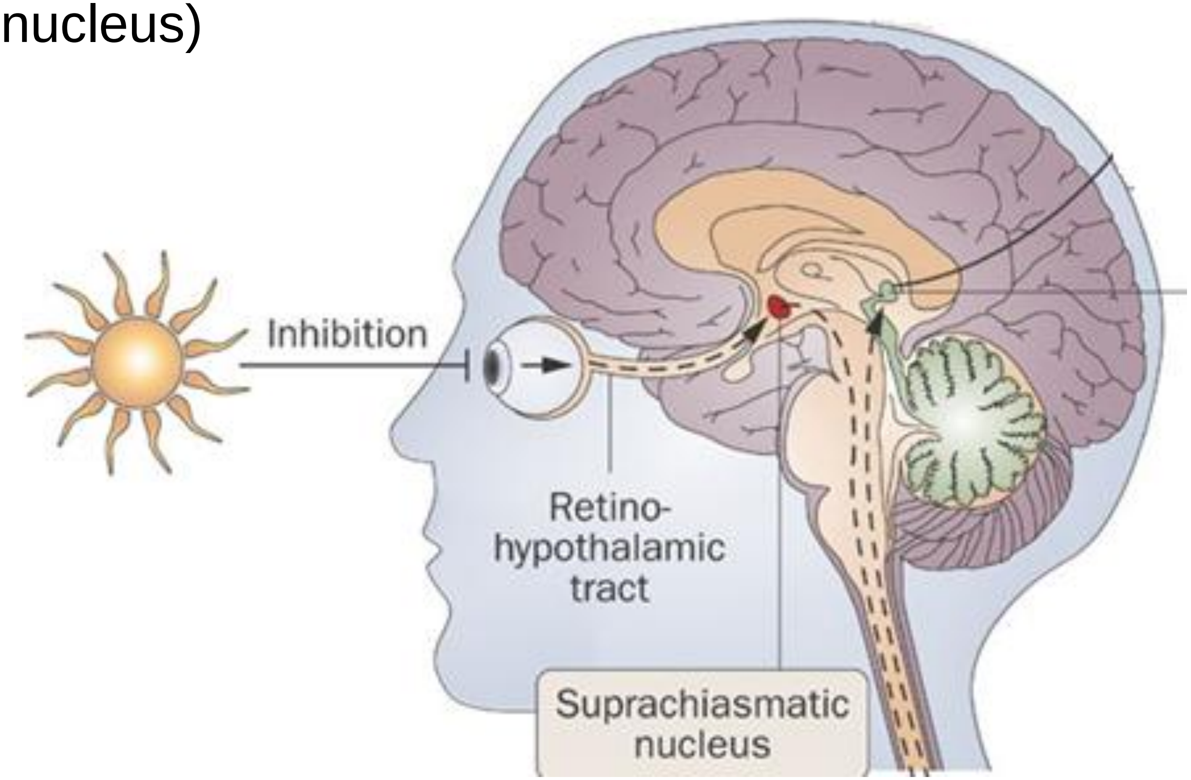
Wiring diagram of the brain



[1]

Fundings

- Connectomes
  - Macro
    - Node is gray matter region (e.g. retina and suprachiasmic nucleus)



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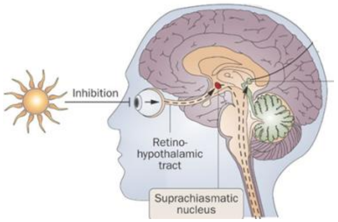
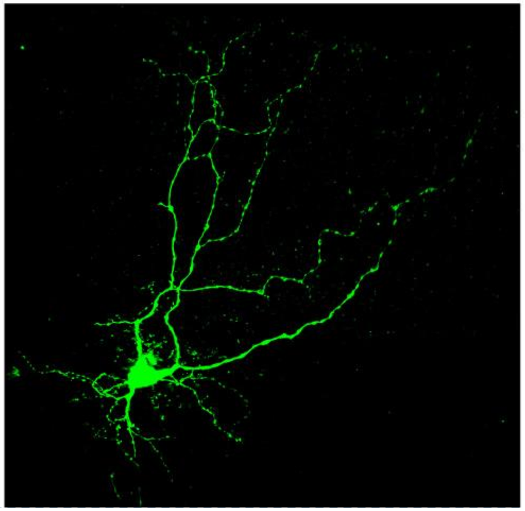
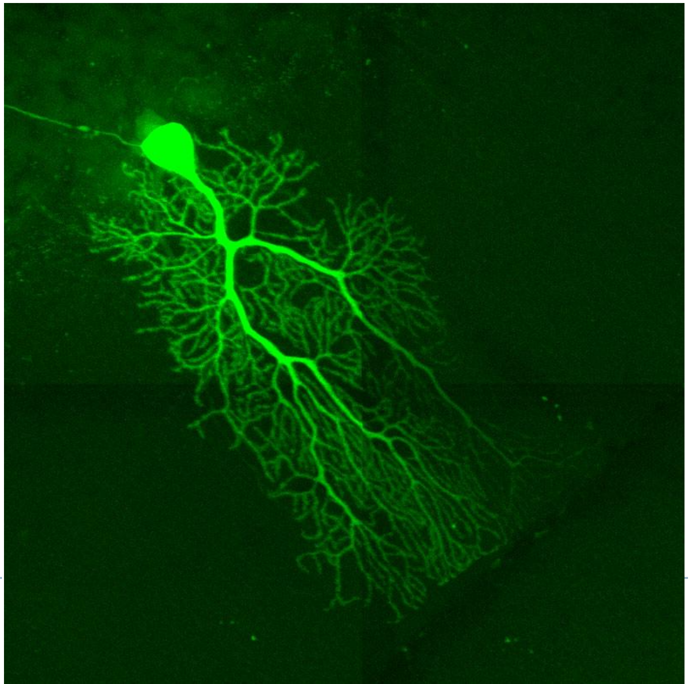


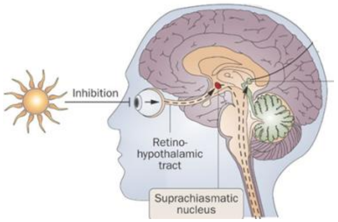
  - Meso
    - Node is neuron **type** (e.g. granule cells, Purkinje cells)

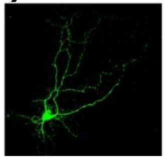


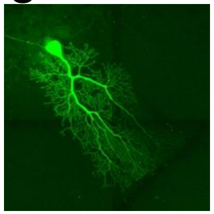


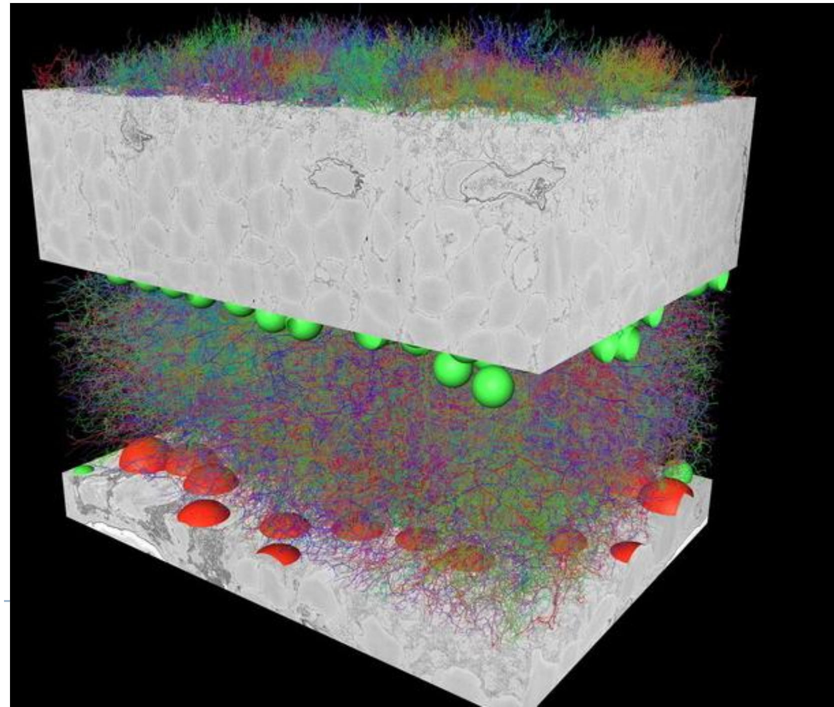
Fundings

- Connectomes
  - Macro
    - Node is gray matter region (e.g. retina and suprachiasmic nucleus)
  - Meso
    - Node is neuron type
  - Micro
    - Nodes are neurons









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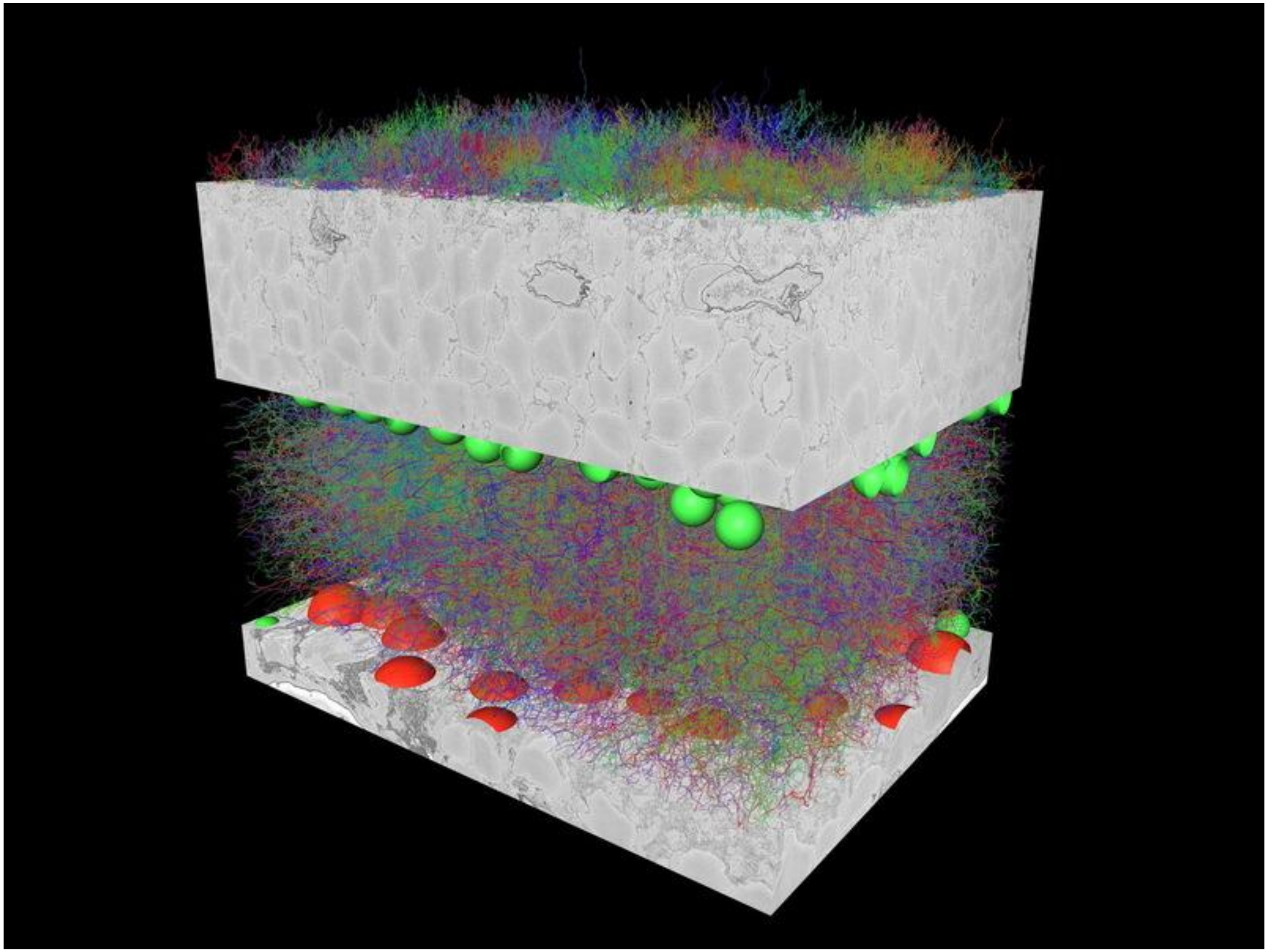
Fundings



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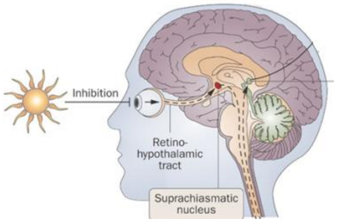
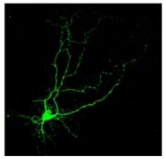
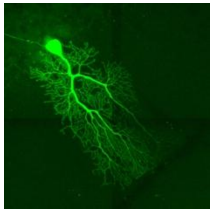
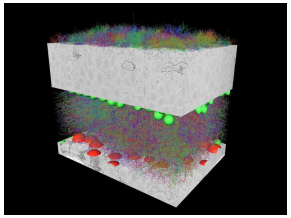
  - Nano
    - Nodes are synapses









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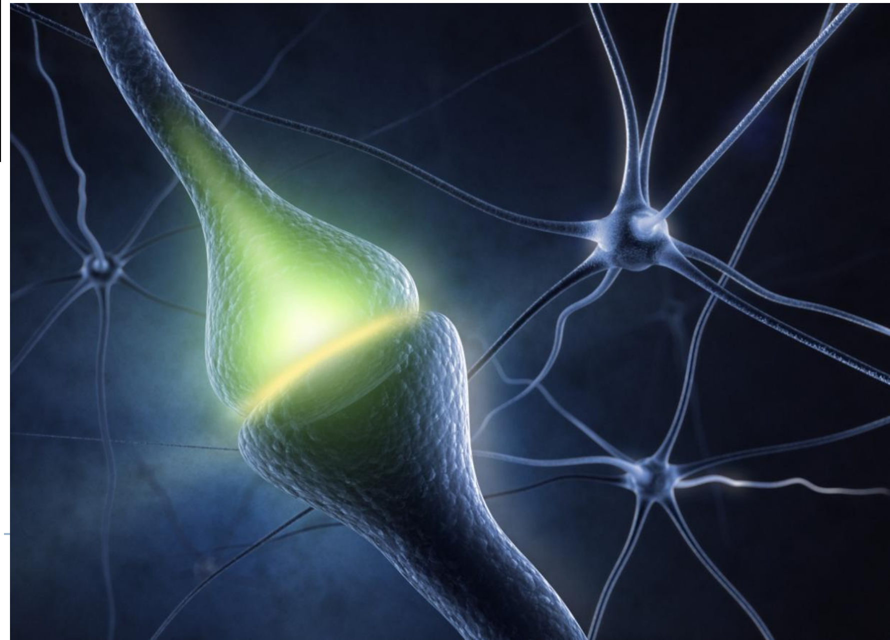

[7]

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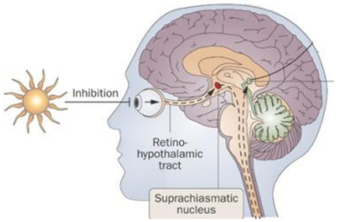

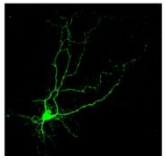

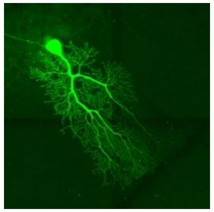

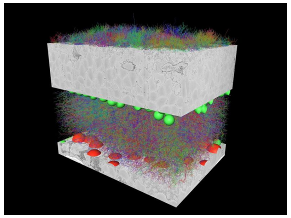

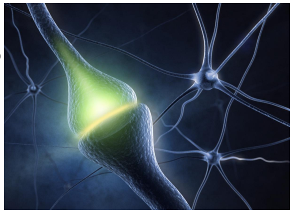

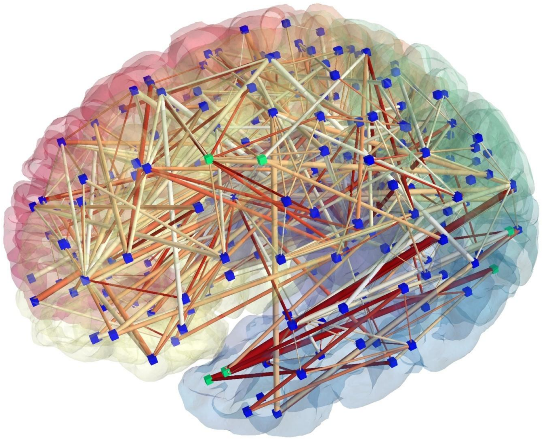

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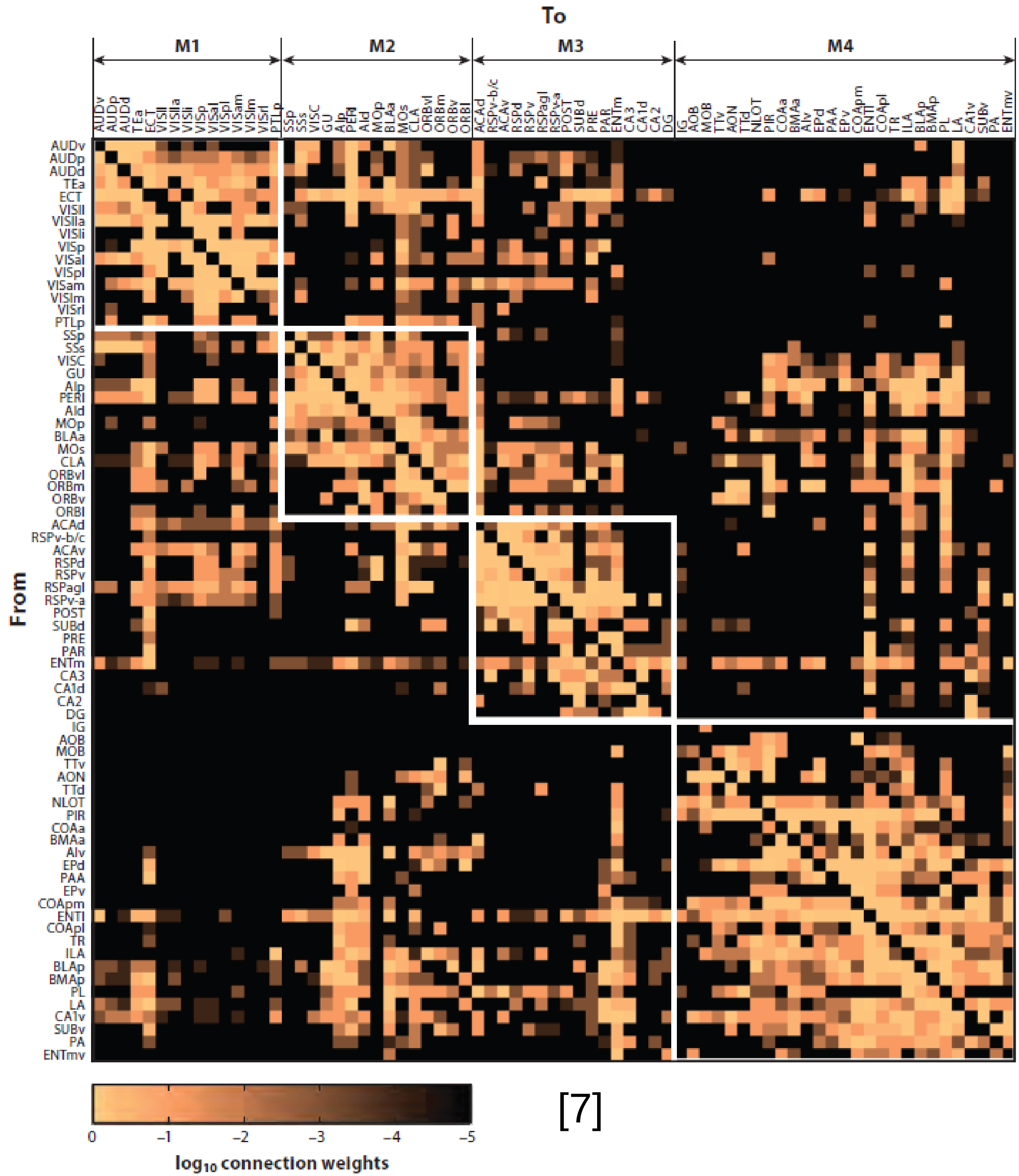
Fundings

- Connectivity Matrix

  + connectivy

  - Distance
  - # of synapses
  - Size of synapse
  - Type of synapse



[7]

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Computational Cognitive Neuroscience

- Model Brain activity
  - Single neuron
    - Leaky integrate and fire model
    - Hodkin Huxley
    - Compartments
  - Learning
    - Reinforcment Learning (Homer Bild)
    - Hebbian Rules
    - Long Term Potentation
      - Dopamine as Reward
      - Stratium vs Frontal Cortex
    - Long Term Depression

Computational Cognitive Neuroscience

- Goal:
  - Modeling the neurodynamics of cognition

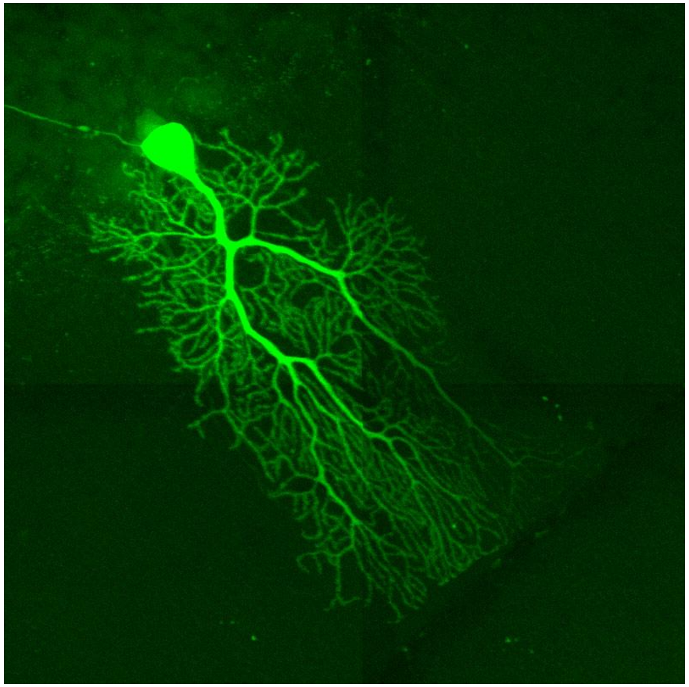
- Concretely?
  - Single/ multiple neuron/ regions behavior
  - Learning

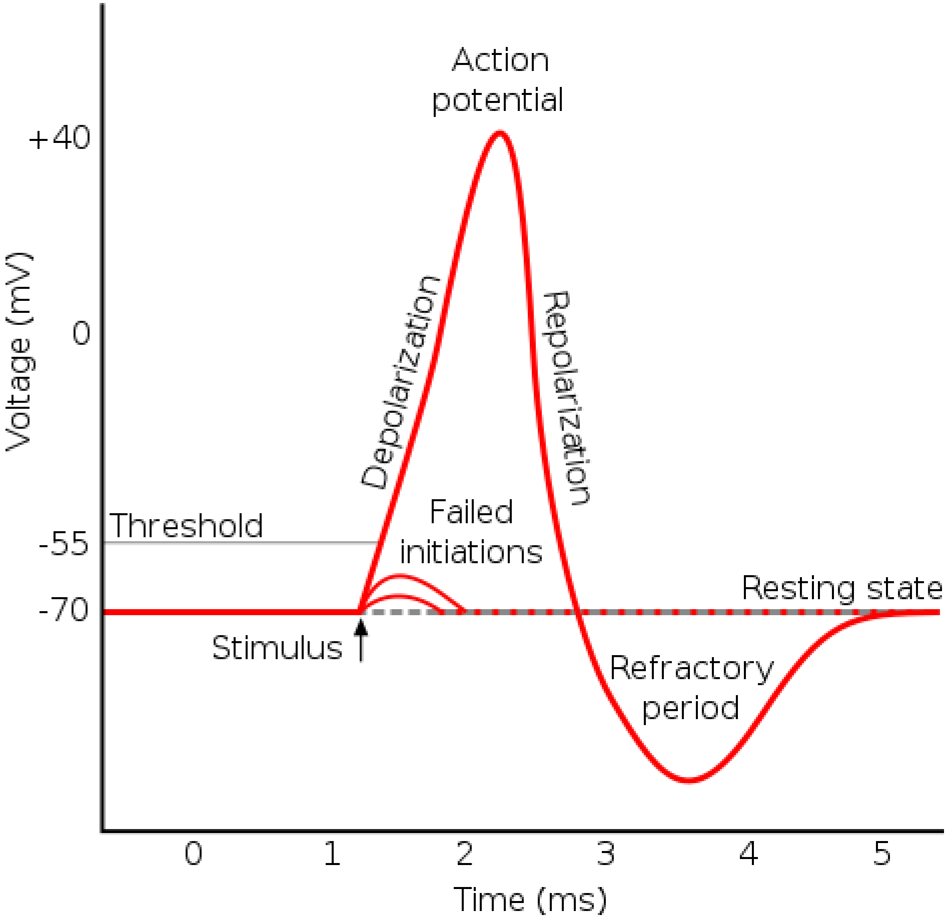
Computational Cognitive Neuroscience

- Rules
  - Brain area Connections must exist
  - Must fit excitatory and inhibitory discoveries
  - Must obey single neuron behavior (single neuron meas.)
  - Match region activity from fMRI data
  - Make testable assumptions and predictions (TMS)

Singe Neuron Model Spiking

- Hodgking Huxley
- Leaky integrate and fire





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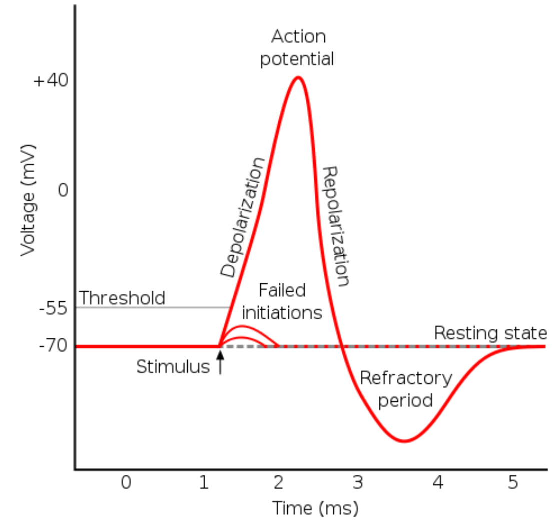
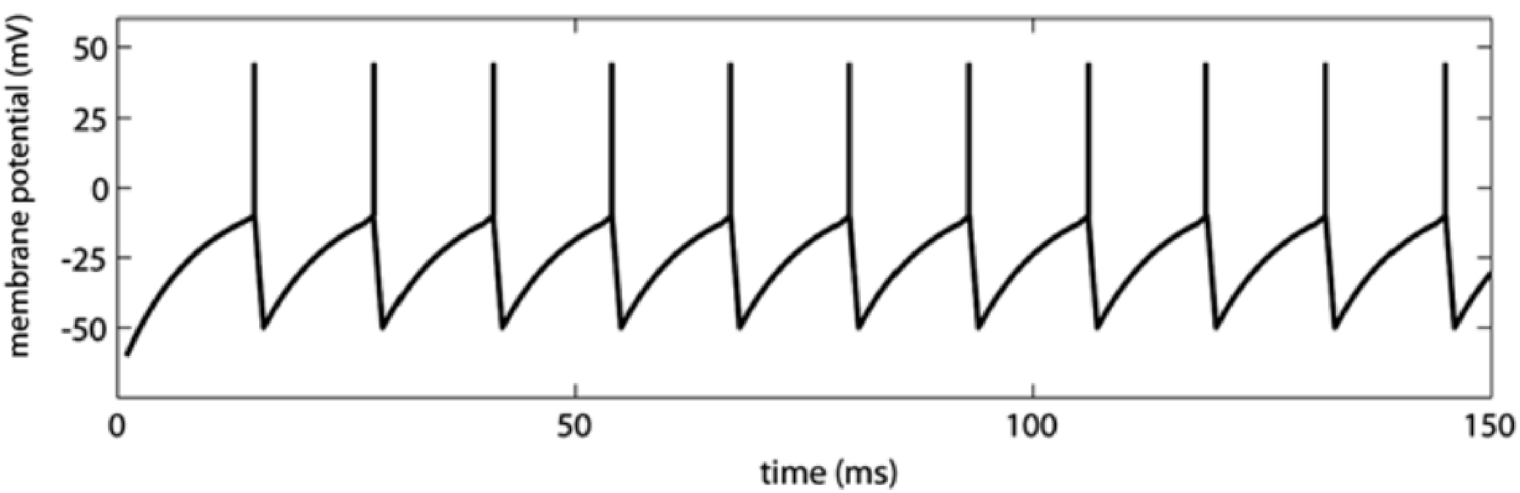
Singe Neuron Model Spiking

- Hodgking Huxley
- Leaky integrate and fire

$$\frac{dV_B(t)}{dt} = \alpha f[V_A(t)] + \beta + \gamma[V_B(t) - V_r][V_B(t) - V_t]$$

$$V_{\text{peak}} = -10 \text{ and } V_{\text{reset}} = -50.$$





[6]

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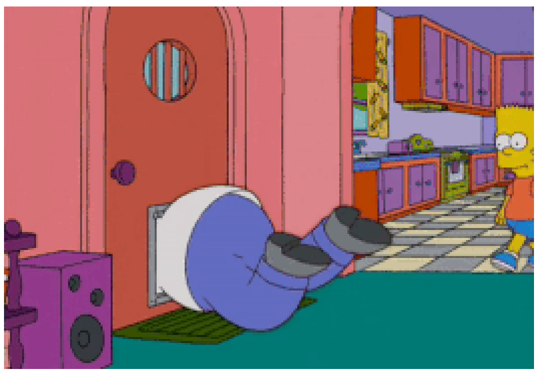
Hebbian Learning

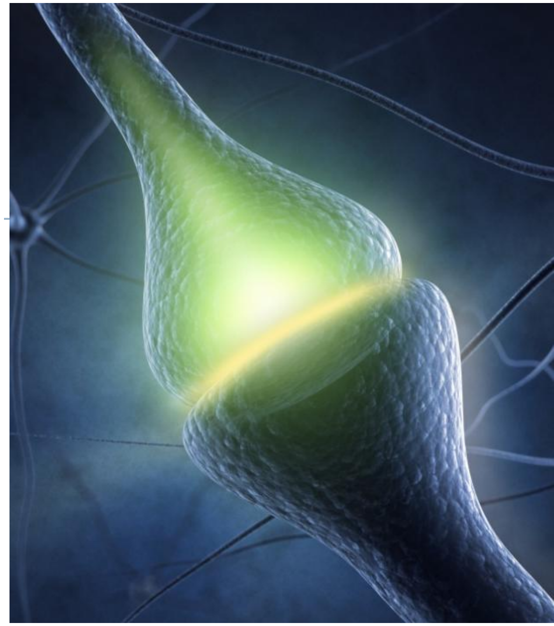
- What?
- Hebb: Father of synaptic plasticity
- What fires together wires together
- Use it or loose it

Reinforcement Learning

- Why?
- Obtained Reward – Predicted Reward



Time Model For Learning



- How?
- LTP and LTD discrete
- Synapses grow with input
- Slow dopamine uptake
- Decay with output, Cortex, Hippocampus

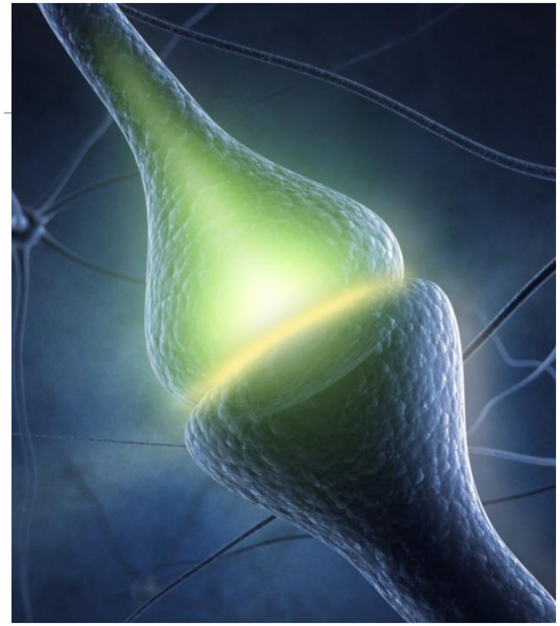
$$
\begin{aligned}
w_{A,B}(n+1) &= w_{A,B}(n) \\
&+ \alpha_w \int f[V_A(t)]dt \left[\int [V_B(t)]^+ dt - \theta_{NMDA} \right]^+ [w_{\max} - w_{A,B}(n)] \\
&- \beta_w \int f[V_A(t)]dt \left\{ \left[\theta_{NMDA} - \int [V_B(t)]^+ dt \right]^+ - \theta_{AMPA} \right\}^+ w_{A,B}(n)
\end{aligned}
$$

[6]

[7]

Time Model For Learning

- How?
- LTP and LTD
- Fast dopamine uptake, Stratium
- More like RL
- D for Dopamine



$$w_{A,B}(n+1) = w_{A,B}(n) + \alpha_w \int f[V_A(t)]dt \left[\int [V_B(t)]^+ dt - \theta_{\text{NMDA}} \right]^+ [D(n) - D_{base}]^+ [w_{max} - w_{A,B}(n)]$$
$$- \beta_w \int f[V_A(t)]dt \left[\int [V_B(t)]^+ dt - \theta_{\text{NMDA}} \right]^+ [D_{base} - D(n)]^+ w_{A,B}(n)$$
$$- \gamma_w \int f\,[V_A(t)]\,dt \left\{ \left[\theta_{\text{NMDA}} - \int [V_B(t)]^+ dt \right]^+ - \theta_{\text{AMPA}} \right\}^+ w_{A,B}(n)$$

[6]

Time Model For Learning

- Local vs glboal
  - All active synapses same update (all models)
  - All synapses different update (backpropagation not in CCN, Monte Carlo Policy Gradient)

- Problems of global Learning
  - Needs noise (otherwise equal synapses stay equal)

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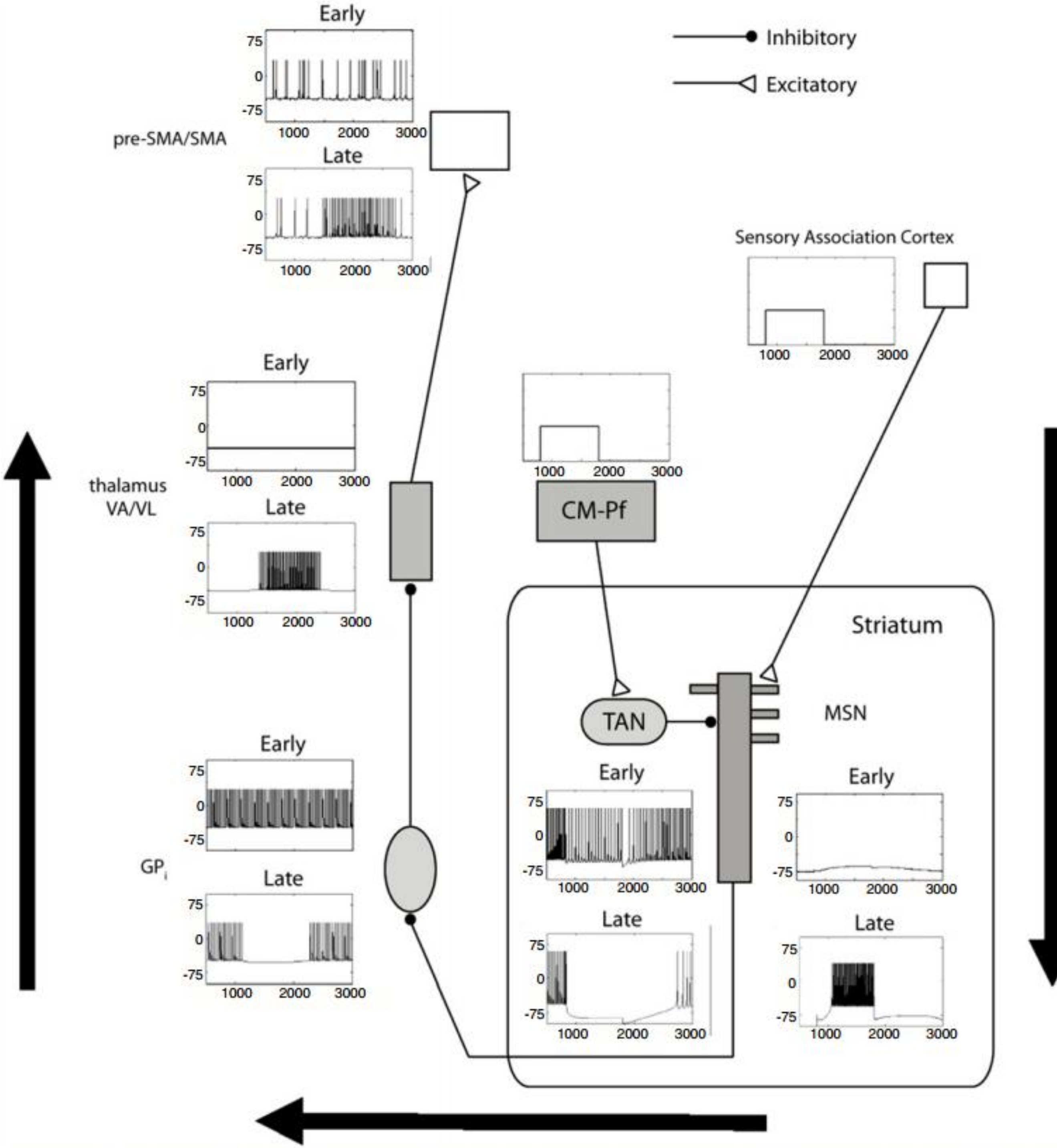
Stuff Left Out

- Compartment model

[6]

Example


Inhibitory
Excitatory
pre-SMA/SMA
Early
Late
Sensory Association Cortex
thalamus VA/VL
CM-Pf
Striatum
TAN
MSN
GP$_i$

[6]

CCN vs ANNs

- No Backprop
- Global
- Spiking

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Test

- Mind of a worm

Test

- Mind of a worm

Information in the connectome reproduces behavior

Test

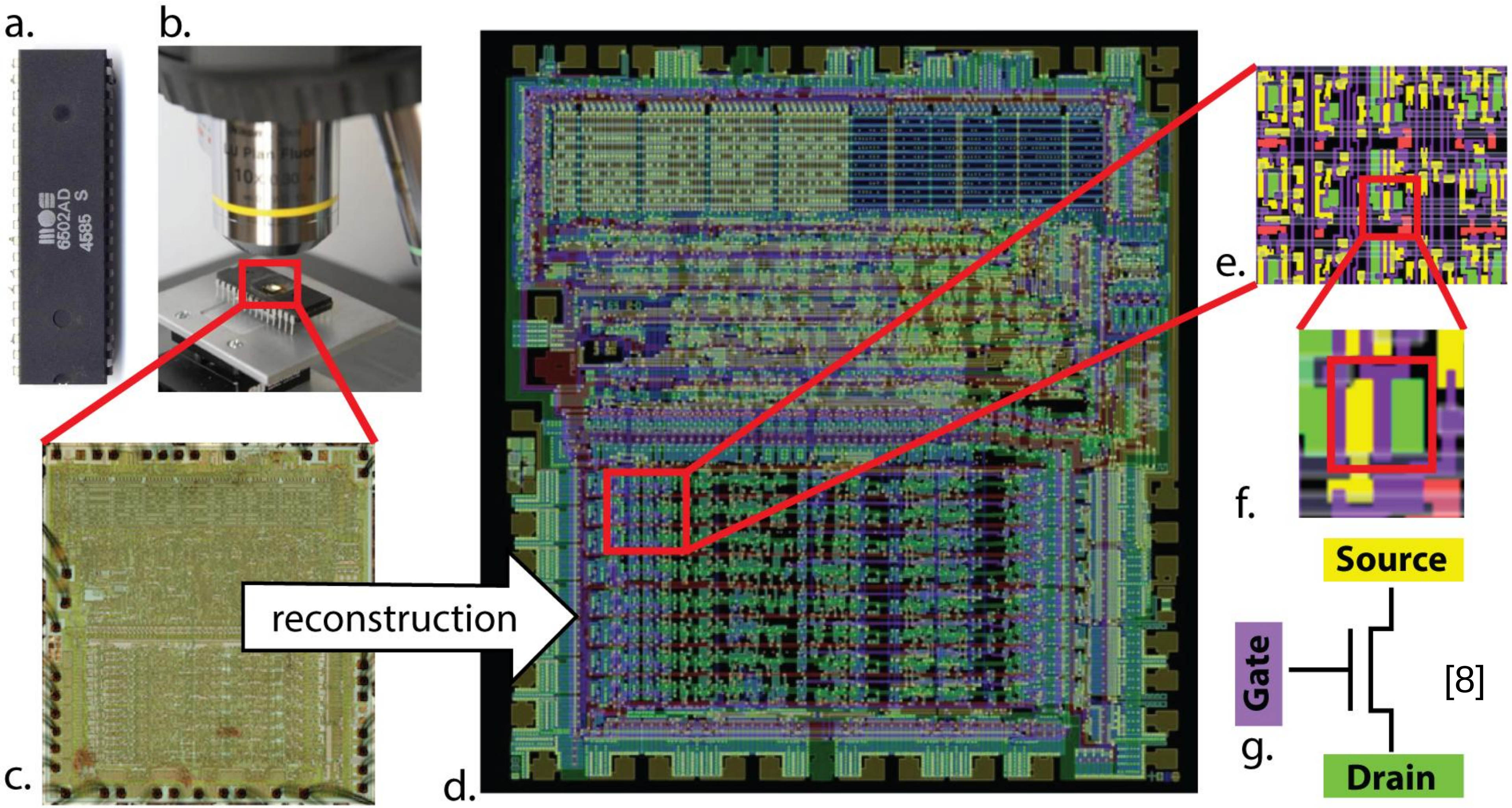
- Can we understand a microprocessor with the neuroscientific methods?

Test

- Can we understand a microprocessor with the neuroscientific methods?
- Brain = Microprocessor?
  - Interconnections of large number of small processing units
  - Specialized modules hierarchically organized
  - Flexibly route information
  - Retain memory over time
- When do we understand something?
  - Labznick

Understanding a Mircroprocessor

- MP: MOSA6502 Atari, Apple I



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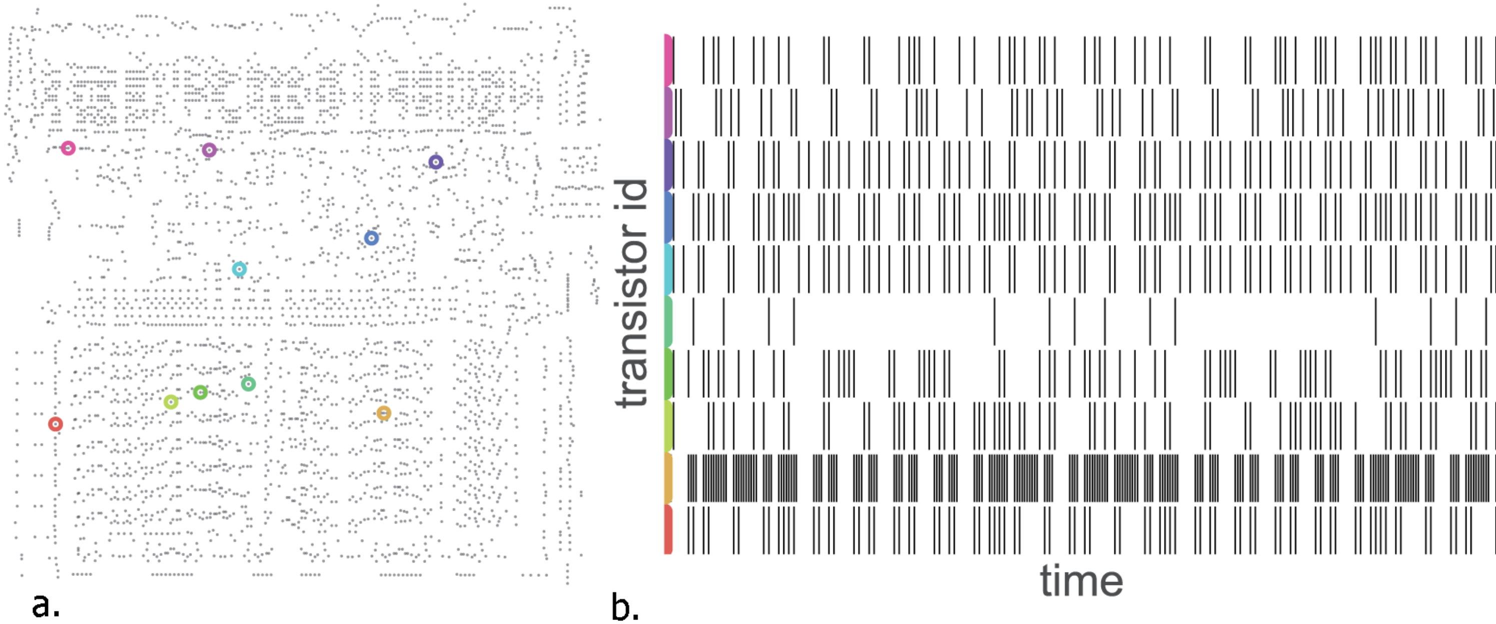
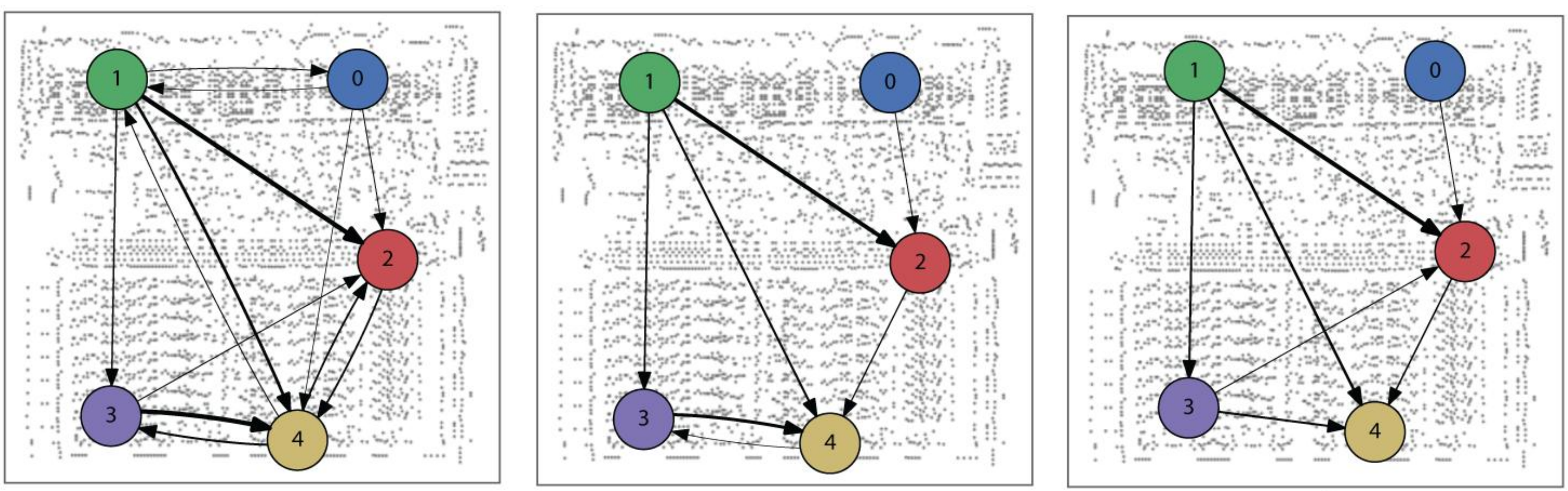
Understanding a Mircroprocessor - Spiking Patterns

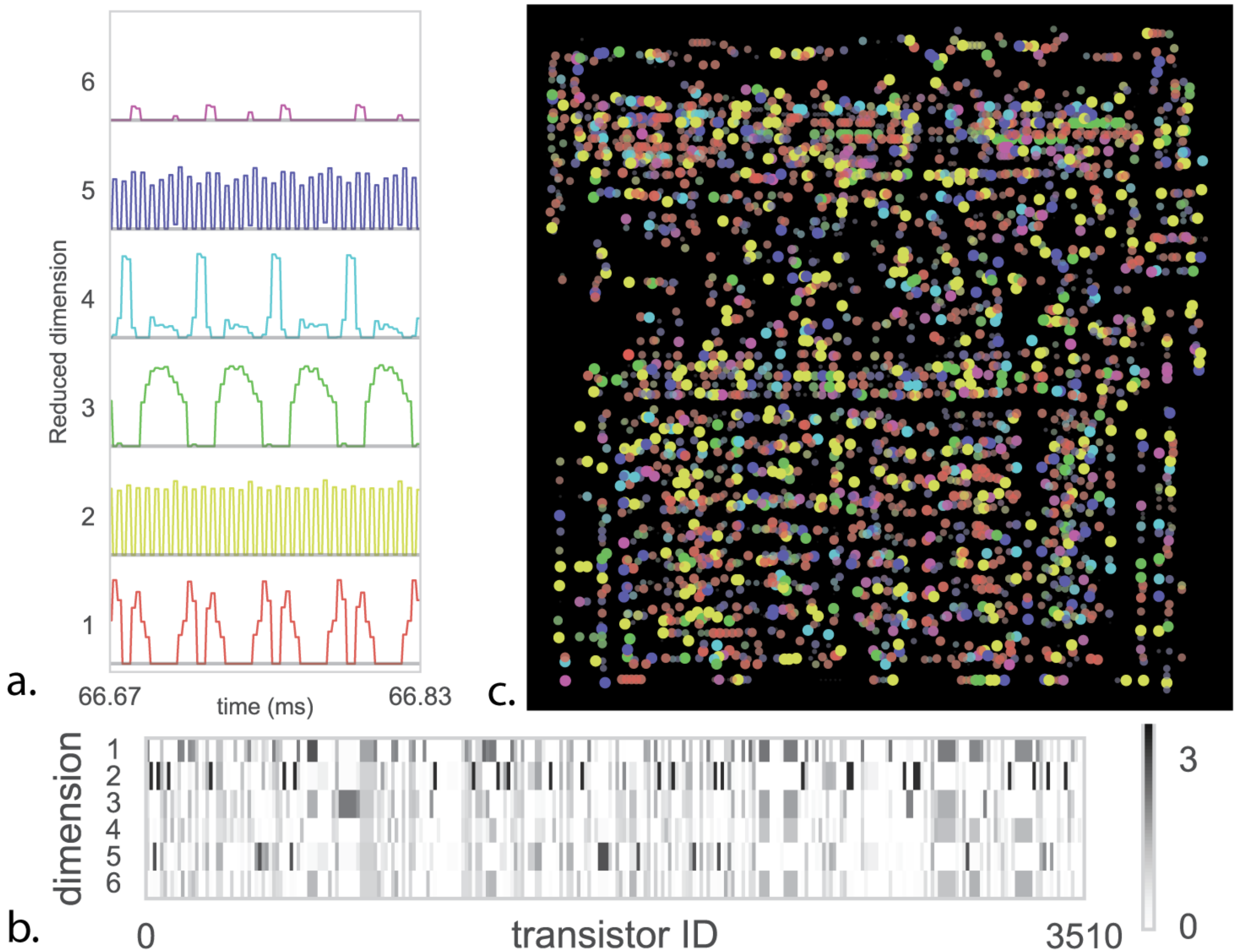




a. Donkey Kong b. Space Invaders c. Pitfall

[8]

Understanding a Mircroprocessor - NMF



Understanding a Mircroprocessor

- We understood many behaviors but fall short understanding Miroprocessers.

Still time

- Tasks proportional to depth
- Short term memory apes

Conclusion

- Brain understanding at different levels
- Modeling of plasticity
- Methodic can be applied but not understood

References

- [1] https://www.google.de/url?sa=i&rct=j&q=&esrc=s&source=images&cd=&cad=rja&uact=8&ved=0ahUKEwj5str2hbnUAhVGvBoKHVQKD3cQjRwIBw&url=http%3A%2F%2Fwww.connectomics.org%2Fviewer%2F&psig=AFQjCNESoHcHPQwFPkstwD6fMDr7O4Xz3A&ust=1497382305361033
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- [3] http://www.cellimagelibrary.org/images/40124
- [4] https://www.mpg.de/7491772/connectome-retina
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- [9] www.openworm.org