Exceptional service in the national interest

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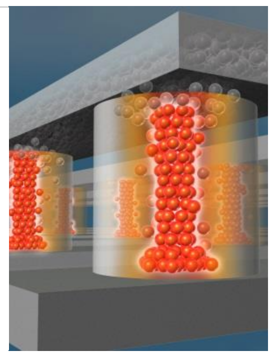

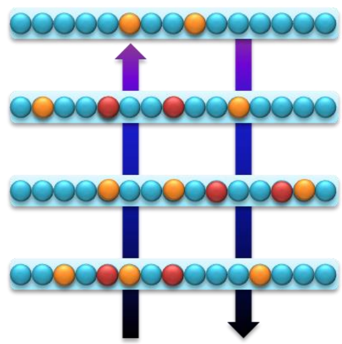

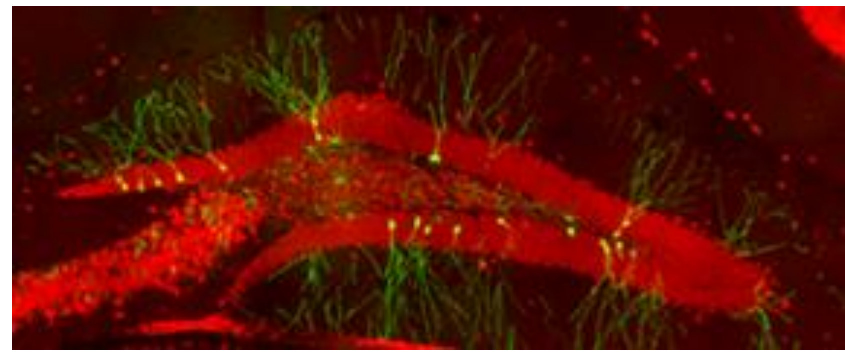

Neural Computing: What Scale and Complexity is Needed?

Neuromorphic Computing Workshop, Oak Ridge, TN 2016

Brad Aimone, Kris Carlson, Fred Rothganger
Sandia National Laboratories

Neuromorphic computing at SNL leverages a legacy of research efforts

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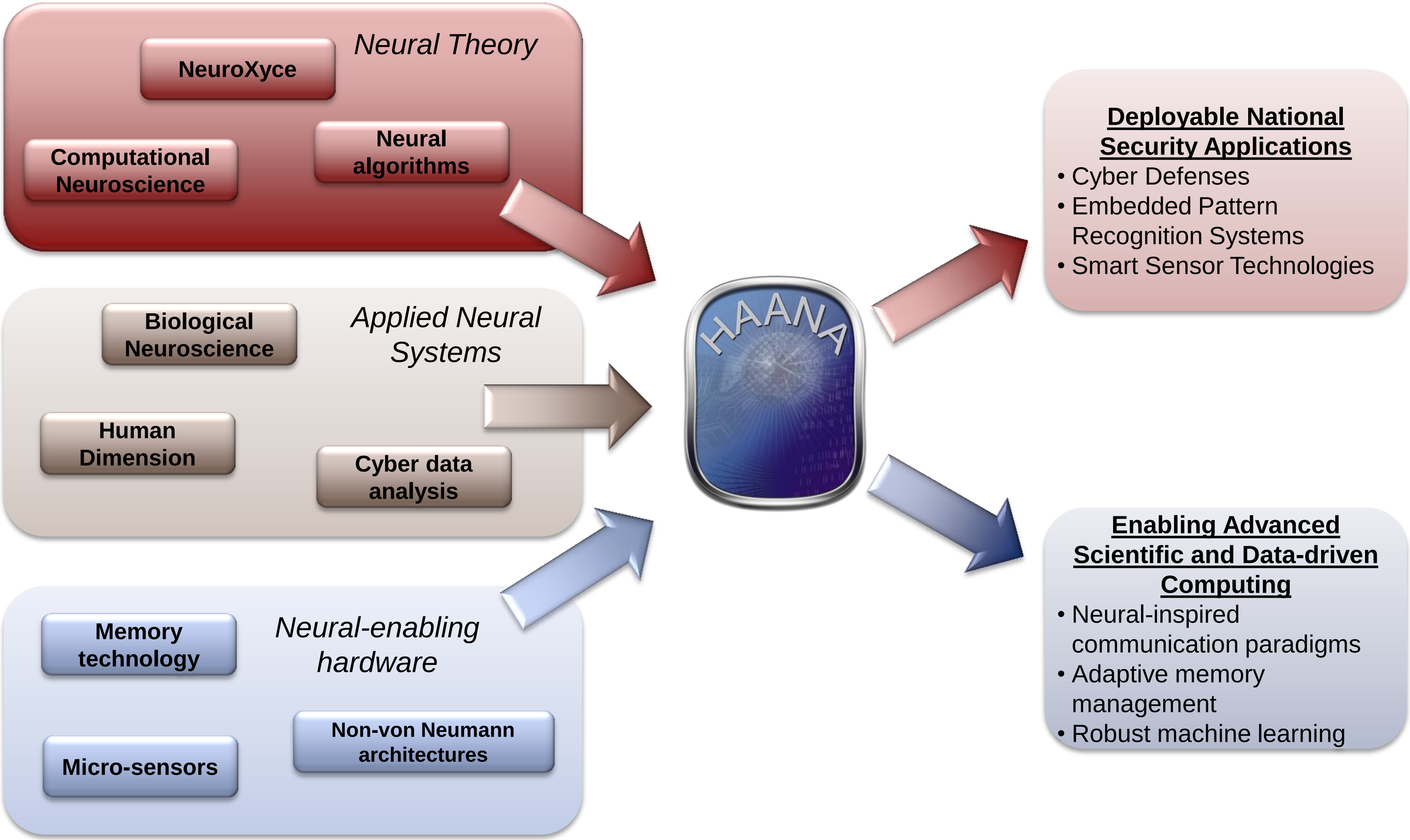
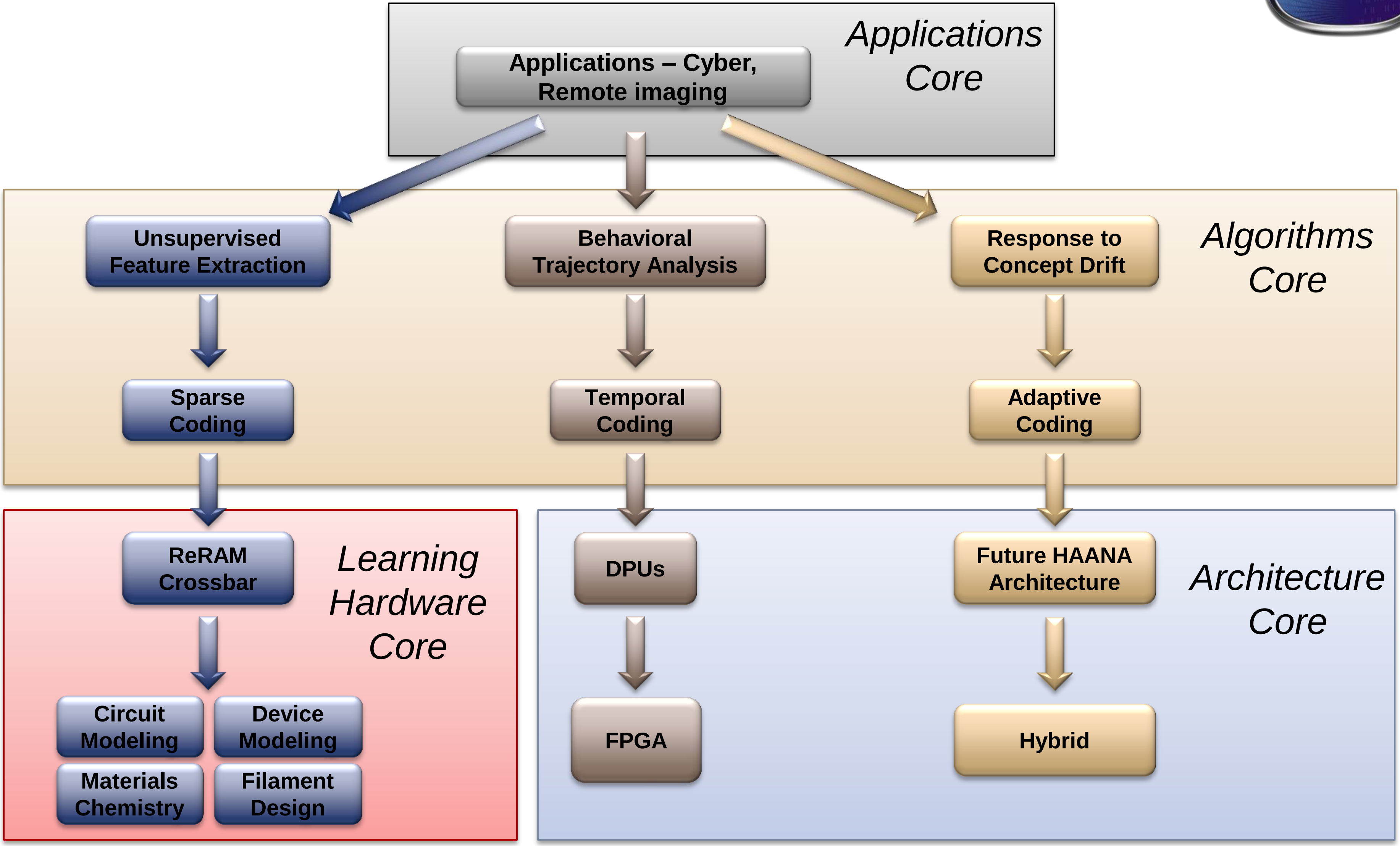


HAANA is taking a broad approach to leverage neural algorithms in applications



HAANA is taking a broad approach to leverage neural algorithms in applications

Applications Core

Applications – Cyber, Remote imaging

Algorithms Core

Unsupervised Feature Extraction

Sparse Coding

ReRAM Crossbar

Circuit Modeling

Device Modeling

Materials Chemistry

Filament Design

Architecture Core

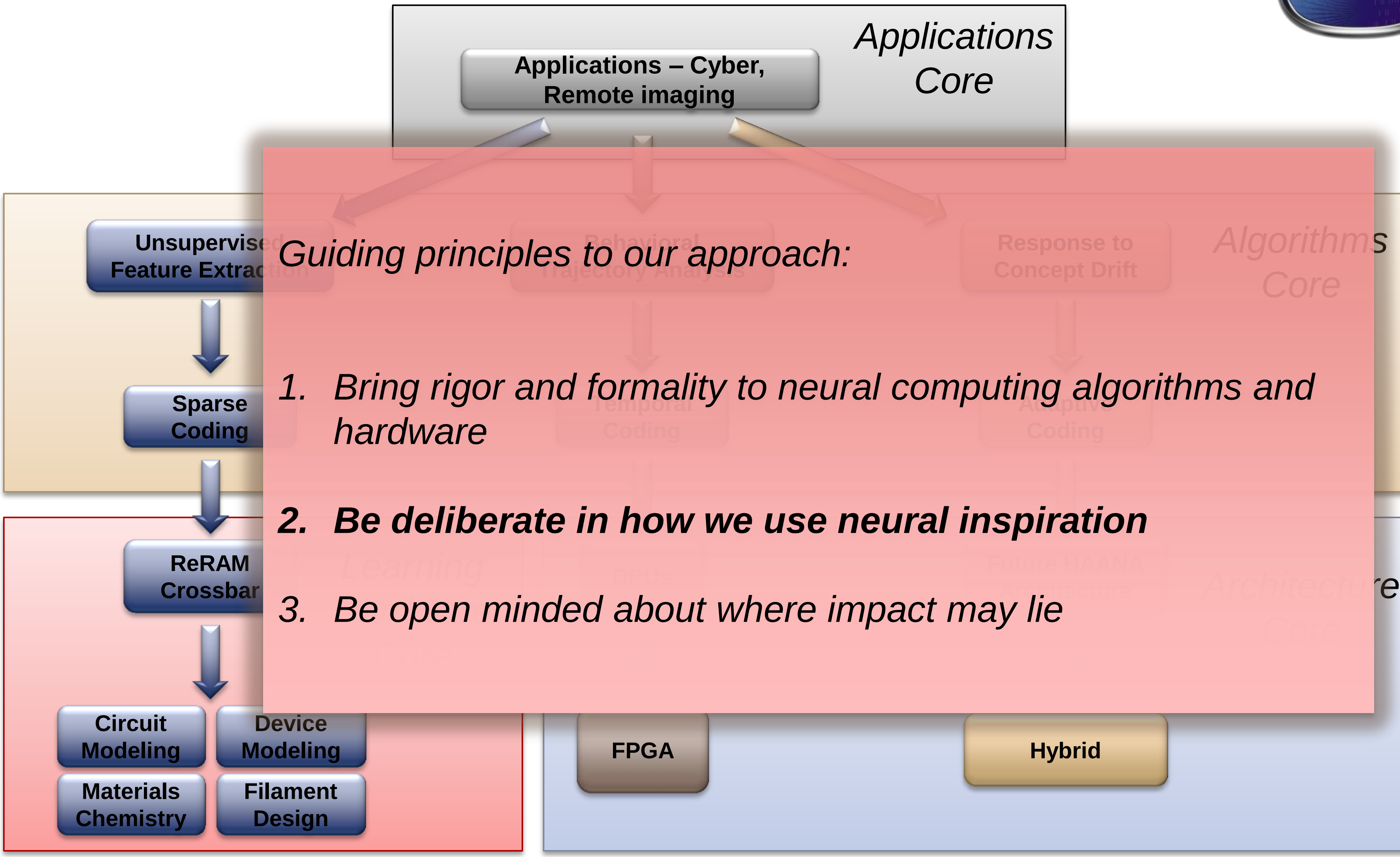
FPGA

Hybrid

Guiding principles to our approach:

1. *Bring rigor and formality to neural computing algorithms and hardware*
2. *Be deliberate in how we use neural inspiration*
3. *Be open minded about where impact may lie*

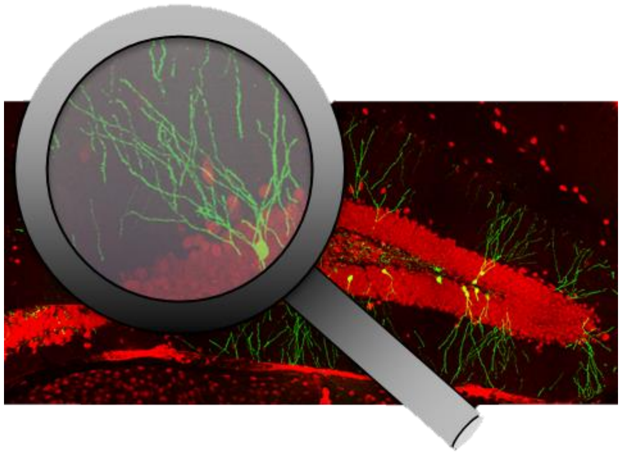
HAANA is taking a broad approach to leverage neural algorithms in applications

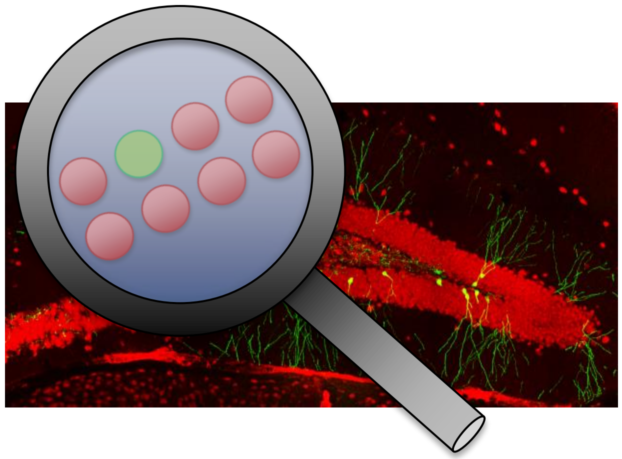


Guiding principles to our approach:

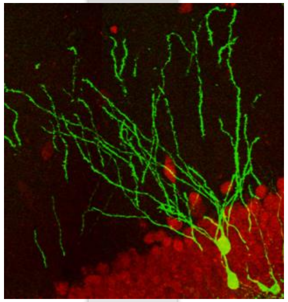
1. *Bring rigor and formality to neural computing algorithms and hardware*
2. ***Be deliberate in how we use neural inspiration***
3. *Be open minded about where impact may lie*

Neuromorphic research often confuses neural *scope* with desired computational *abstraction*



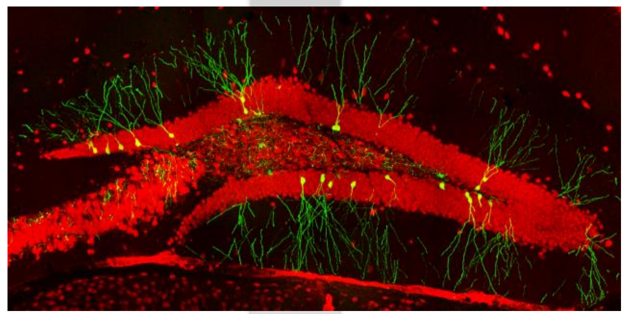


Scope

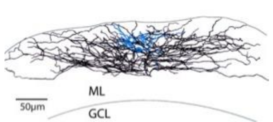


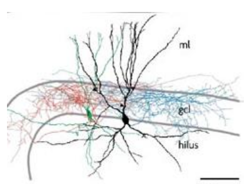
Adult neurogenesis
Continuous formation of granule cell neurons throughout life

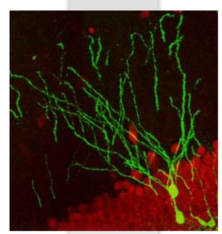
Scope

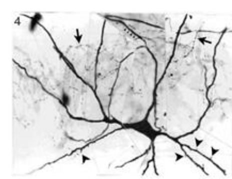


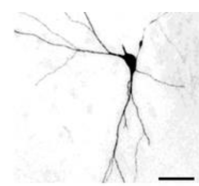
Dentate Gyrus
Millions of primarily GCs
but many different
varieties



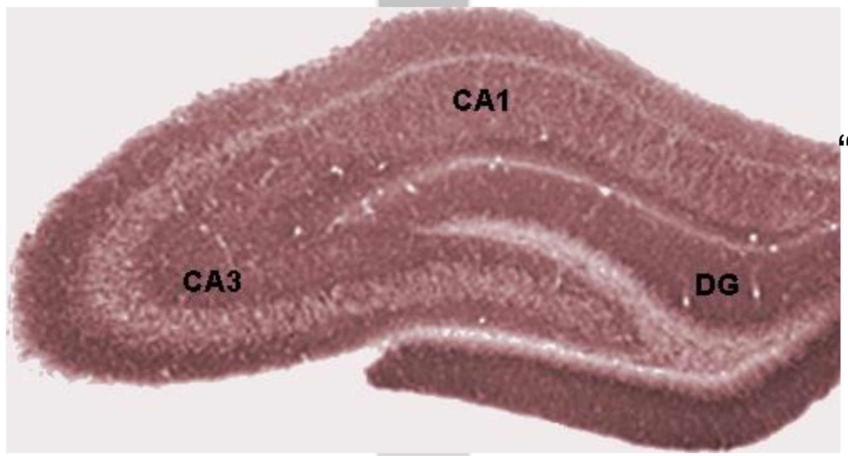




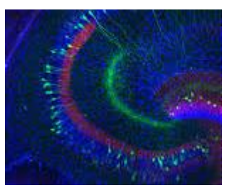


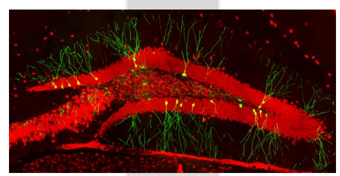


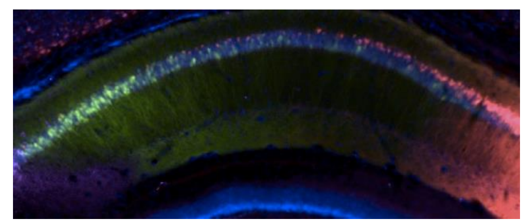
Scope

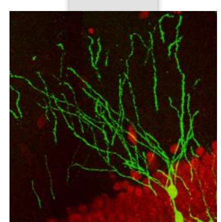


Hippocampus
“Three layer” cortical like region responsible for memory and spatial processing

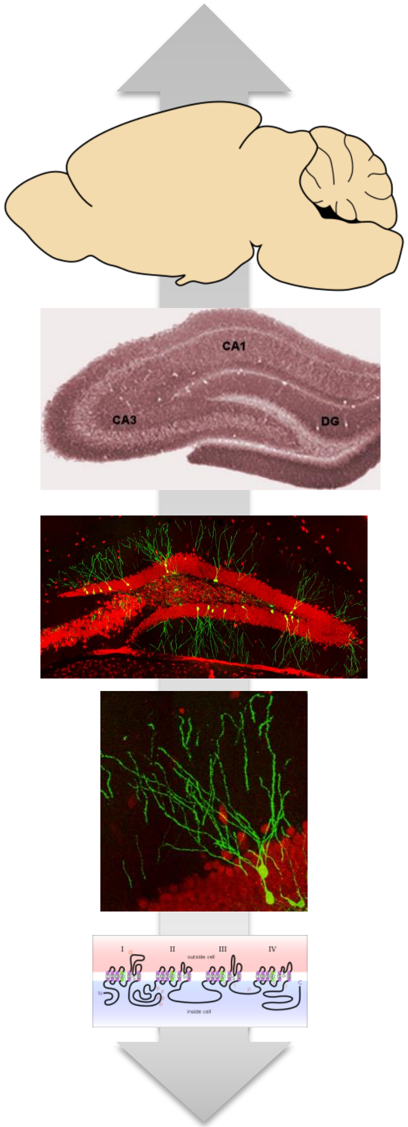








Scope



Brain

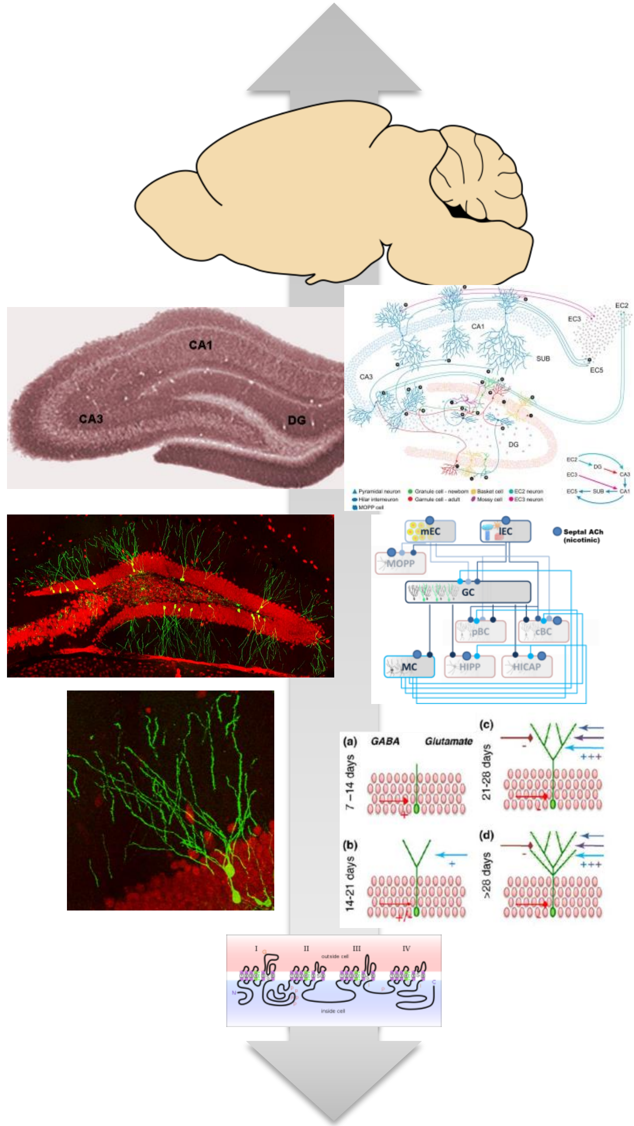
Regions

Layers

Neurons

Proteins, DNA, and cellular structures

A good approach to look at is the scope that provides a useful function…



Brain

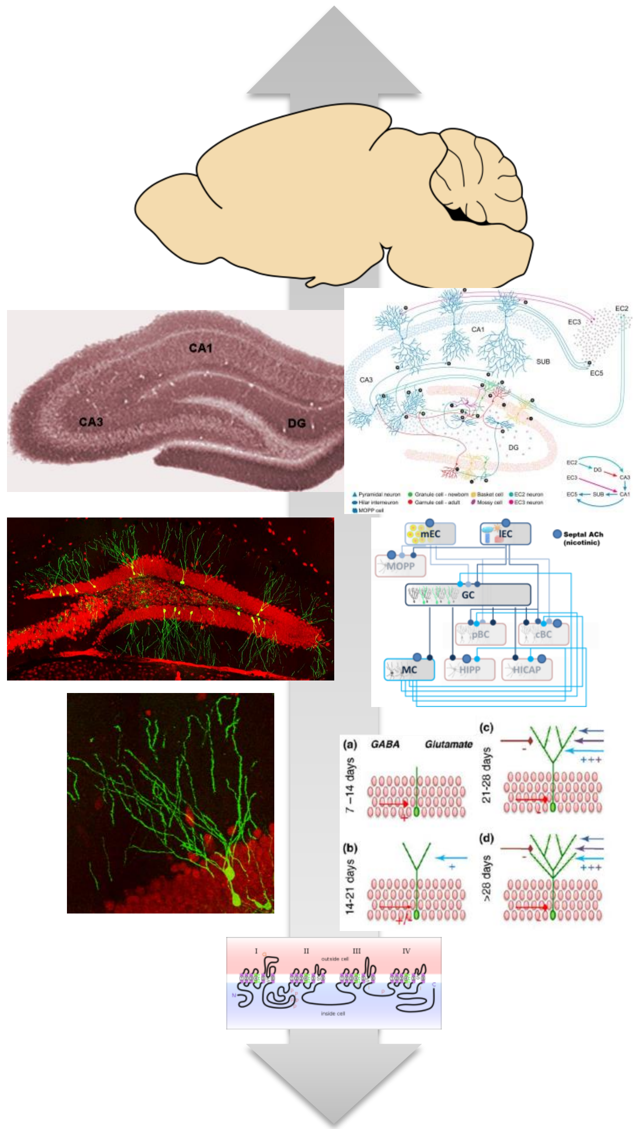
Hippocampus

Dentate Gyrus

Neurogenesis

Na+ Channels

Identify functions that are both clear and have value



Cognition

Brain

One shot learning, associative memory

Hippocampus

Pattern separation, conjunctive encoding

Dentate Gyrus

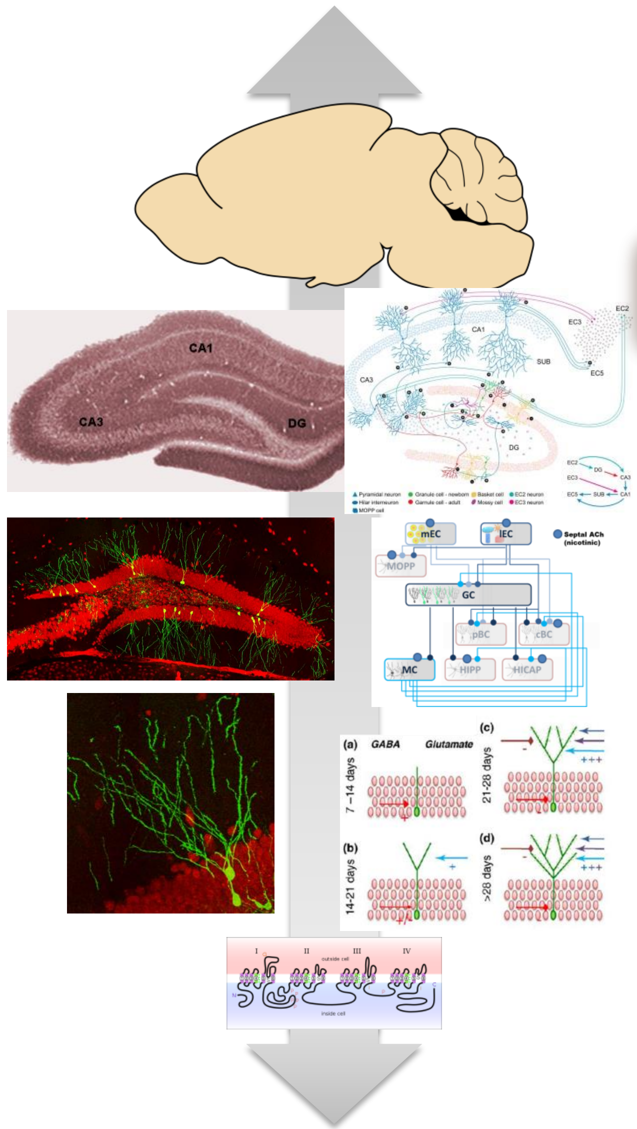
Novel information encoding

Neurogenesis

Spiking dynamics

Na+ Channels

Desired computational function should determine scope



Cognition

Brain

One shot learning, associative memory

Hippocampus

Pattern separation, conjunctive encoding

Dentate Gyrus

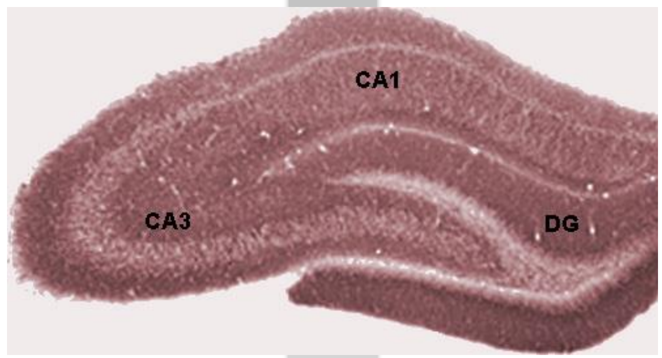
Novel information encoding

Neurogenesis

Spiking dynamics

Na+ Channels

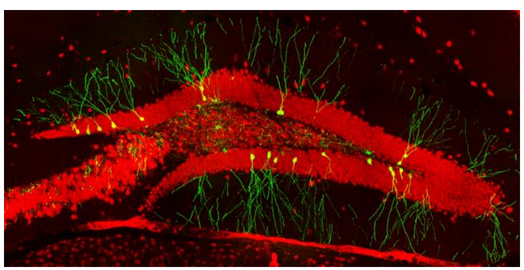
Level of neural abstraction should be determined by functional need



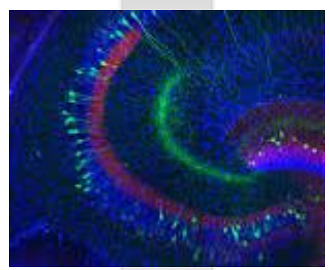
Pattern separation & conjunctive encoding

Auto-association & Recursive Dynamics

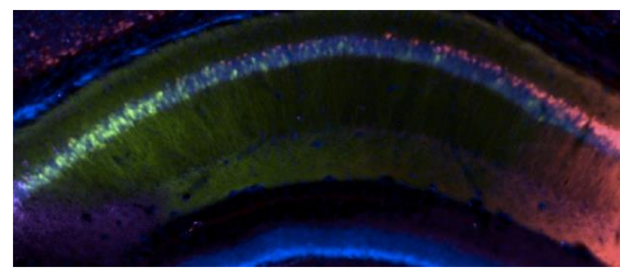
Temporal associations & Cortical-Hippocampal Comparisons



Dentate Gyrus

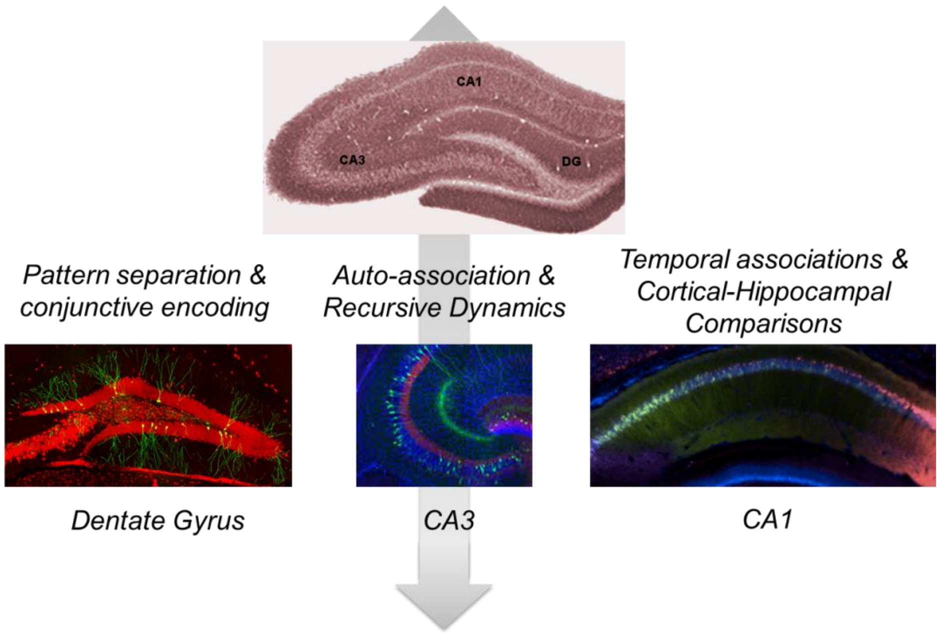


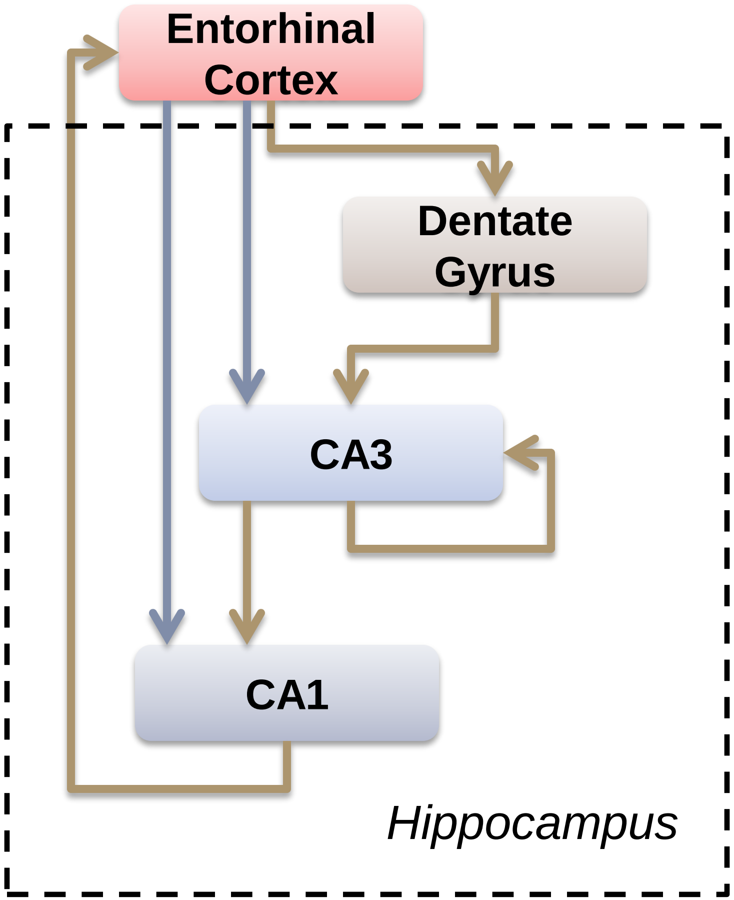
CA3



CA1

Produce high level model and provide increased resolution as needed





Systematic abstraction becomes necessary with high complexity

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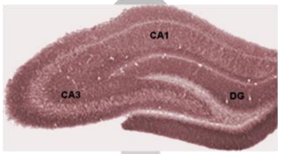
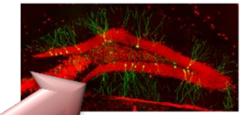
Computational Dentate Gyrus

→ Goal of proving larger model with clear function

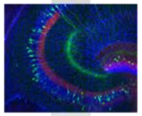


Pattern separation & conjunctive encoding



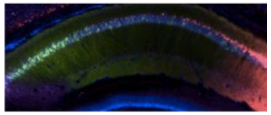
Dentate Gyrus

Auto-association & Recursive Dynamics

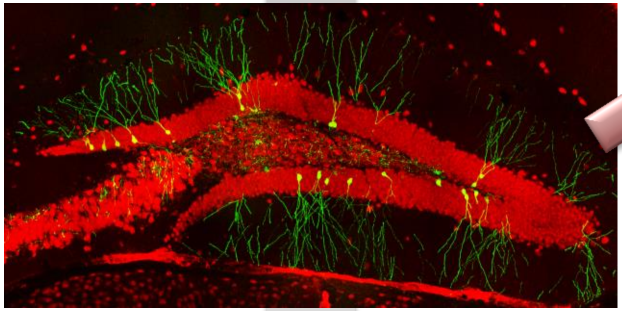


CA3

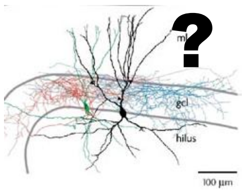
Temporal associations & Cortical-Hippocampal Comparisons

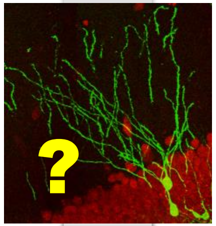


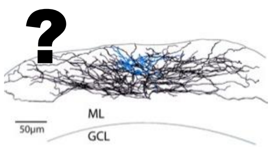
CA1



Which components are necessary to produce desired pattern separation function?

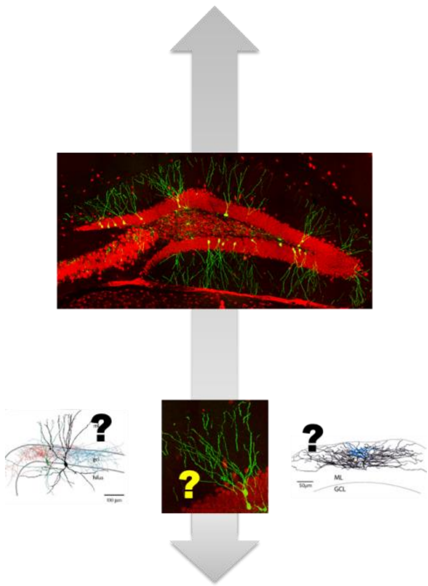






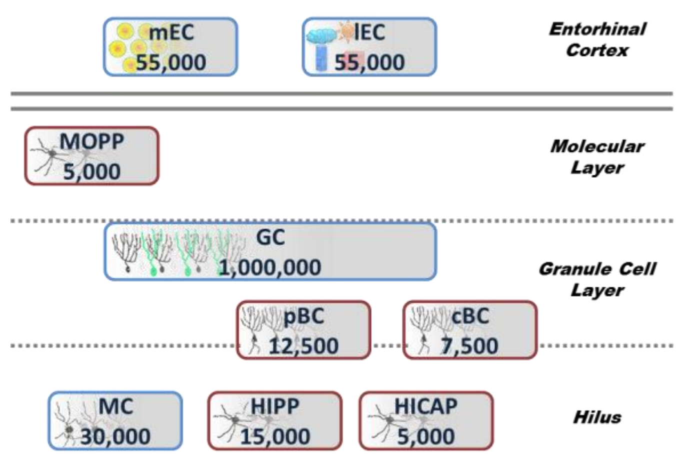
- *What scale?*
- *What types of plasticity?*
- *What resolution?*
- *What types of neurons?*

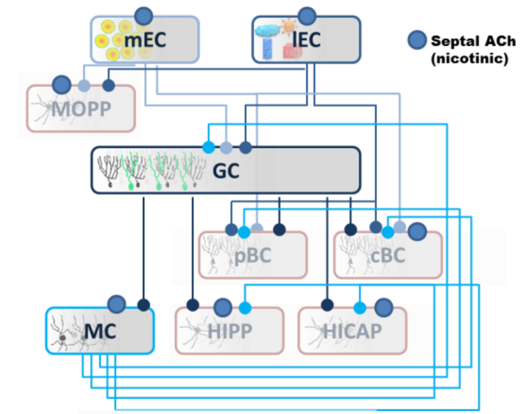
Realistic simulations can guide abstraction for computing

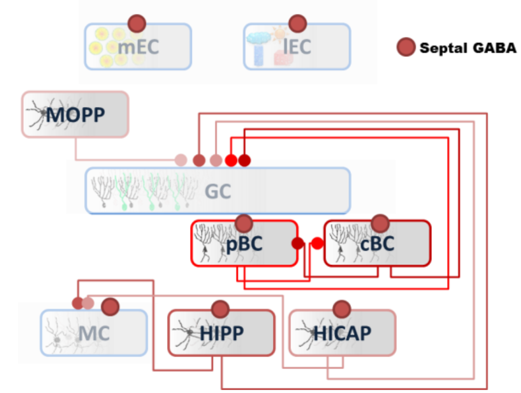


- *What neural scale?*
- *What cell types?*
- *What plasticity?*
- *Neurogenesis?*
- *Etc…*

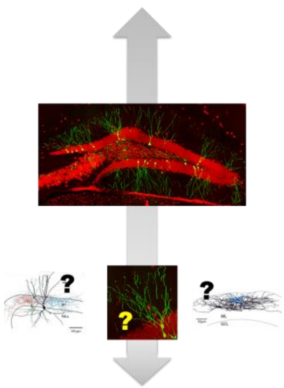
DG model with realistic neuron types and numbers, anatomy-guided connectivity, and detailed neurogenesis

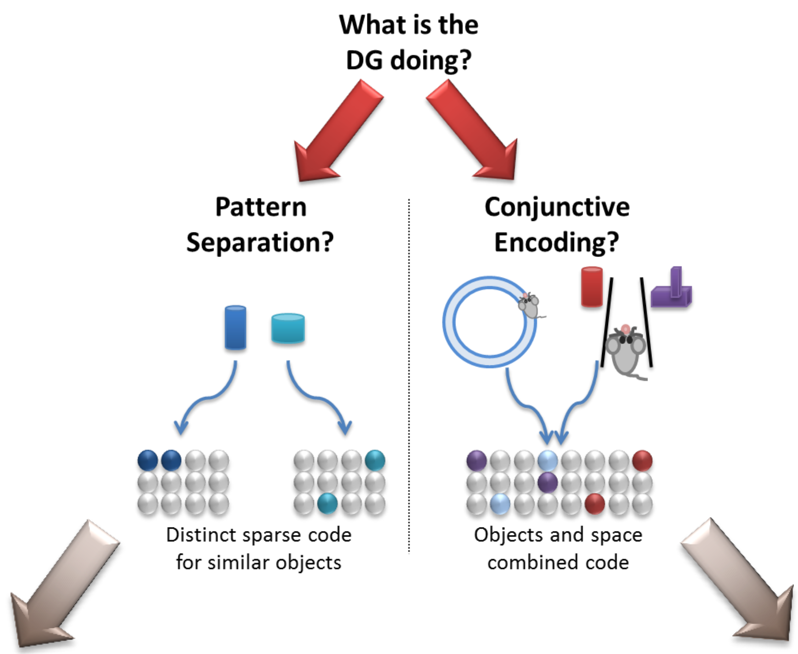




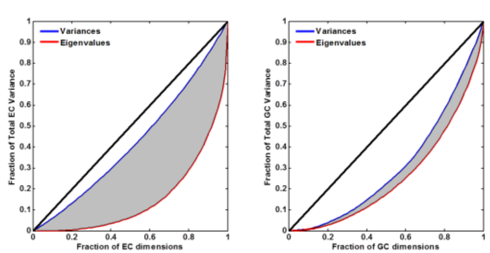


Realistic simulations can guide abstraction for computing

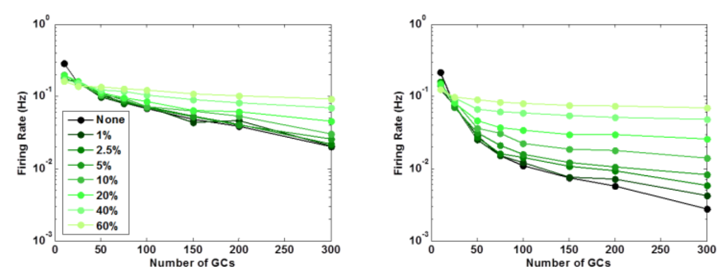




Measure “compressiblility” of activity



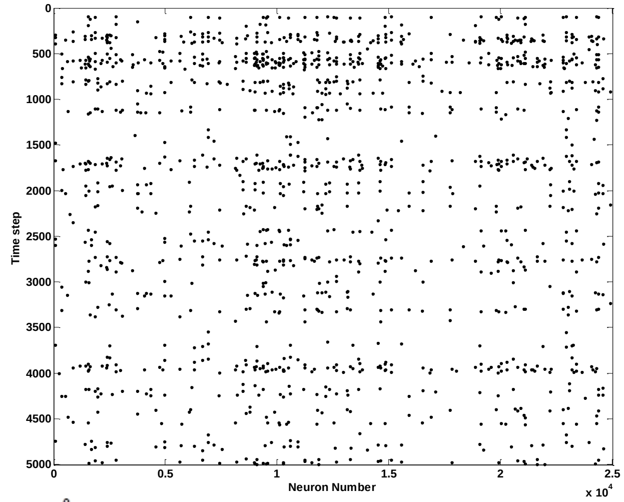
Measure magnitude of activity

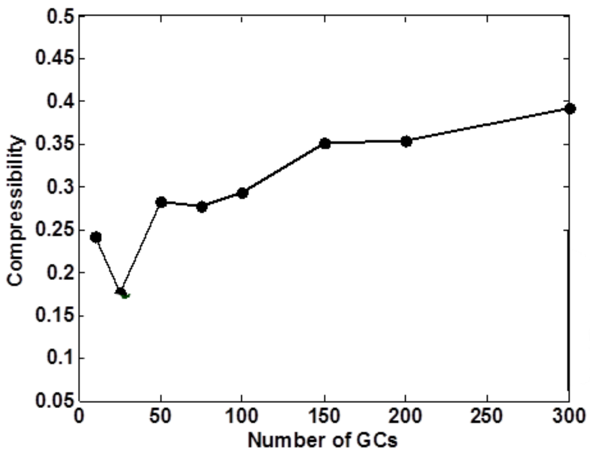


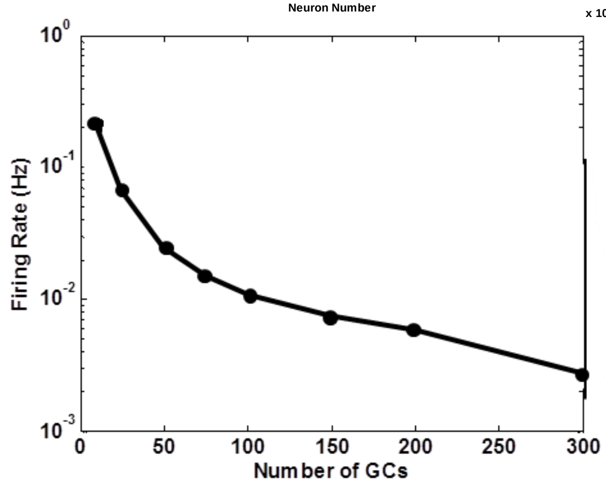
Reduced scale simulations are qualitatively different than realistic scales

25,000 Granule Cells

300,000 Granule Cells

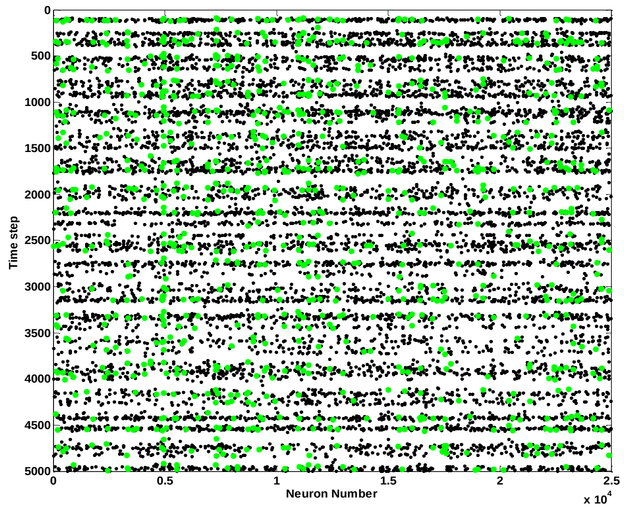




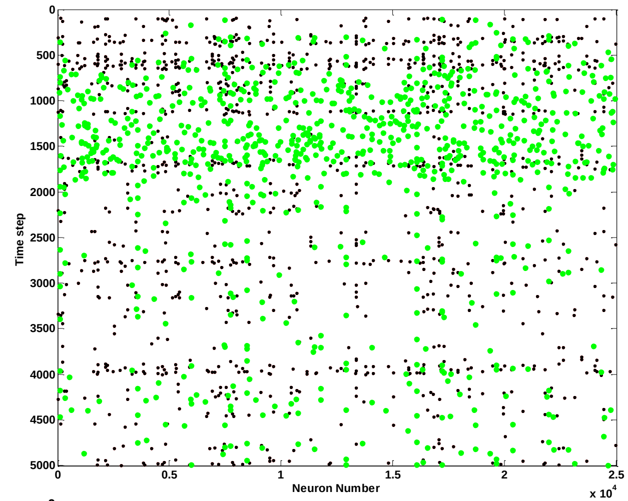


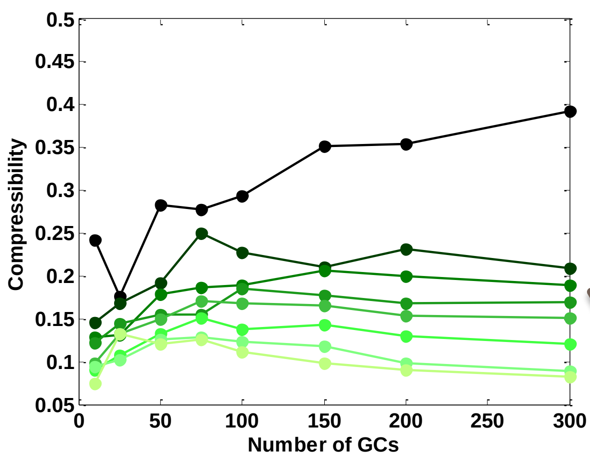
Neurogenesis is critical for encoding and separation, but depends on scale

25,000 Granule Cells

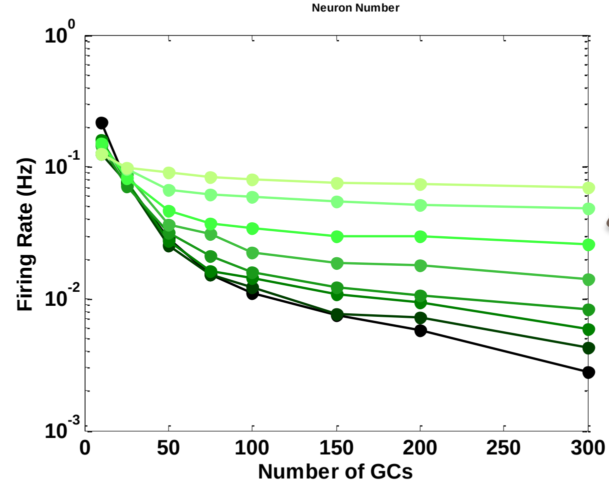


300,000 Granule Cells





Improved pattern separation

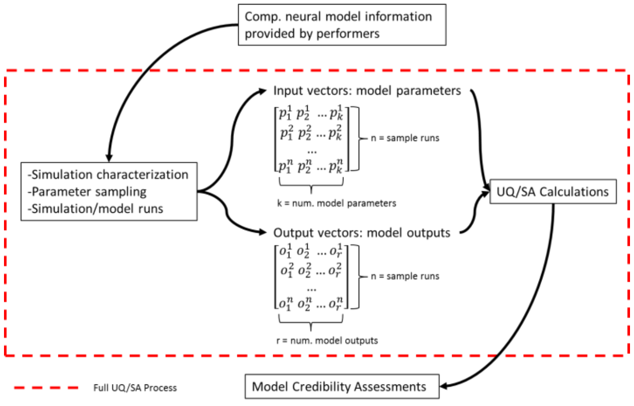


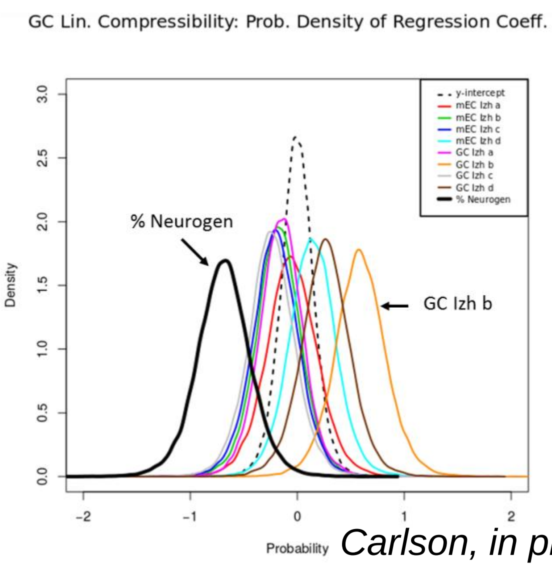
More information encoded

Can use formal UQ / SA techniques to inform path to abstraction

- Important*:
  - Scale is critical
  - Neurogenesis is necessary form of plasticity to encode novel information
- Less important*:
  - Interneuron diversity
  - Specific neuron dynamics

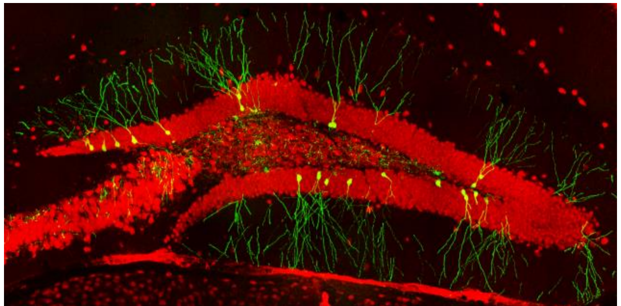
* *For these specific functions*



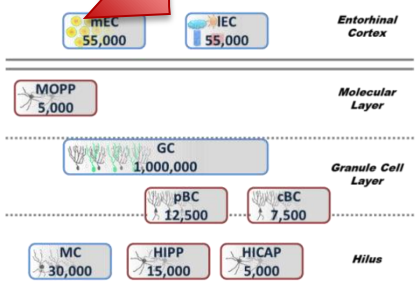


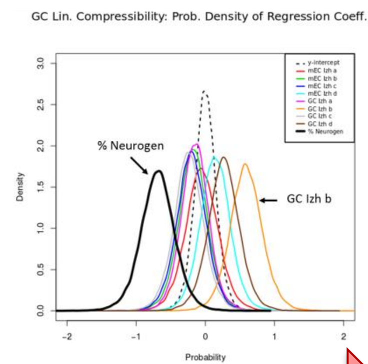
Carlson, in preparation

Abstracted concepts can become computing-friendly



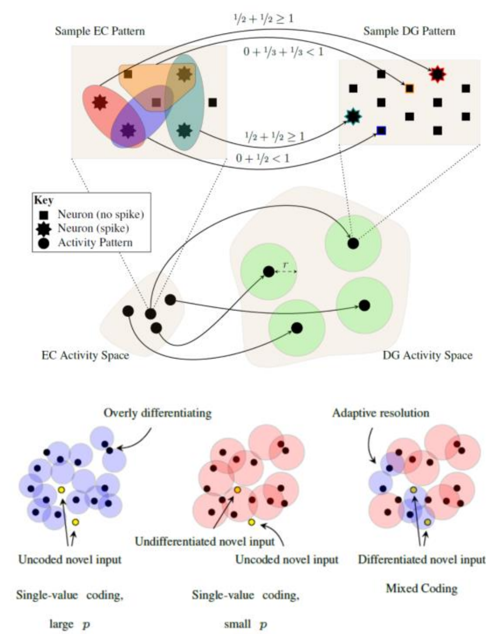
Simulate at high level of neural fidelity





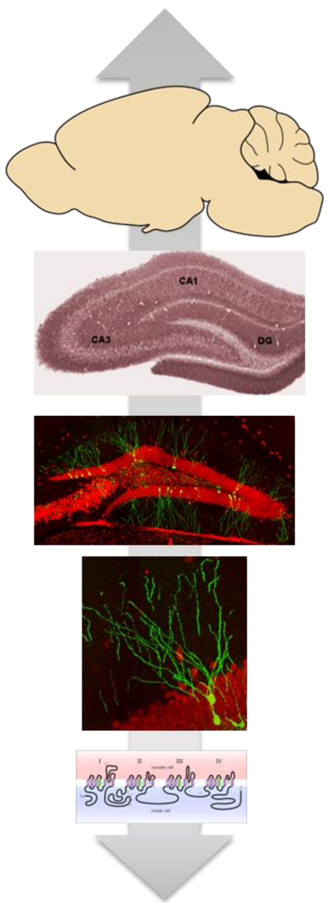
Identify critical aspects of computation (expansive scale; sparse activation; neurogenesis)

Formalize dentate gyrus / neurogenesis sparse coding algorithm



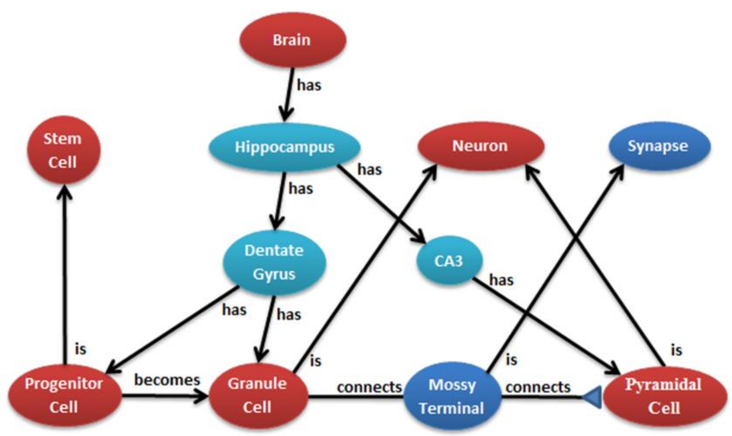
Severa et al., submitted

Can we systematically use this approach?



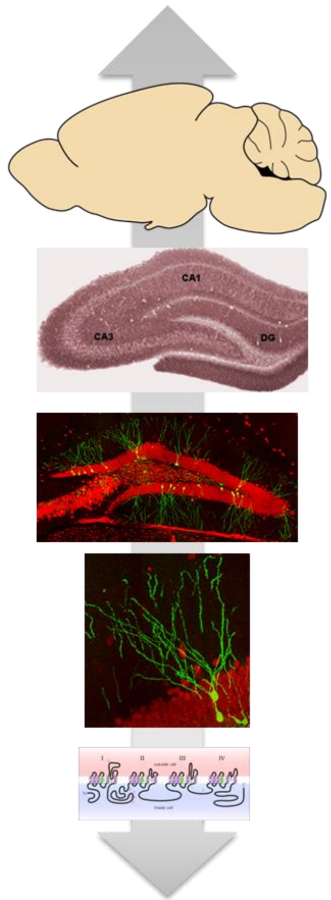
N2A model framework and software

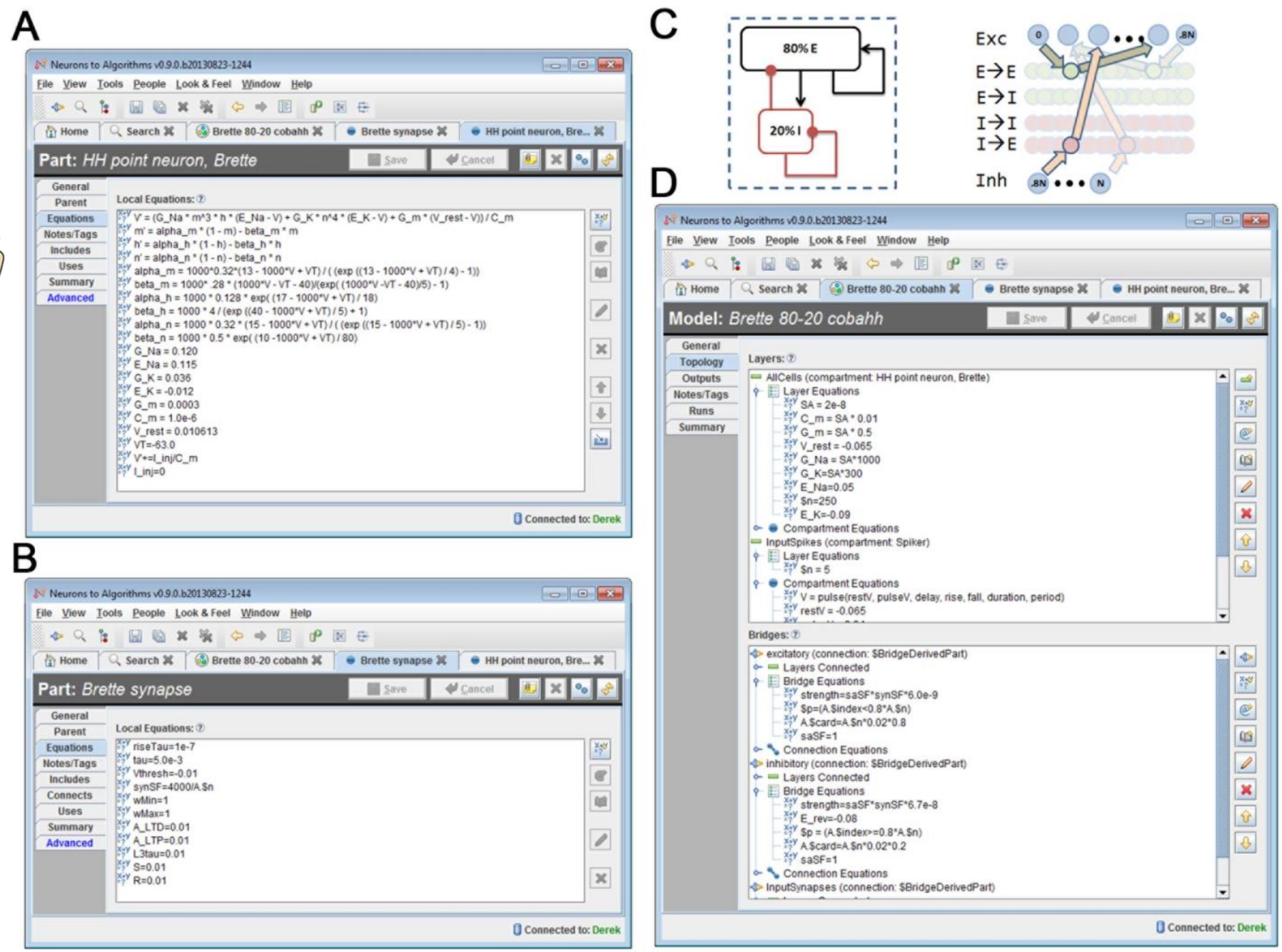
- compositionally construct dynamical neural models
- compiles simulation codes
- potential “front-end” to neural hardware



Rothganger et al., Frontiers in Neural Circuits 2

Can we systematically use this approach?





Rothganger et al., Frontiers in Neural Circuits 2014

Thanks!