

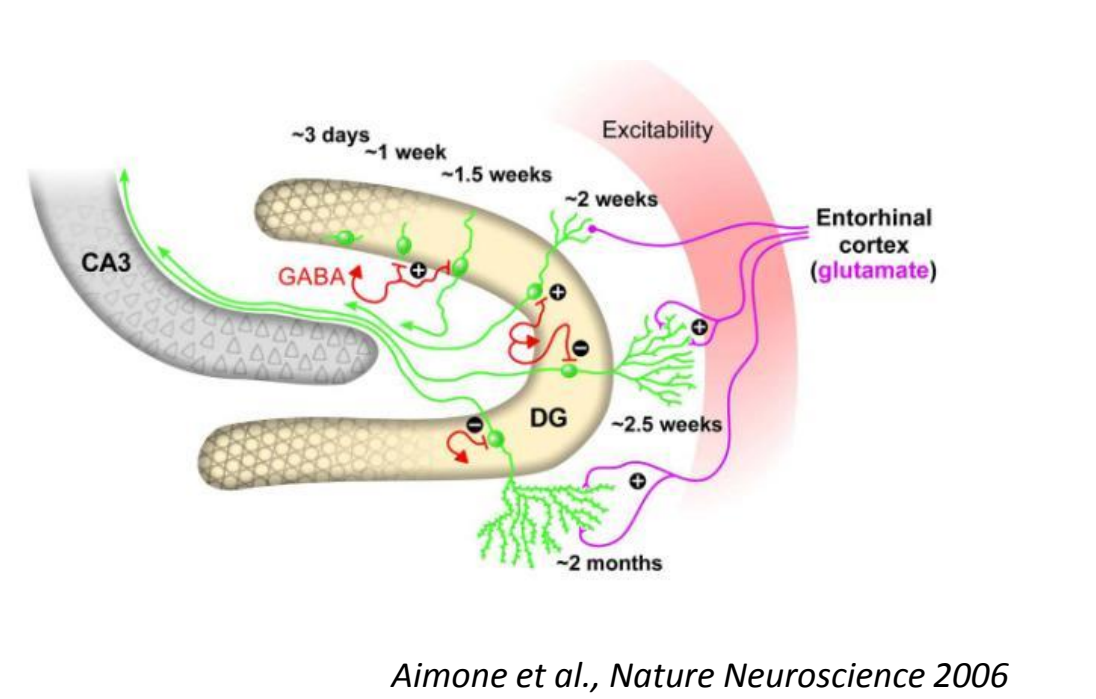
How neurogenesis and the scale of the dentate gyrus affect the resolution of memories

James B Aimone and Craig M Vineyard

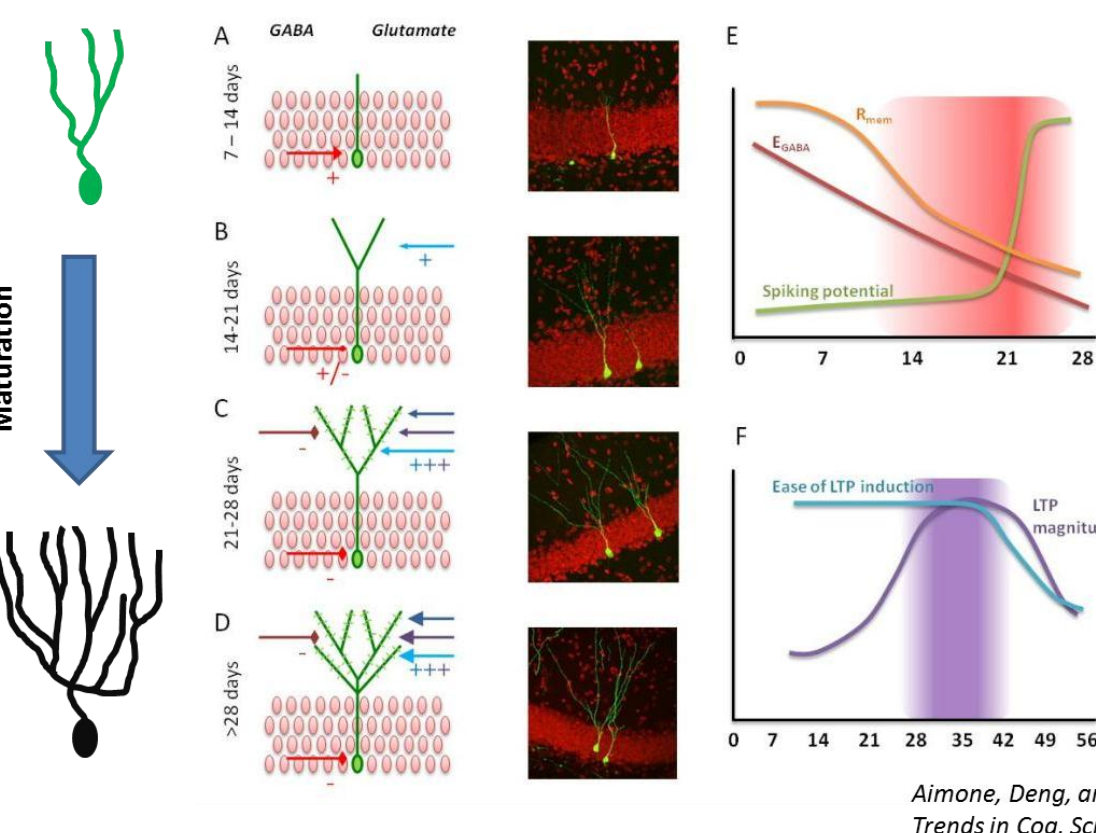
Cognitive Modeling Group, Sandia National Laboratories, Albuquerque NM

Overview of Adult Neurogenesis

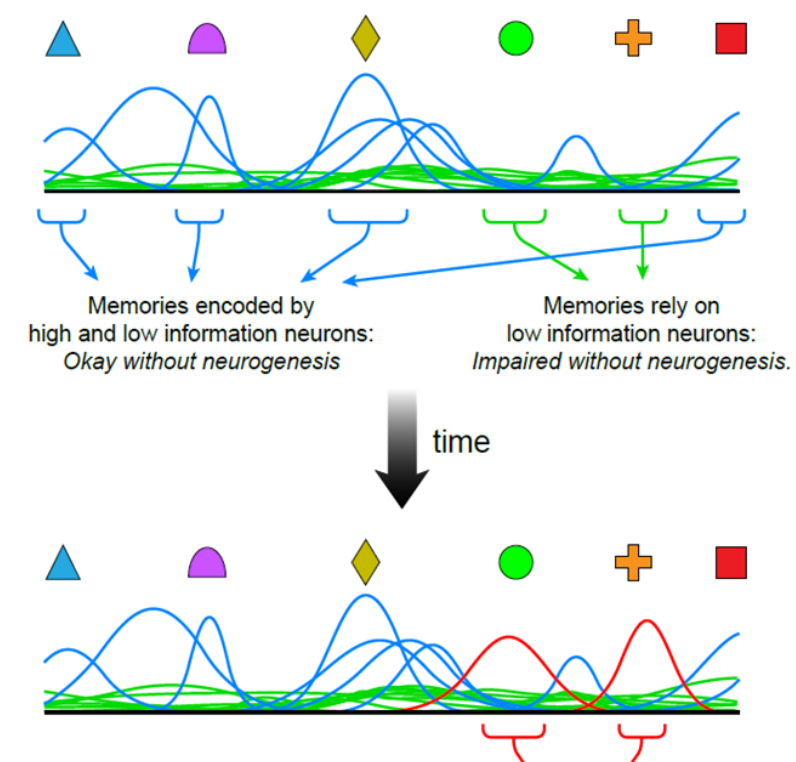
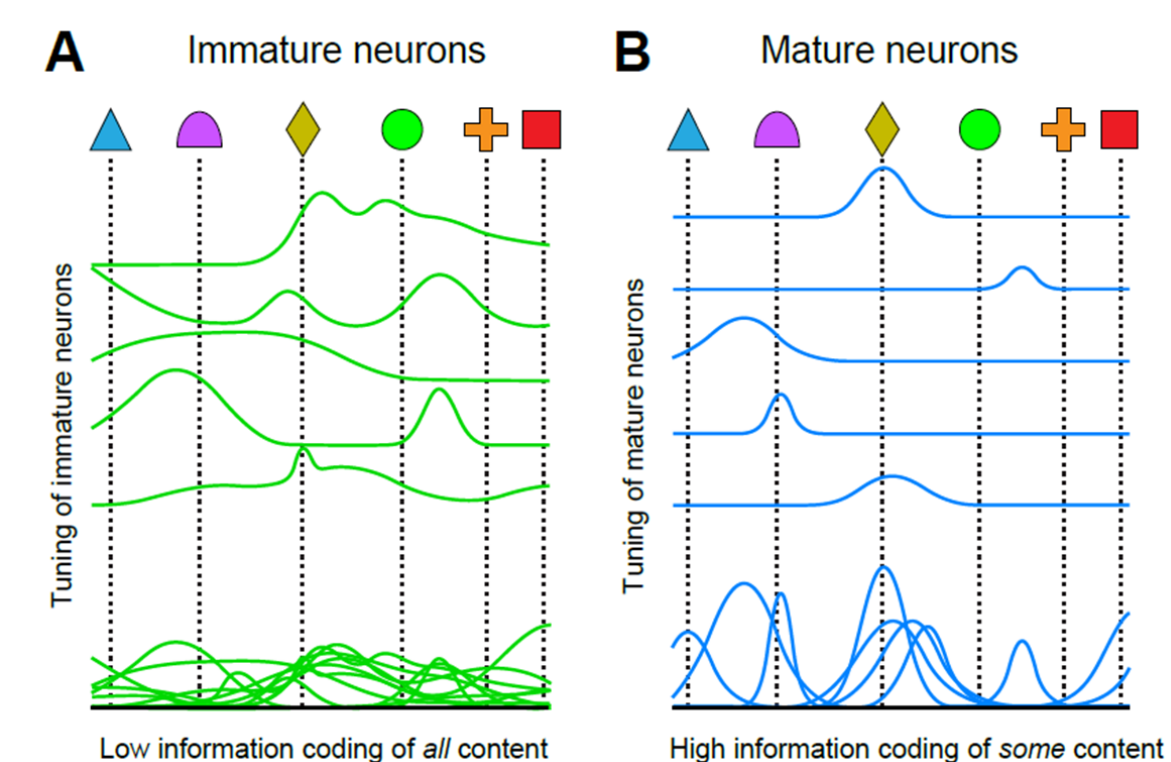
- 1000s of new granule cells integrate into DG monthly
- Only excitatory neurons are born; no new inhibitory neurons in DG
- Process heavily regulated by behavior; for example, running and enrichment increase, stress and aging decrease.
- Maturation process extends over months, excitatory and inhibitory pathways develop in parallel
- Young neurons are more “excitable” than mature counterparts due to distinct physiological and connectivity



Aimone et al., Nature Neuroscience 2006



Aimone, Deng, and Gage Trends in Cog. Sci. 2010



Aimone, Deng and Gage Neuron; 2011

Memory resolution hypothesis

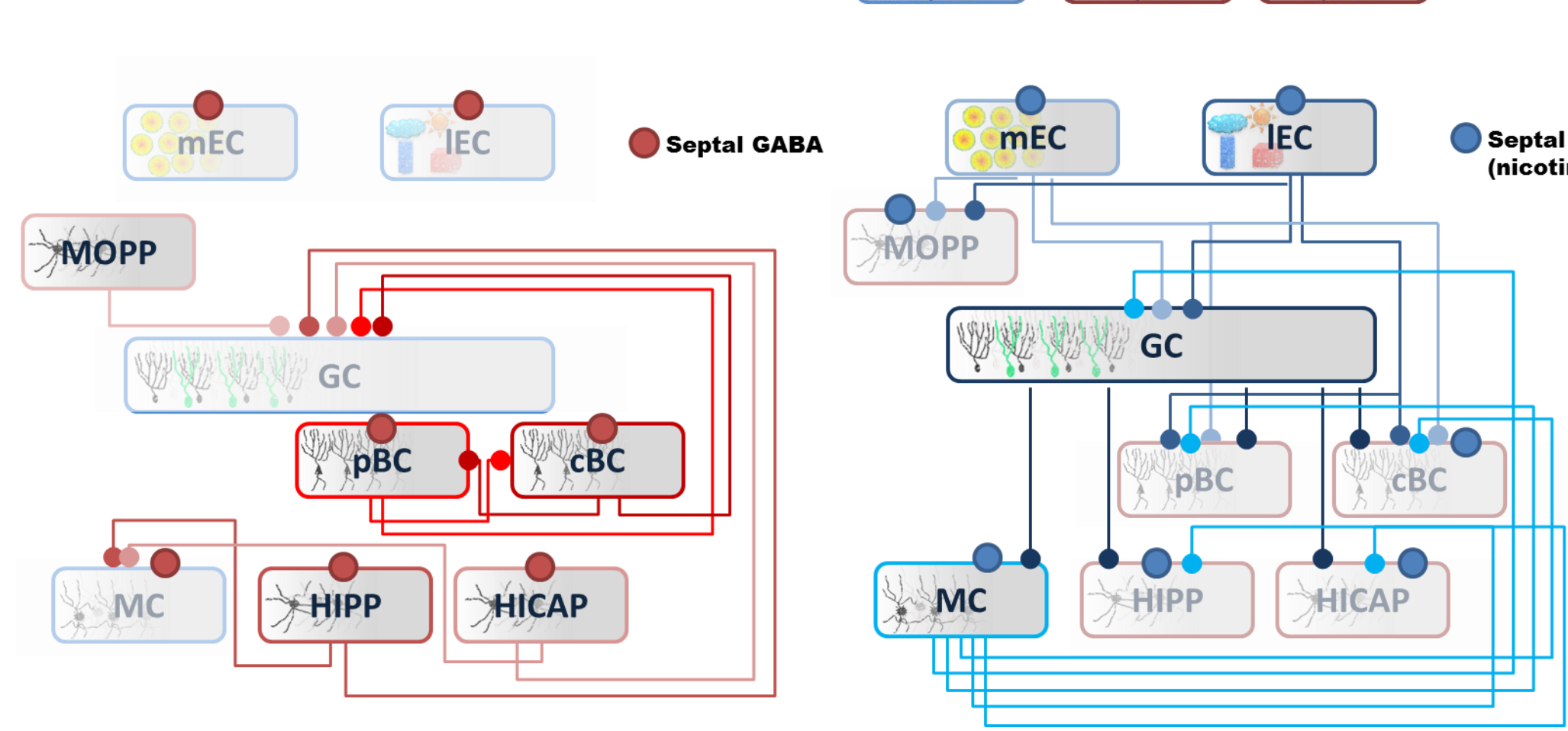
- Mature neurons utilize high fidelity, low redundancy sparse code that effectively represents familiar features
- Young neurons form distributed code made up of individually low fidelity units but cumulatively represent novel and familiar information
- Over time, those young neurons that survive develop to become tightly tuned mature neurons
- Combined sparse and distributed code ensures novel features are encoded within new memories while preserving familiar features

Pattern Separation

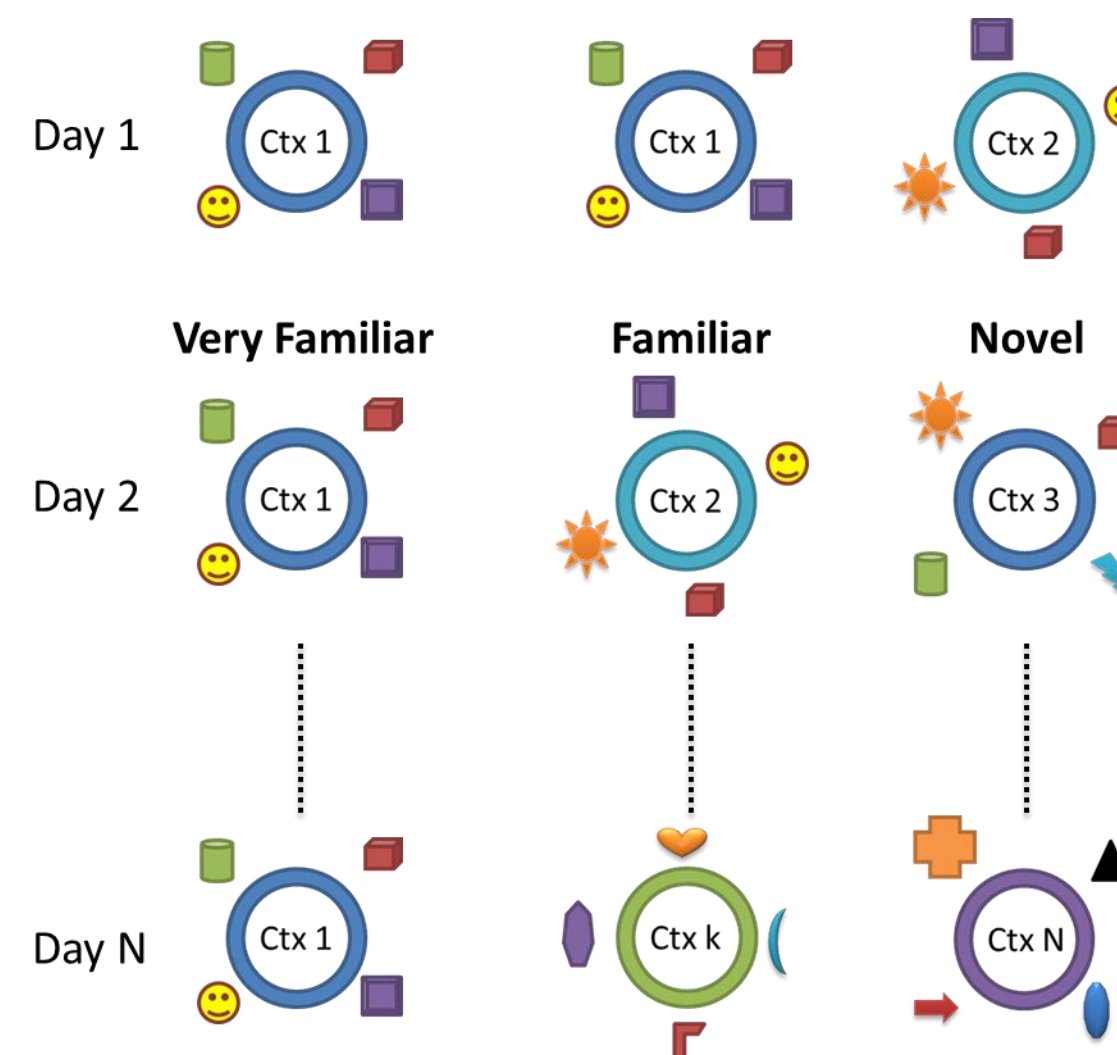
- Based on behavioral data (poor spatial discrimination in neurogenesis knockdown animals) and classic models of sparse coding DG function
- Facilitates encoding of information in downstream CA3 network by reducing interference between attractor states
- Almost certainly a function; question is whether it is everything?

Overview of Modeling Approach

- Nine layer model of DG and entorhinal cortex inputs
- Oscillating modulatory inputs
- Feed-forward and feedback inhibitory and excitatory pathways
- Biologically realistic neuron numbers and ratios



- Modified Izhikevich spiking dynamics
- Neuron dynamics fit to actual electrophysiology data from mature and immature granule cells and hilar interneurons
- Inputs are spatial (mEC; grid cells) and object (IEC; object cells)

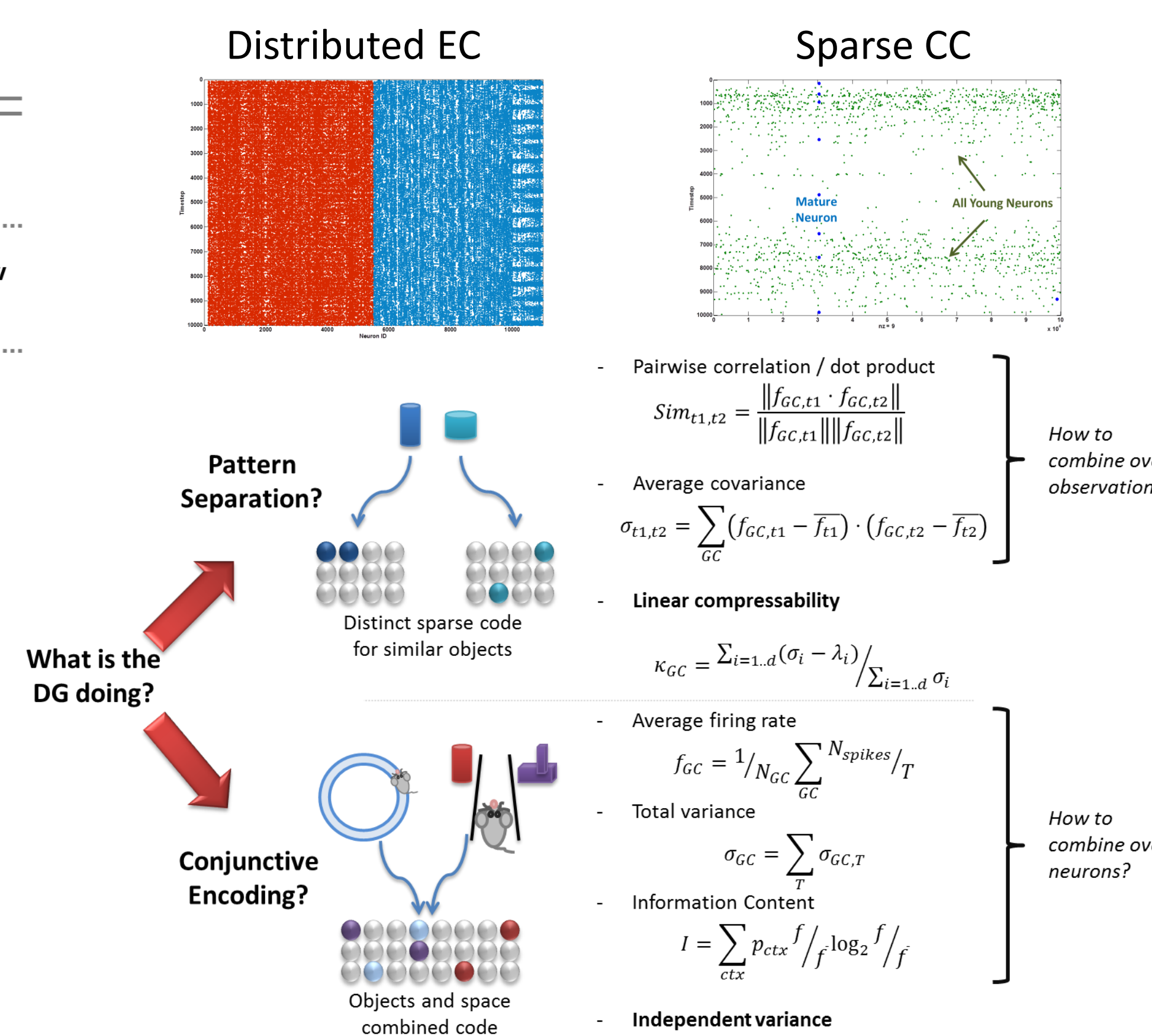


- Multi-day simulation to capture acute and long-term effects of neurogenesis
- Each day has novel contexts and (after initial day) familiar contexts
- Contexts can vary by which objects, object locations, and broader features

Acknowledgments

We would like to thank Lucas Mongiat, Yangling Mu, and Wei Zhang for raw electrophysiology data. This work was funded in part through the Laboratory Directed Research and Development program at Sandia National Laboratories.

Analysis Method



Digital Compression Method

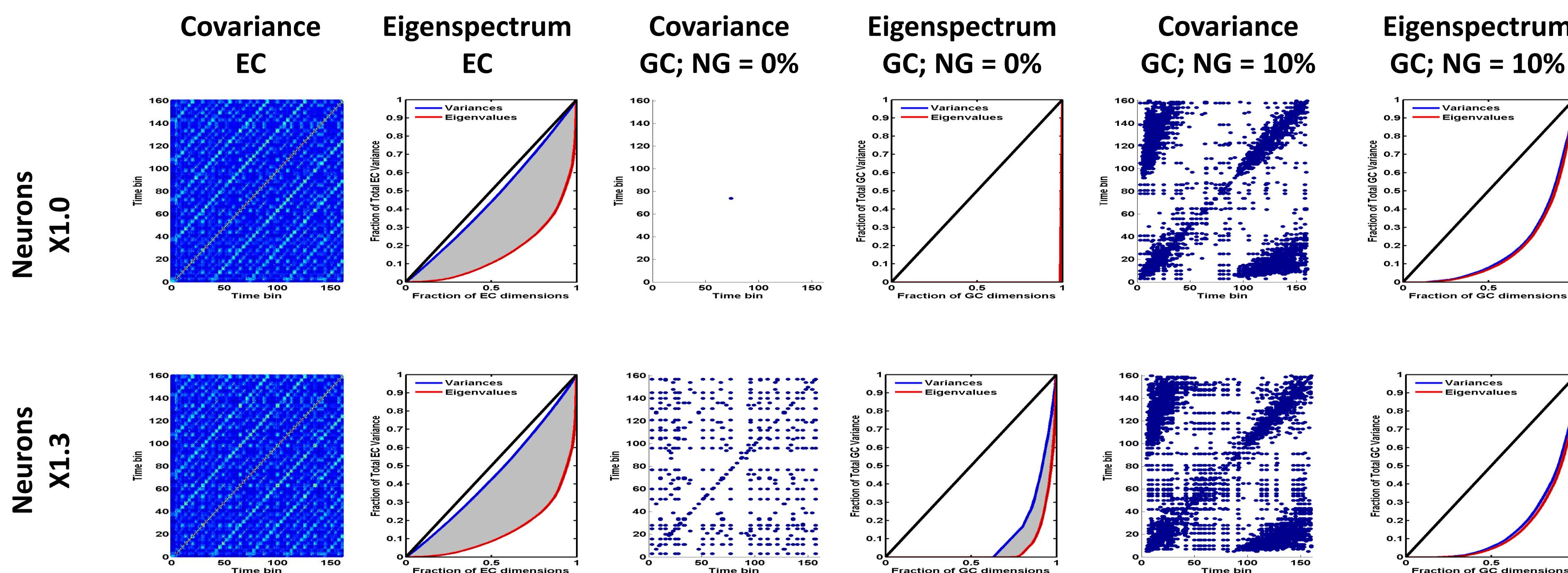
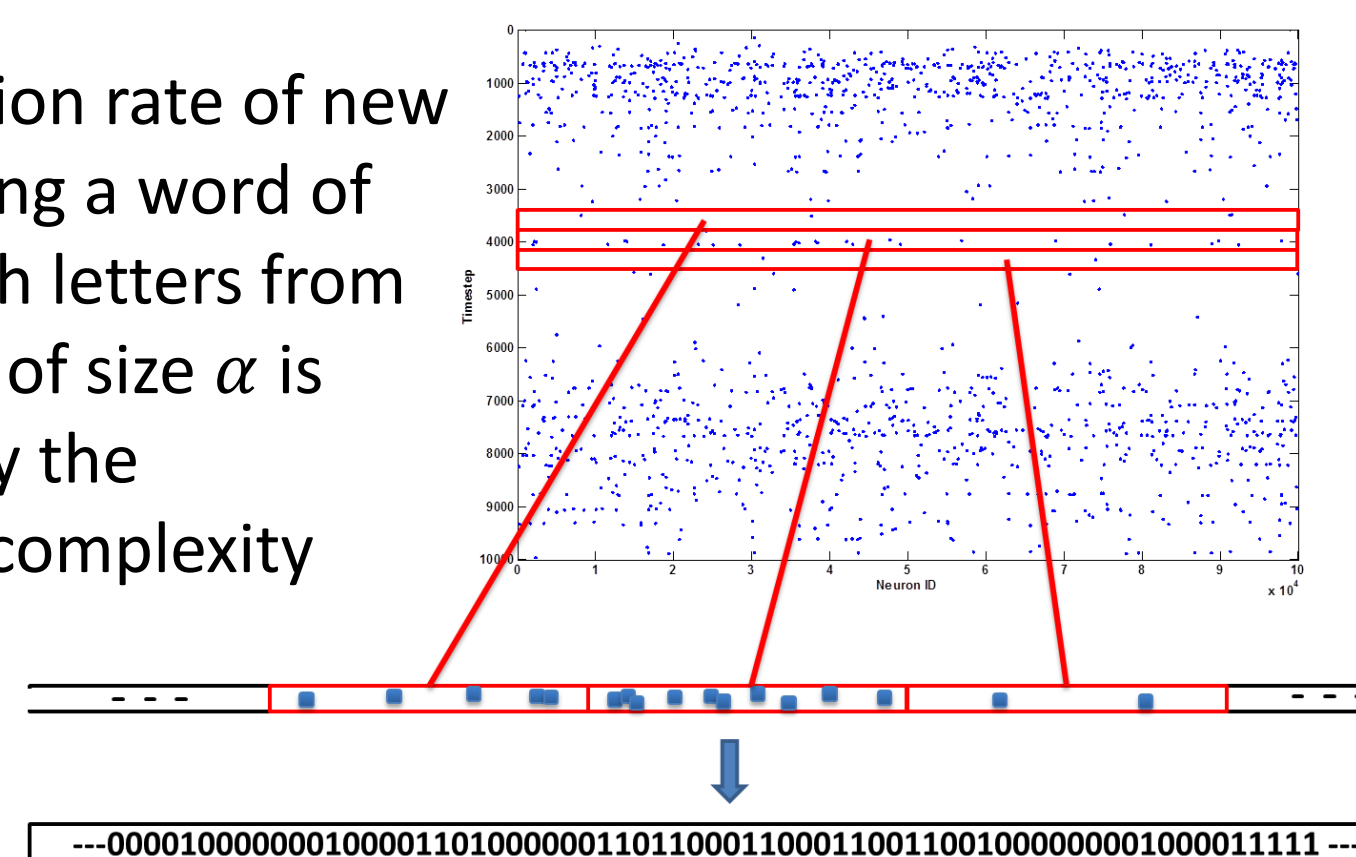
Normalized LZ Complexity, c , measures the rate of generation of new patterns along a sequence

$$c_{\alpha}(x^n) = \frac{C_{\alpha}(x^n)}{n} \log_{\alpha} n$$

$$\lim_{n \rightarrow \infty} \sup c_{\alpha}(x^n) \leq H_{\alpha}(S)$$

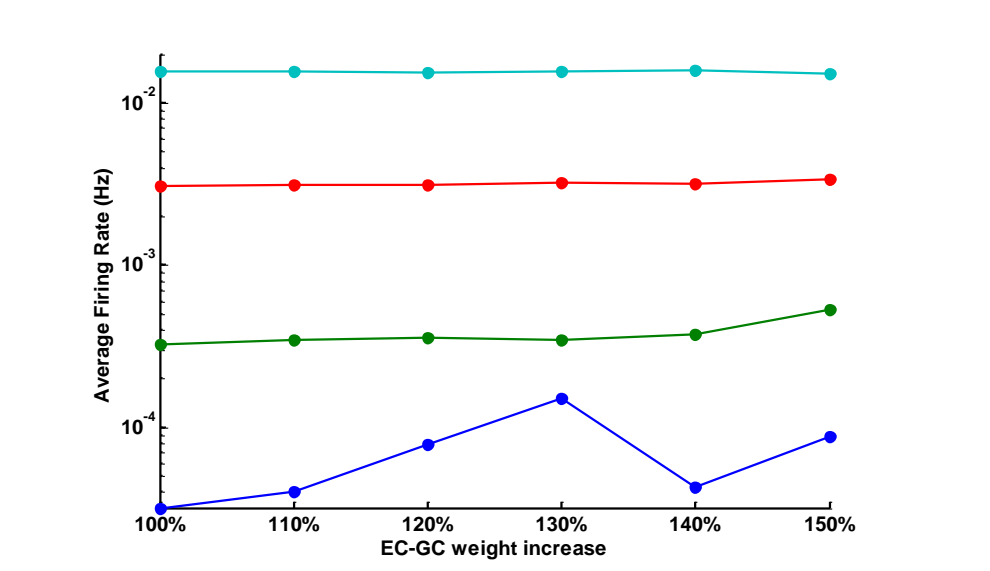
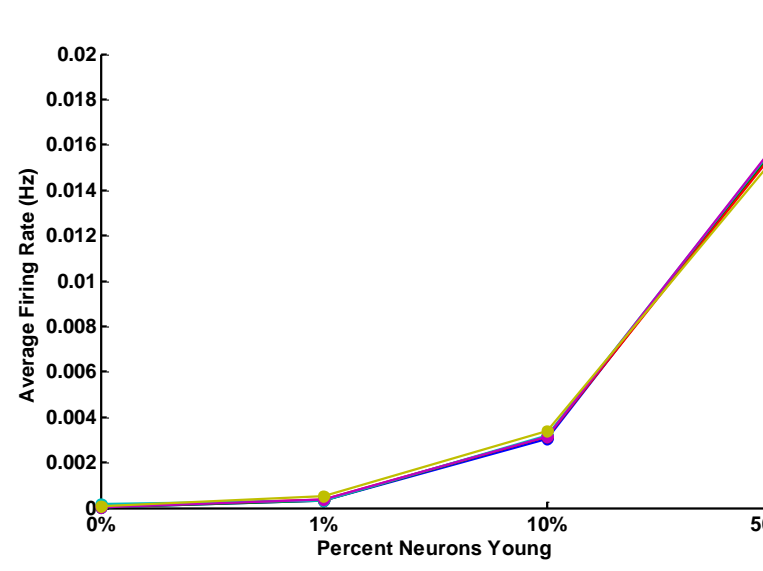
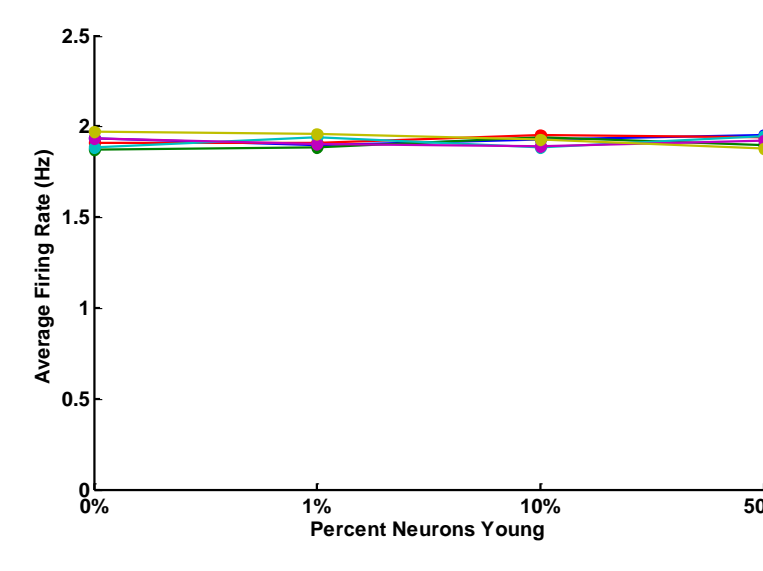
Lempel and Ziv, IEEE Information Theory, 1976
Szczepanski, Janusz, et al. Network: Computation in Neural Systems 2003

The generation rate of new patterns along a word of length n with letters from an alphabet of size α is measured by the normalized complexity



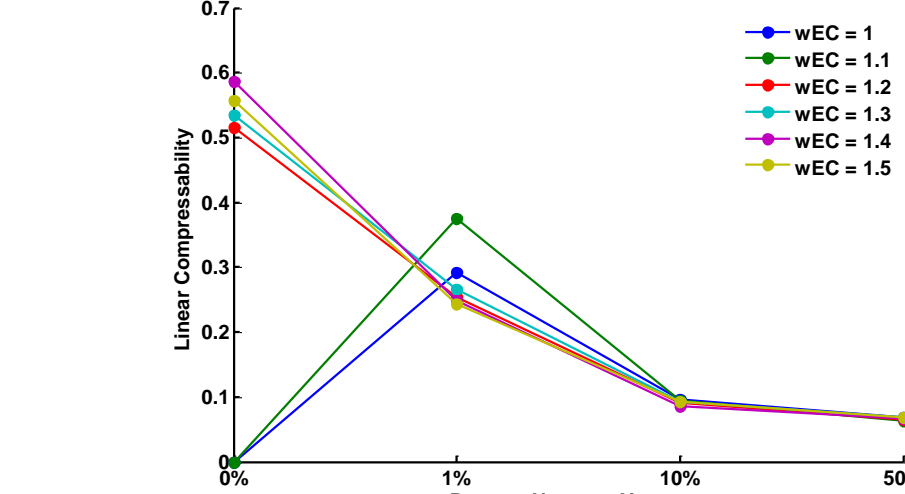
Overall firing behavior

- GCs are much less active than EC neurons
- Young GCs are vast majority of active GCs
- Neurogenesis is major factor in overall GC responsiveness
- EC-GC weight increase has only marginal effect on GC responsiveness

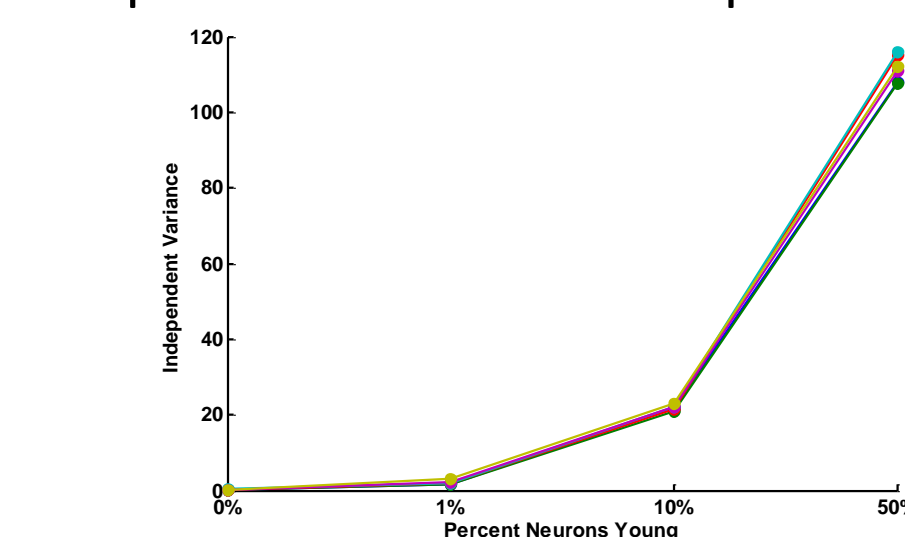


Results

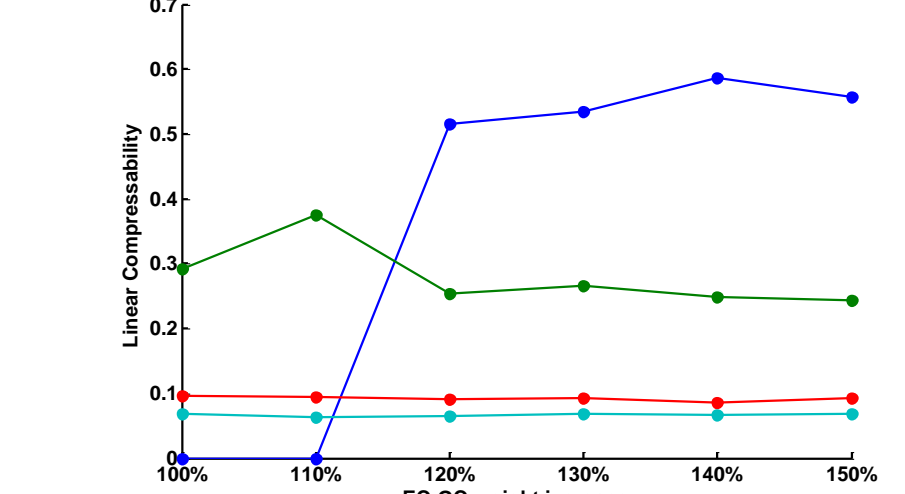
Adding new neurons decreases overall compressibility of GC output



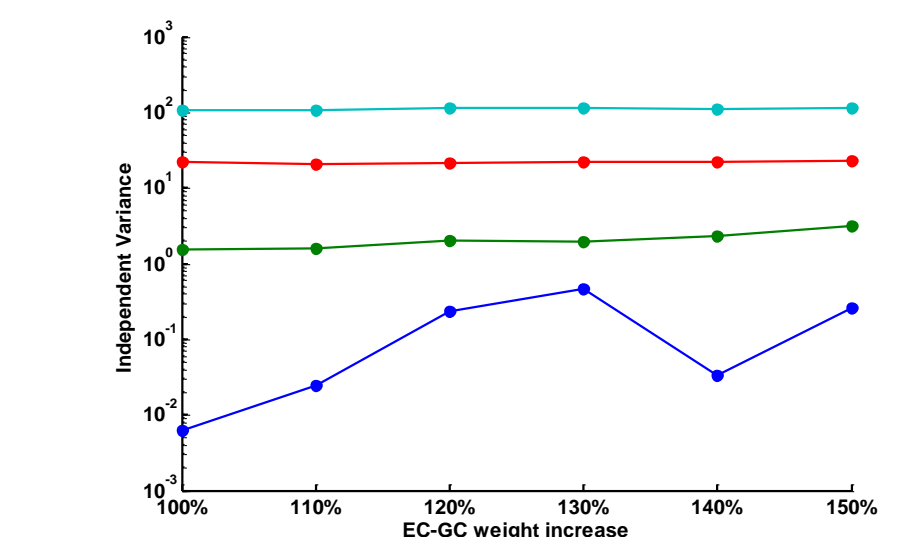
... and increases the total representation in the output



Increasing EC-GC strengths impairs separation



... but does not improve coding



Effect of scaling

- Non-neurogenic networks over 100k GCs are essentially silent
- Increasing EC-GC weights is not strong factor
- Limited activity in no NG networks is not accompanied by increased pattern separation
- Neurogenesis does not impair pattern separation in larger networks yet increases coding capacity

