Beyond the crossbar: materials based design and emulation of neuromemristive devices and architectures

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Drosophila melanogaster

Complex visual, olfactory systems

Capability to operate airborne

Learning and memory

Drosophila melanogaster

Complex visual, olfactory systems

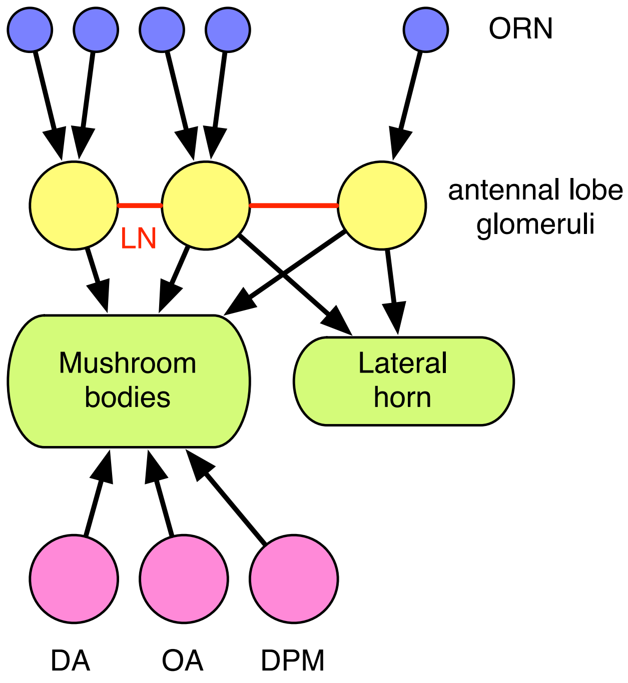
Capability to operate airborne

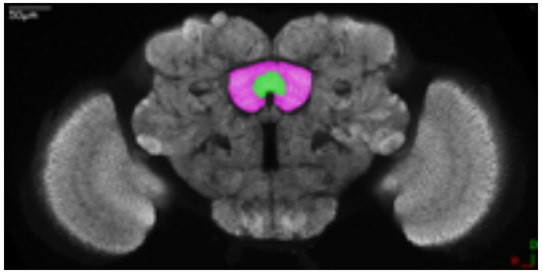
Learning and memory

~100,000 neurons

Drosophila melanogaster

Subset of olfactory neural system





Complex structure

> 30 neuropils (LPUs) in the central neuron system

All canonical neurotransmitters: acetylcholine, GABA, glutamate, dopamine, serotonin, histamine, octopamine, tyramine

Beyond information processing

Great example of an integrated system

How to integrate stimuli and recall to make decisions

Self-learn and adapt to new environments

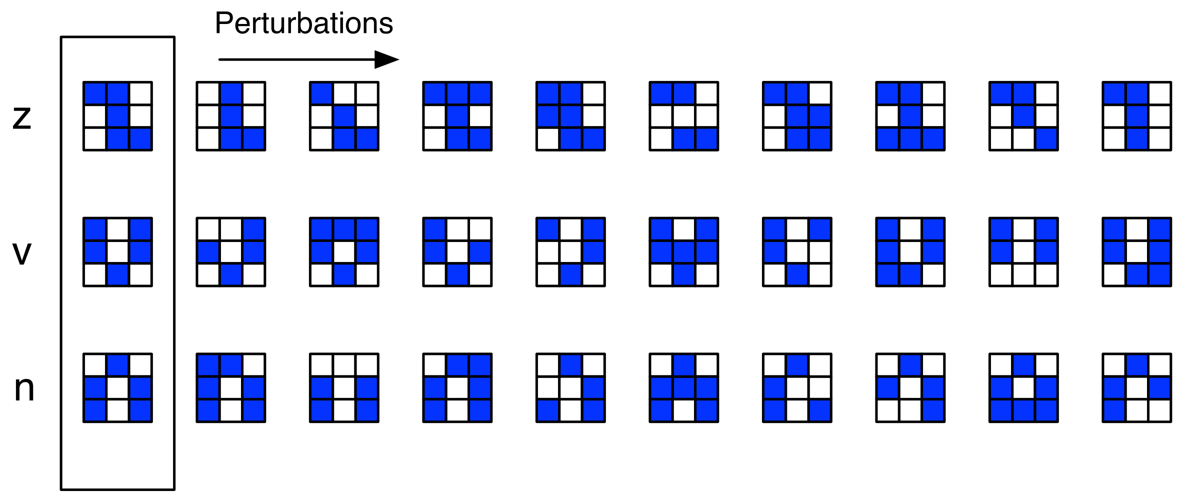
Structure vs training

A lot of the functionality is given by its architecture: evolution and structure as a substitute for training

Morphogenesis, genetic variability implies that the functional valley is broad (bright and dull breeds), and that the resulting connectivity has an stochastic component

Structure vs training

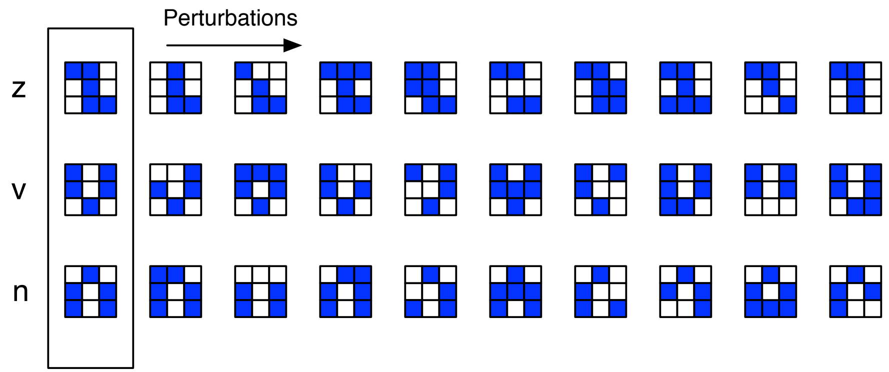
Prezioso et al: *Training and operation of an integrated neuromorphic network based on metal-oxide memristors*, Nature 521, 61(2015).



Trained 9x6 cross bar to identify image and one-pixel perturbations

Structure vs training

Instead, let's create a crossbar with yes/ no connectivity based on the ideal case



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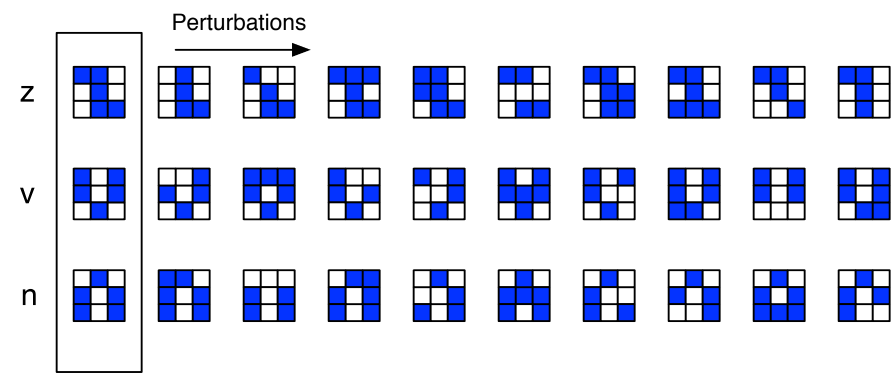

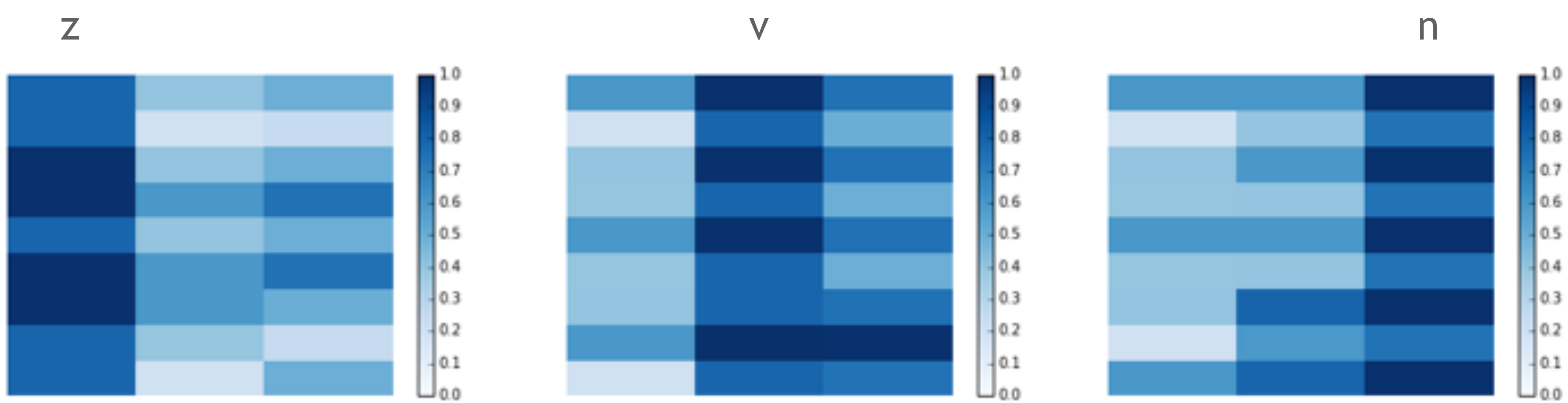

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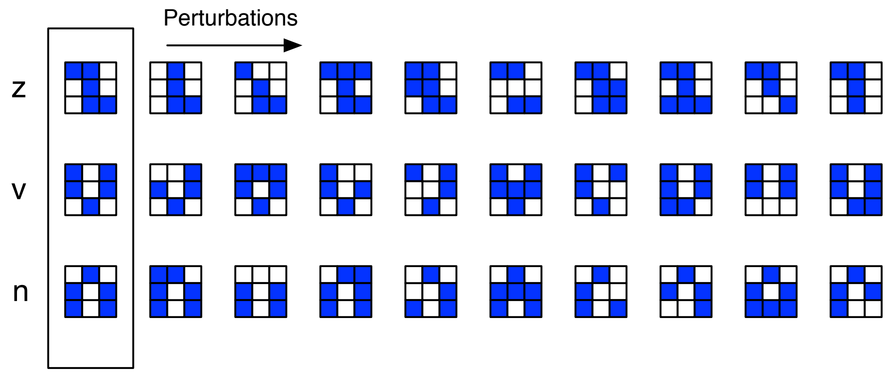
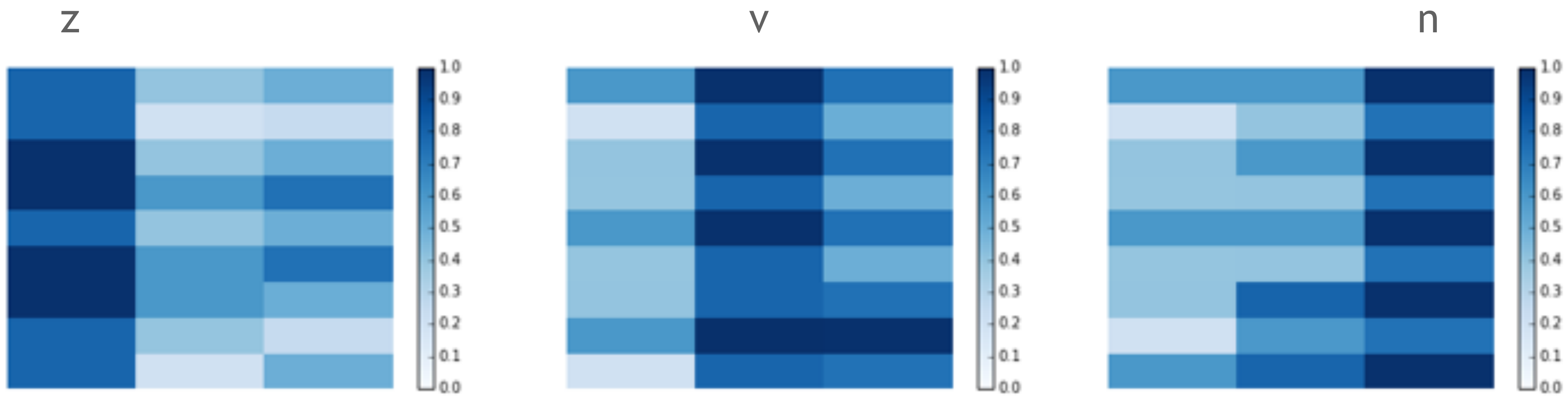




How does it work for more complex networks/ deeper levels?

The role of materials variability

Why are there so many neurotransmitters?

Is it a consequence of parallel evolution or are they functionally needed?

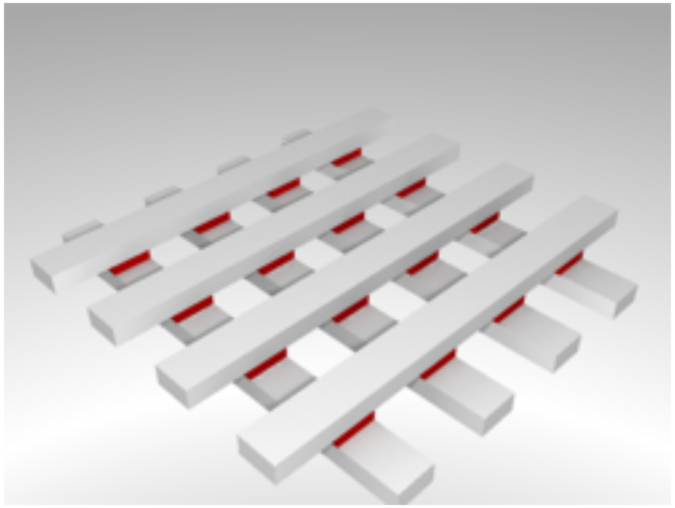
What is the relationship between device/material and the optimal architecture? Is there a strong or just a weak coupling?

What if we wanted to design a neuromorphic system such as the CNS of the fruit fly?

1) We need the ability to incorporate a plurality of functional units in order to understand the role of materials diversity found in biological systems

2) We need to strengthen our ability to define structural units and their interconnections, while abstracting away the complexity taking place at a functional unit level

#1 Hybrid CMOS/memristive systems as a physical layer for neuromorphic systems



Hybrid CMOS/memristive systems

Great diversity on materials properties

Implementation of complex functionality at the synapse

Scalable and manufacturable

Provide a natural intermediate length scale (unit of connectivity)

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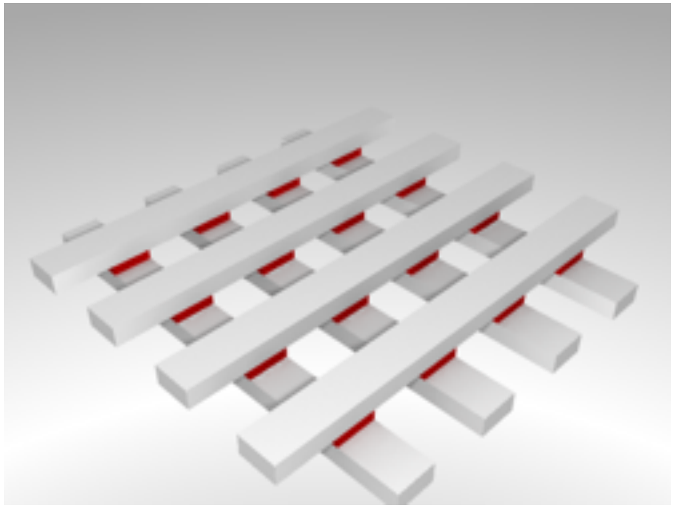

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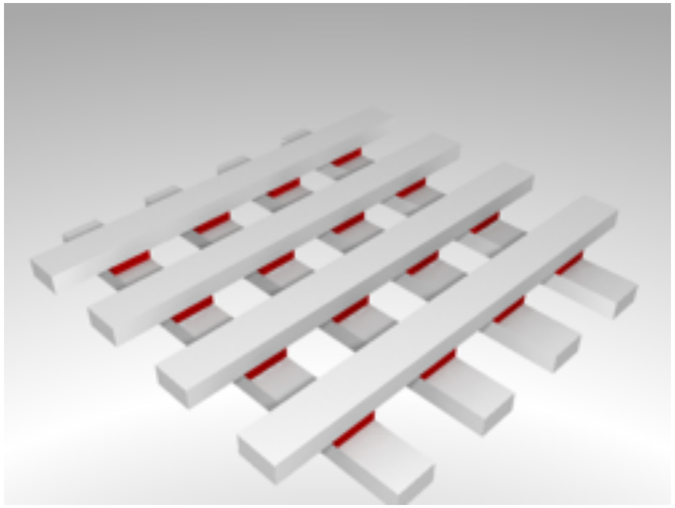

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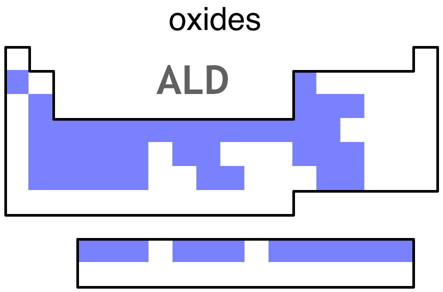
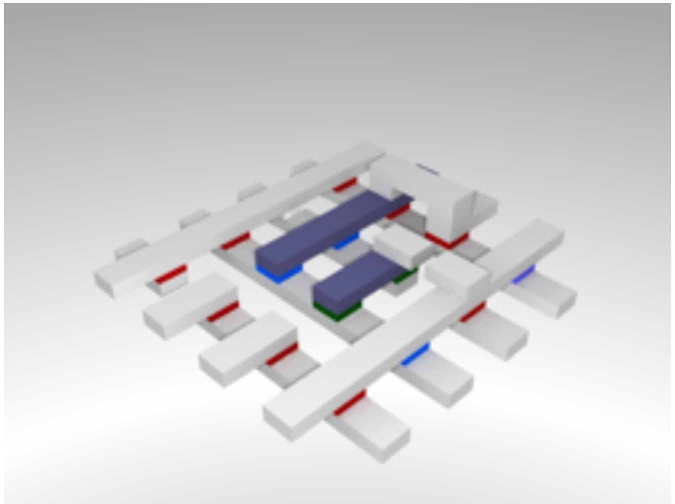


Generalizing crossbar architectures



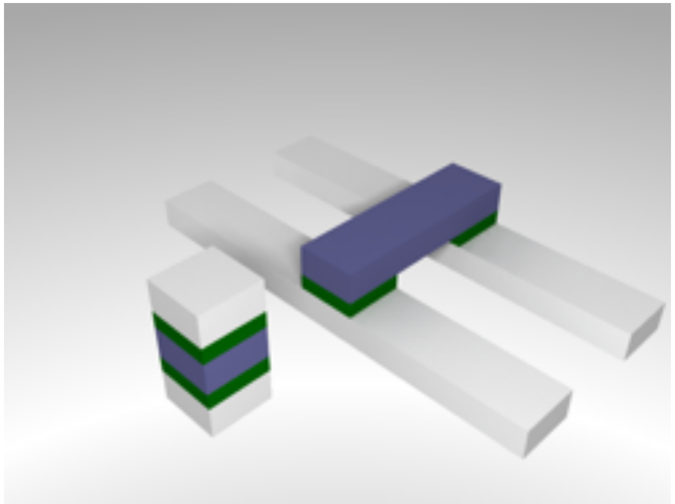
1) At the synaptic level: different stacks of multiple memristive elements per synapsis

2) Changes at the metallization level to tailor the connectivity of the network

3) Adding new levels to the cross-bar architecture: packing density but also to define new interactions

4) Different types of artificial neurons in the CMOS component in hybrid architectures

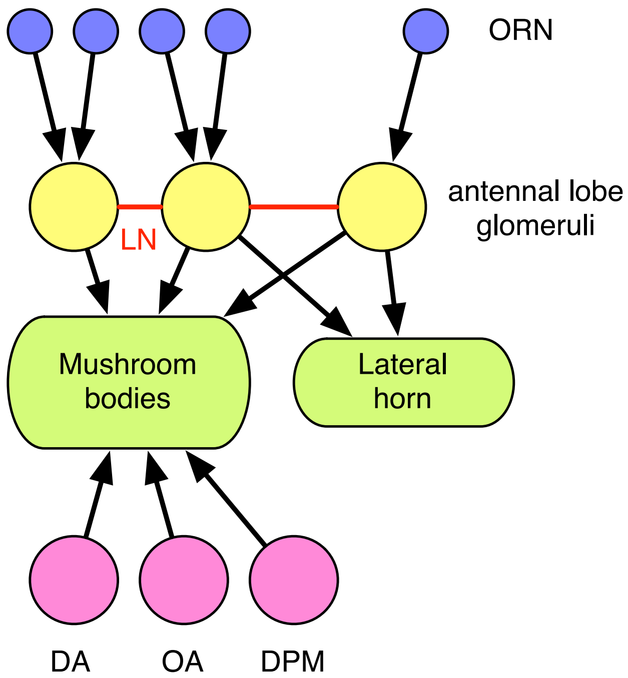
Two target applications



Implementation of logic operations in a cross-bar architecture based on multiple memristive devices

Implementation of excitatory-inhibitory networks

A short stop in excitatory-inhibitory networks



Two types of functions:

Sharpening of response

Scaling of dynamic range of response: attention, multisensory integration, value estimation

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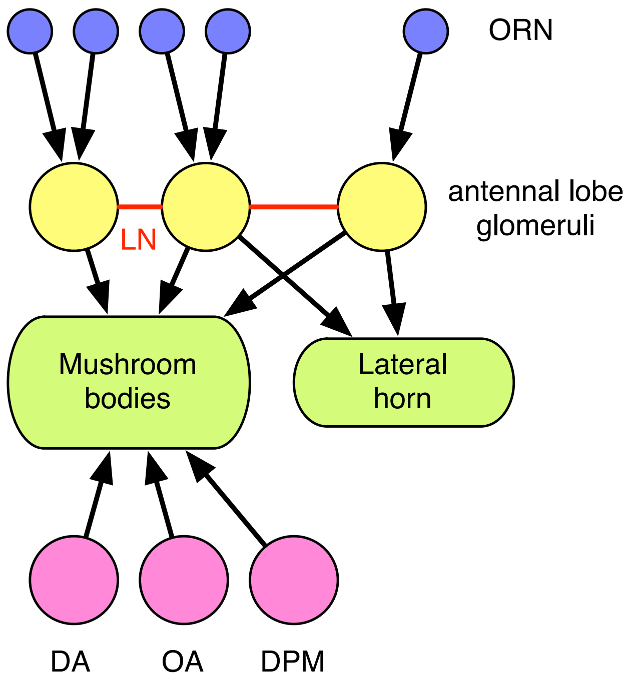


Two types of functions:

Sharpening of response

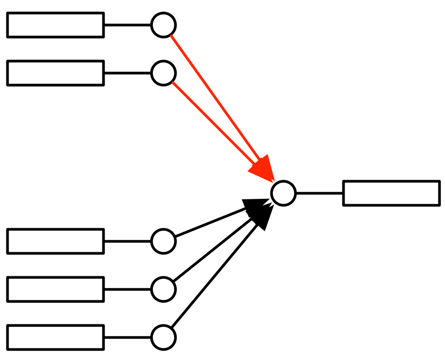
Scaling of dynamic range of response: attention, multisensory integration, value estimation

Reciprocal inhibition is an effective mechanism for neural synchronization

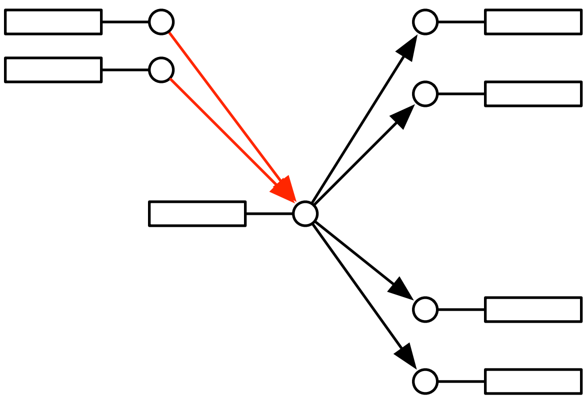
A short stop in excitatory-inhibitory networks

Two potential approaches in cross-bar architectures

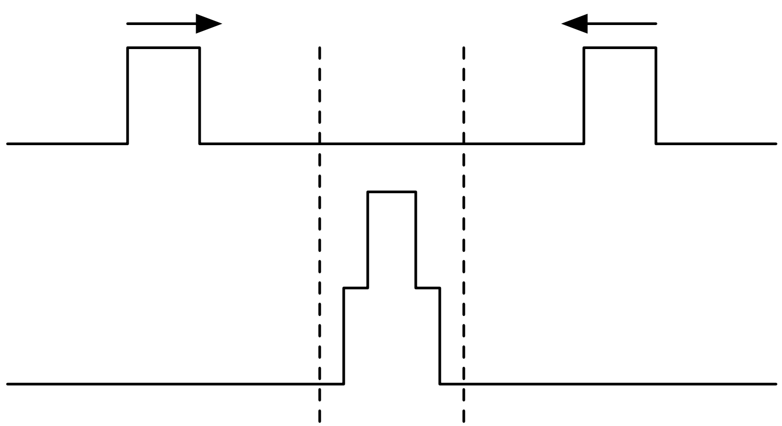
Inhibition at the post-synaptic level: topologically equivalent to cross bar, diversity in material/neuron



Inhibition at the pre-synaptic level: non-equivalent

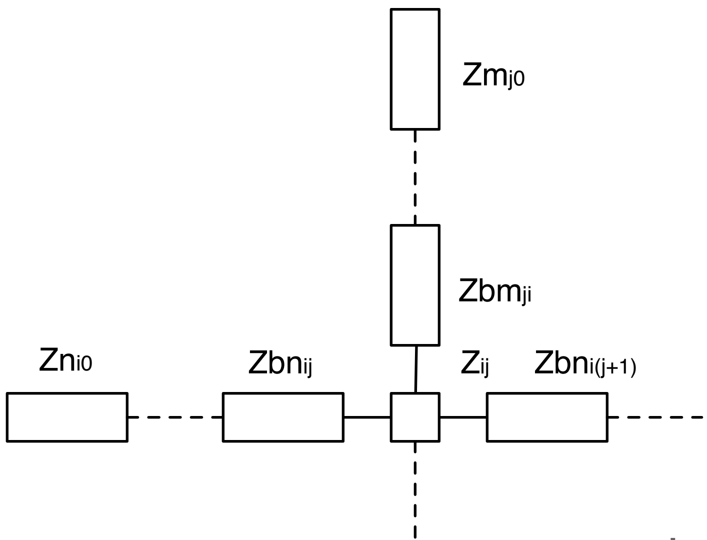


Can we achieve synchronization using inhibitory networks?

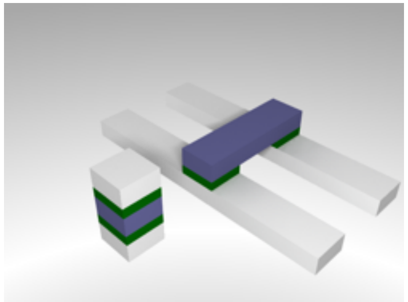


Hardware validation and design

Generalized cross-bar model

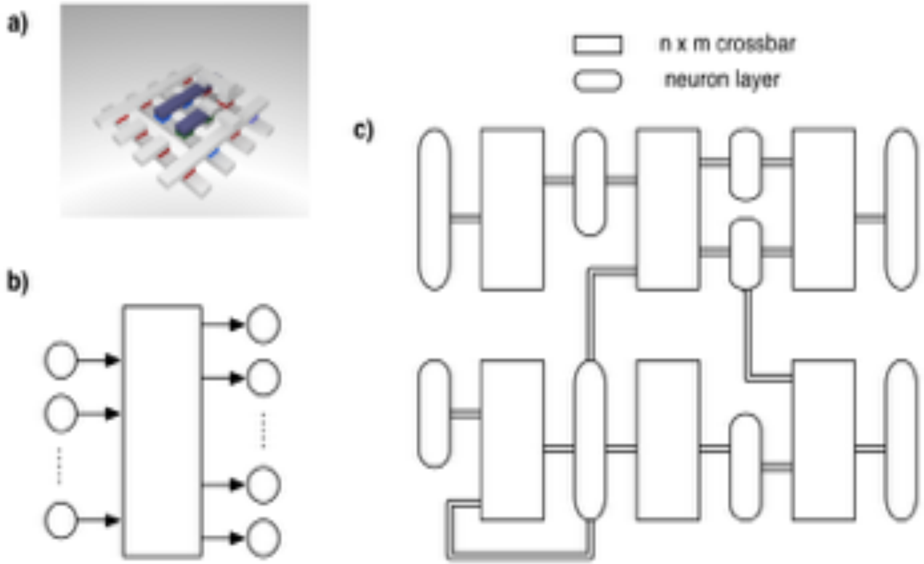


Fabrication and characterization at the component level



large scale integration

#2 From component to architecture



How to transform this structural unit into interconnected LFUs from data input to execution?

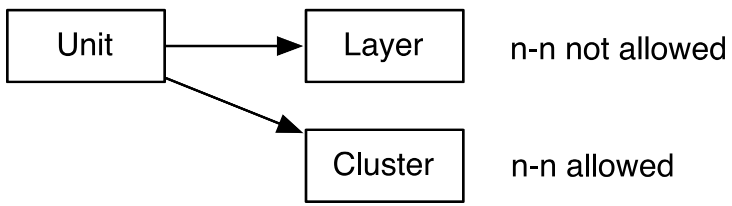
Can we identify an optimum architecture?

Architecture: morphogenesis-inspired networks

We are looking at networks with a degree of stochasticity in their connectivity

The details of connectivity are determined randomly

brane



layer: size

cluster: size, *p*

connection: unit1, *p1*, unit2, *p2*

repulsive: conn1, conn2, ...

attractive: conn1, conn2, ...

Evaluate performance

Characterize statistical properties

Evolve?

Return netlist

Random thoughts and lessons from a fruit fly

evolved architecture vs neuromorphic programming

evolved architecture vs training

Can we separate architecture from component?

How broad is the performance valley of a neural architecture?

How much complexity is really needed?

Conclusions

First Draft of a Report
on the EDVAC

by

John von Neumann

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Thanks!