Patterns in Brain and Mind

Yaneer Bar-Yam

New England

Complex Systems Institute

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Dynamics of Complex Systems

Three approaches:

1. How do interactions give rise to patterns of collective behavior?
2. How do we describe complex systems?
3. How do complex systems arise through evolution?

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Concept

What is the simplest model that can capture key features of mind? (Universality class)

What additional model properties are needed to capture additional characteristics of the brain / mind?

Start the inquiry from a higher level.

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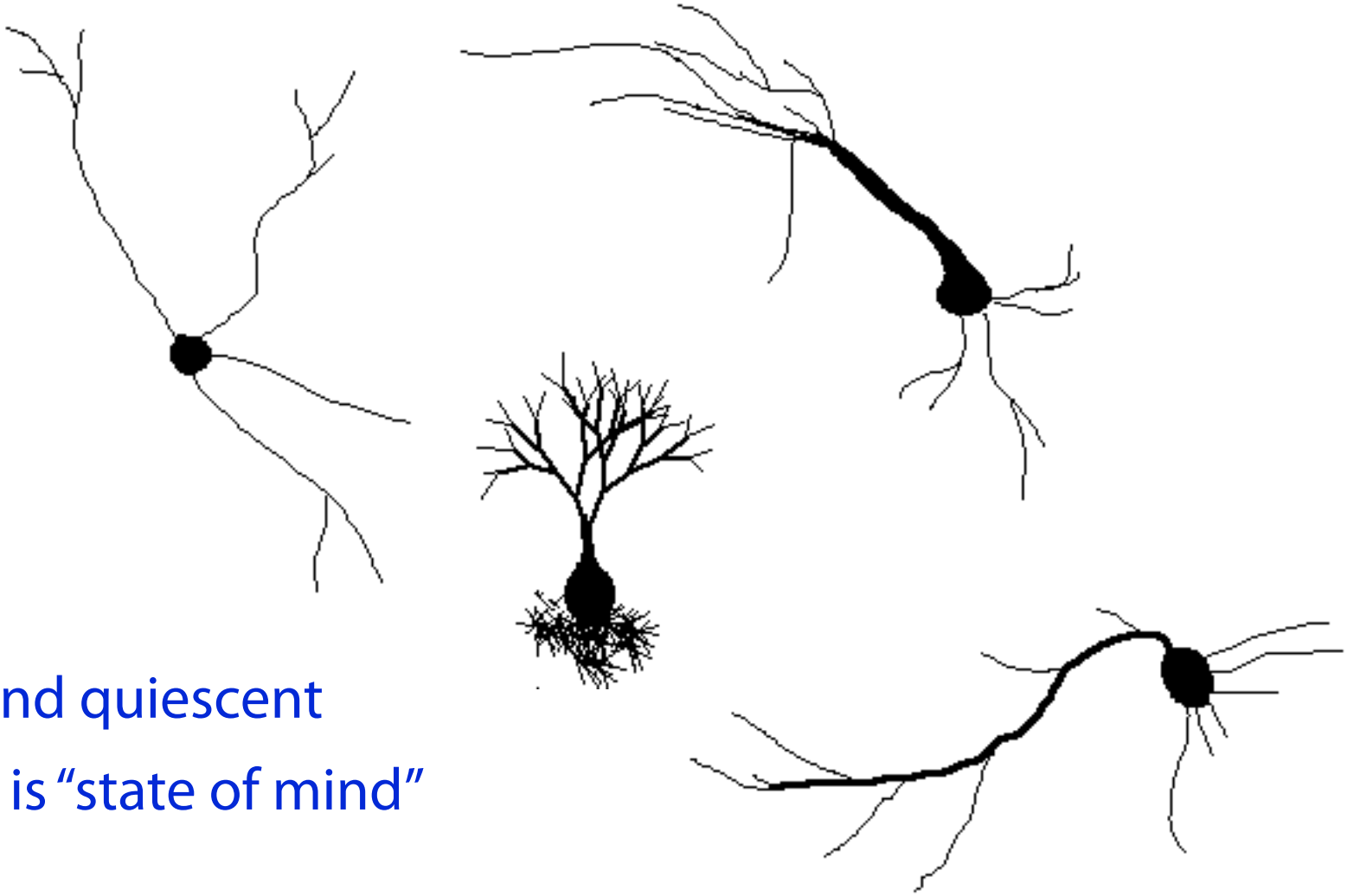
Neurons



Firing and quiescent

Pattern is “state of mind”

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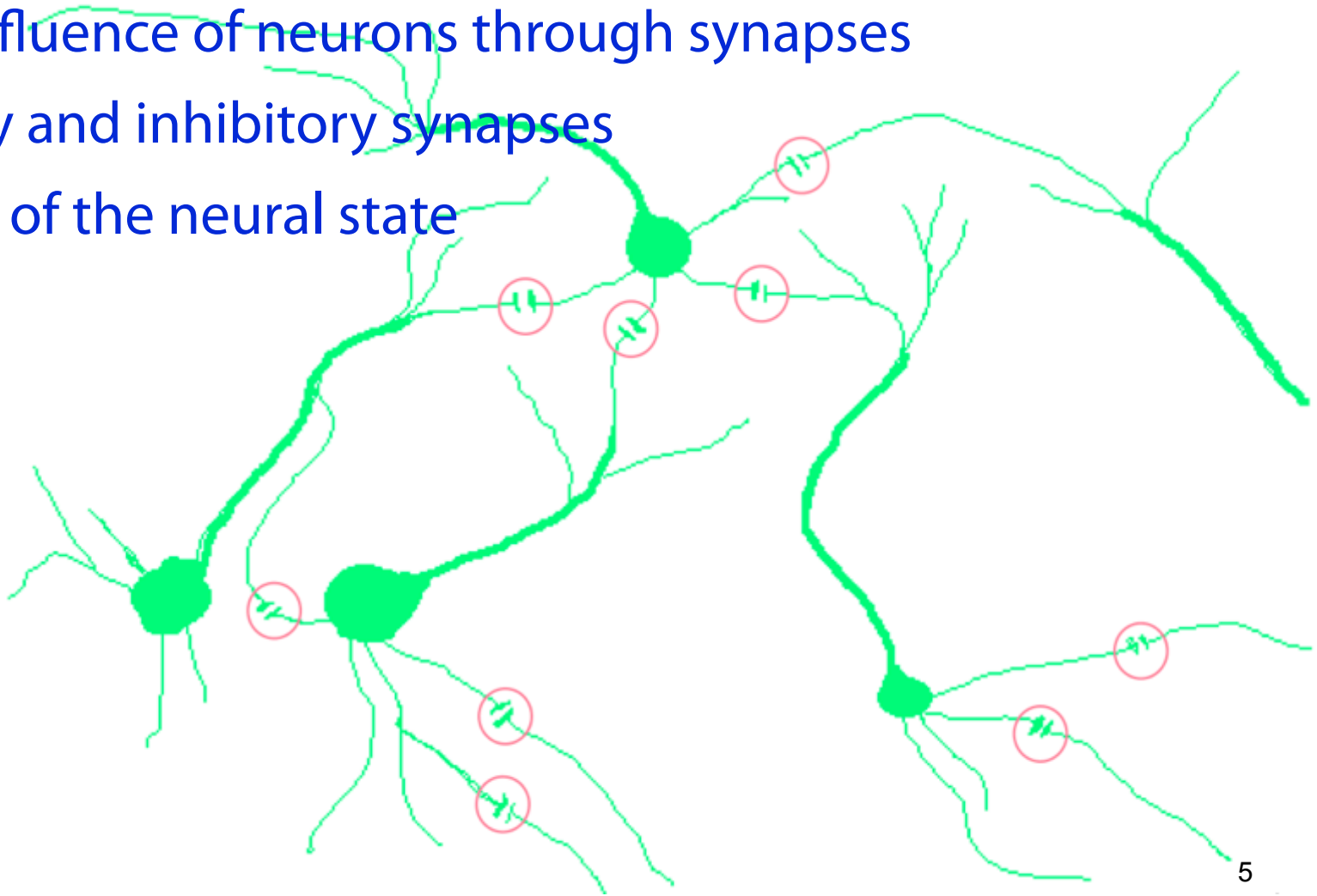
Synapses

Mutual influence of neurons through synapses

Exhitatory and inhibitory synapses

Evolution of the neural state



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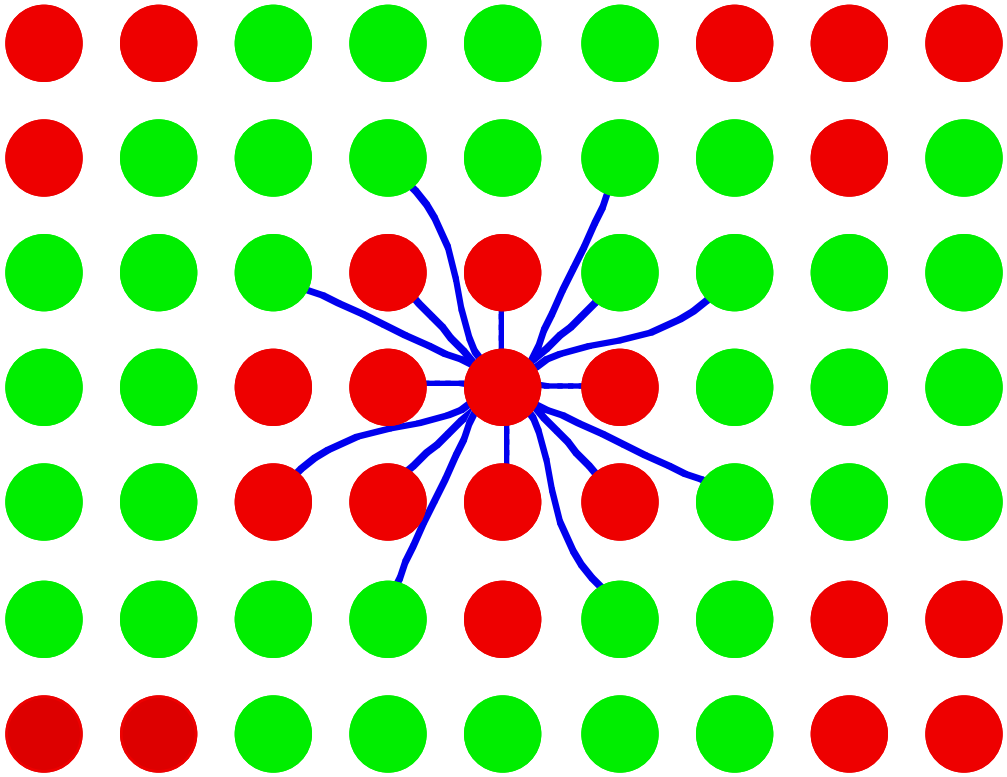
Active-element model

Generalize:



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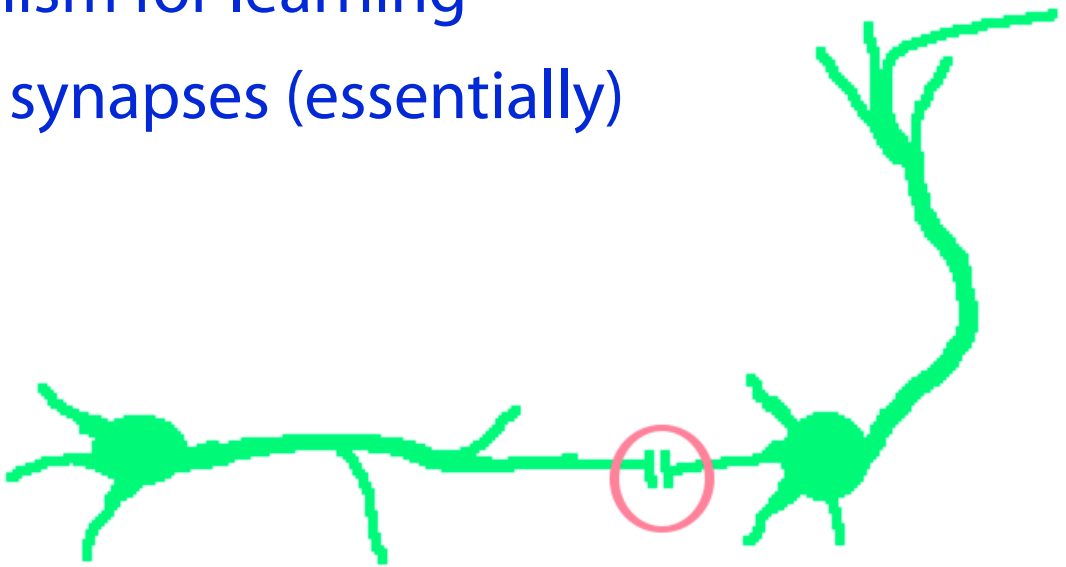
Synaptic plasticity

Hebbian imprinting

Basic mechanism for learning

Memory is in synapses (essentially)



ON	Exhitatory	ON
ON	Inhibitory	OFF

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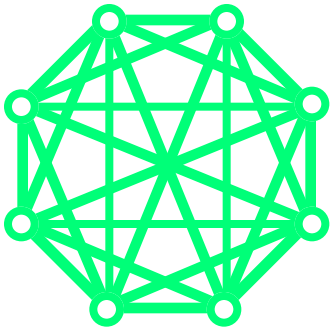
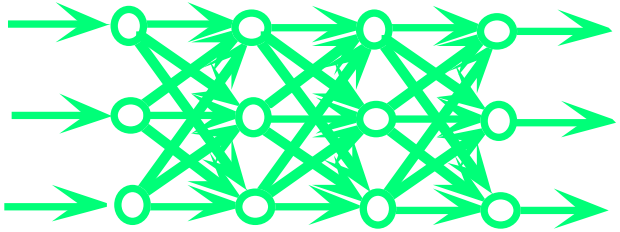
Attractor & Feedforward





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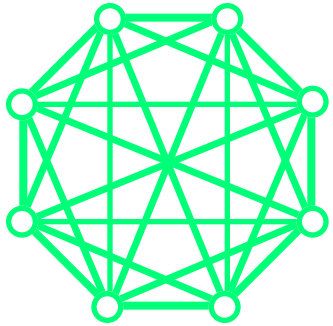
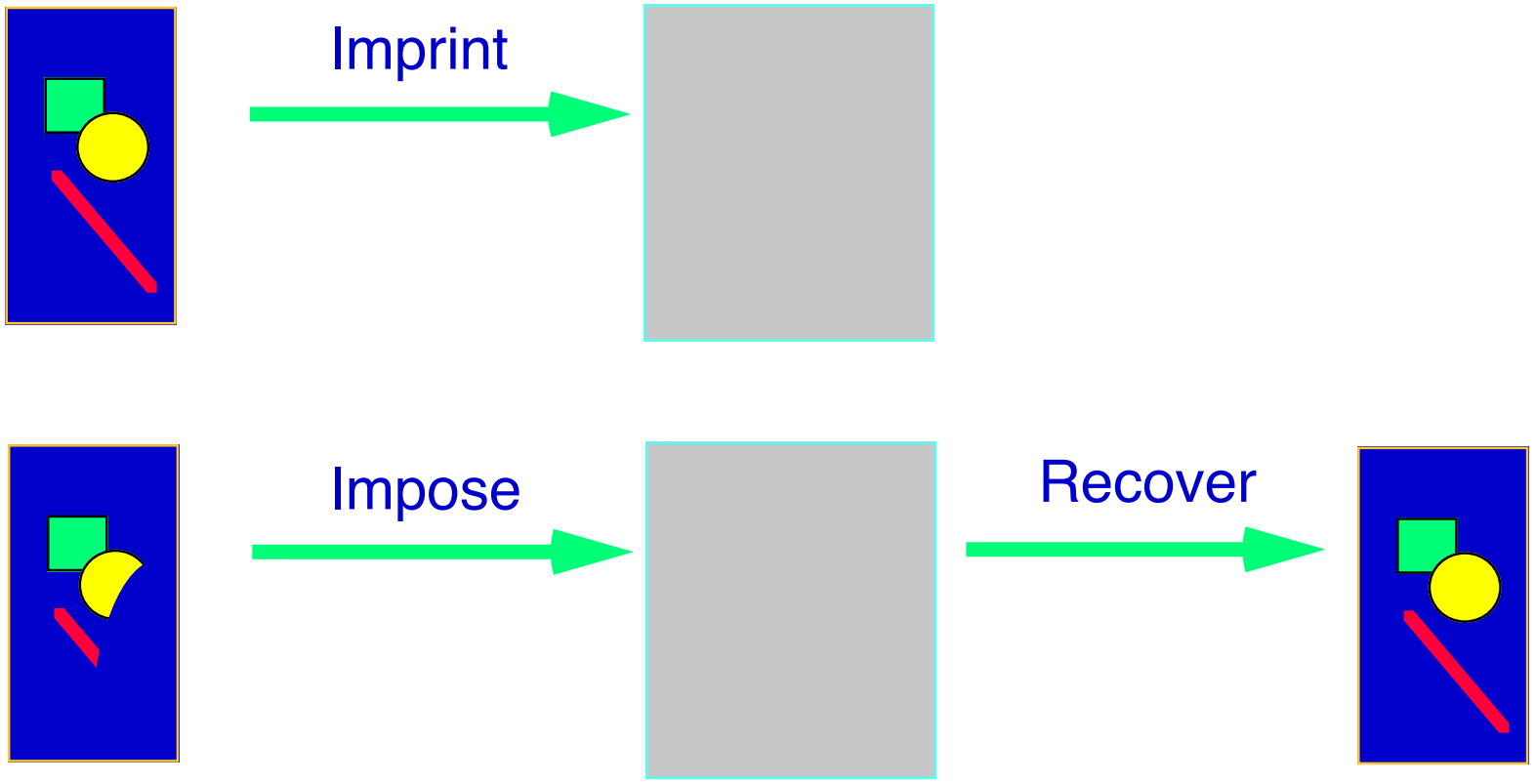
Attractor neural network:



Imprint and recover: A kind of memory



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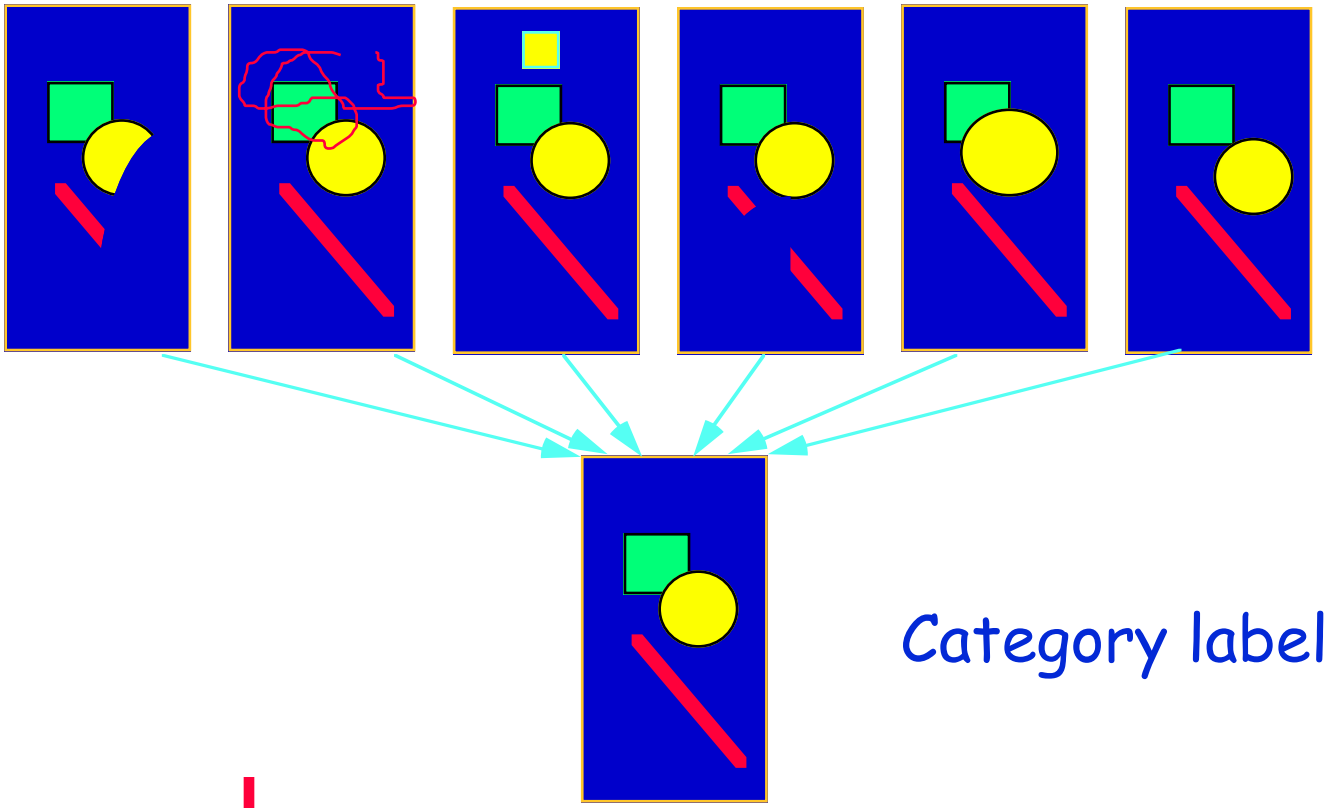
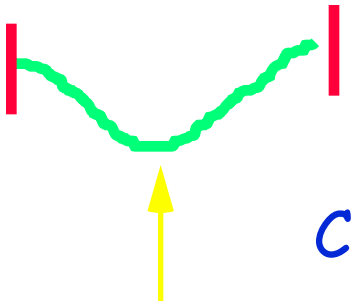
Attractor network as a classifier



Category label



Classification by proximity (overlap)

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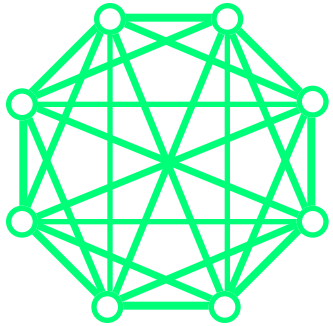
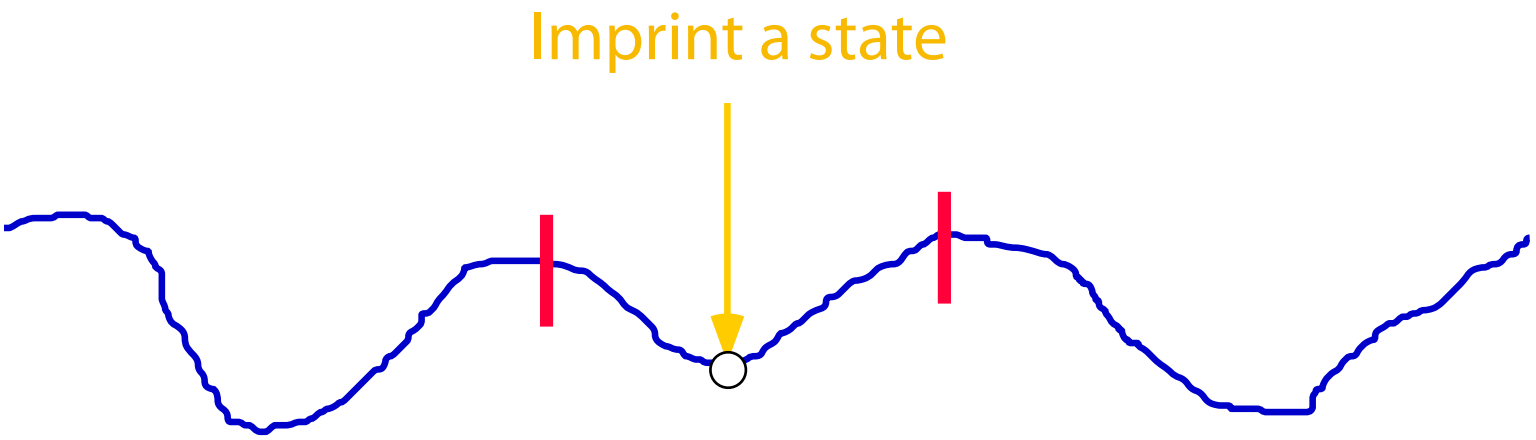
Attractor networks



Space of possible patterns



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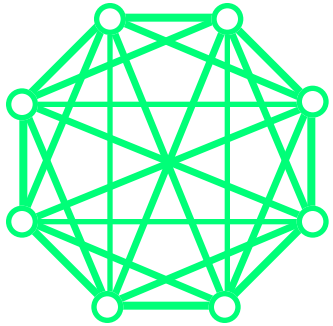
Attractor networks



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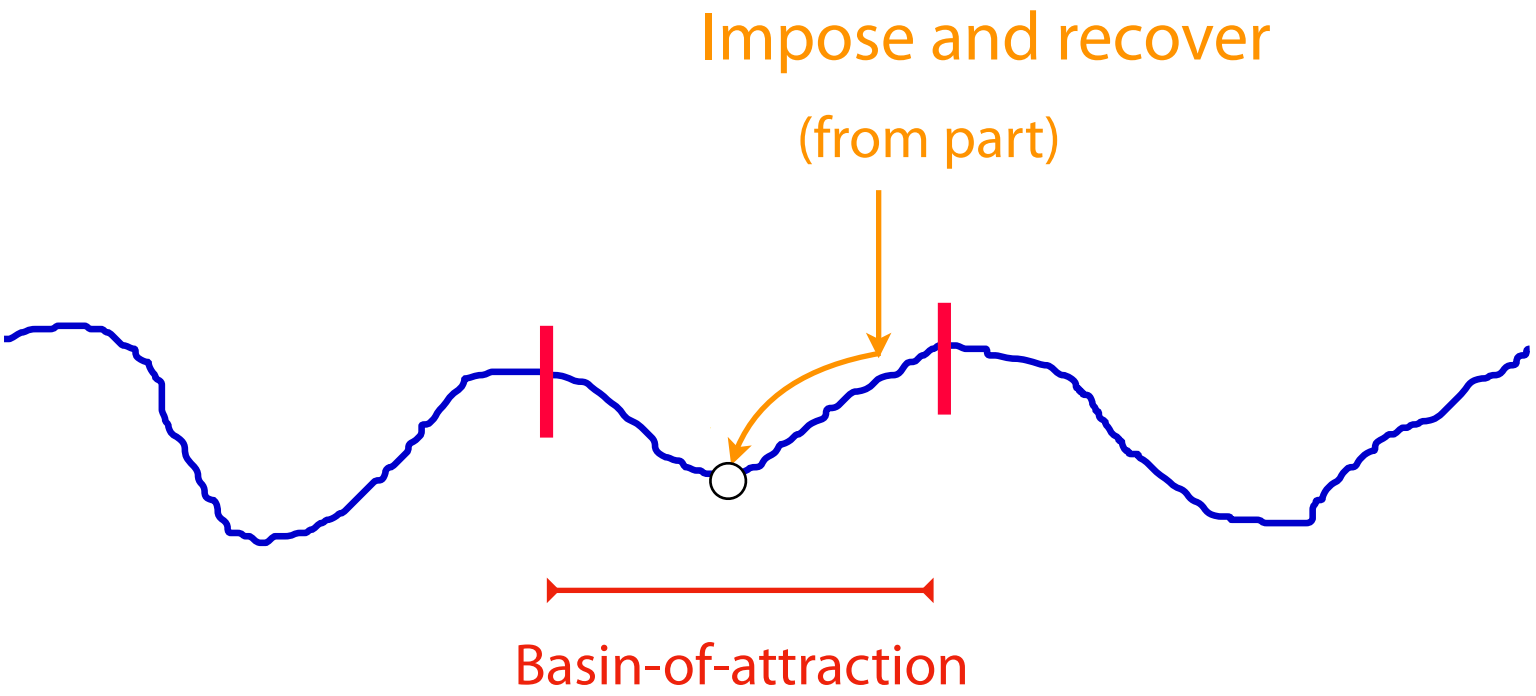

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Attractor networks

Functionality

- Content-addressable memory
- Limited Classifier
- Limited Pattern Recognition
- Limited Generalization

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Active element model

Updating:

$$s_i(t) = \text{sign}(\sum_j H_{ij} s_j(t-1))$$

Hebbian Imprinting:

$$H_{ij}(t) = H_{ij}(t-1) + c s_i s_j$$

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Network Capacity & Overload

Fully connected network storage capacity

Number of complete imprints: $\alpha N \quad \alpha \approx 0.145$

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Part II: Substructure

Interacting patterns

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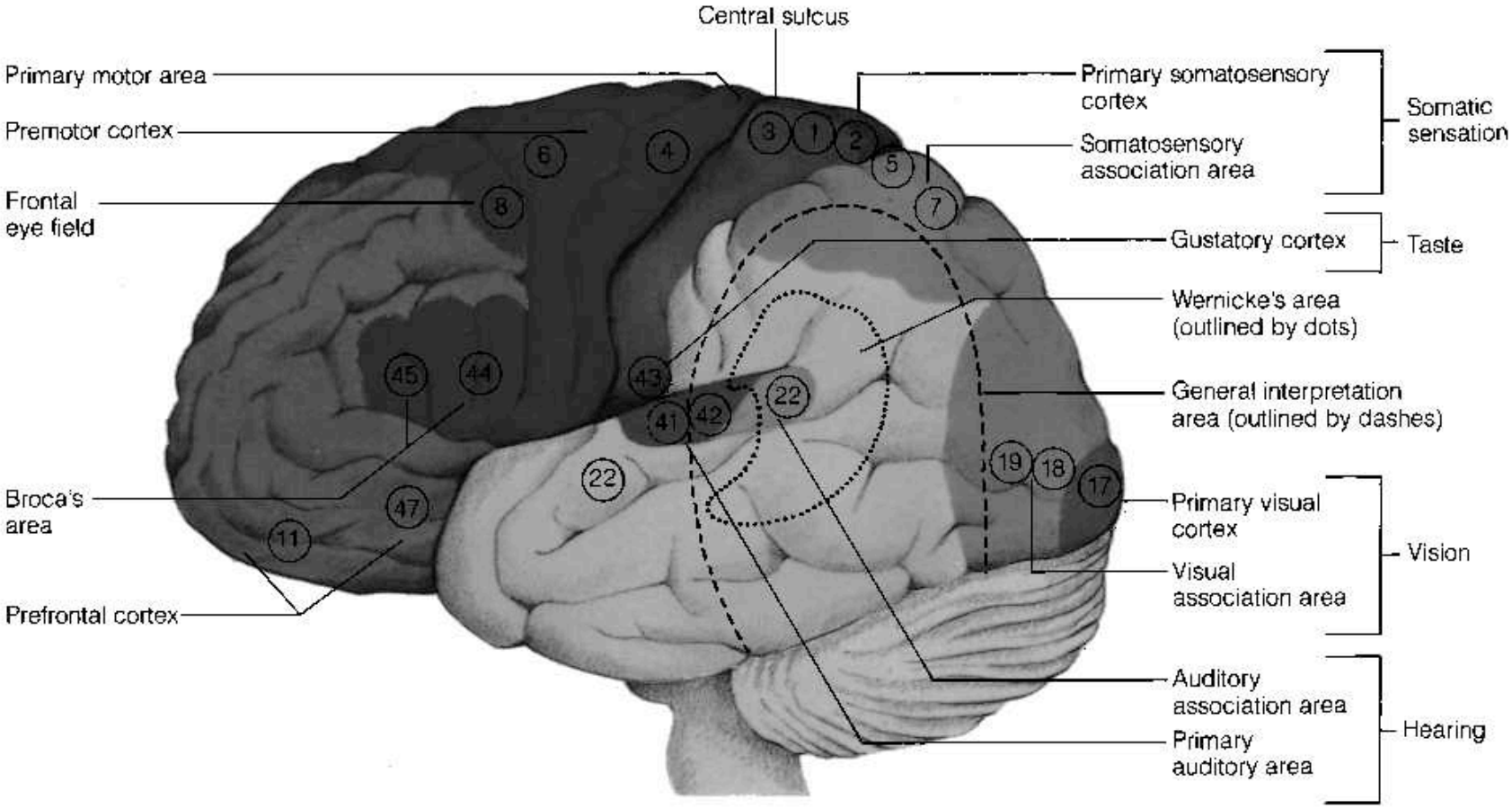
Substructure



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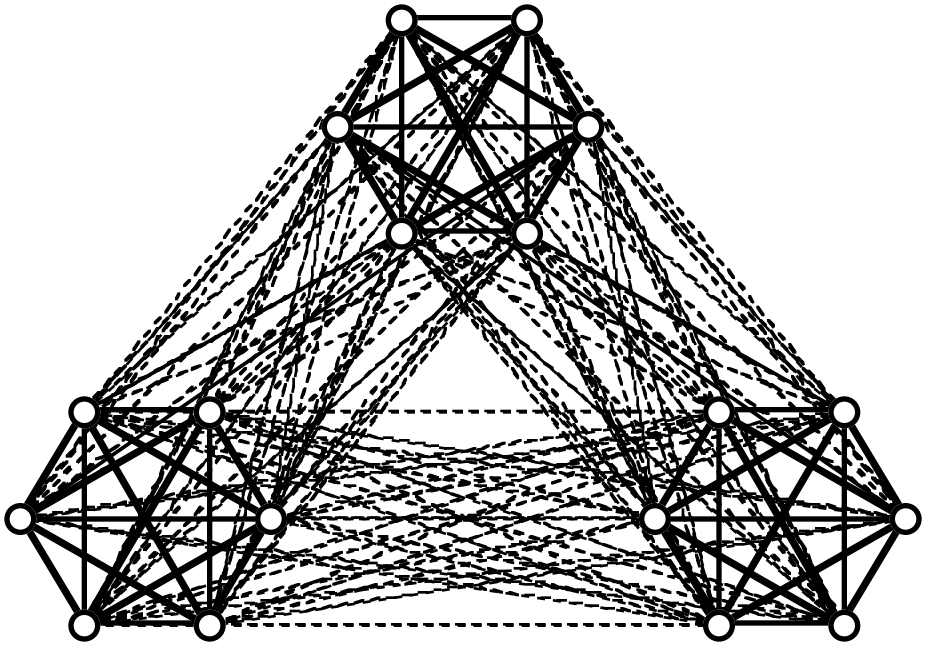
Why Subdivide a Network?



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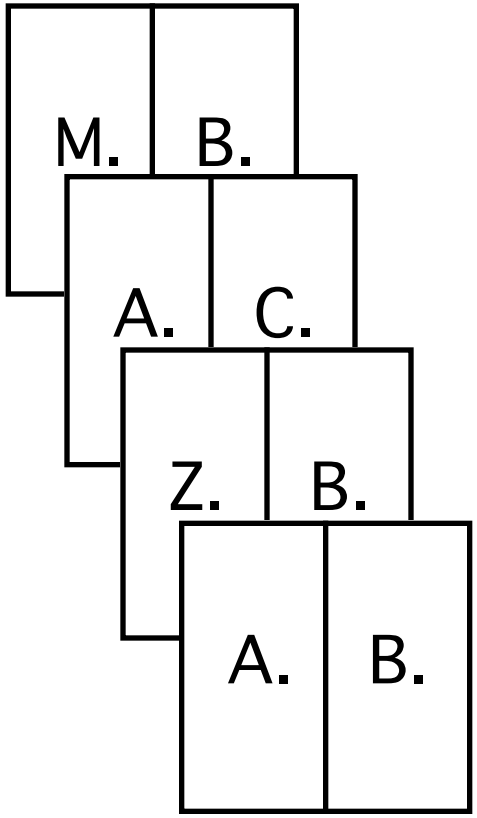
Left-Right Universe



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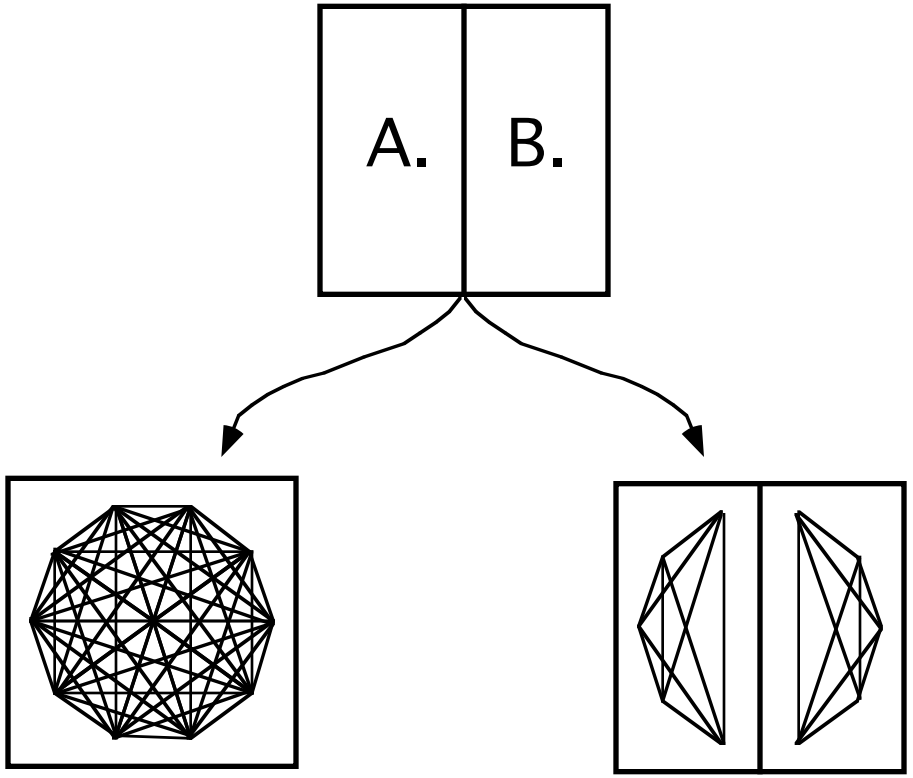

Fully connected network

Subdivided network

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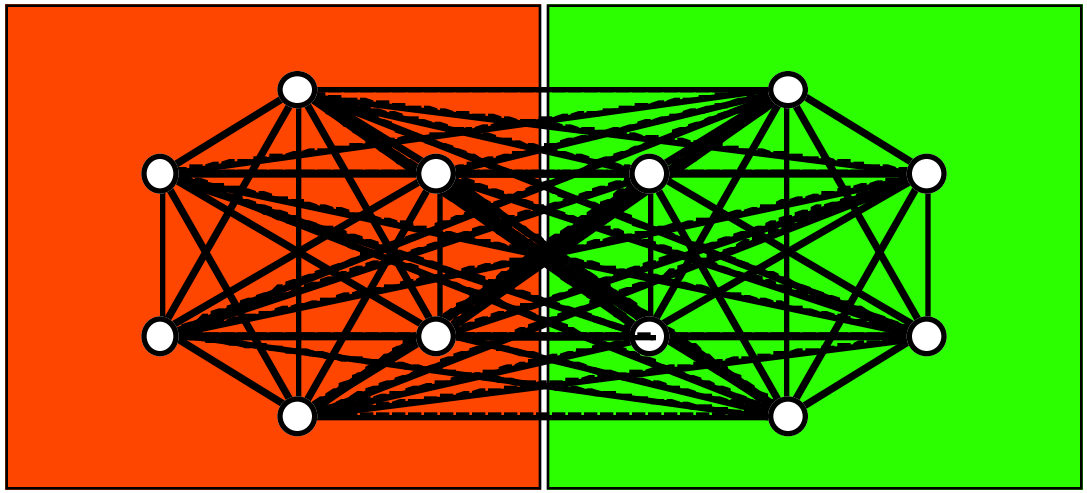
Why Subdivide a Network?

Left and Right Universe



Complete Network: $\alpha N \approx 10^{10}$ images

Network Divided in Two: $(\alpha N/2)^2 \approx 2 \times 10^{19}$

(Imprint only $\alpha N/2$)

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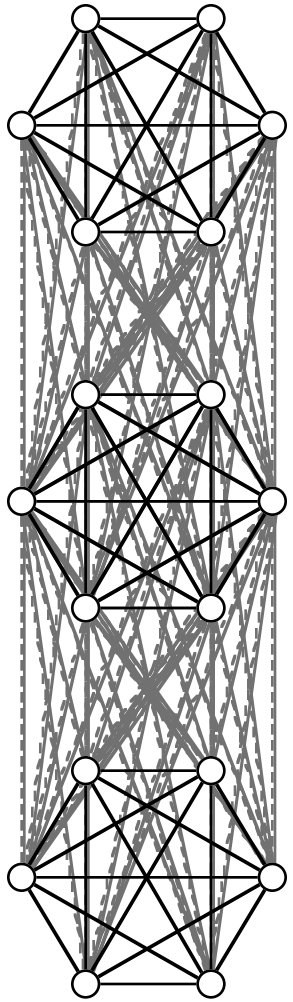
Subdivided Networks

Weak inter-subnetwork synapses

State of network is combination of parts

Each subnetwork contains:

- an aspect
- an attribute



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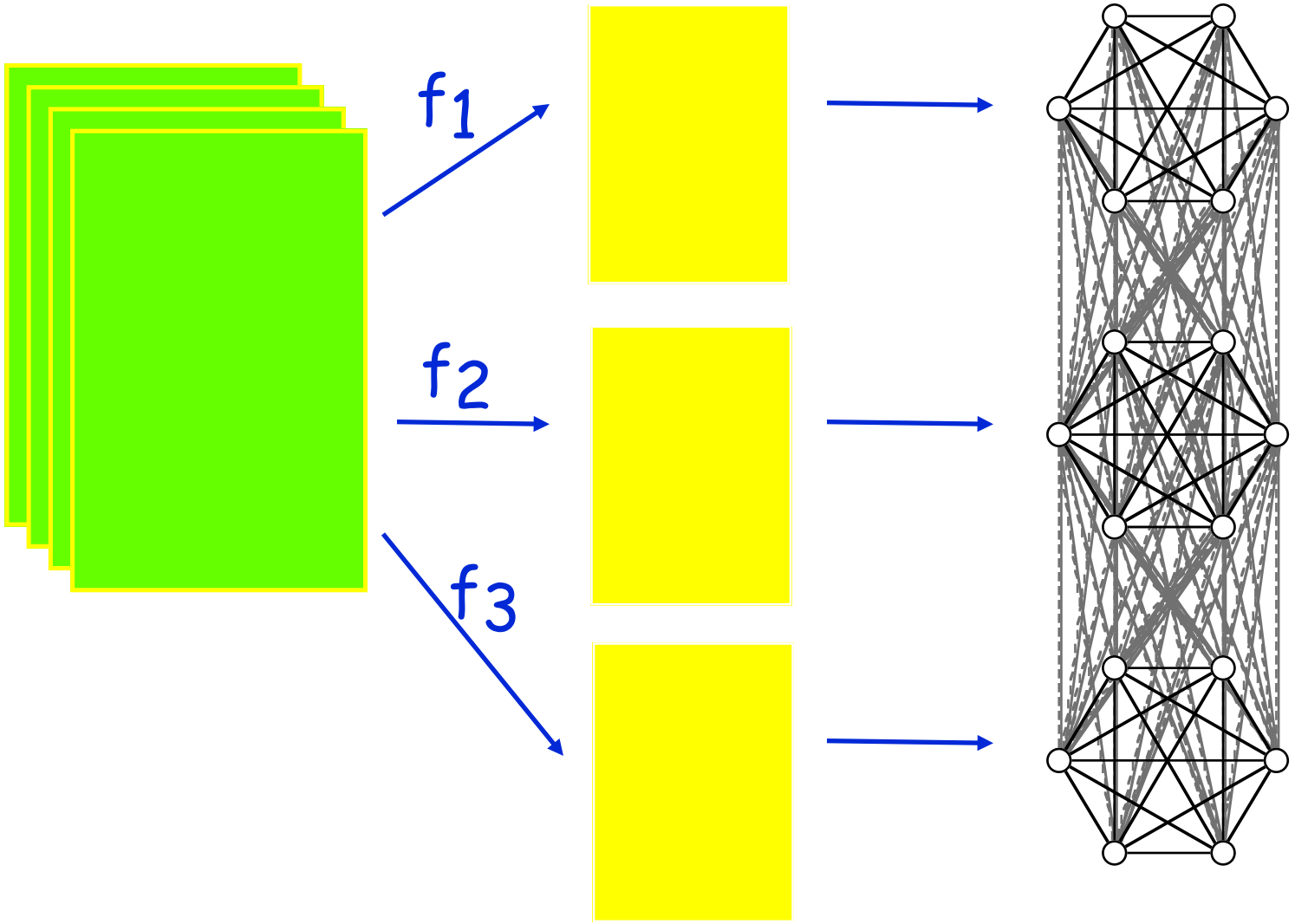
Parallel channels



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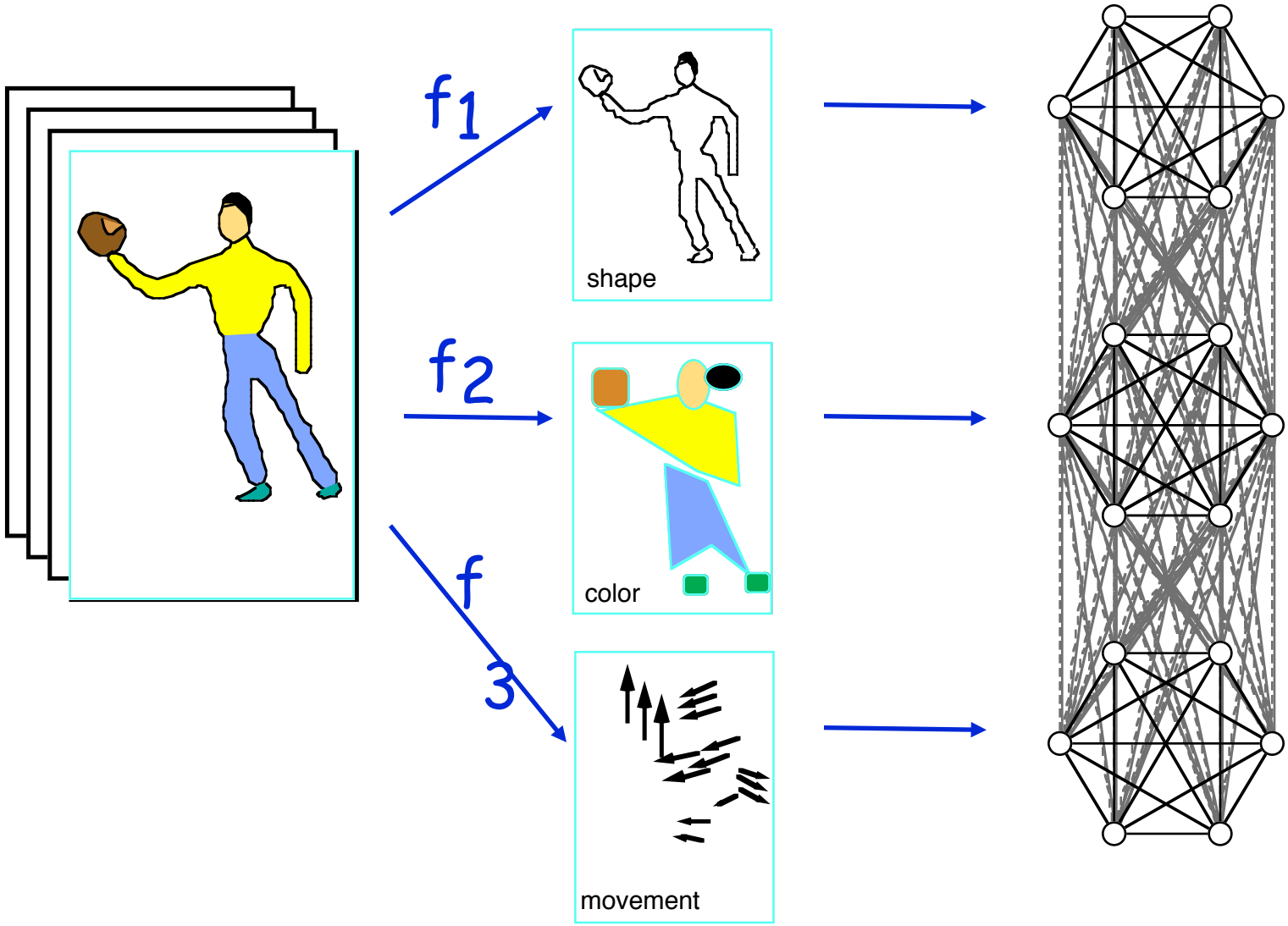
Parallel channels



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Vision: Color, Shape, Motion

Attribute category: attributes

Colors: red, blue, yellow, green, purple, …

Shapes: circle, square, triangle, rectangle, …

Motion: moving-left, -right, -up, -down, -away, ...

Categories: red circle moving-up; blue circle moving-down; …

combine attributes in any way

number of categories is product of

number of attributes in each attribute category

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Vision: Color, Shape, Motion

note: Attributes are partially independent and so is processing.

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'Natural' Language

Fully Connected Network
Imprint and recall

Big	Bob	ran.
Kind	John	ate.
Tall	Susan	fell.
Bad	Sam	sat.
Sad	Pat	went.
Small	Tom	jumped.
Happy	Nate	gave.
Mad	Dave	took.
Tired	John	slept

Subdivided Network
Imprint and recall

Big	Bob	ran.
Kind	John	ate.
Tall	Susan	fell.

Big	**Bob**	**ran.**
Big	Bob	ate.
Big	Bob	fell.
Big	John	ran.
Big	John	ate.
Big	John	fell.
Big	Susan	ran.
Big	Susan	ate.
Big	Susan	fell.
Kind	Bob	ran.
Kind	Bob	ate.
Kind	Bob	fell.
Kind	John	ran.
Kind	**John**	**ate.**
Kind	John	fell.
Kind	Susan	ran.
Kind	Susan	ate.
Kind	Susan	fell.
Tall	Bob	ran.
Tall	Bob	ate.
Tall	Bob	fell.
Tall	John	ran.
Tall	John	ate.
Tall	John	fell.
Tall	Susan	ran.
Tall	Susan	ate.
Tall	**Susan**	**fell.**

Content vs Grammar

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Fundamentals of Language

Chomsky: hard-wired language acquisition device (still controversial)

Argument: Poverty of Stimulus (Language acquisition).
--- Can be formalized using this model.

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Creativity - Composite states

Subdivided network: Shape and motion

Person sees:

- Bird flying
- Person walking

Imagines:

- Person flying

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Creativity Literature

Literature suggests that creativity is new combinations of previous information.

Not connected to neural model.

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Understanding

Role of the brain is not to remember, not to process, but to forget --- most information is irrelevant.

Need to respond to new circumstances not old, so need to recognize how new circumstances are similar to old ones, respond to class of possible circumstances --- proximity map.

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Conclusions

Attractor network:

- Representation of state

Feedforward network:

- Representation of process

Subdivided network:

- Composites states
- Attributes, Creativity, …

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