

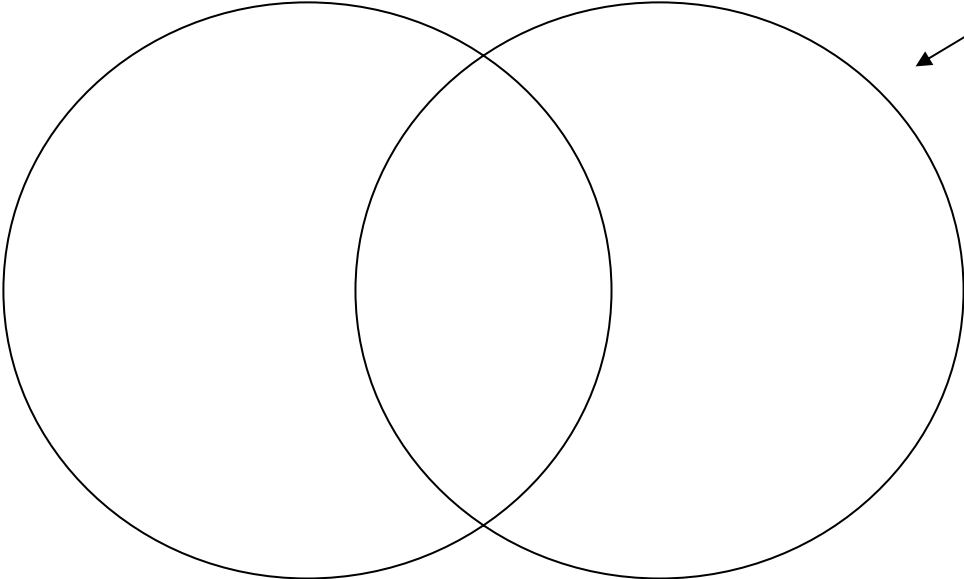
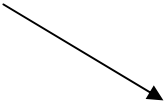
# Emergence into Consciousness viewed from the Levels Framework

Tony Bell

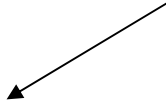
Redwood Center for Theoretical Neuroscience

University of California at Berkeley

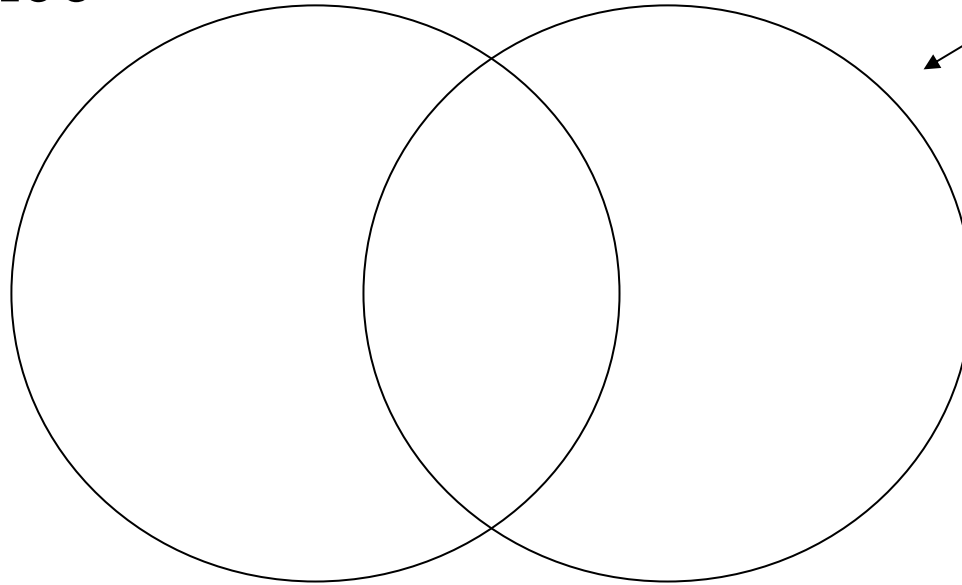
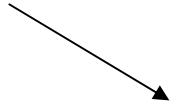
Neuroscience



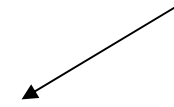
Machine  
Learning



Neuroscience



Machine  
Learning



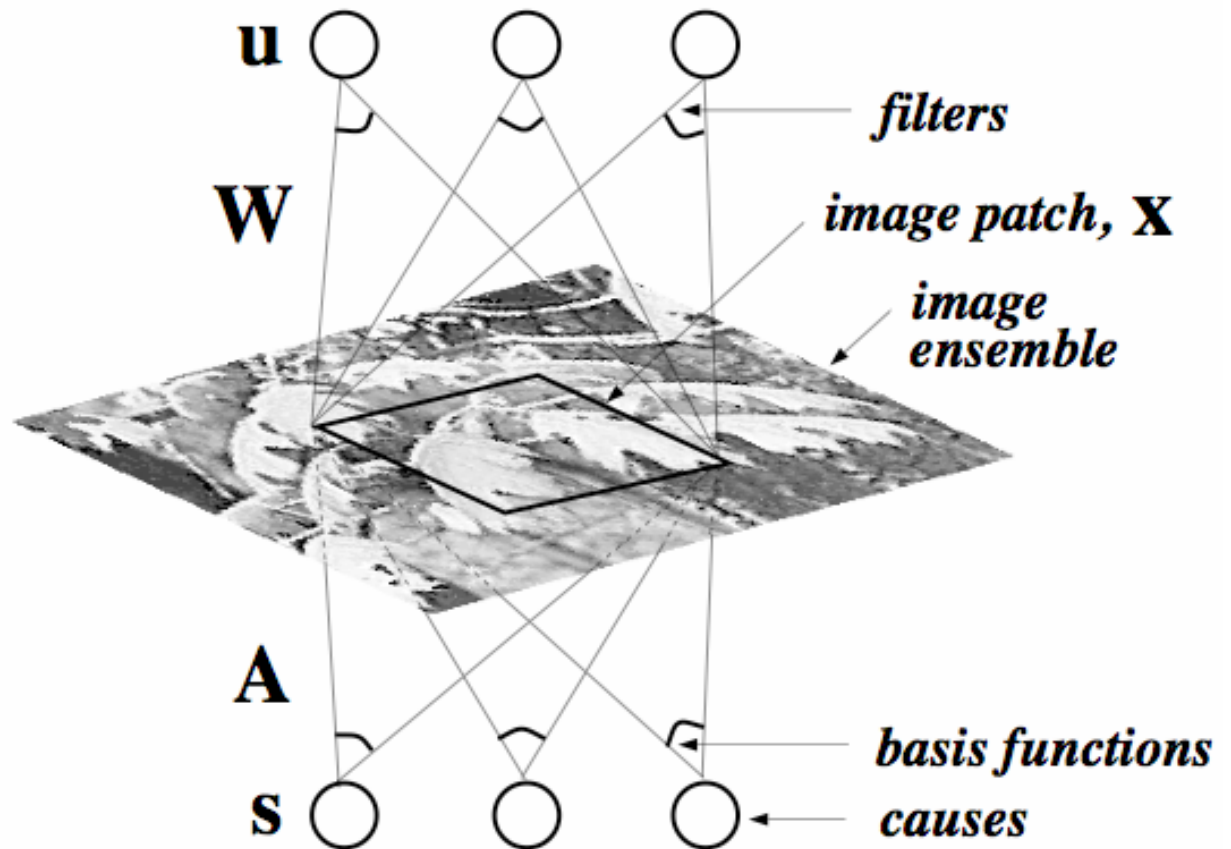
$$\Delta \mathbf{W} \propto \nabla_{\mathbf{W}} Q(\mathbf{x}, \mathbf{y}, \mathbf{W})$$

at time  $t$ , the **weight change** is proportional to the **gradient** of the **objective** function of the **input**, the internal **state**, and the **weights**

# ICA (a simple statistical model)

linear  
static  
'brain':

$$\mathbf{u} = \mathbf{W}\mathbf{x}$$



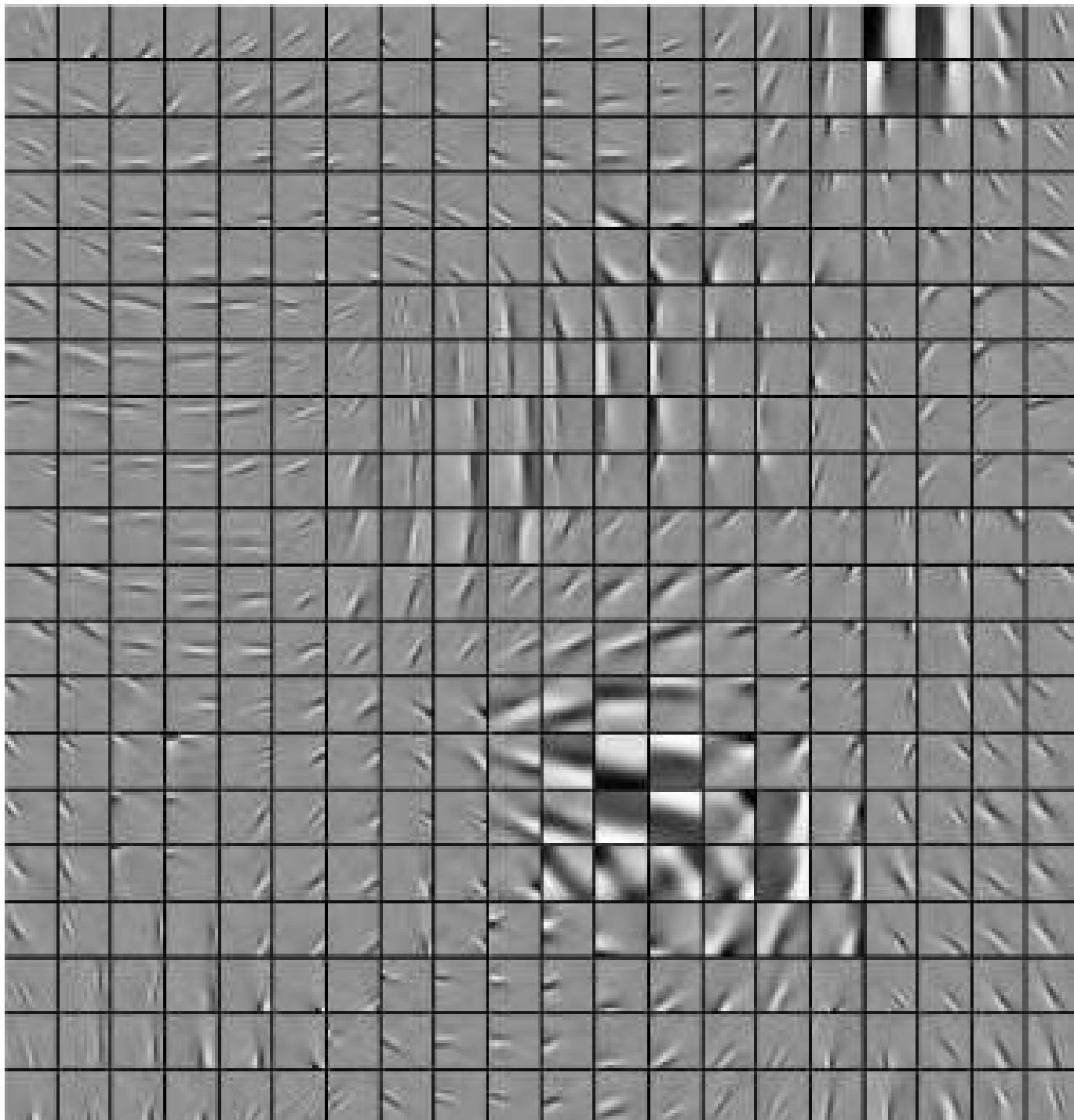
Statistical model of images:

$$q(\mathbf{x}) = |\mathbf{W}| \prod_i q(u_i)$$



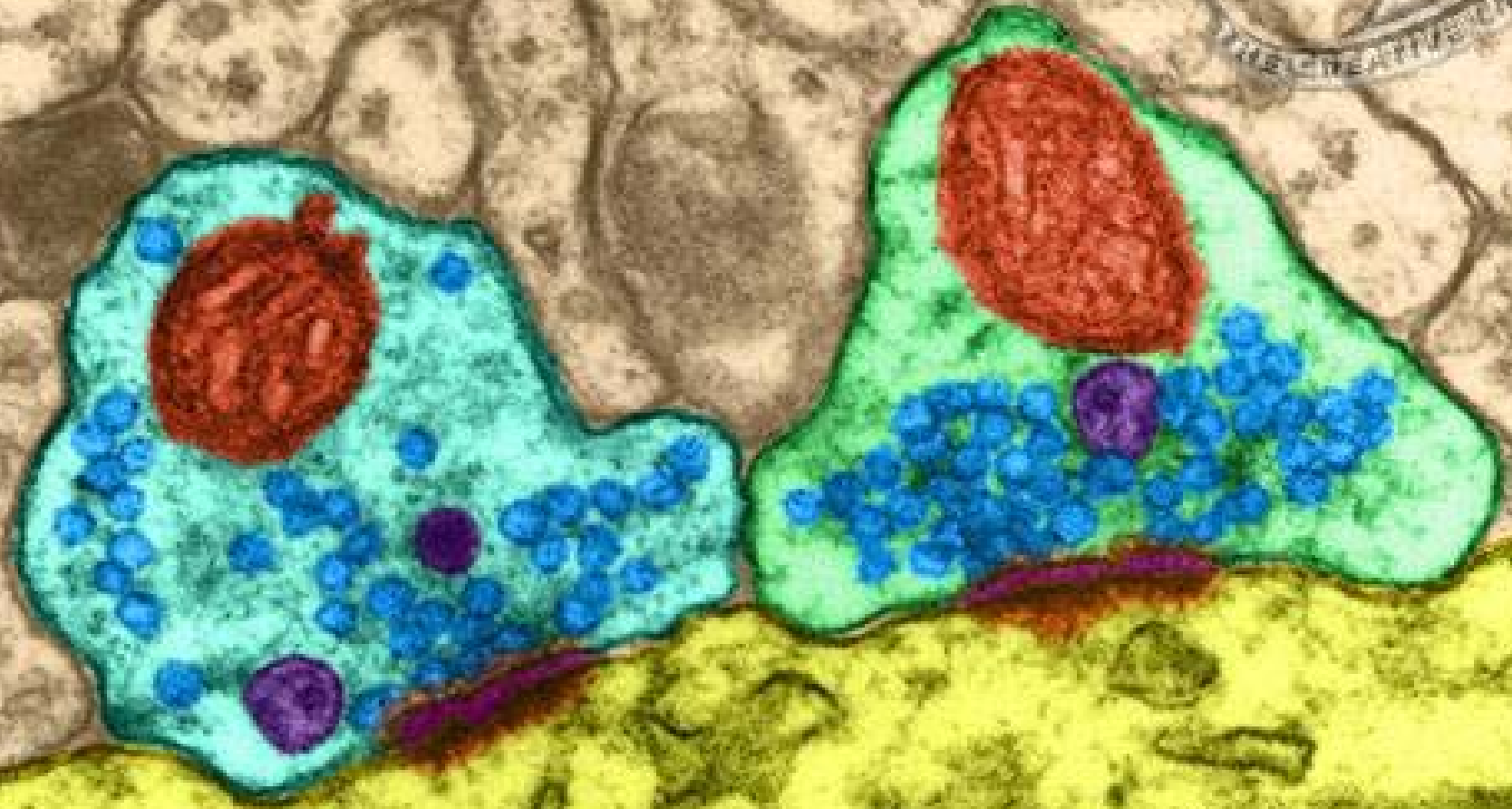
V1  
'simple  
cells'

Bell &  
Sejnowski, 97



orientation  
column

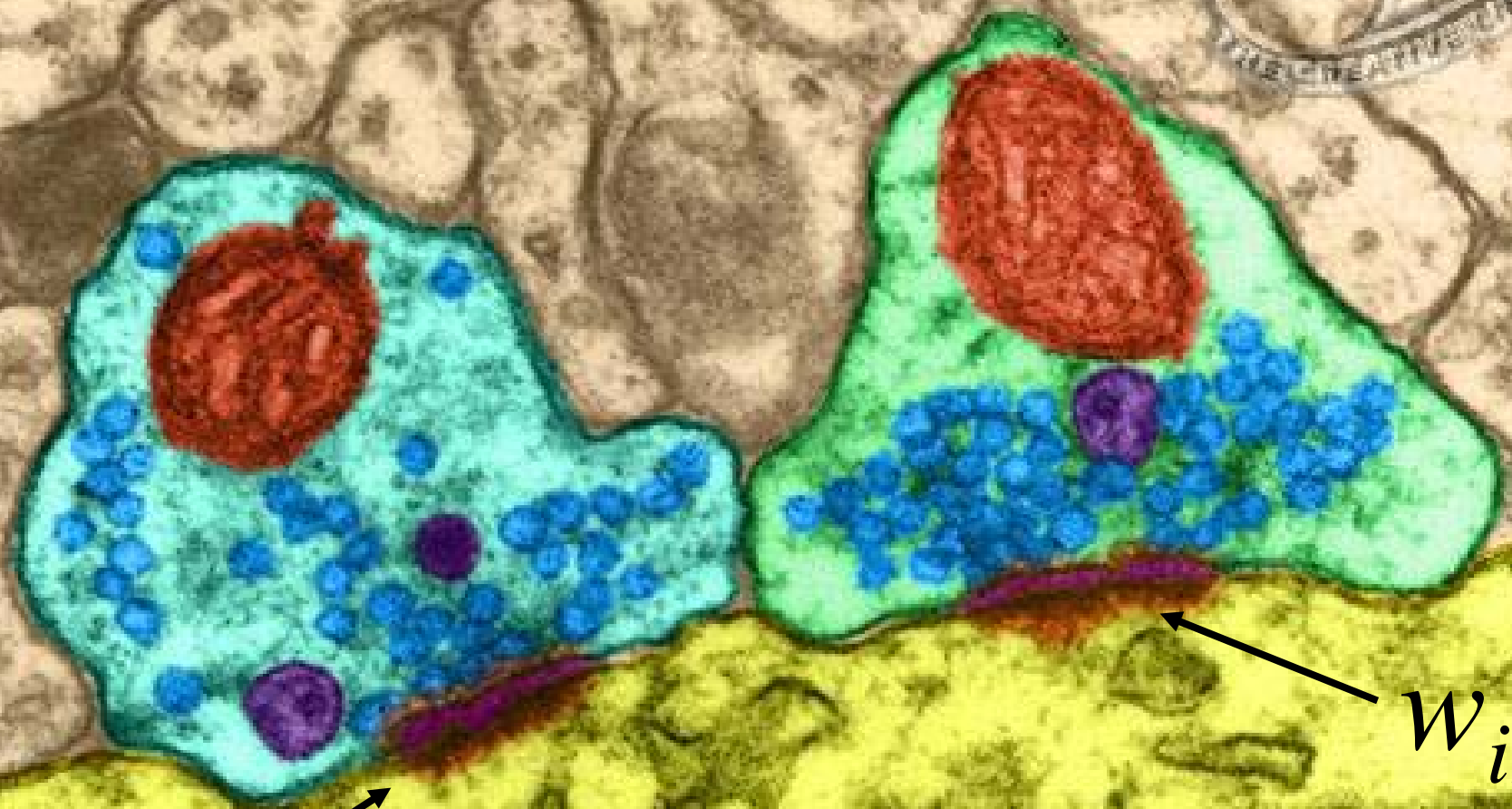
Hyvarinen &  
Hoyer, 01



CFNESYN100000-01

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Viewed by Tony Bell on 10/1/2003

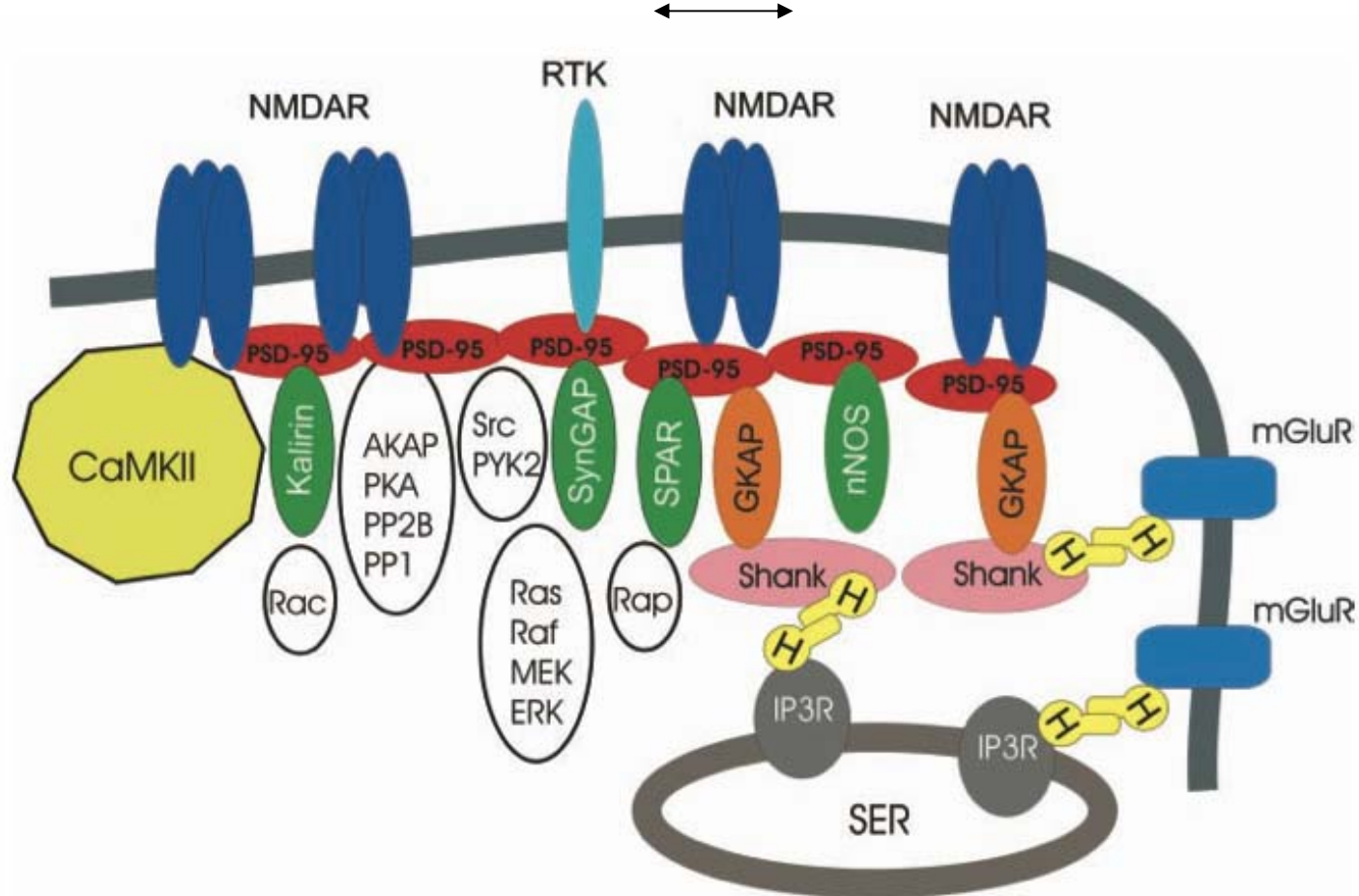


$w_{ij}$

$w_{ik}$



The synapse is *itself* a structurally organised network - Morgan Sheng  
 Calcium microdomains down to 20 nm.



**Fig. 1.** A schematic of the NMDAR-associated protein complex. Major individual proteins of the PSD are shown as colored shapes, and their interactions are indicated by overlapping shapes (see text for details). Some specific sets of interacting proteins (e.g., the Ras-MAPK pathway) are grouped together for simplicity. The proteins GKAP, Shank, and Homer (H) link together the NMDAR complex, metabotropic glutamate receptors (mGluR), and IP<sub>3</sub> receptors (IP<sub>3</sub>Rs). It should be emphasized that the PSD is a dynamic structure, in which protein interactions may be transient and stoichiometries variable. nNOS, neuronal nitric oxide synthase; RTK, receptor tyrosine kinase; SER, smooth endoplasmic reticulum.

# Biology is 'fractal': networks within networks:

network of neurons

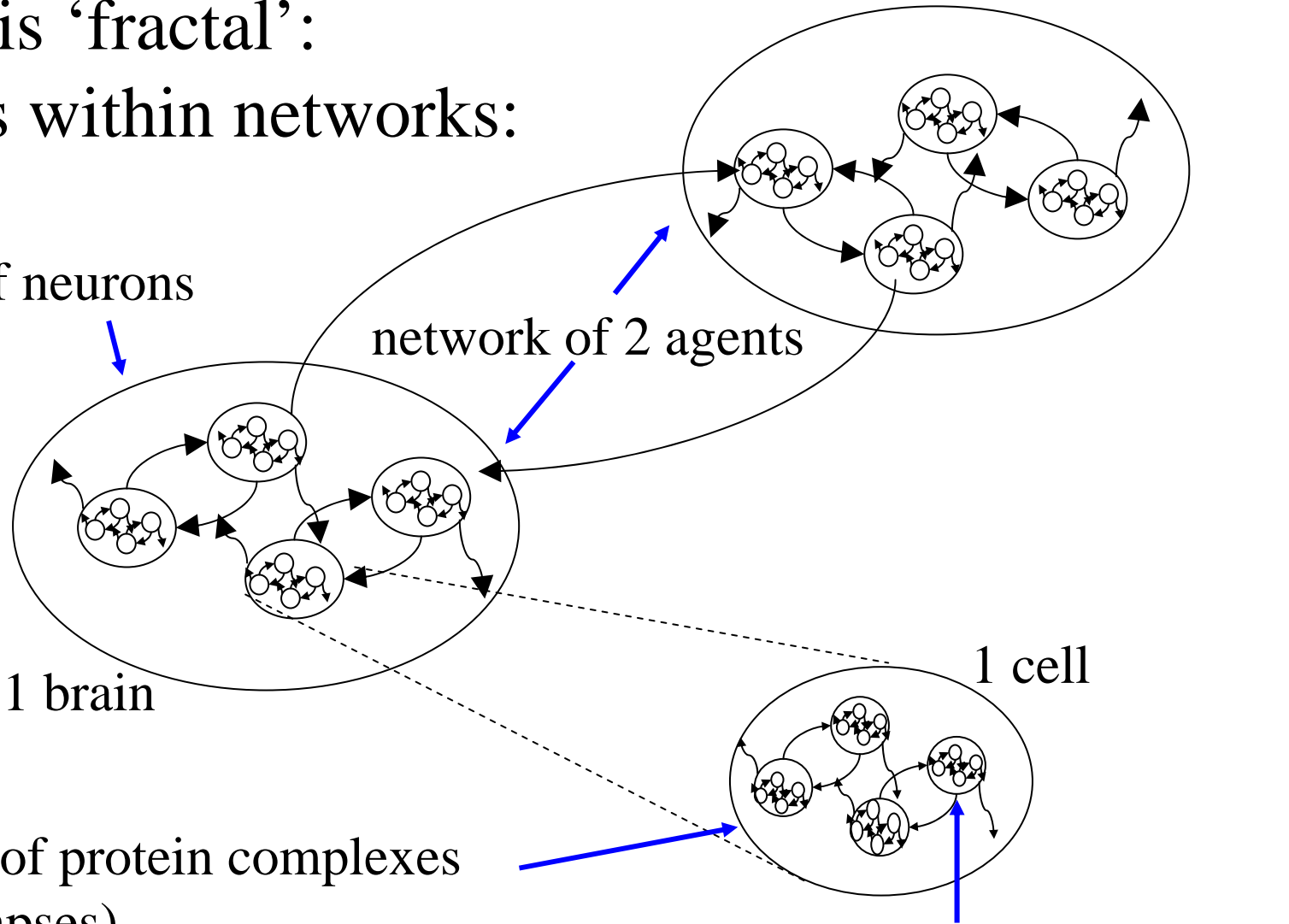
network of 2 agents

1 brain

1 cell

network of protein complexes  
(eg: synapses)

network of macromolecules



microscopic networks are located within the nodes of macroscopic networks, with the input/output microscopic nodes being located at the sites of connection between the macroscopic nodes.

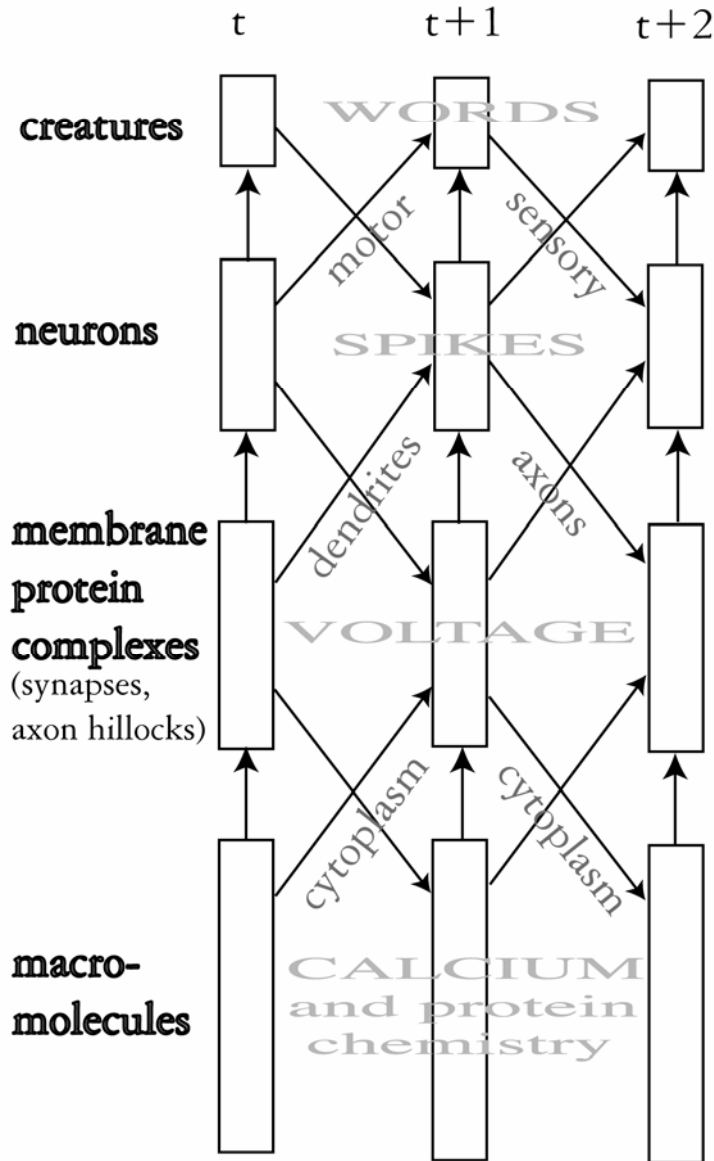
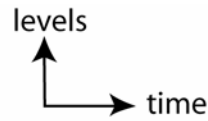
# Multi-Level View of Learning

LEVEL	UNIT	INTERACTIONS	LEARNING
ecology	society	predation, symbiosis	natural selection
society	organism	behaviour	sensory-motor learning
organism	cell	spikes	synaptic plasticity
cell	synapse	voltage, Ca	bulk molecular changes
synapse	protein	direct, V, Ca	molecular changes
protein	amino acid	molecular forces	gene expression, protein recycling

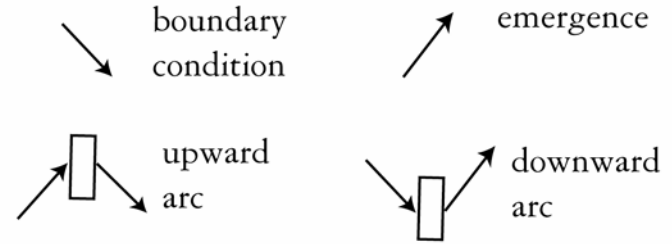
(   =  $\Delta \mathbf{W}$  )

These levels may be *insulated*, but only insofar as they satisfy the constraint of being *the same thing*, expressed at different resolutions.

# THE REDUCTIONIST HIERARCHY:



## CAUSAL RELATIONS, $G$ :



## STRUCTURAL RELATIONS, $F$ :

ie: coarse graining.  
or complex 'pooling'.

## Compositionality:

$$\mathbf{x}_l^t = F_l(\mathbf{x}_{l+1}^t)$$

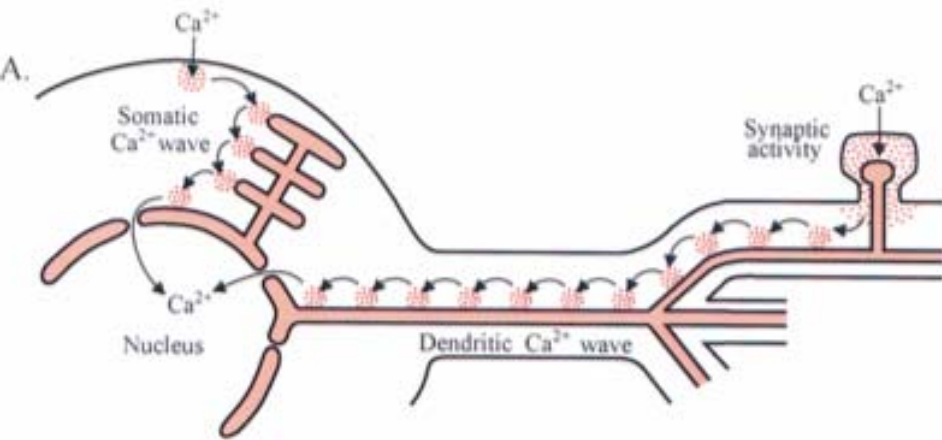
## Causality:

$$\mathbf{x}_l^t = G_l(\mathbf{x}_{l-1}^{t-1}, \mathbf{x}_{l+1}^{t-1})$$

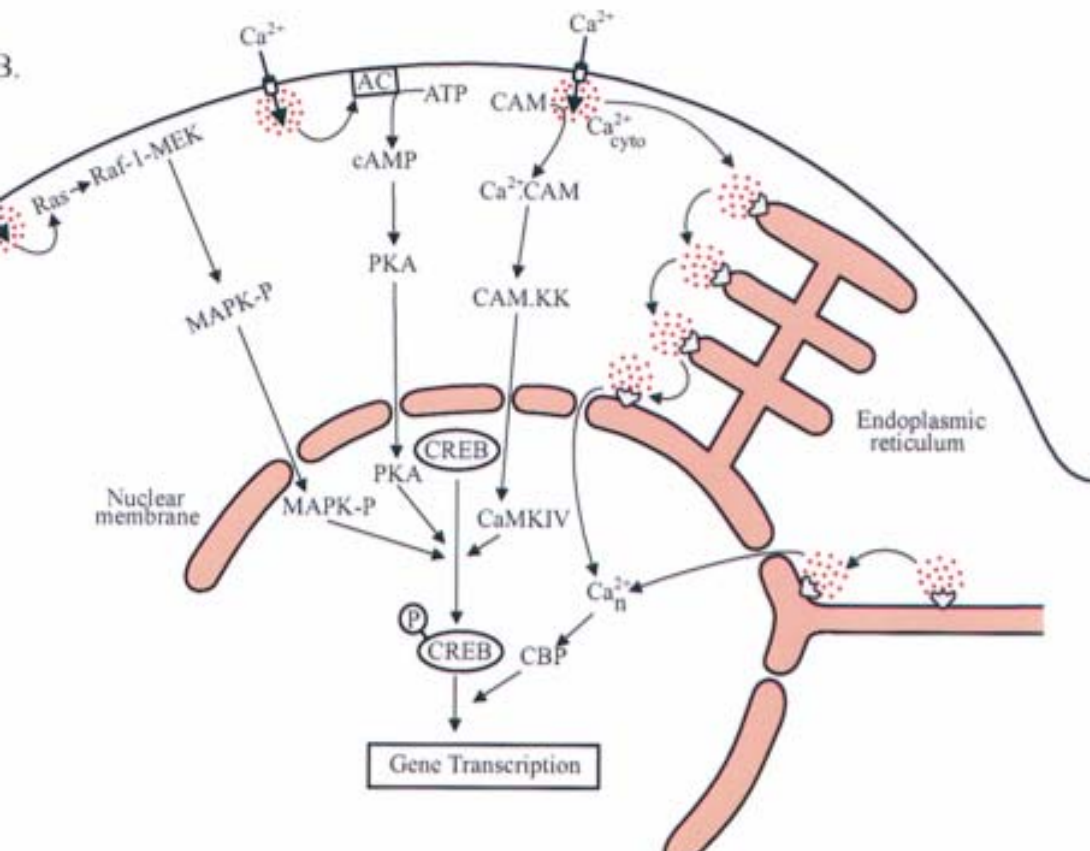
Information goes all the way down and all the way up,  
and if you don't believe this, you have to consider 2 facts:

1. A photon can make the difference between life and death for a dark-adapted creature.
2. A word from one person to another can rewrite that other person's genes (through transposons) or at least change his gene expression.

**Implication:** there is no *functionalist cut-off level* in biology (Bell, '99, 'Levels and Loops').

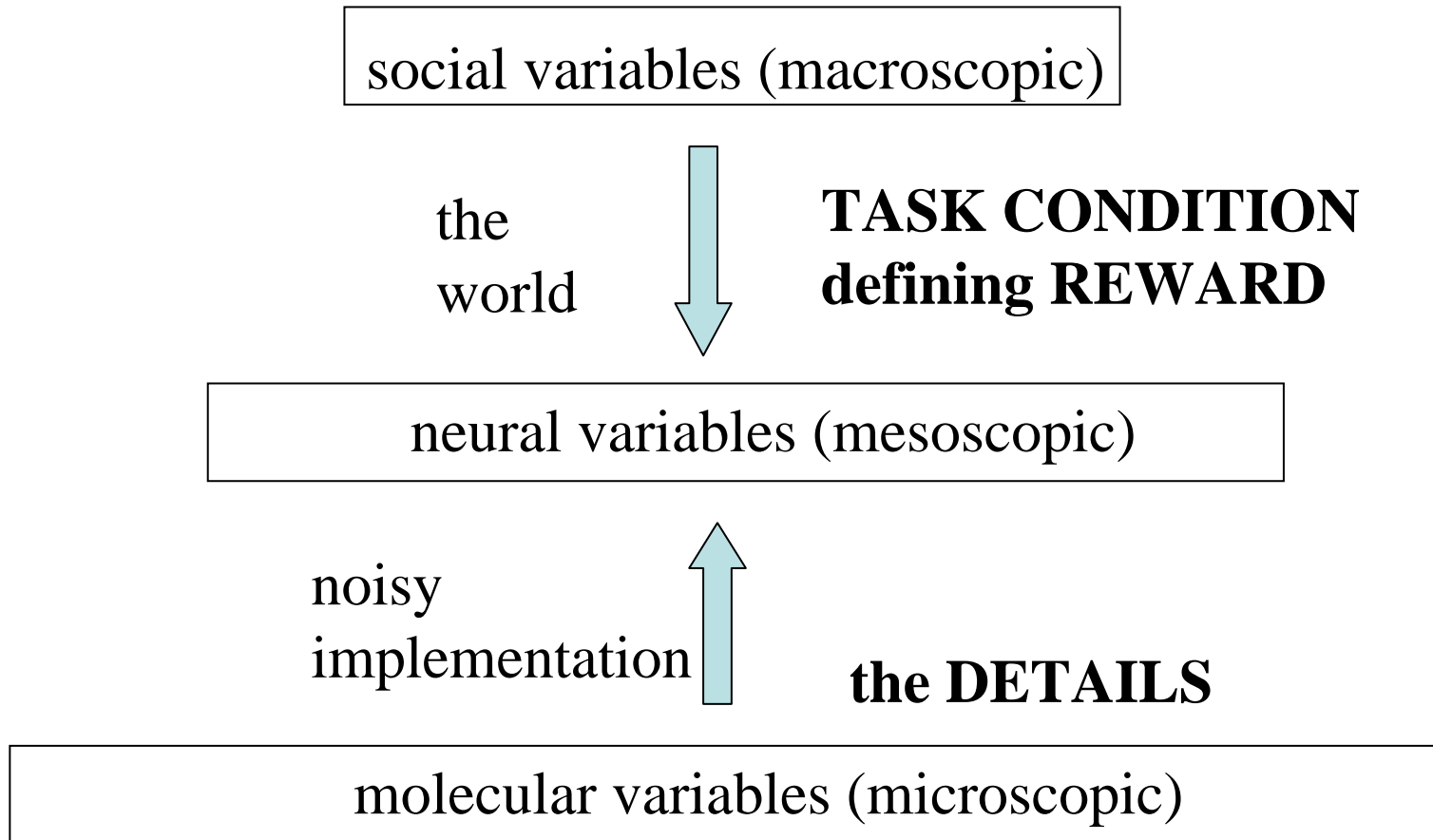


How a synaptic input changes transcription.  
(according to Berridge)



so why do we get stuck at particular levels?

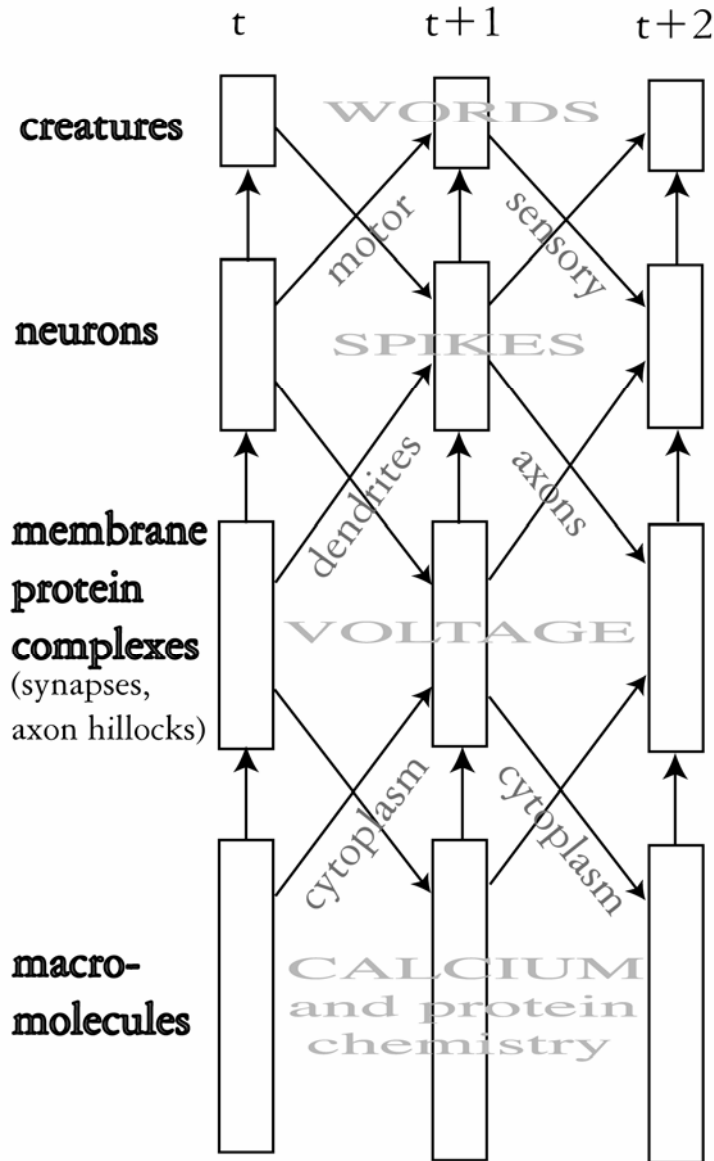
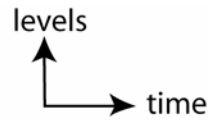
**Hazard of the Scientific Method:** engineering the *macrosphere* so that the *mesosphere* is lawful and the *microsphere* is irrelevant.



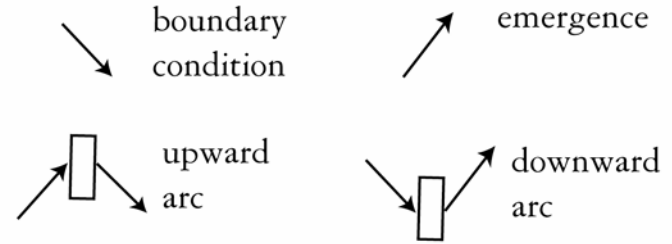
**Rather**, *levels insulation* is the exception rather than the rule.



# THE REDUCTIONIST HIERARCHY:



## CAUSAL RELATIONS, $G$ :



## STRUCTURAL RELATIONS, $F$ :

ie: coarse graining.  
or complex 'pooling'.

$$\mathbf{x}_l^t = F_l(\mathbf{x}_{l+1}^t)$$

$$\mathbf{x}_l^t = G_l(\mathbf{x}_{l-1}^{t-1}, \mathbf{x}_{l+1}^{t-1})$$

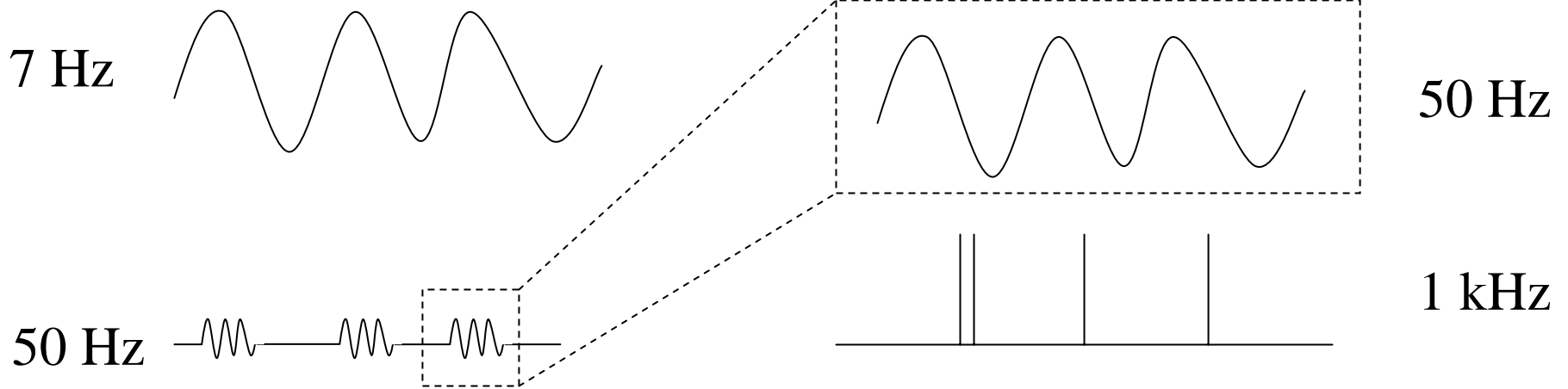
What about the brain?



# Structured boundary condition relations in the EEG:

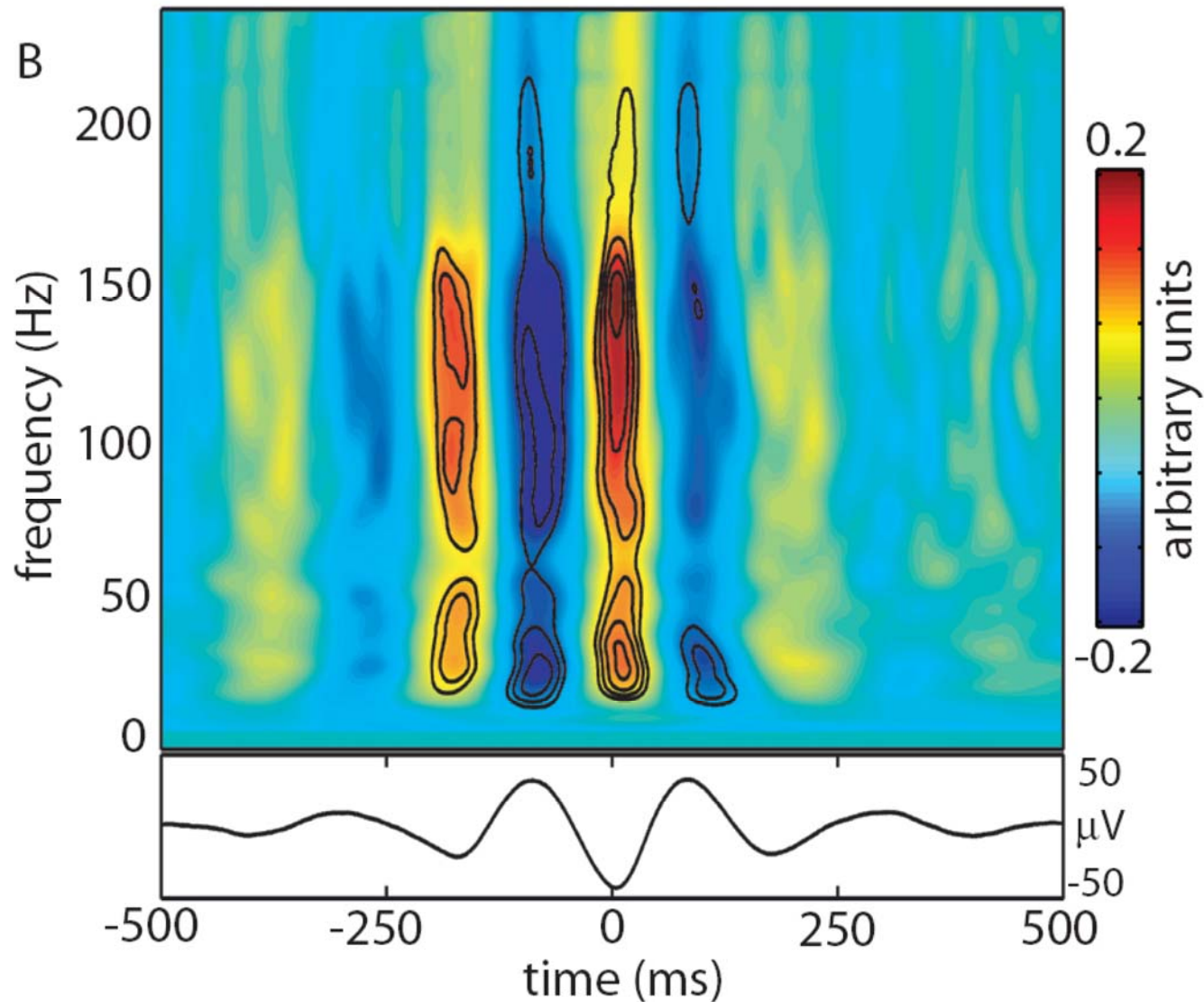
Coupling between  
theta phase and  
gamma amplitude  
(Buzsaki; Canolty)

Coupling between  
gamma phase and  
spiking probability  
(Fries)



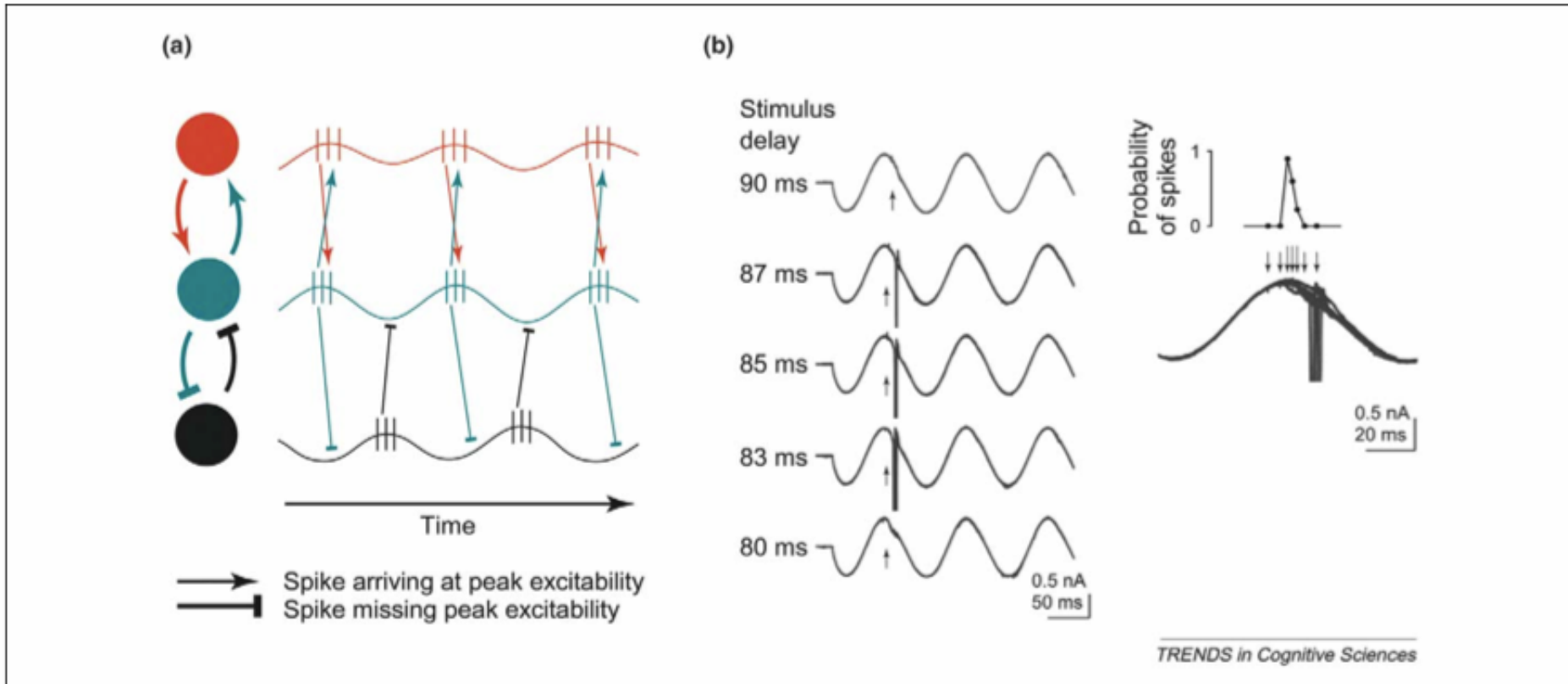
(signals are band-pass filtered)

# Theta to gamma: phase/amplitude relations



High gamma power is phase-locked to theta oscillations in human neocortex, Canolty et al, Science 2006

# Gamma to spike-timings: phase/prob(spike) relations

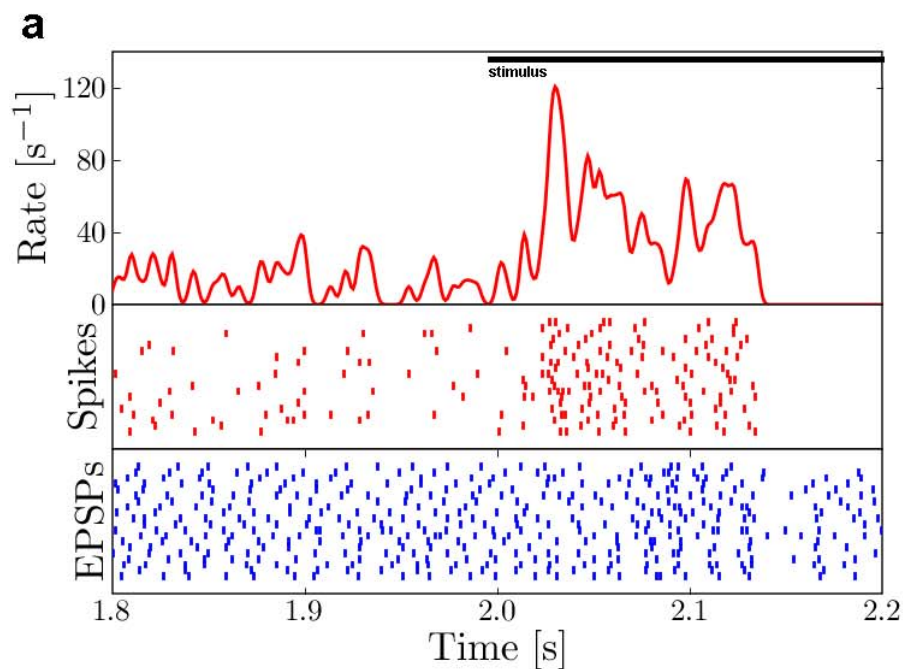


**Figure 3.** 'Neuronal communication through neuronal coherence' and some supporting evidence. (a) Same general format as in Figure 1a. Spikes that arrive at excitability peaks of the receiving neuronal group have pointed arrowheads. Spikes that miss excitability peaks have blunt arrowheads. The red and green neuronal groups undergo coherent excitability fluctuations and their communication is therefore effective. The black neuronal group however undergoes excitability fluctuations that are not coherent with the green neuronal group and therefore communication between the green and the black neuronal group is prohibited. (b) Membrane potentials during combined injection of sinusoidal current and electrical stimulation of one afferent axon. The timing of the axon stimulation was varied such that the synaptic input arrived at the recorded neuron either precisely at its excitability peak or shortly before or after it. (Adapted from [28].)

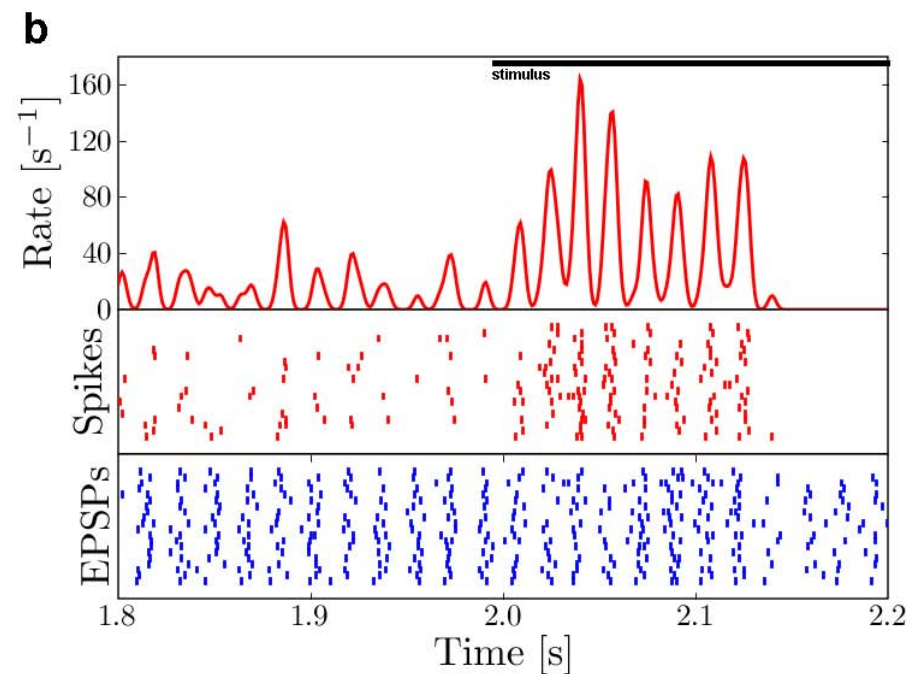
A mechanism for cognitive dynamics: neuronal communication through neuronal coherence, Fries P. 2005. *Trends Cogn. Sci.*

In thalamic relay cells, response rate is reproducible, but spike -  
timings in each trial are phase-locked to ongoing network activity:

original data

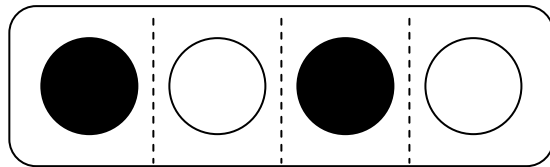


after phase-realignment



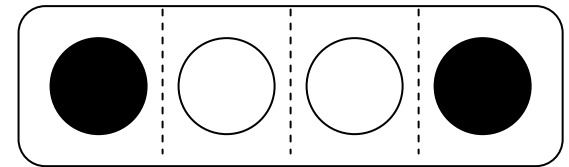
# An idea for how problem-solving occurs:

The *question* is  
a macroscopic  
constraint



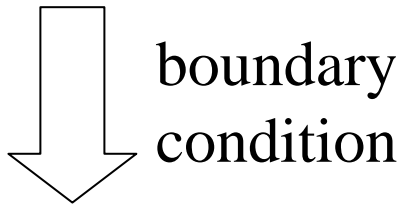
(eg: EEG theta or beta)

The *answer* is  
a microscopic  
emergence



macroscale

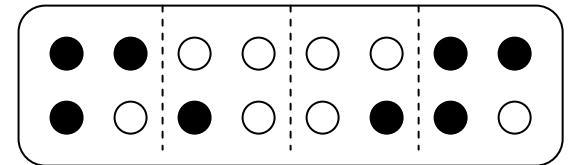
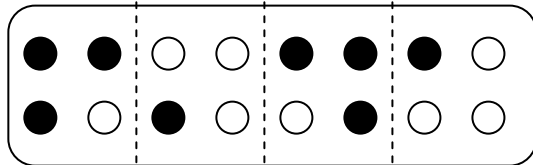
emergence



$$\int d(\mathbf{r}, t)$$

microscale

(eg: EEG gamma, or spikes)



→ temporal dynamics

## Lots of words:

In this picture, the contents of consciousness are those patterns that make it from the microscale to form lawful relations at the macroscale.

The macroscale here is defined as available for social report.

There are many more non-conscious states than conscious states.

There are also many more microstates than macrostates.

It seems natural therefore to identify the non-conscious with microscopic organisation and the conscious with macroscopic organisation.

In this picture, the conscious is just a gross way of talking about the microscopic details. When that account has macroscopic deterministic structure, we have 'a conscious process'.

The power of non-conscious lies in the detailed structure at the microscale

The power of the conscious lies in its ability to force the microscopic to reorganise to satisfy macroscopic constraints.

# Summary

Conscious contents are macro.

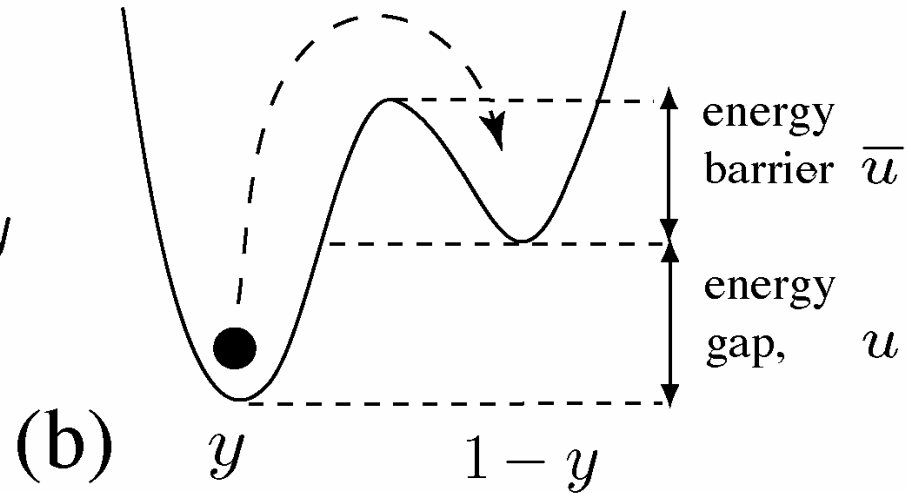
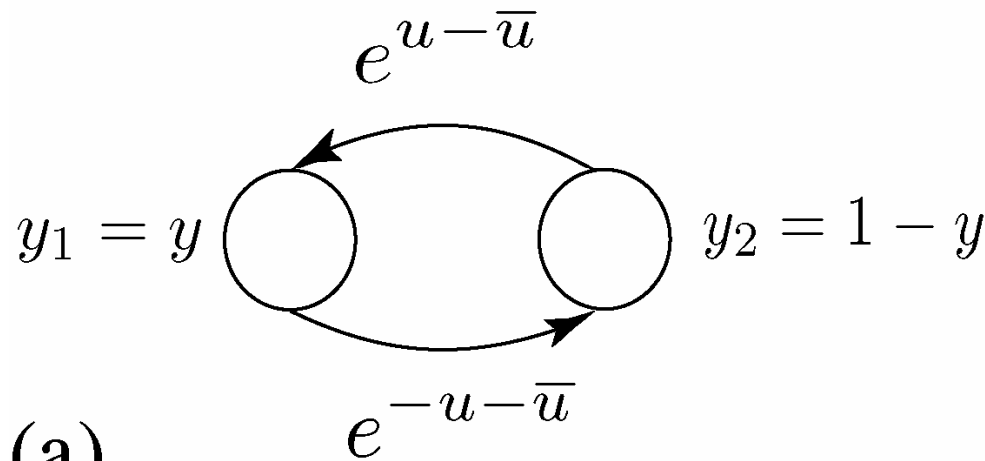
Non-conscious contents are micro.

Great, but what do we/I do next?

....some hard mathematics, perhaps...

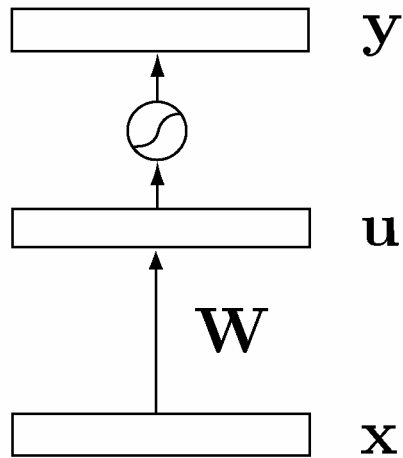
# Learning in a kinetic scheme.

Dynamic:  $\dot{y} = e^{u-\bar{u}}(1-y) - e^{-u-\bar{u}}y$





A new, levels-based, learning algorithm for time series:

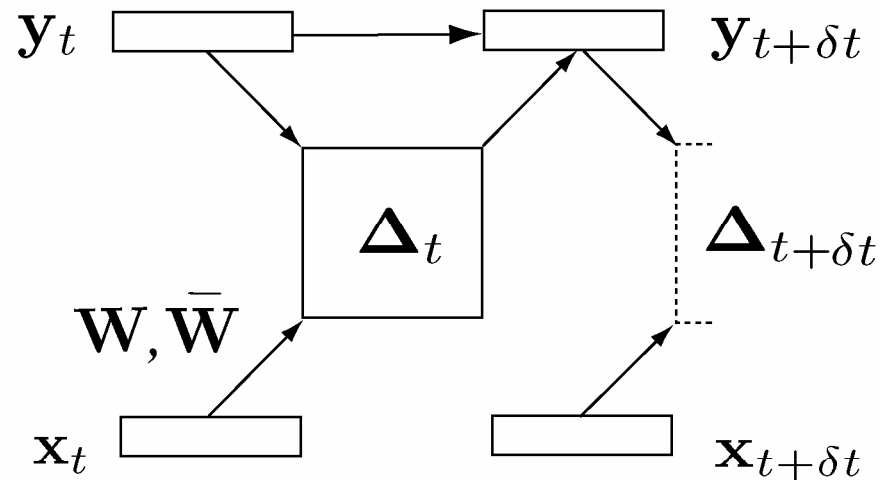


$$\left. \begin{aligned} \mathbf{u} &= \mathbf{W}\mathbf{x} \\ y_i &= \frac{1}{1 + e^{-u_i}} \end{aligned} \right\}$$

NETWORK

$$\left. q(\mathbf{x}) = \left| \frac{\partial \mathbf{y}}{\partial \mathbf{x}} \right| \right\}$$

MODEL



$$\left\{ \begin{aligned} u_{ij} &= \mathbf{w}_{ij}^T \mathbf{x} & \bar{u}_{ij} &= \bar{\mathbf{w}}_{ij}^T \mathbf{x} \\ \Delta_{ij} &= y_j e^{u_{ij} - \bar{u}_{ij}} \\ y_i^{t+\delta t} &= y_i^t + \delta t \sum_j \Delta_{ij} - \Delta_{ji} \end{aligned} \right.$$

$$\left\{ q(\mathbf{x}_t | \mathbf{y}_t) = \left| \partial_{\mathbf{x}} \Delta \right| \right.$$

(a) Infomax ICA

(b) Kinetic Automaton

# EXTRA MATERIAL

A **neuron** can only know about **spikes**. It does not have antennae for **the EEG**.

A **molecule** can only know about **conformational interactions with other molecules or ions**. It doesn't have antennae for **spikes**.

A **person** can only know about **what other people are doing**. He does not have antennae for, say, **government activity**.

**RED**            unit at level  $l$

**BLUE**           communication event at level  $l+1$

**ORANGE**       communication event at level  $l-1$

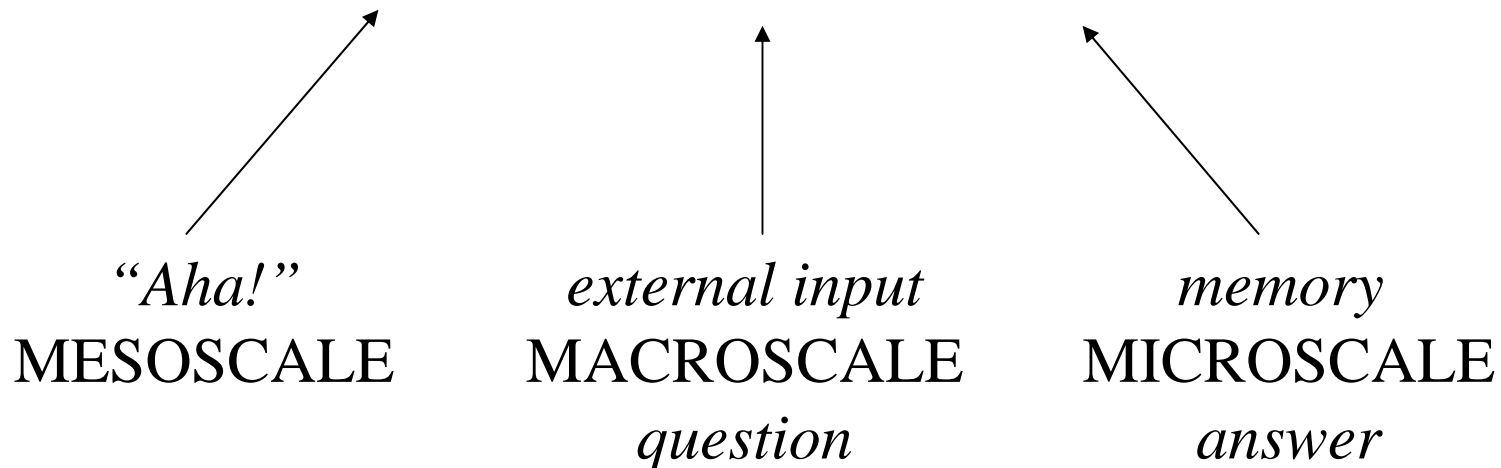
*If the EEG is irrelevant to neuroscience,  
then the government is irrelevant to people.*

# Mathematical Formalisation (3 levels)

Given a level,  $l$ , a state vector,  $\mathbf{x}_l^t$ ,  
structural relations,  $F$ , and causal relations  $G$ :

$$\mathbf{x}_l^t = F_l(\mathbf{x}_{l+1}^t) \quad (\textit{Reductionism})$$

$$\mathbf{x}_l^t = G_l(\mathbf{x}_{l-1}^{t-1}, \mathbf{x}_{l+1}^{t-1}) \quad (\textit{Determinism})$$



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