

Why the Brain is Not a Computer

Professor Christof Koch

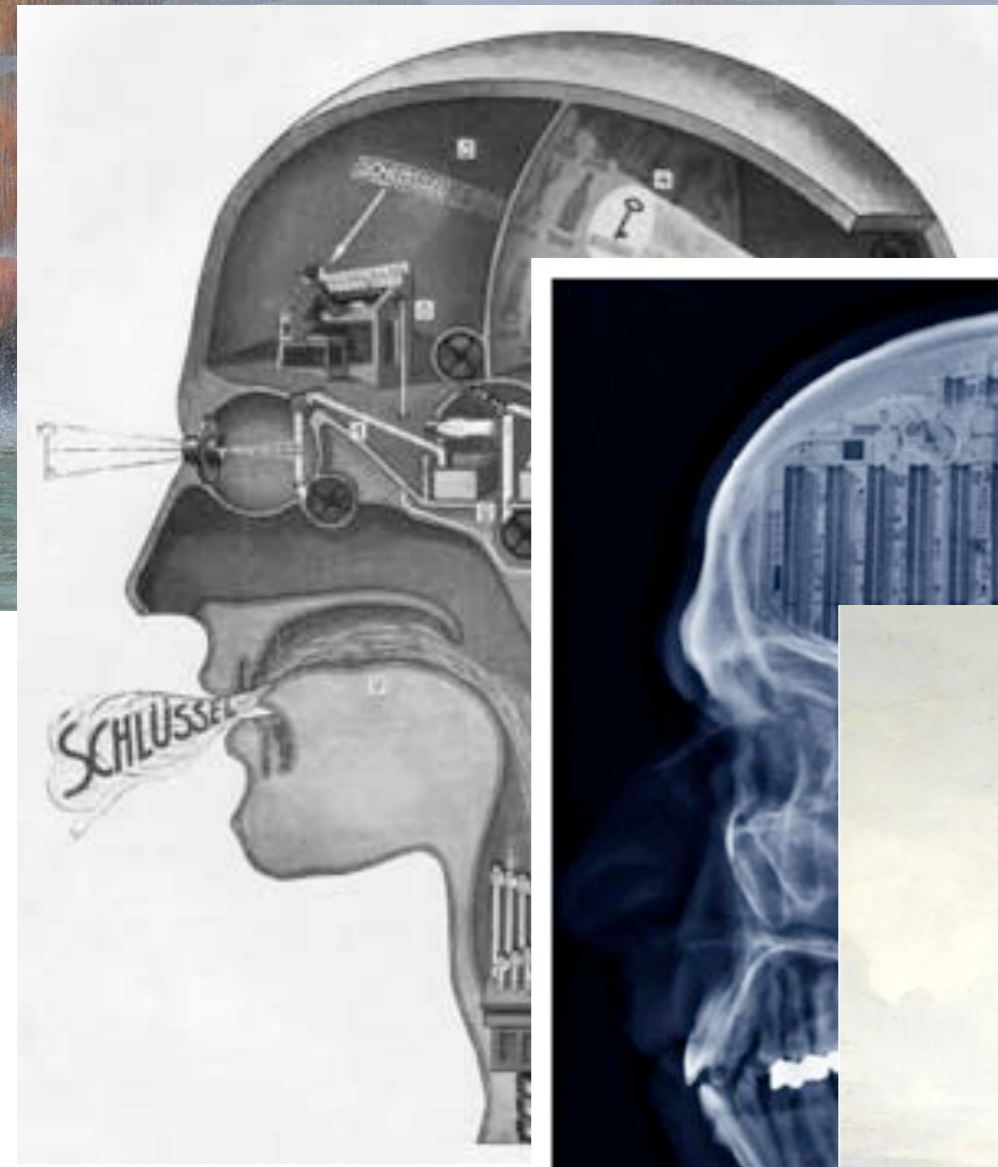
California Institute of Technology

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The Brain is Always Compared to the Technology of the Day



17th century (R. Descartes)



20th century (F. Kahn)



late 20th century



Early 21th century

What does it mean to compute?

- The brain is an biological organ that performs a series of transformations on sensory input or intrinsic representations to generate behavior and changes in internal state
- These transformation can be called computations
- The difference between computational and mechanical/ causal explanations is that the former refer to the information content of the physical system

The ways in which brains are not computers

- Not universal computational devices
- No separation between memory and computing
 - Memory is (partially) encoded in synapses
- No system-wide clock
 - Coordinated spiking events are critical (synchrony, oscillations in a variety of frequency bands, waves, synfire chain)
- No high-speed bus
 - Communication (partially) using asynchronous, address-event code

The ways in which brains are not computers

- Vertebrate brains mature over time, during which they can acquire enormous amount of environmental specific information
- They have apoptosis
- They have senescence

The ways in which brains are not computers

- It feels like something to be the owner of an awake brain and to consciously experience different states
- This is not true of other adaptive biological networks (liver, enteric nervous system, immune system)
- It is not clear whether conscious states can occur in computers of sufficient complexity (G.Tononi)

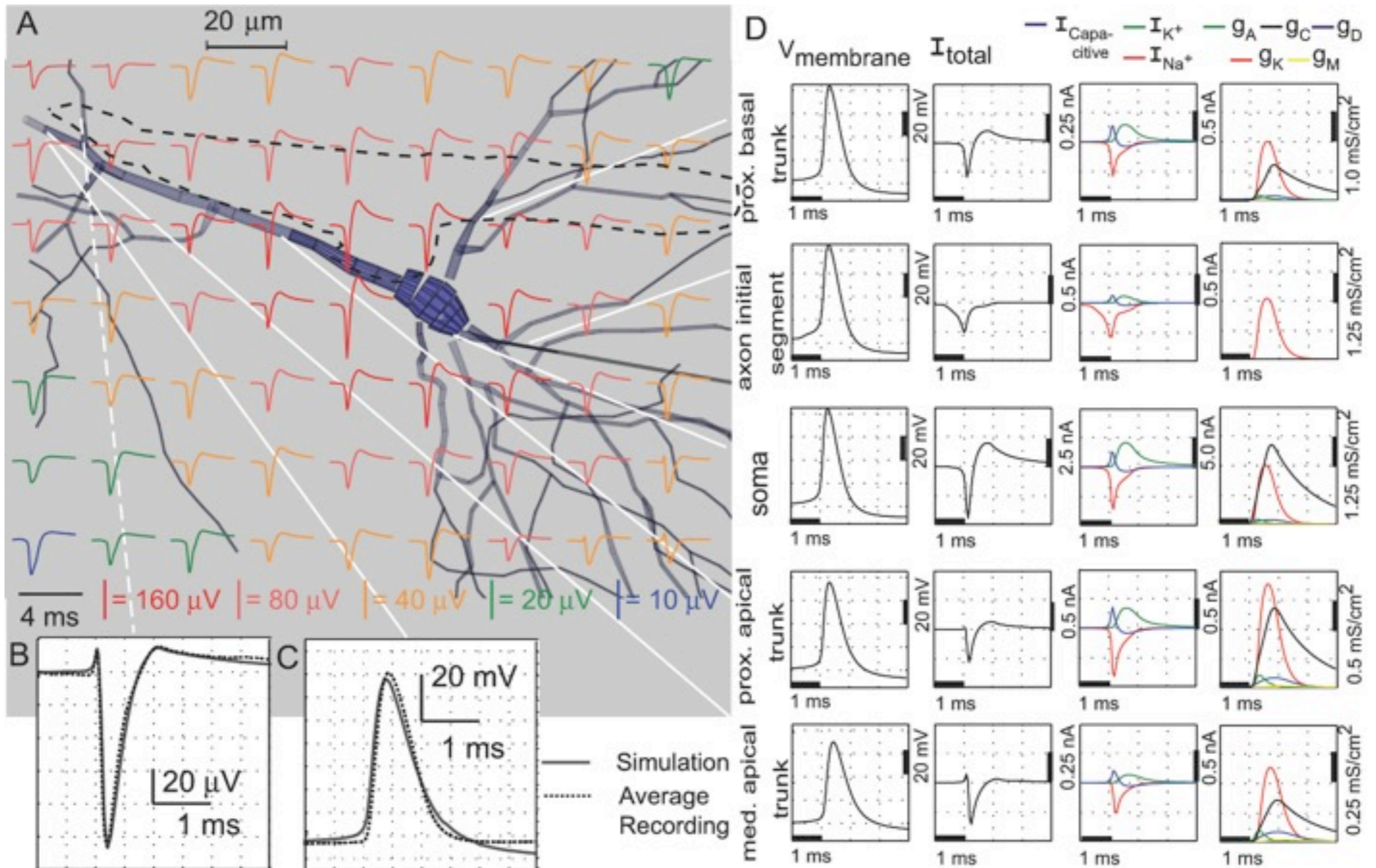
The Brain as a Physical System

Calculation of extracellular potential due to point source via solution of Poisson's PDE

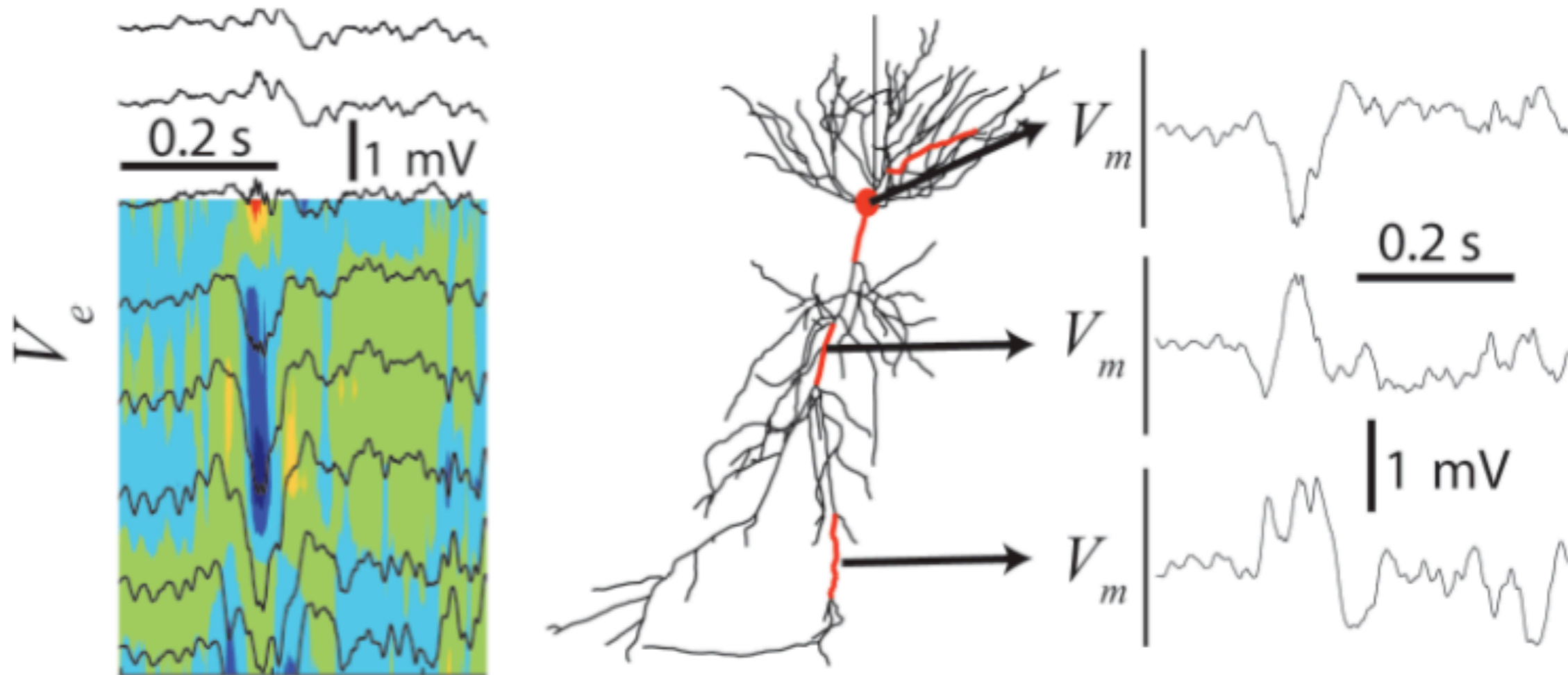
$$\phi = \frac{\rho I}{4\pi r}$$

The Forward Problem

Gold, Henze, Buzsaki & Koch (2006)



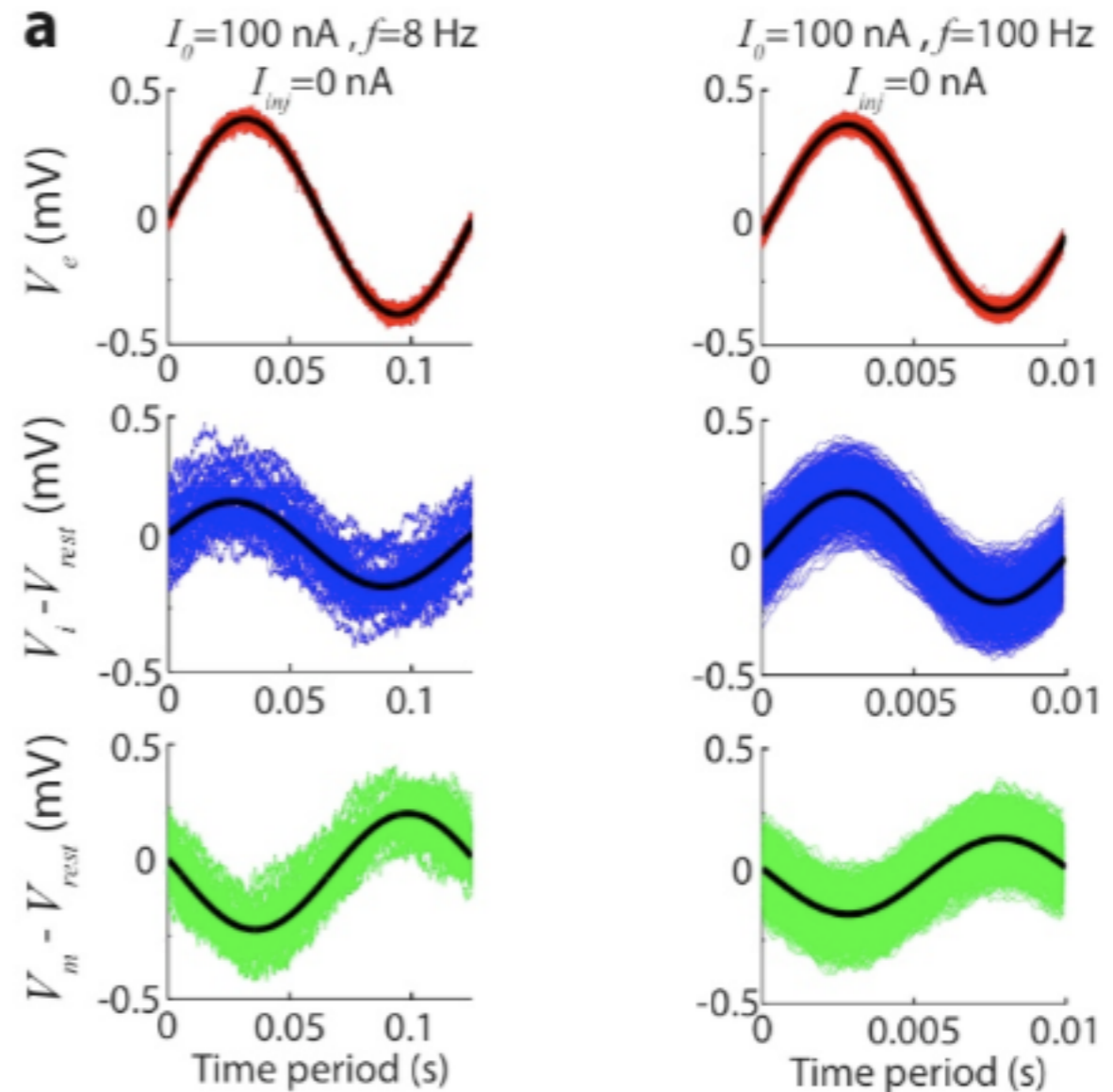
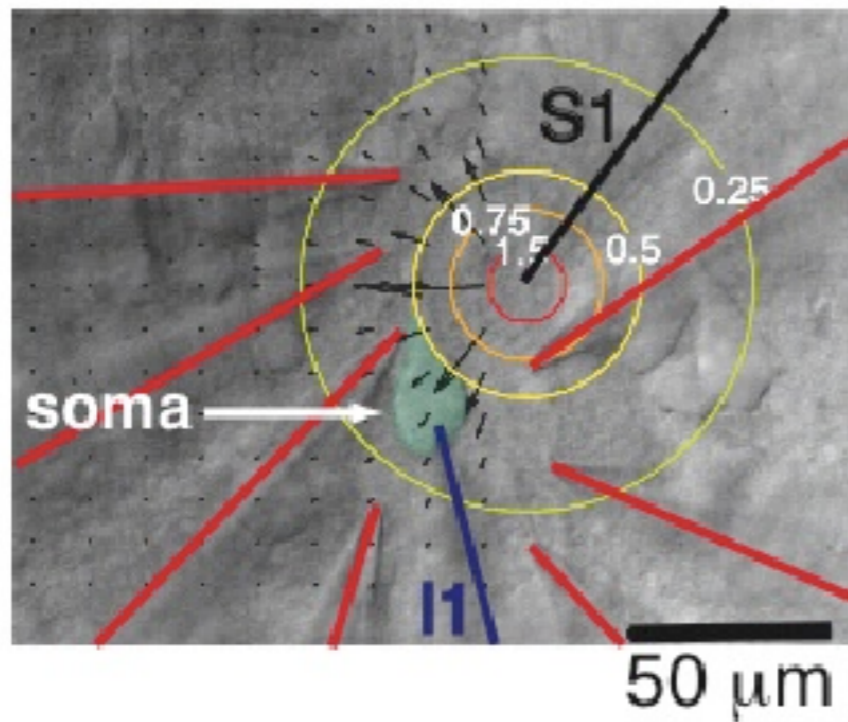
The Feedback Problem



The Local Field Induces **Ephaptic** Potentials

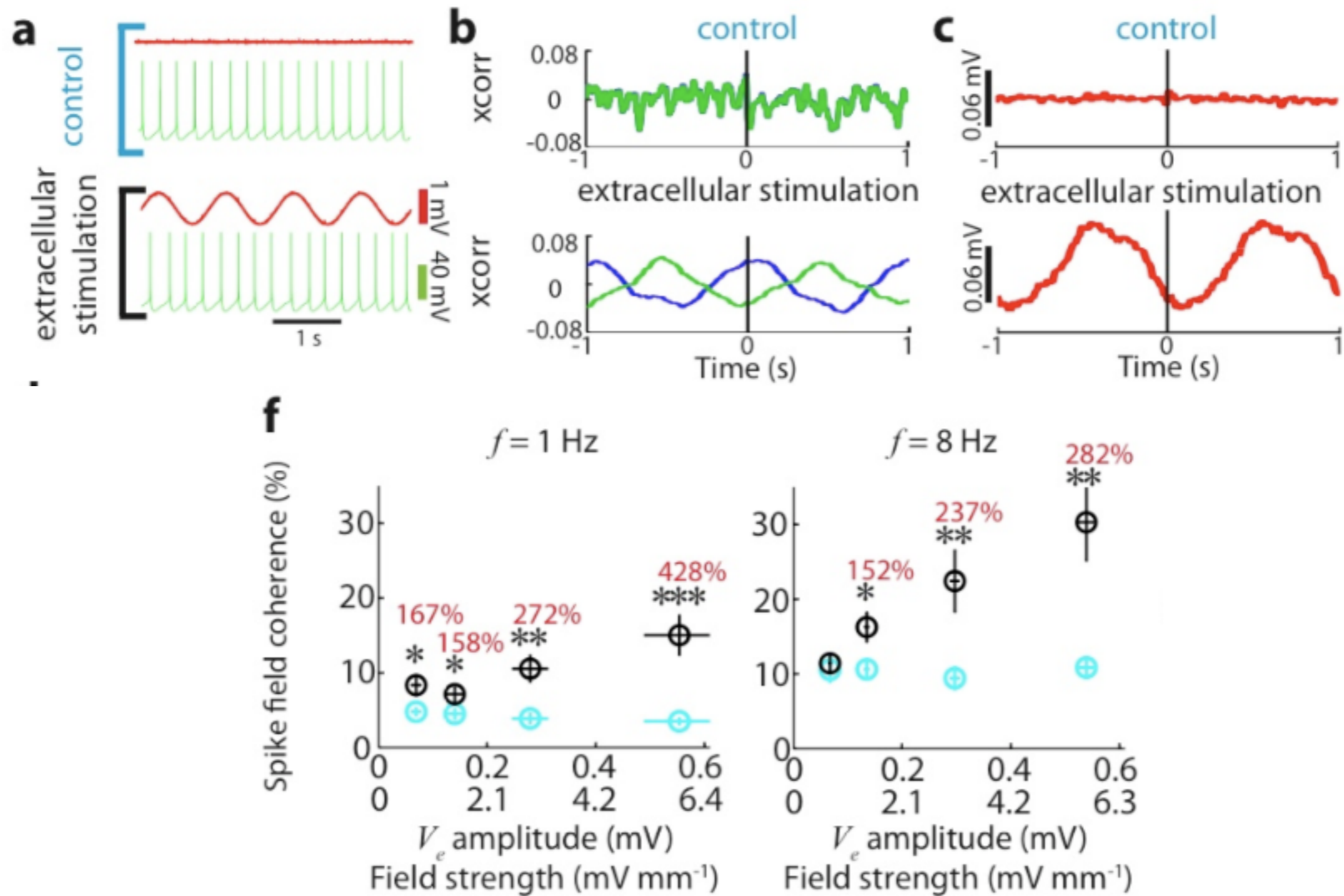
Anastassiou, Montgomery, Barahona & Buzsaki & Koch (2010)

Single Neuron Correlate of Ephaptic Effects



Anastassiou, Perin, Markram & Koch submitted

Single Neuron Correlate of Ephaptic Effects



Spike Triggered Average (STA)

Anastassiou, Perin, Markram & Koch submitted

The Brain as a Physical System

Thus, while electronic circuits are carefully designed and built to minimize interaction among wires, between substrate and transistors etc., ephaptic interactions mediated by oscillating LFP might be critical for instantaneous and para-local interactions

The Brain as a Serial Processor

Even though the hardware is massively parallel, much processing is serial, limited by an attentional bottleneck

How often is the ball passed among the White team?

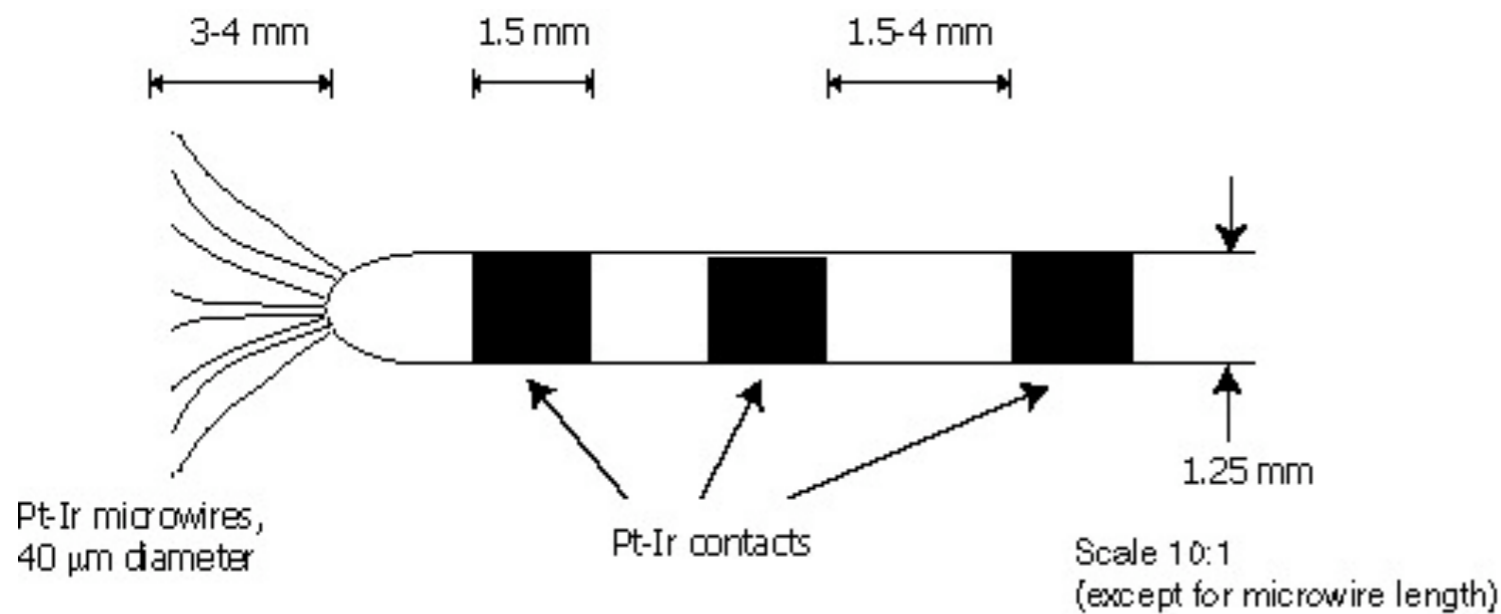
Simons & Chabris (1999)

Feedback from single neurons to patients in combination
with selective attention can override sensory input

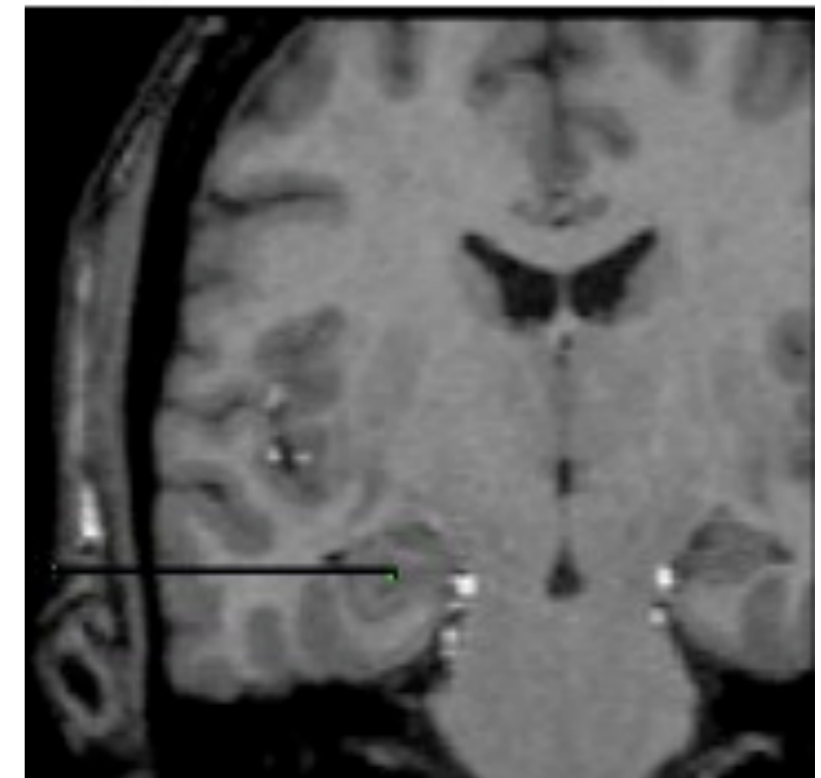
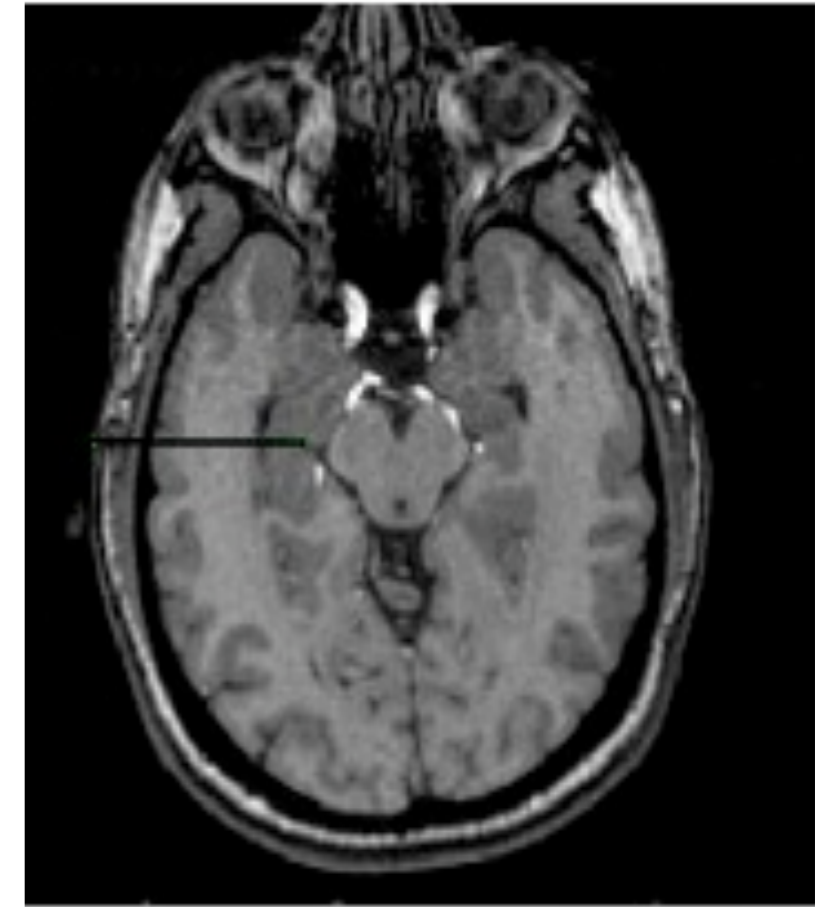
Cerf M, Thiruvengadam N, Mormann F, Kraskov A, Quiñan
Quiorga R, Koch C & Fried I

All surgeries carried out by Dr. Itzhak Fried at UCLA

Around 100 microwires per patient
Data is acquired at 28.7 kHz via 64
electrode Neuralynx system



Fried, I. et al. Cerebral microdialysis combined with single-neuron and electroencephalographic recording in neurosurgical patients. *J. Neurosurg.* 91: 697-705 (1999).



All work is carried out in the clinical ward
and with active participation
of neurosurgeon and neuroscientist Itzhak Fried, MD, PhD
UCLA
&
Tel-Aviv University





A patient on Dr. Fried's ward

The Human Medial Temporal Lobe

