What Does the Brain Compute, and How do we infer it?

Ilya Nemenman

CCS-3/LANL

Shamelessly “borrowed” from: W. Bialek, R. de Ruyter van Steveninck, A. Fairhall, N. Brenner, G. Lewen, C. Gallistel, P. Balsam, D. Baylor, F. Rieke, S. Strong, L. Abbott, S. Fusi, etc.

Center for Nonlinear Studies

The First q-bio Conference on Cellular Information Processing

August 8-11, 2007 | Santa Fe, New Mexico, USA

http://cnls.lanl.gov/q-bio
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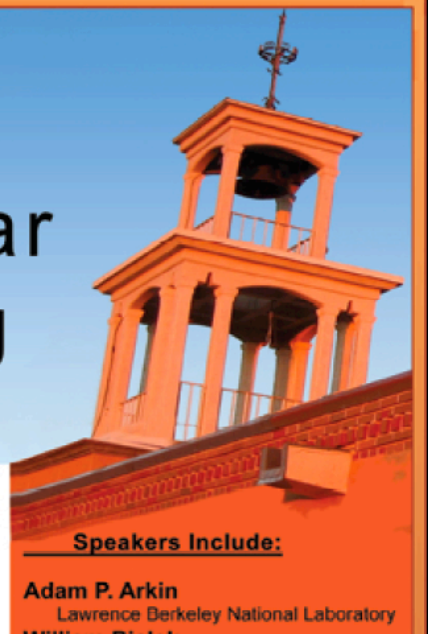

Speakers Include:

Adam P. Arkin
Lawrence Berkeley National Laboratory

Mark Goulian
University of Pennsylvania
Jeff Hasty
University of California, San Diego
Jason M. Haugh
North Carolina State University
Alexander Hoffmann
University of California, San Diego
Ravi Iyengar
Mount Sinai School of Medicine
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Deadlines:

Abstract submission	April 15, 2007
Summer School registration	April 15, 2007
Early registration	June 1, 2007

**Travel awards for graduate students and postdocs may be available.*
More information and applications are available on the conference website.

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The First q-bio Conference Information P

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First q-bio Conference on Cellular Information Processi
This conference is intended to advance predictive mod
genetic regulatory systems. The emphasis is
experimentation for the purposes of understanding
particular regulatory systems and of elucidating gene
information processing.

The single-track program will include invited talks
theoretical researchers as well as shorter talks, pos
demonstrations selected from contributed submissio
banquets, six sessions covering a range of topics, ar
sessions.

There will be an opportunity for selected participants
presentations made at the conference to a special is
journal indexed by ISI and PubMed.

Lodging is available for participants on the campus of St. John's College, which should facilitate interactions and stimulating informal discussions about quantitative biology. Space is available for 200 participants. In the event that registration demand exceeds capacity, preference will be given to individuals selected to present contributed talks or posters. Abstracts should be submitted for review via the conference web site.

First q-bio Summer School on Cellular Information Processing
This school is designed for researchers new to modeling cellular regulatory systems. It will take place in Los Alamos from July 23 to August 7. Participants will attend daily lectures about signal transduction, gene regulation and stochastic effects in biochemical networks and work in small teams on selected research projects. Tuition includes conference registration.

Deadlines:

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Organizing Committee: Jeremy S. Edwards (University of New Mexico); James R. Faeder, William S. Hlavacek, Yi Jiang, Ilya Nemenman, and Michael E. Wall (Los Alamos National Laboratory).

Advisory Committee: William Bialek (Princeton University); Byron Goldstein, John E. Pearson, William H. Press, David H. Sharp, and Pat J. Unkefer (Los Alamos National Lab); Michael A. Savageau (University of California, Davis)

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Center for Nonlinear Studies

Images are of St. John's College, the conference location

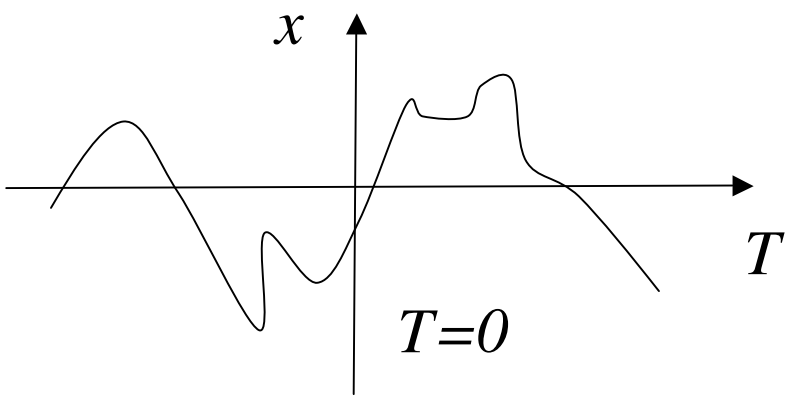
What and How?

	Digital computer	Brain
What	Programmable	?
Memory	Bits	?
How	Boolean gates	?

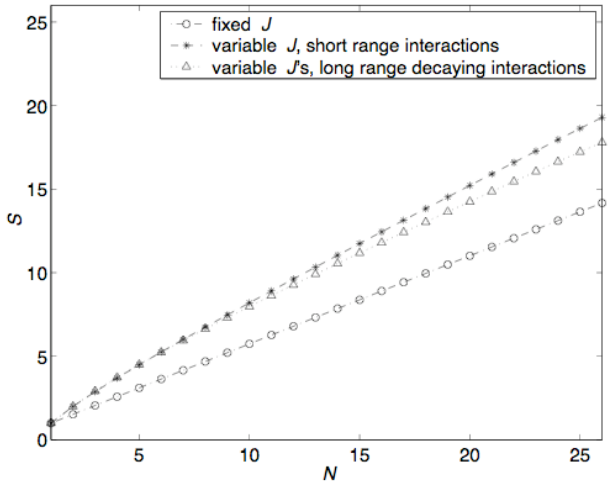
What?

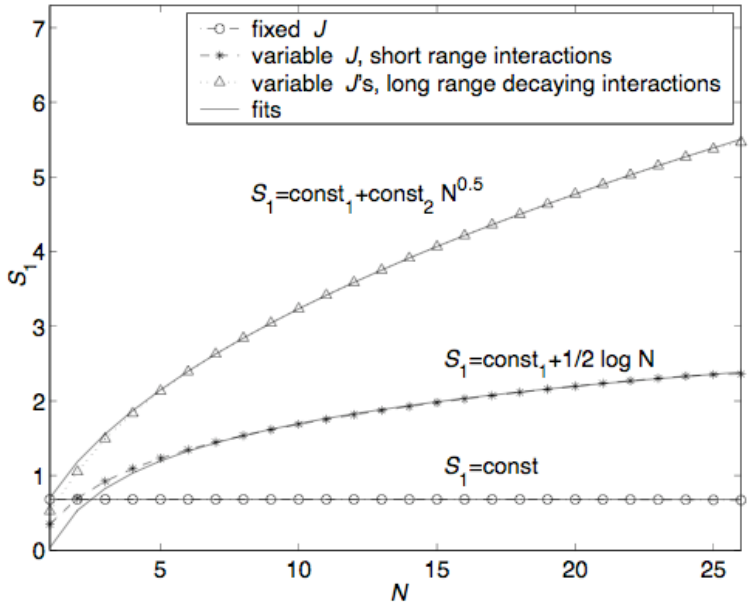
Our brains are not general purpose computers!

What? (Predictability)



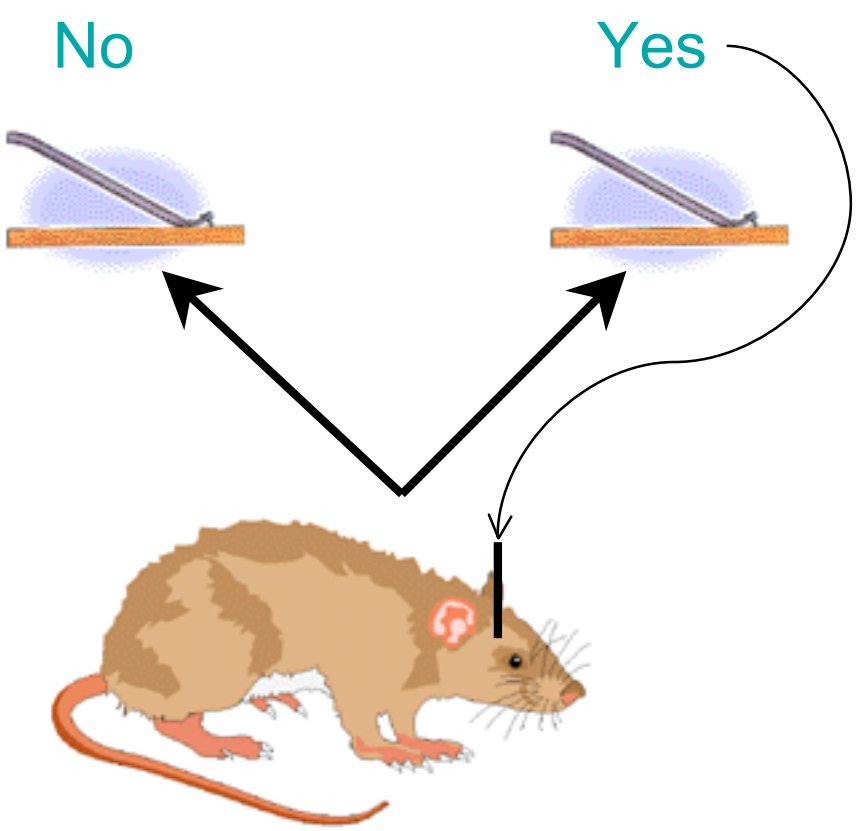
$$I_{pred} = I\left(\left\{x_{past}\right\} \mid \left\{x_{future}\right\}\right) < I_0\left(\text{length of past}\right)$$



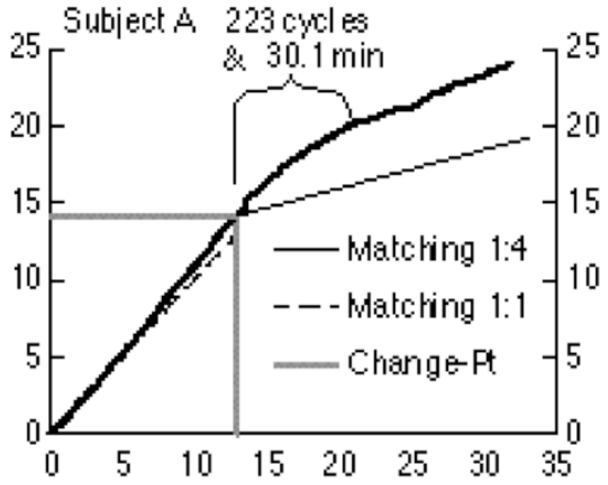


Maybe, but don't know yet…

More details on What? (prediction in rats)

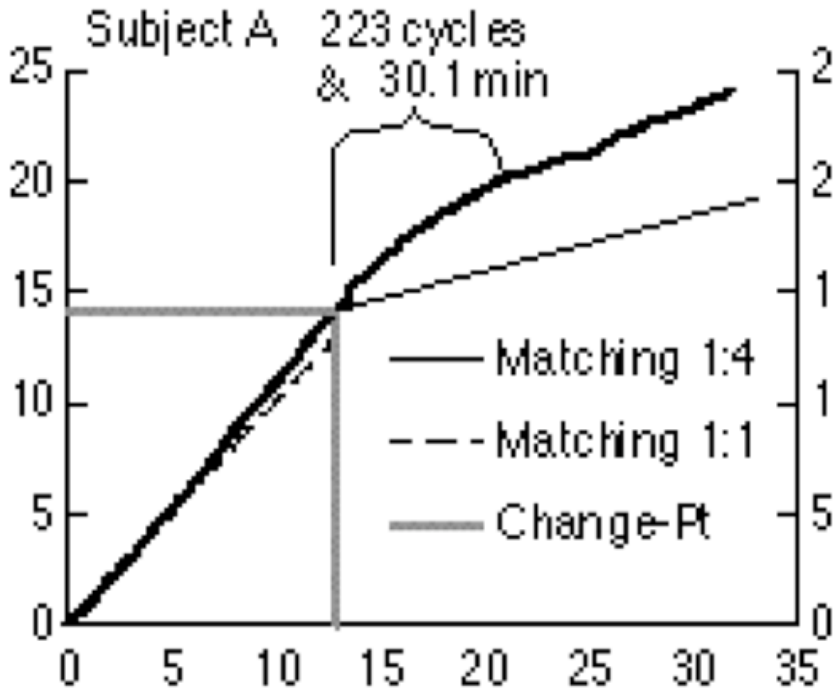


- Poisson deposition of rewards
- Rewards do not accumulate
- Possibly variable rate
- Changeover delay
- Rat matches

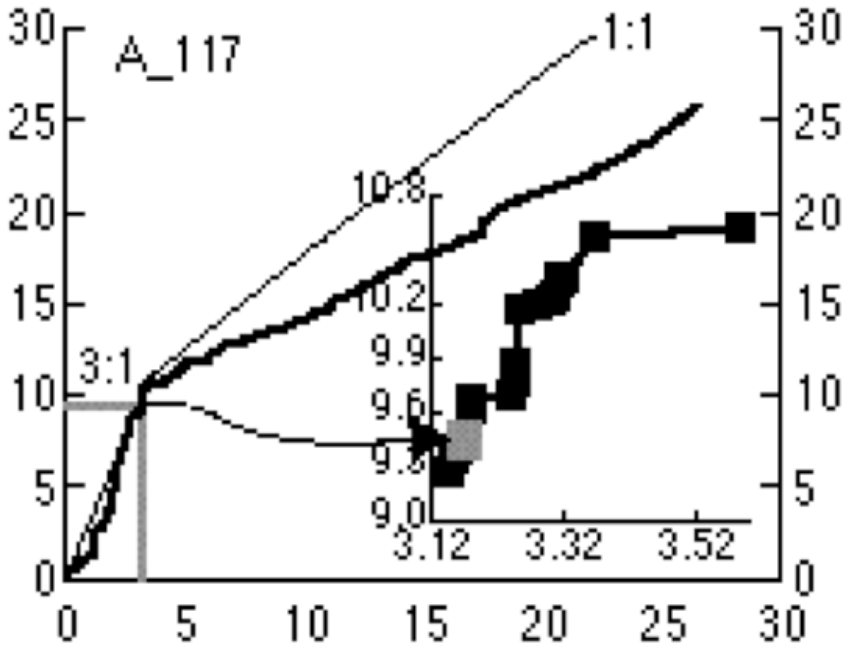


For Greg: info is used!

History dependent time scales



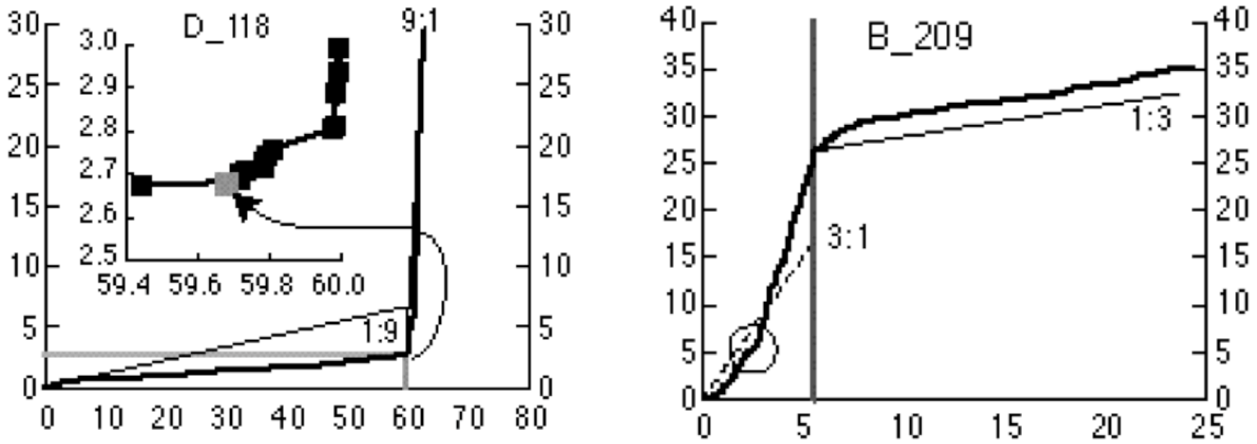
$\tau = 30 \ldots 100 + \text{min}$



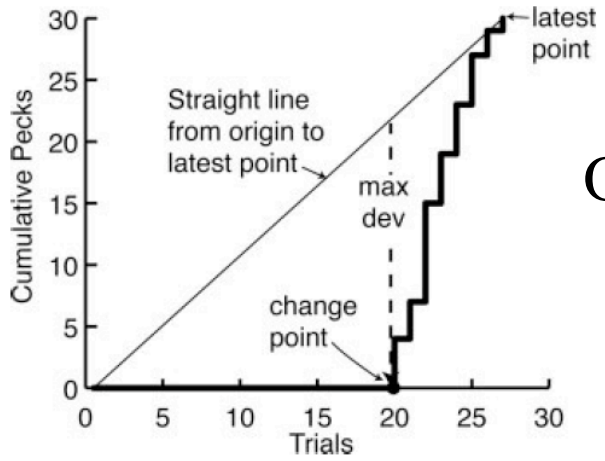
$\tau = 1 \ldots 2\,\text{min}$

Ideal Bayesian change detector

Abrupt changes

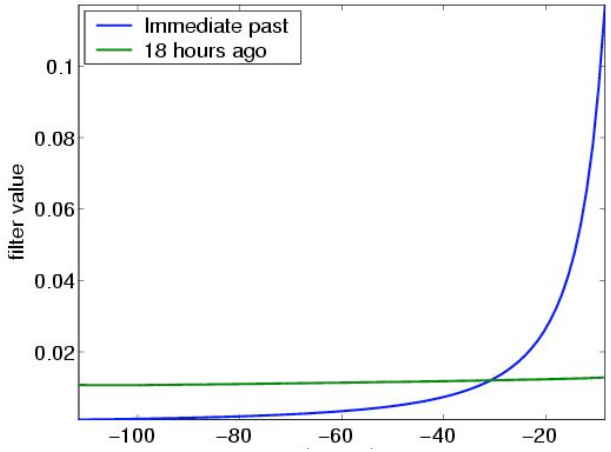


Often unwarranted, but only after a few prior changes. Metastability?

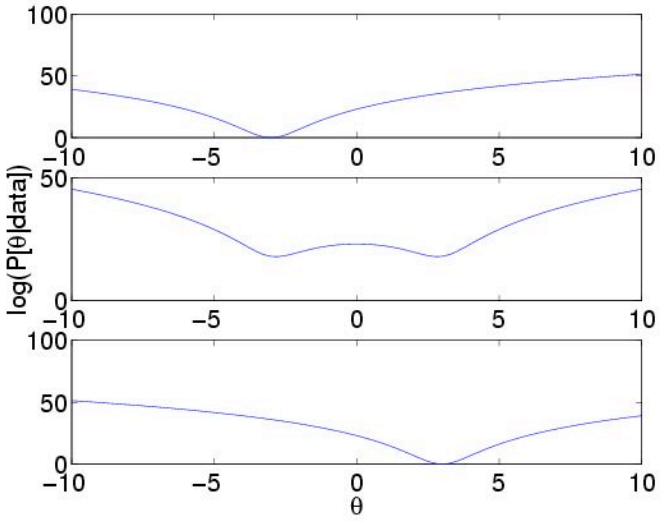


Other animals (again notice delay)

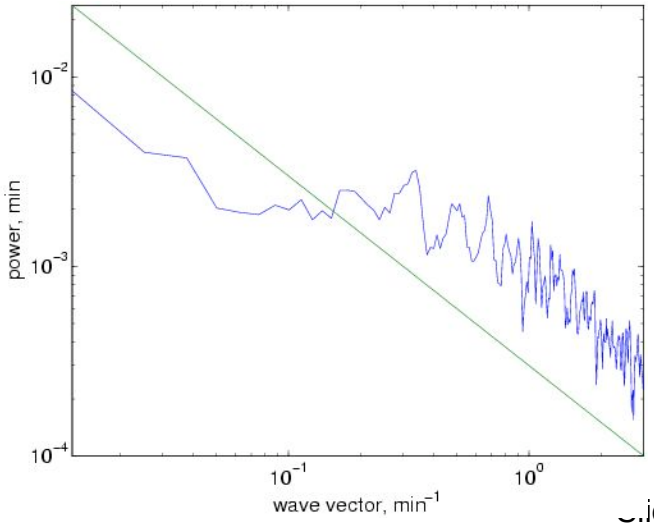
All (+CP) explained by long term memory



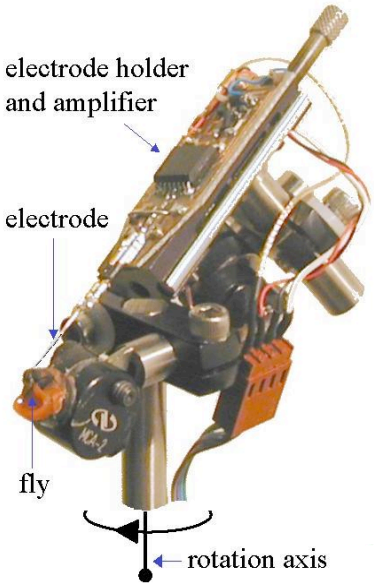
Must be non-exponential filter
+ non-Gausian



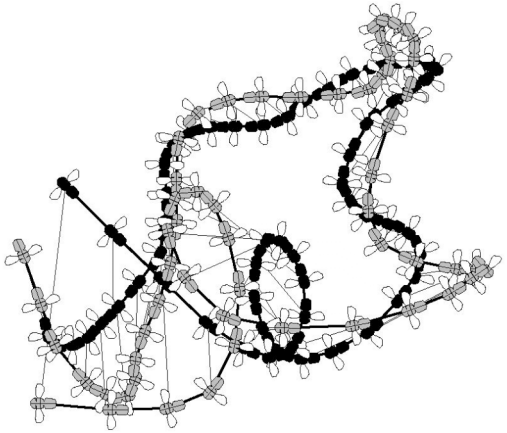
But is it really power law?
(more to come)

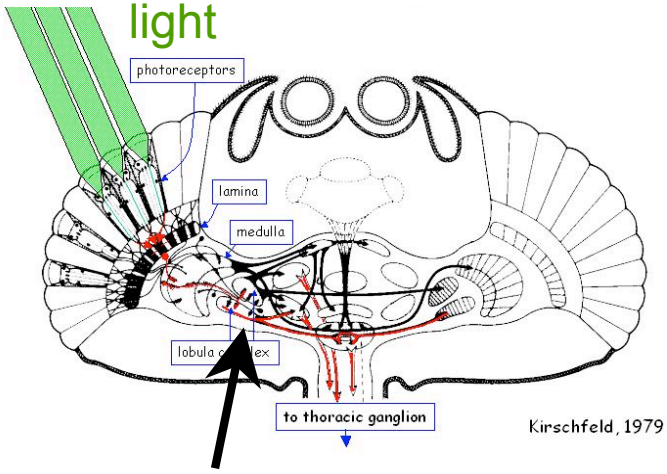


More on What? (flies)



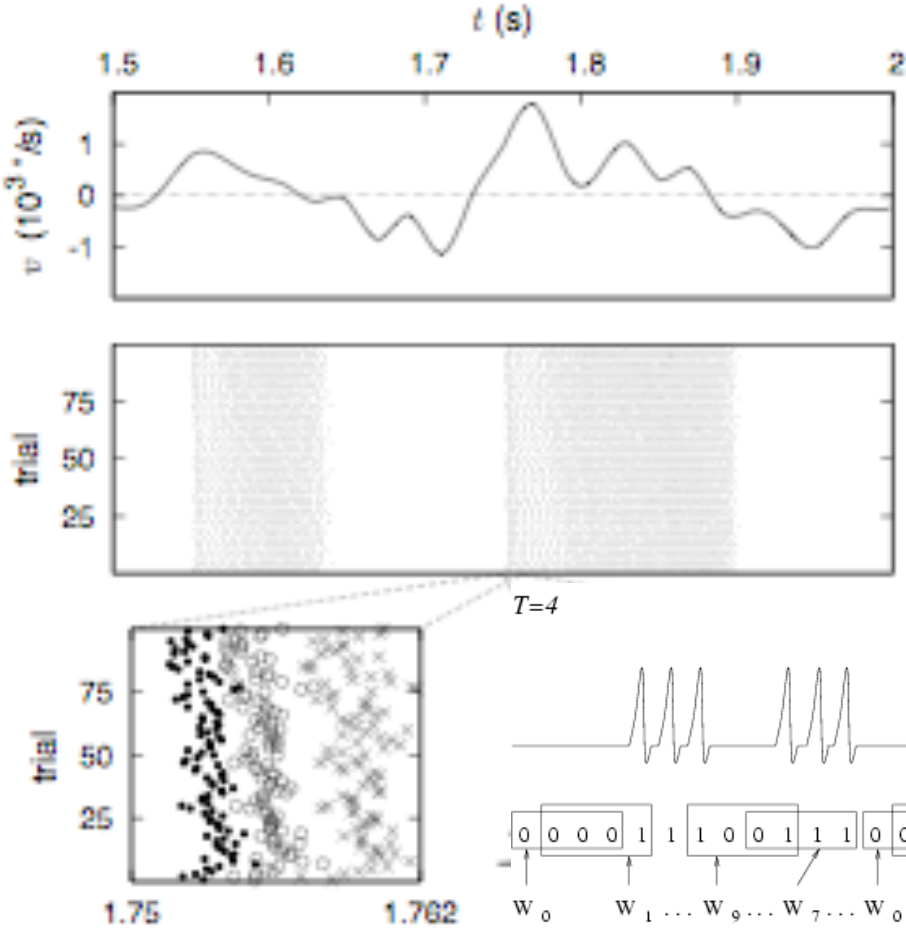
(Lewen et al, 2001)



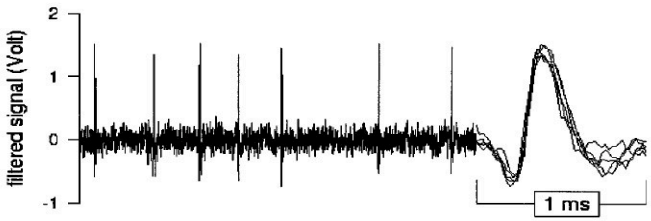


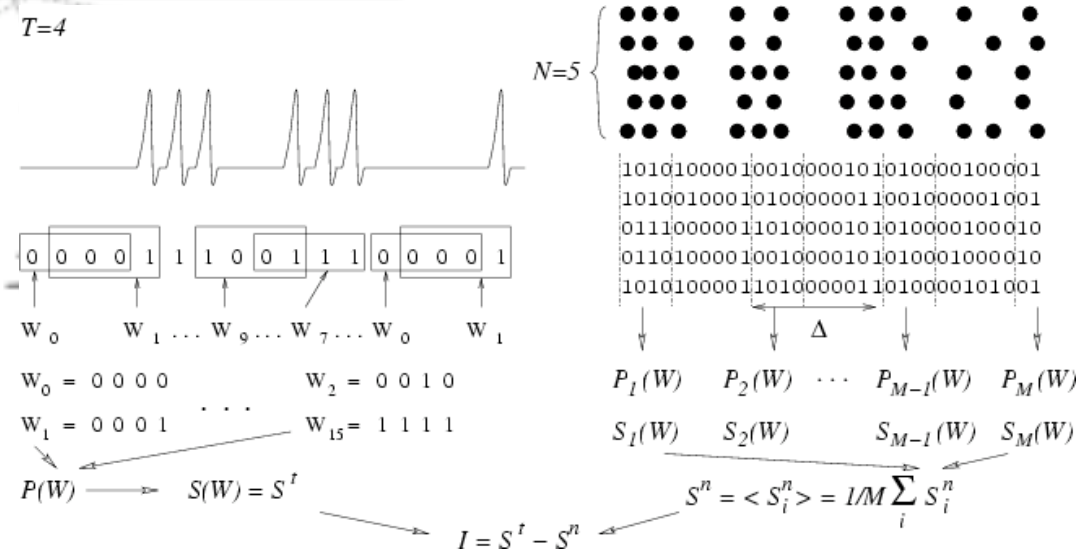
record

How we infer?



Firing rate, IT analysis
No subthreshold analysis

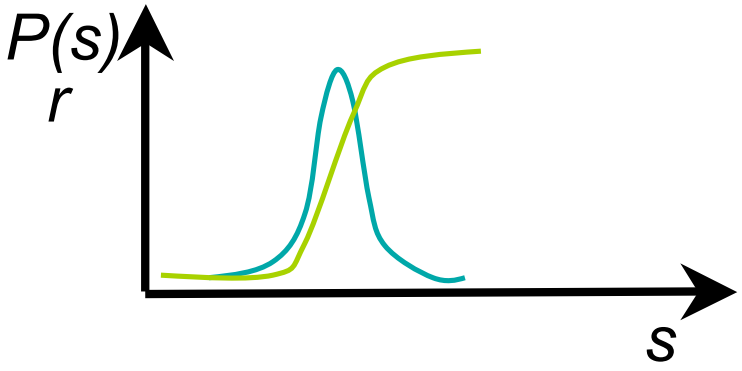


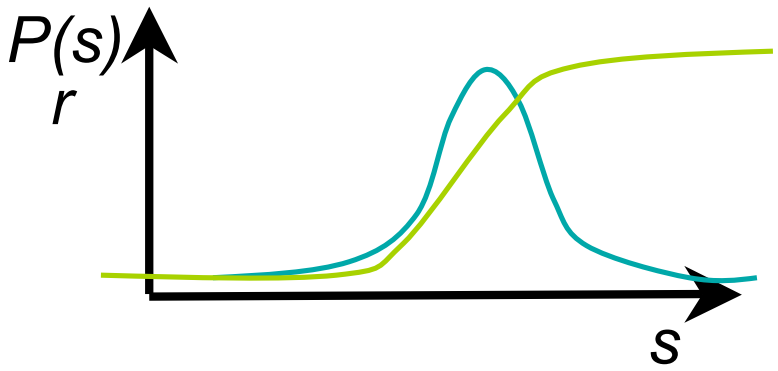


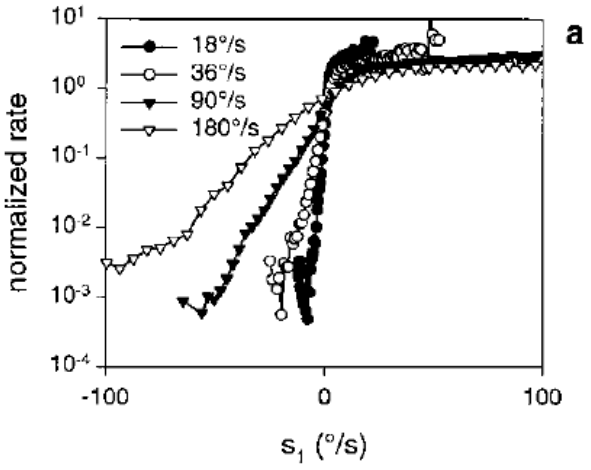
Adaptation 1-2 (just memory, Adrian 1929)

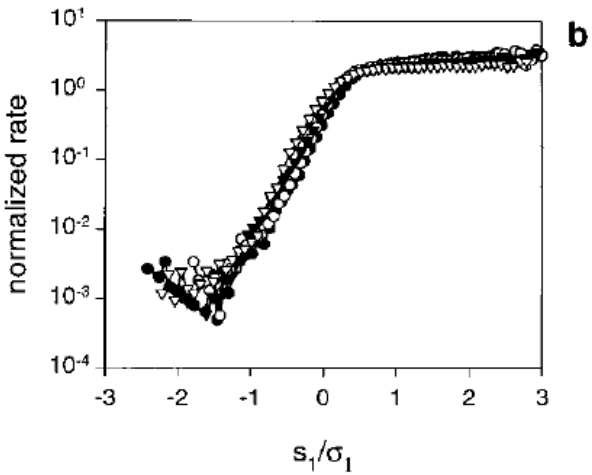
$$P(s,r) \rightarrow I[P] = \left\langle \log \frac{P(s,r)}{P(s)P(r)} \right\rangle$$

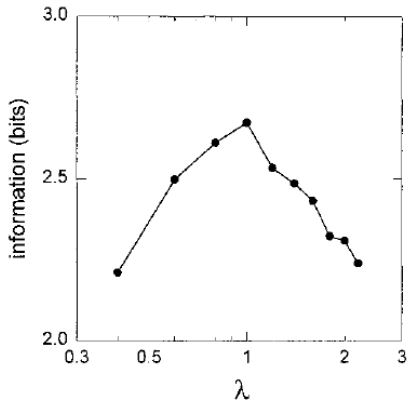
Matching mean and variance (whitening) maximizes information transmission.



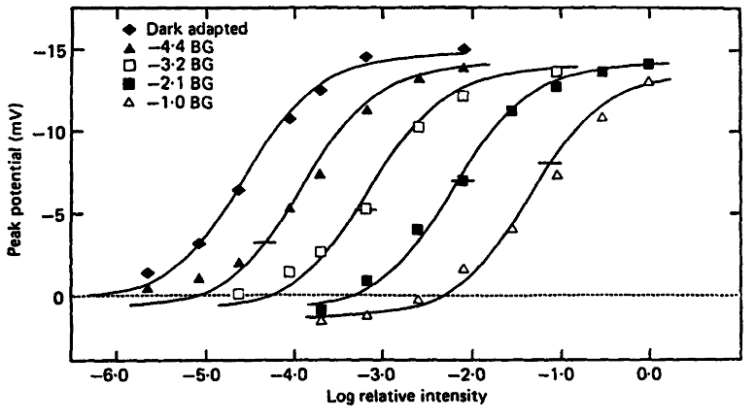








And in a different system (turtle cones)

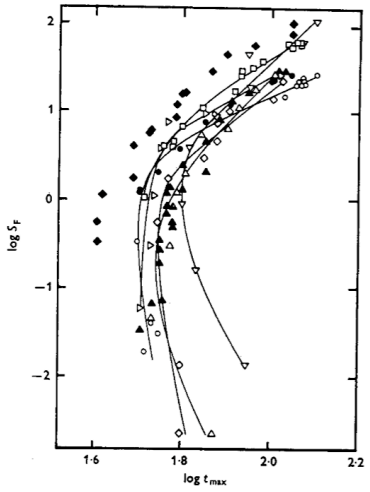


(Normann & Perlman, 1979)

Bckgr, log I	Adap, log I
dark	-4.4
-4.4	-3.8
-3.2	-3
-2.1	-2.3
-1	-1.3

$$I_a \propto I_0^{0.73}$$

(Baylor & Hodgkin, 1974)

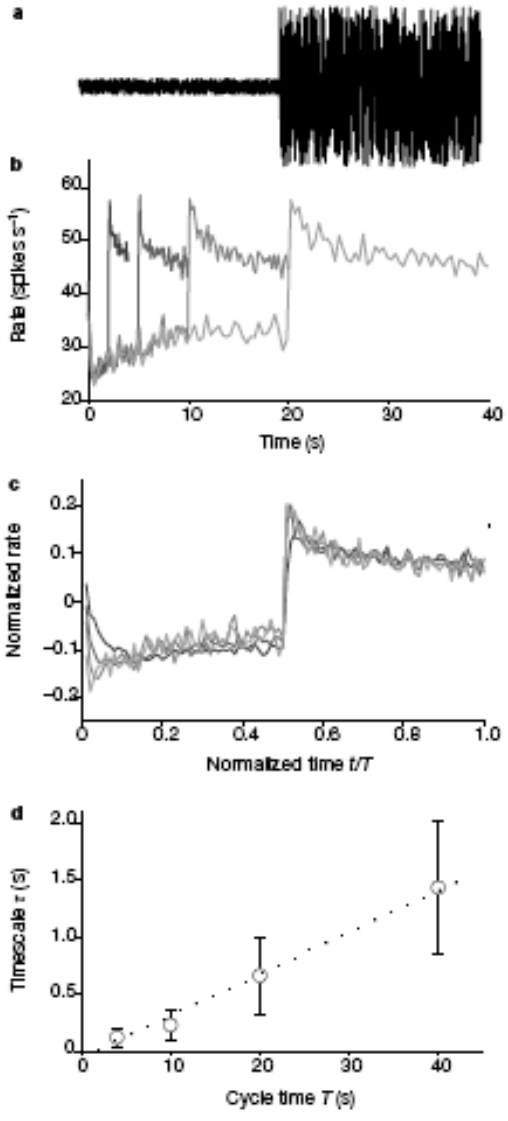


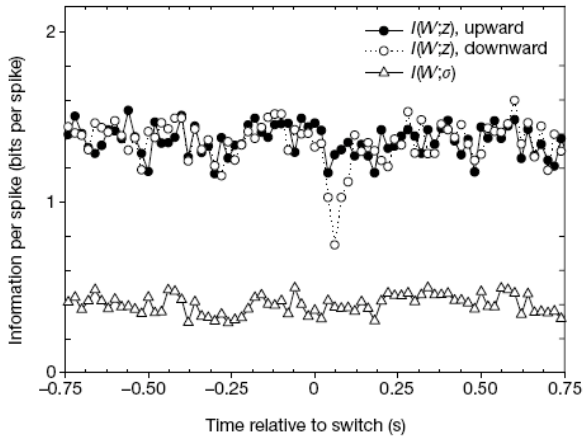
Adapting to integrated flux.

$$\tau \propto I_0^{1/3 \cdots 1/5} \qquad I_a \propto I_0 \tau$$

Leads to Adaptation 3

Adaptation 3 (power law memory)





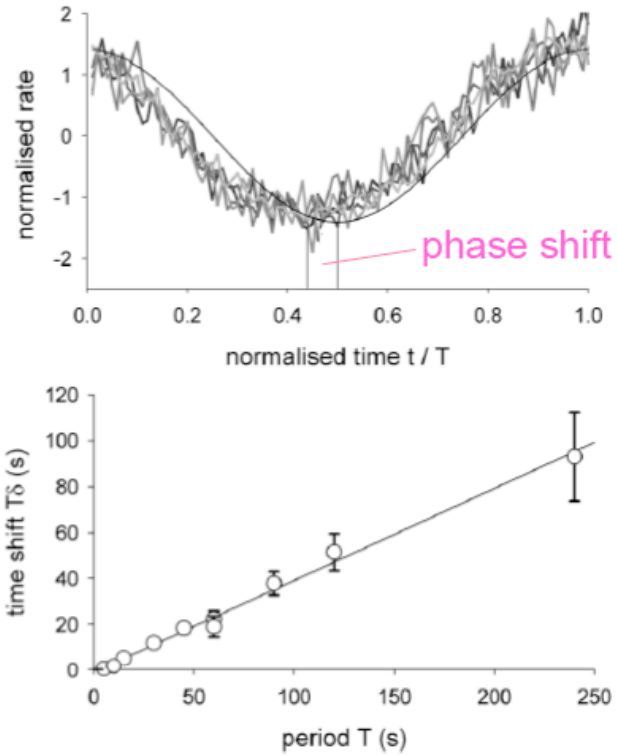
Long time disambiguation

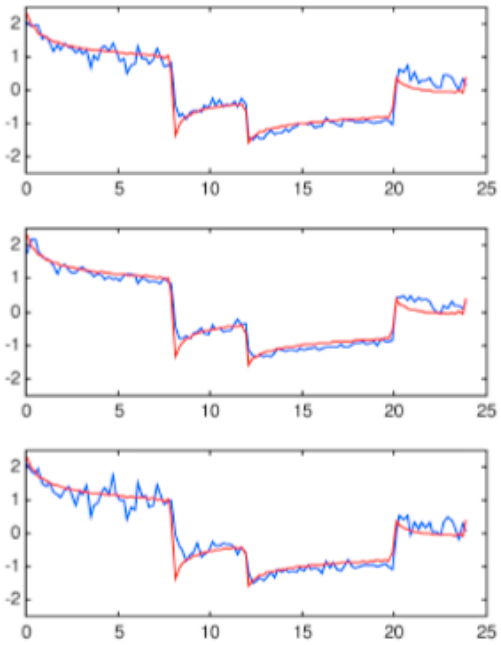
No single time scale. Power law?

Fractional differentiation (nonlocal!)

$$d^{\alpha} \rightarrow (i\omega)^{\alpha} \rightarrow \frac{\pi}{2}\alpha$$

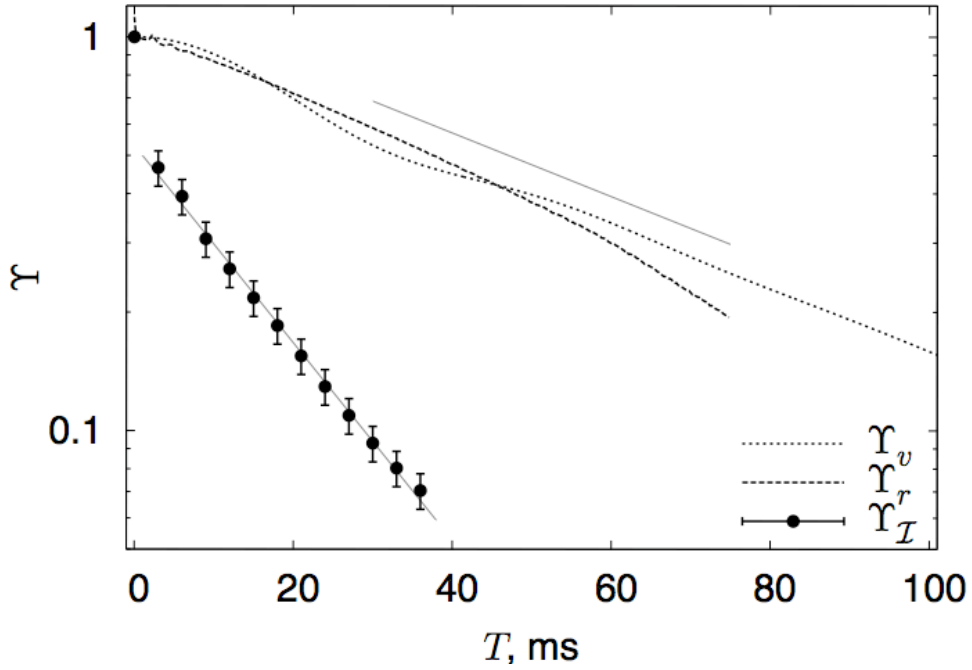
$$\alpha \approx 1.6$$





Nonlocal filter!
Power law memory
Linear
Fast: is there time for STP?

More on decorrelation (whitening)



$$I(T) = I(\text{stim; resp. dur. } T)$$

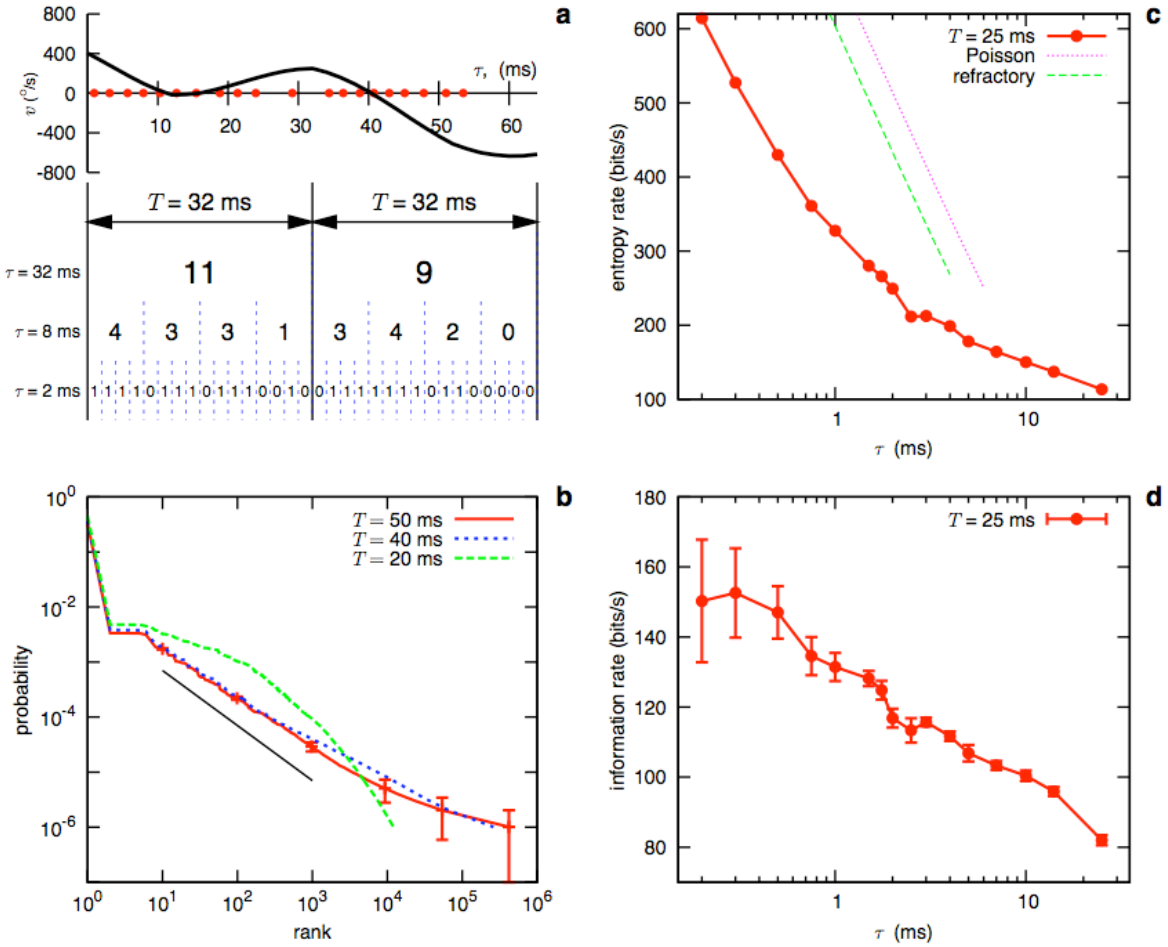
$$\Upsilon = \frac{2I(T) - I(2T)}{I(2T)}$$

Sends new bits about almost the same stimulus.

Delta coding?

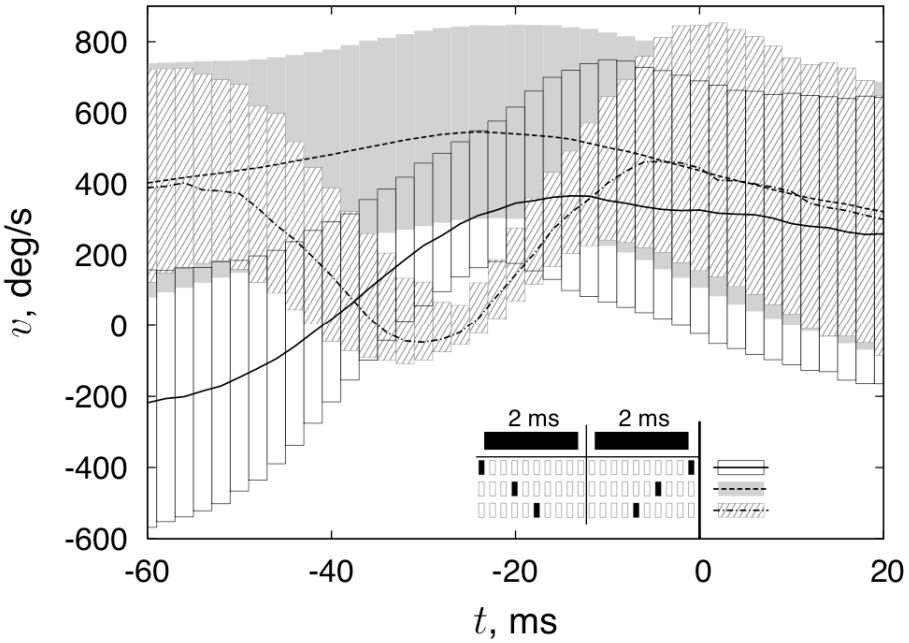
Need fast spiking to send these new bits? Is it there?

How? Computing with timing

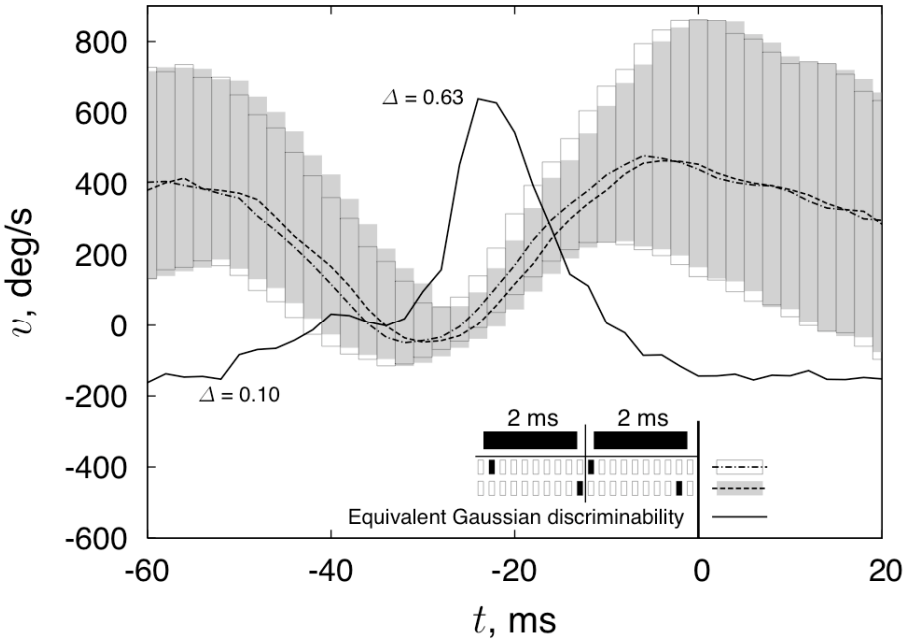


- Information present up to τ =0.2 ms (comparable to exparimental noise)
- 30% more information at τ<1ms.
- ~1 bit/spike at 150 spikes/s and low-entropy correlated stimulus. Design principle?

How? Computing with timing 2



Signal shape



Zero-crossings time

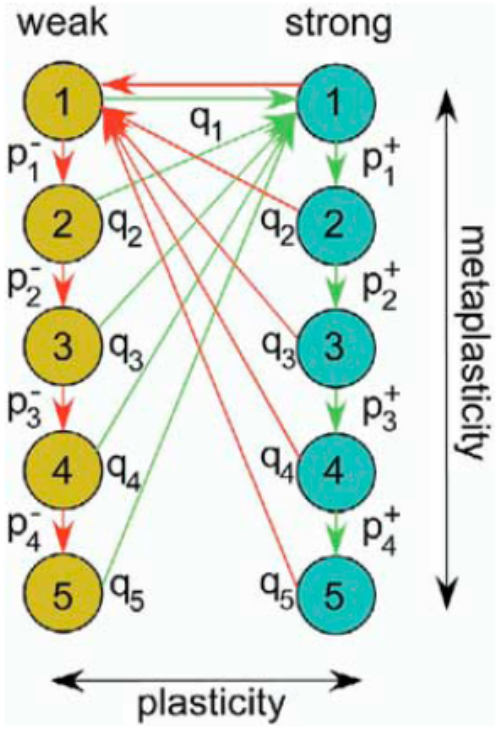
But: how? (see Fairhall et al, Bialek et al, previous talk)

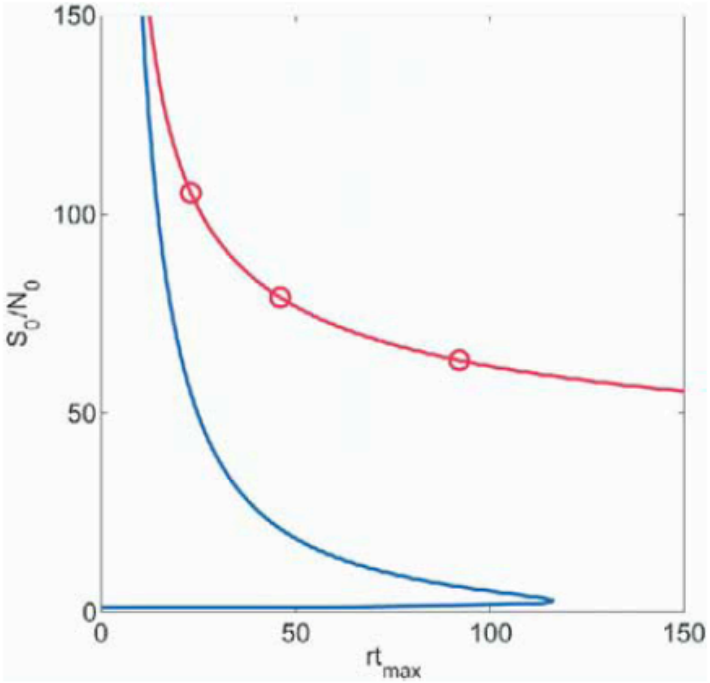
How? Long term memory

- No long range memory in 1d systems (unless long range interactions put in by hand). H1 - no feedbacks, no “by hand.” How?
- Biochemical? STDP? But is there time for STDP for 1s long adaptation? For Delta-coding? Will LTP/D be destroyed by other activities?
- Even if “yes”, still no mechanism.

Multiple time scales in a synapse?

Fast to write, long to keep.
Strong to write.
Stable to other memories written.
No need to recall to store.





But put in by hand,
Simple redundancy,
and no known biology.

What and How?

	Digital computer	Brain
What?	Programmable	Programmable? Not sure! PDFs, Long Range Correlations, Adaptation, Spatiotemporal Decorrelation, +
Memory?	Bits	Synaptic plasticity?
How?	Boolean gates	Spike timing + …