Neural Coding of Natural Stimuli: Information at Sub-Millisecond Resolution

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Geoffrey Lewen (Hun School of Princeton)
William Bialek (Princeton)
Rob de Ruyter van Steveninck (Indiana)

Home	Agenda	Registration	Hotel and Transportation	CNLS Home Page

Keynote Speakers:

J. Hopfield, Princeton University
President of the American Physical Society
D. Van Essen, Washington University
President of the Society for Neuroscience

Banquet Speaker:

C.R. Gallistel
Rutgers Center for Cognitive Science

Invited Speakers Include:

H. Abarbanel
University of California, San Diego
W. Bialek

Conference Proceedings (Abstracts)

This will be a unique workshop, dedicated to identifying the Scientific Grand Challenges required for quantitatively understanding the nature of computation in the brain and its application toward more powerful neuromimetic computing. The workshop will be organized around several major themes: Experiment and Analysis, Theory and Modeling, and Applications.

Leading scientists will review their fields, talk about the challenges facing them, and about their own work in this context. National program managers are are invited to offer their ideas and inform their judgement on the Grand Challenges for the field.

http://cnls.lanl.gov/neuralcomp/

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
q-bio@cnls.lanl.gov

First q-bio Conference on Cellular Information Processing

This conference is intended to advance predictive modeling of signal transduction and genetic regulatory systems. The emphasis is on modeling and quantitative experimentation for the purposes of understanding and predicting the behavior of particular regulatory systems and of elucidating general principles underlying cellular information processing.

The single-track program will include invited talks from leading experimental and theoretical researchers as well as shorter talks, poster presentations, and software demonstrations selected from contributed submissions. The program includes two banquets, six sessions covering a range of topics, and two extended evening poster sessions.

There will be an opportunity for selected participants to submit papers elaborating on presentations made at the conference to a special issue of *IET Systems Biology*, a journal indexed by ISI and PubMed.

Speakers Include:

Adam P. Arkin
Lawrence Berkeley National Laboratory
William Bialek
Princeton University
Blagoy Blagoev
University of Southern Denmark
Naama Brenner
Technion-Israel Institute of Technology
Roger Brent
Molecular Sciences Institute
Arup K. Chakraborty
Massachusetts Institute of Technology
Philippe Cluzel
University of Chicago
Eric H. Davidson
California Institute of Technology
John Doyle
California Institute of Technology
Drew Endy
Massachusetts Institute of Technology
Nina V. Fedoroff
The Pennsylvania State University

Keep LANL on your radar!
(High Performance Neural Computing)

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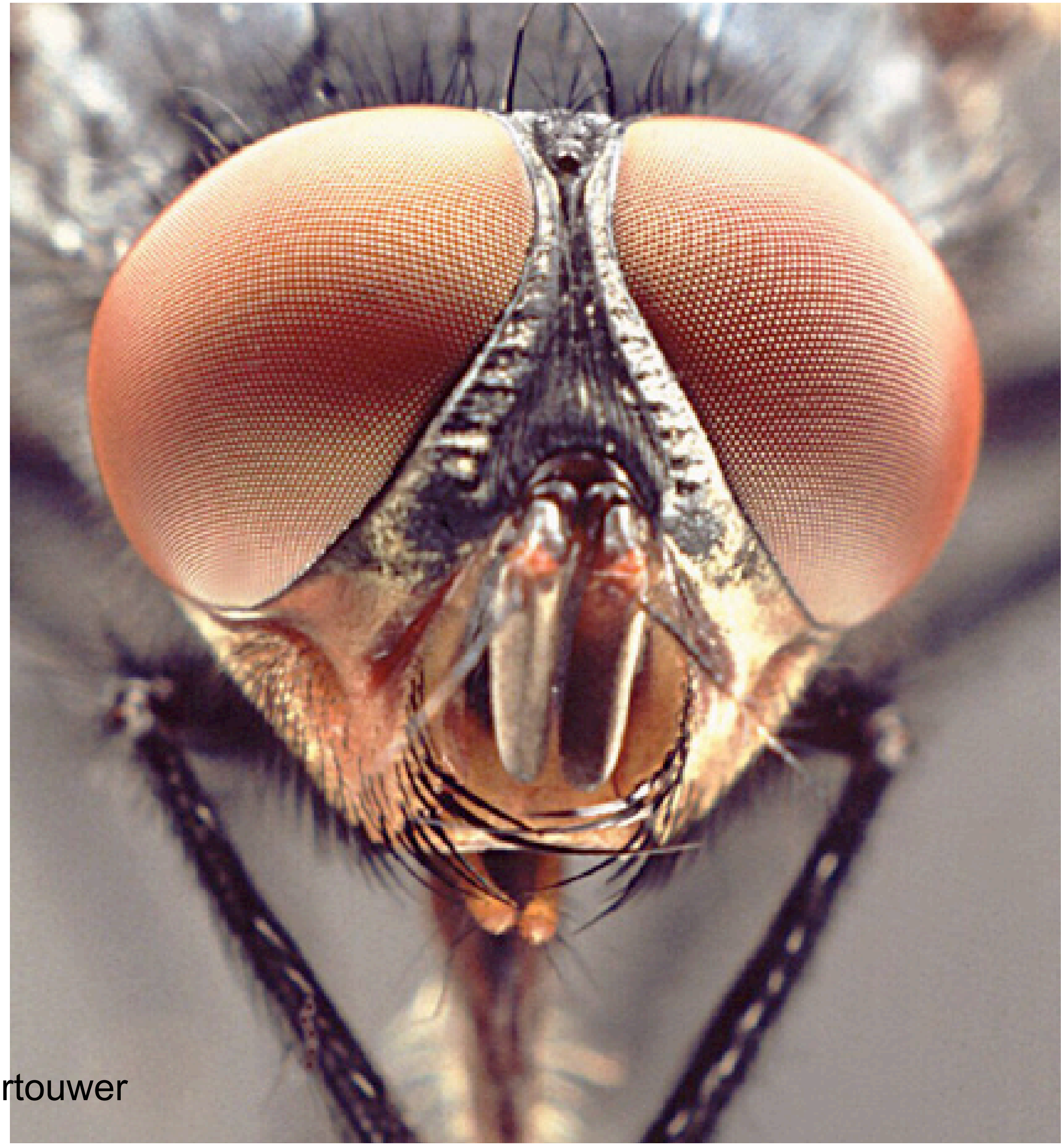


H. L. Leertouwer

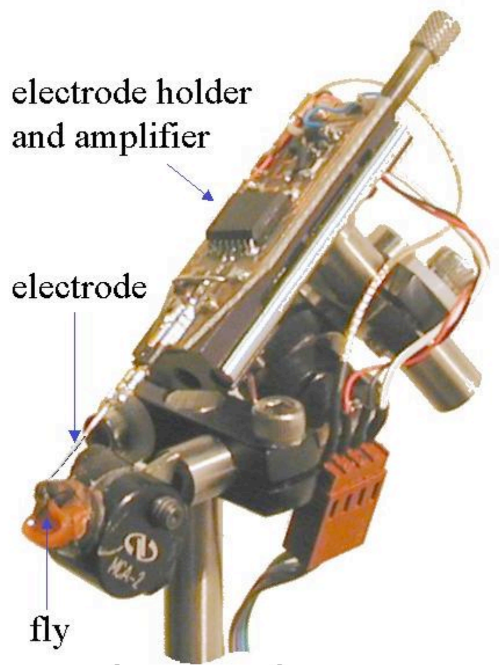
Why fly as a neurocomputing model system?

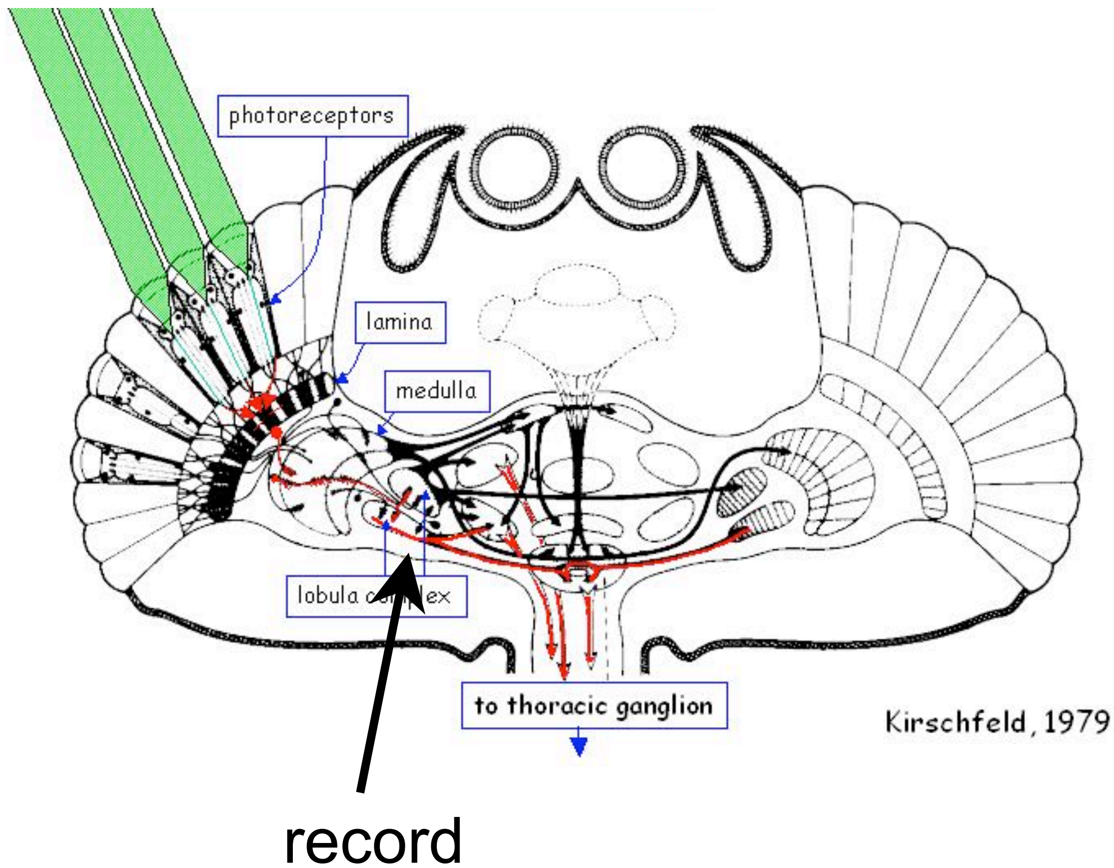
- Can record for long times
- Named neurons with known functions
- Nontrivial computation (motion estimation)
- Vision (specifically, motion estimation) is behaviorally important
- Possible to generate natural stimuli

Questions

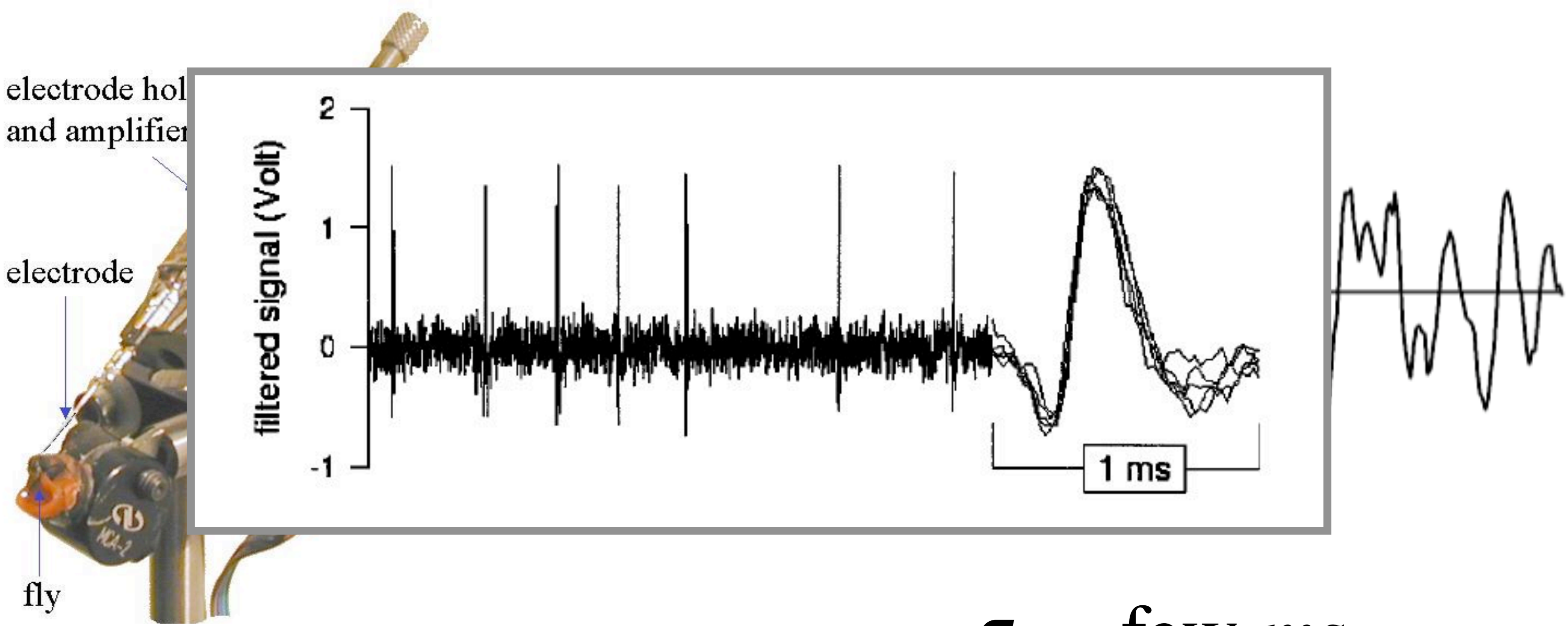
- Can we understand the code?
  - Which features of it are important?
  - Rate or precise timing (how precise)?
  - Barlow-like temporal decorrelation?
  - …
- Is there an evidence for optimality?

Recording from fly's H1





Motion estimation in fly H1



$\tau =$ few ms

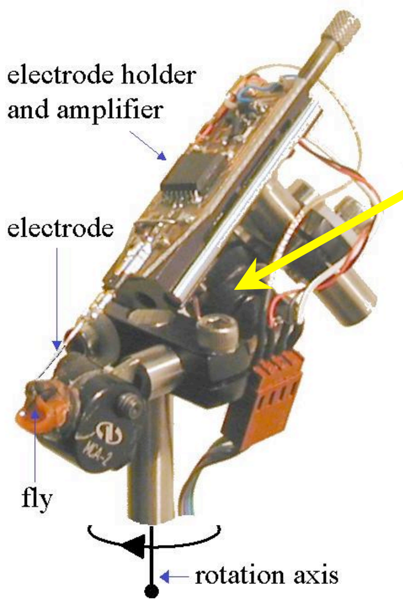
(Strong et al., 1998)

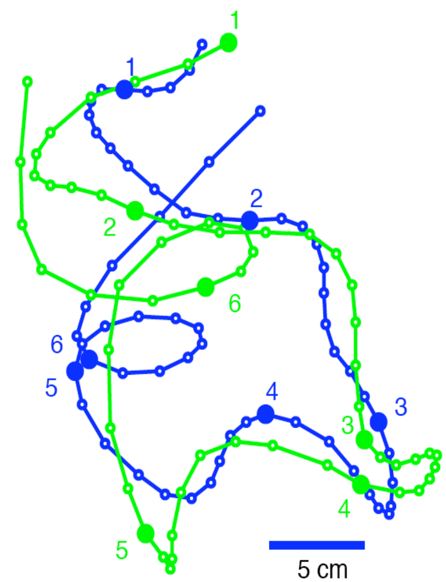
Results

- Slow signals: rate code
- Fast (white) signals: 2 ms resolution important
- Could such ~1 ms precise spikes be due to ~1 ms correlations in stimulus?
- What if stimulus has natural (long-range) correlations?

Los Alamos NATIONAL LABORATORY EST. 1943
Operated by the Los Alamos National Security, LLC for the DOE/NNSA

Natural stimuli

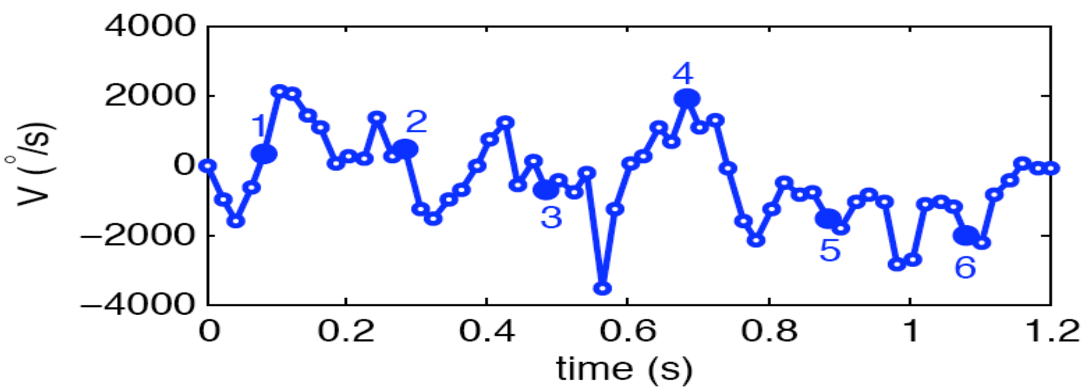




Land and Collett, 1974

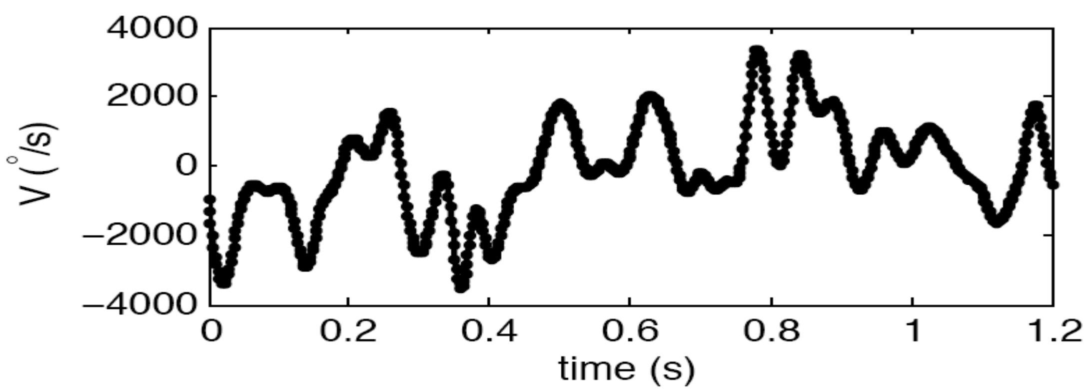
(fastest response 30 ms)

Natural stimuli



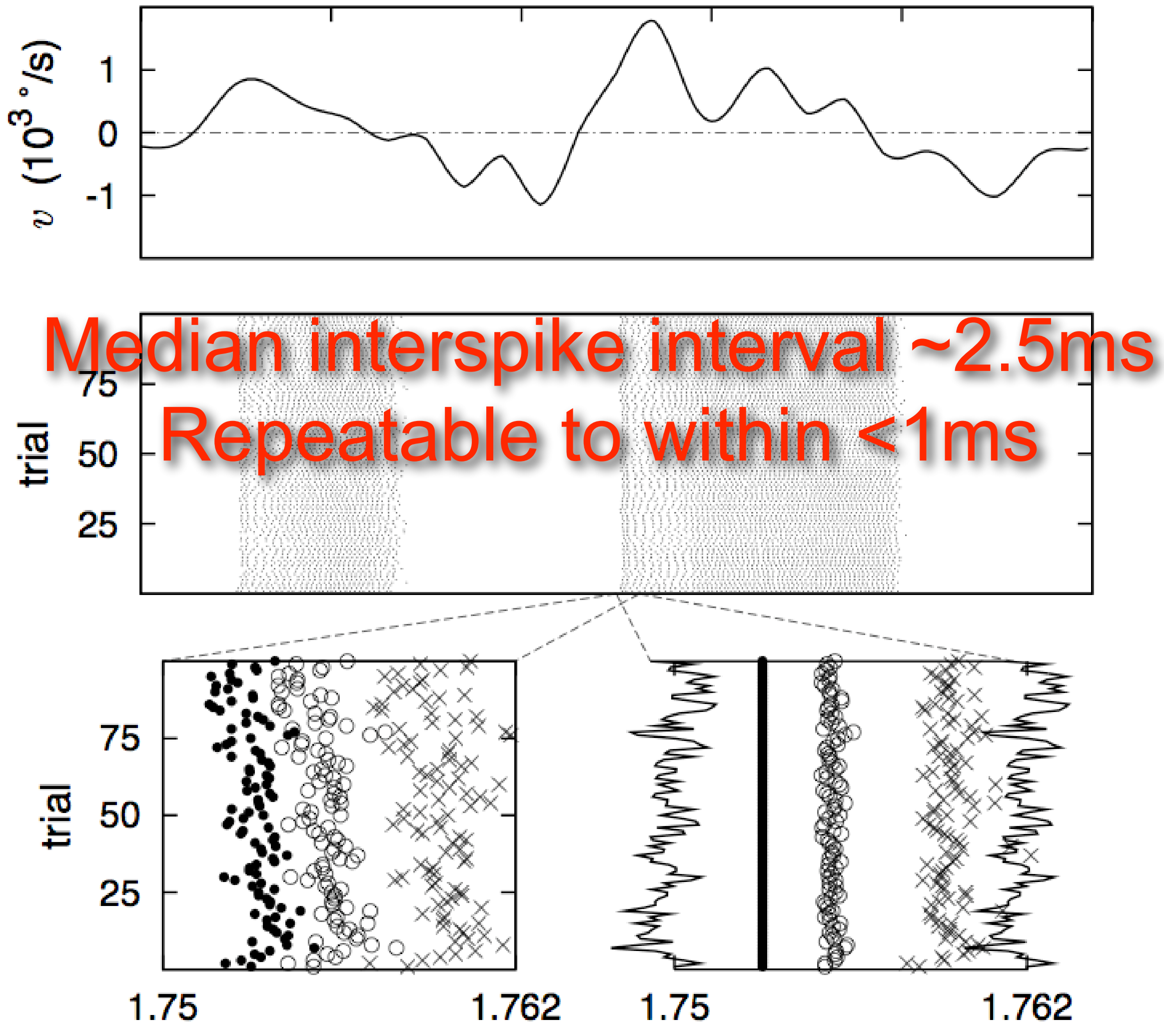
LC stimulus

$\tau = 60\text{ms}$
>99.9% of power below 30Hz



Generated stimulus

Natural stimulus and response



Not rate coding?

Is high timing precision (0.2 ms for first spike, and 0.1 ms for intervals) for natural stimuli relevant for information transmission, or just anecdotal?

Strategy:

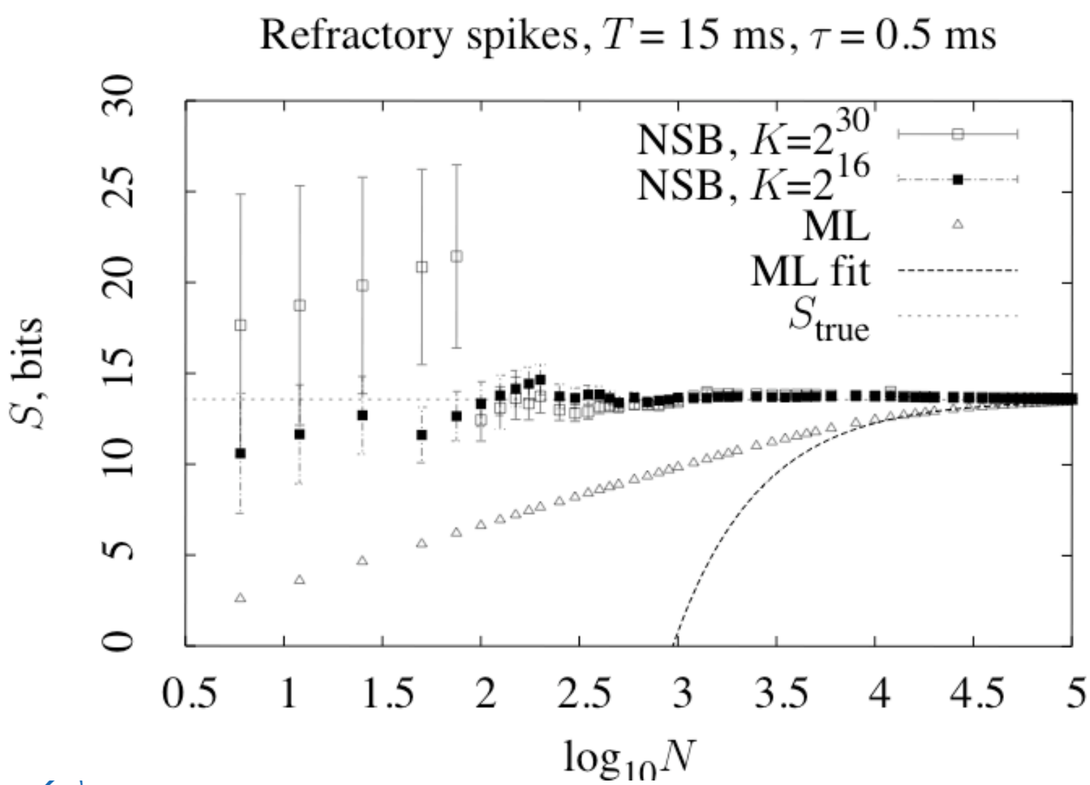
- Present long non-repeated stimulus (i.e., what is H1's vocabulary?)
- Present repeated stimulus (i.e., how much noise is in H1's responses?)
- Discretize responses (0/1 -- no/yes spike) and study stimulus-response mutual information as a function of discretization (down to <1ms)
- Do this for longer and longer responses (>30-60ms)
- Will be looking at binary words of length >100.

  Enormous Undersampling!

- We have solved the undersampling problem (the NSB estimator). More about this at the *IT methods* workshop.

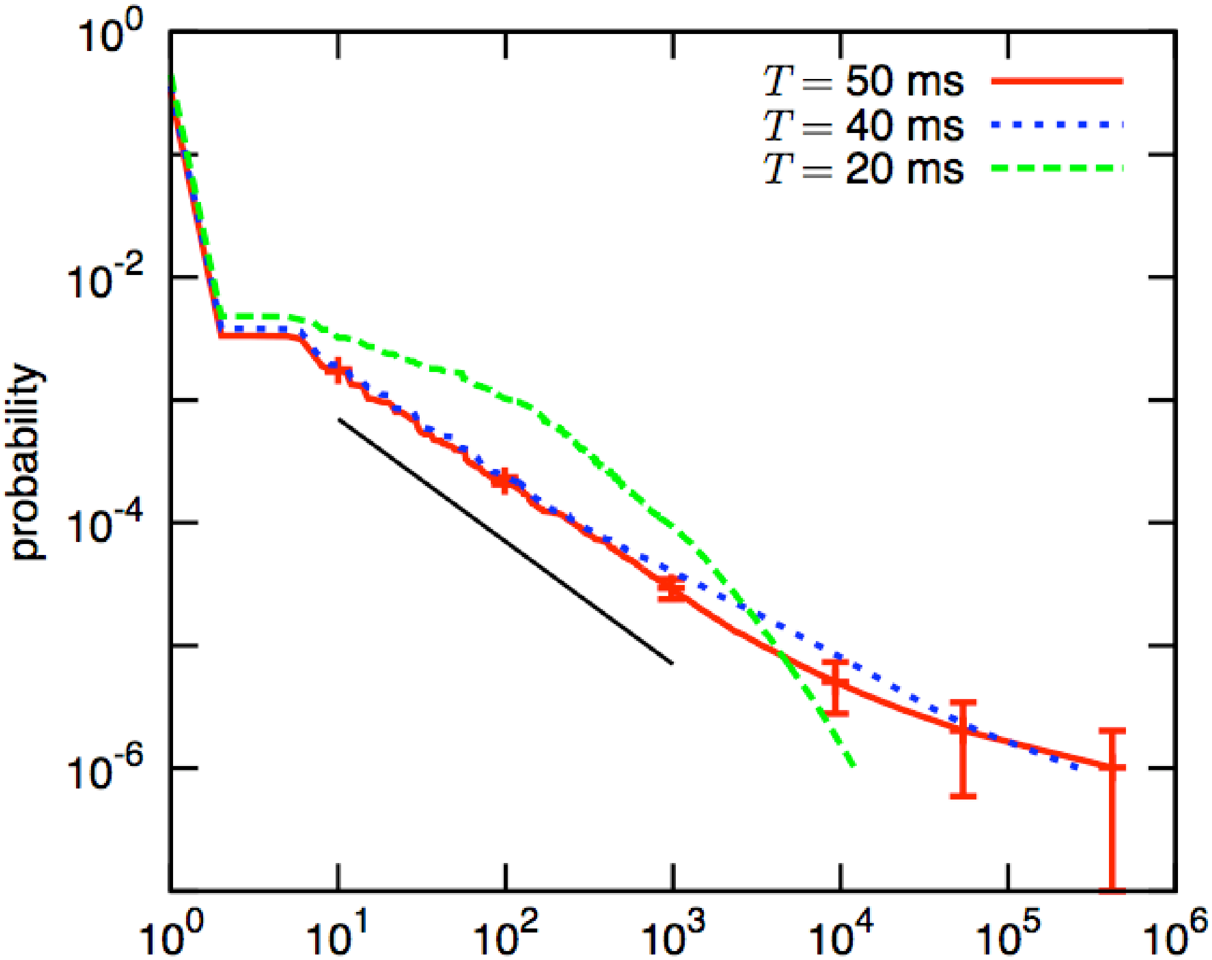
Synthetic test
(same for natural data)

Refractory Poisson, rate 0.26 spikes/ms, refractory period 1.8 ms, *T*=15ms, discretization 0.5ms, true entropy 13.57 bits.



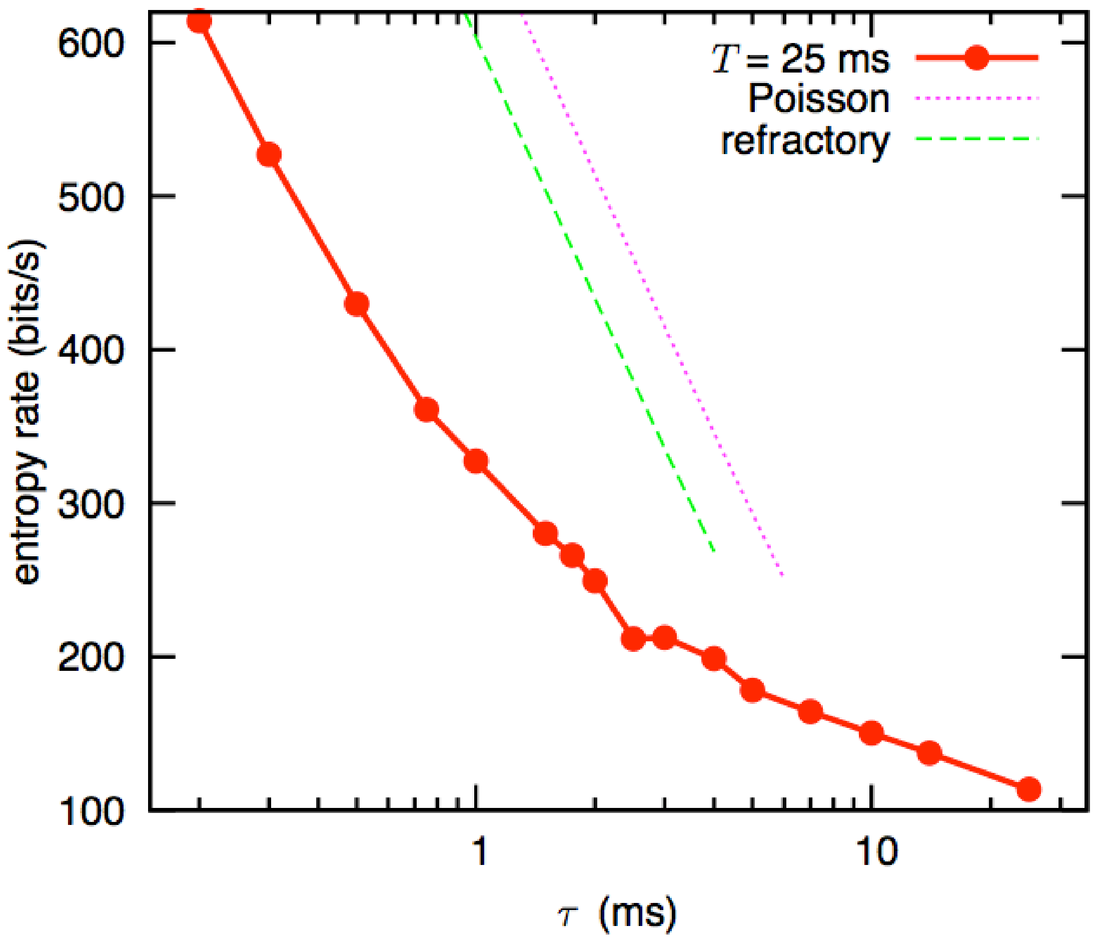
(Nemenman et al. 2004)

Exploring the code: long tails



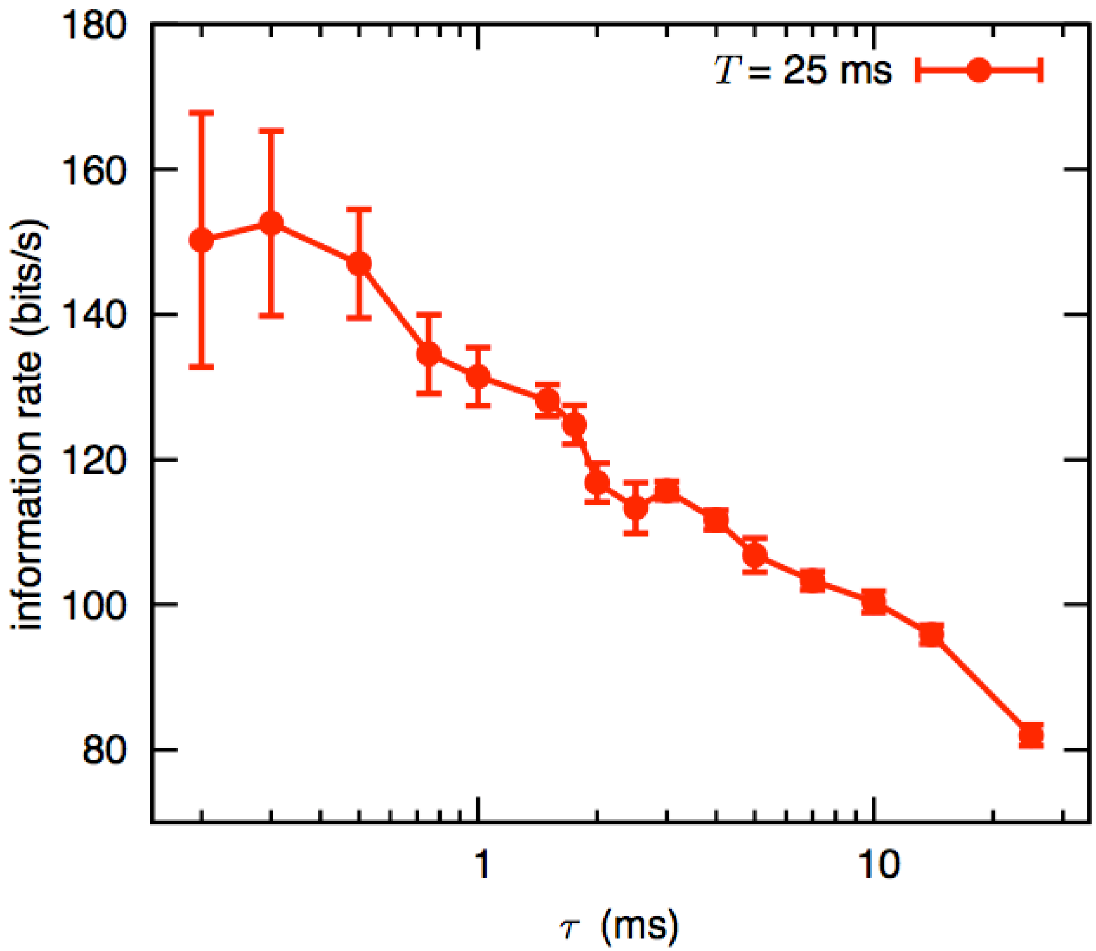
This causes complications

Exploring the code: high entropy



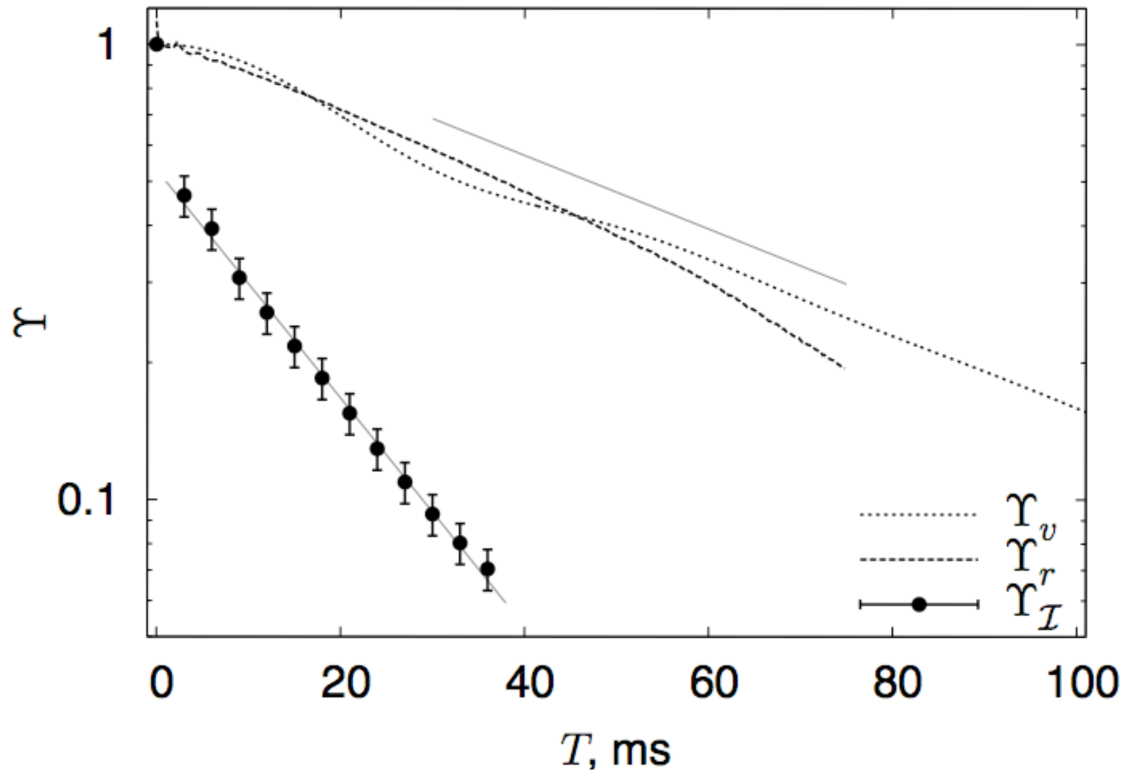
But is all this entropy used in coding?

Information rate at *T*=25ms



- Rate grows up to τ =0.2-0.3 ms
- 30% more information at τ<1ms.
- ~1 bit/spike at 150 spikes/s and low-entropy correlated stimulus. Design principle?
- 0.2 ms - comparable to channel opening/ closing noise and experimental noise.

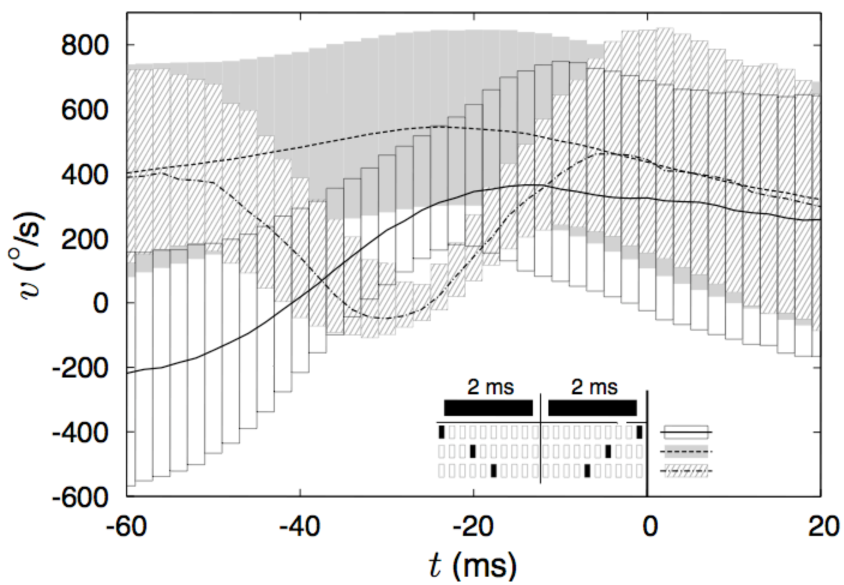
New bits:
Decorrelation in the time domain



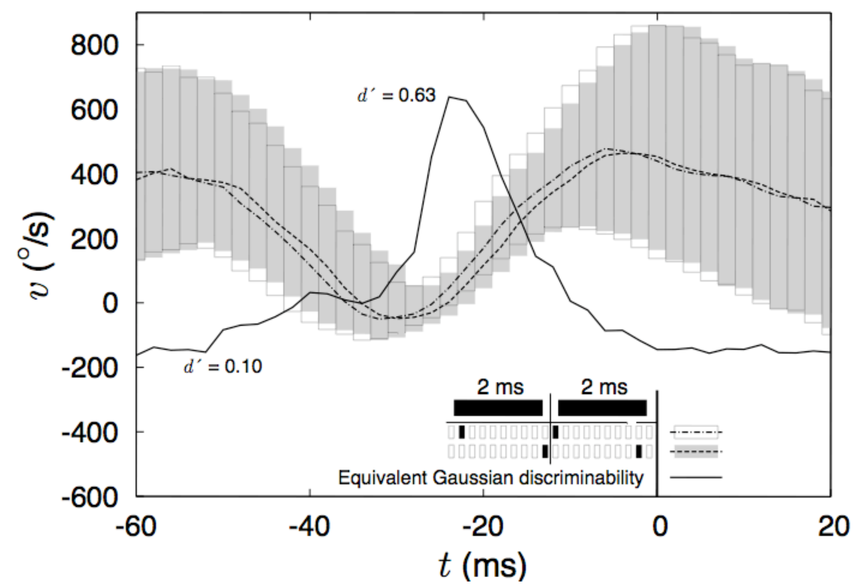
- Corr. func. at half its maximum value (for stimulus and rate), but fly gets new bits every 25 ms
- Not a simple delta-code
- Behaviorally optimized code
- Pretty amazing!

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

Information about…

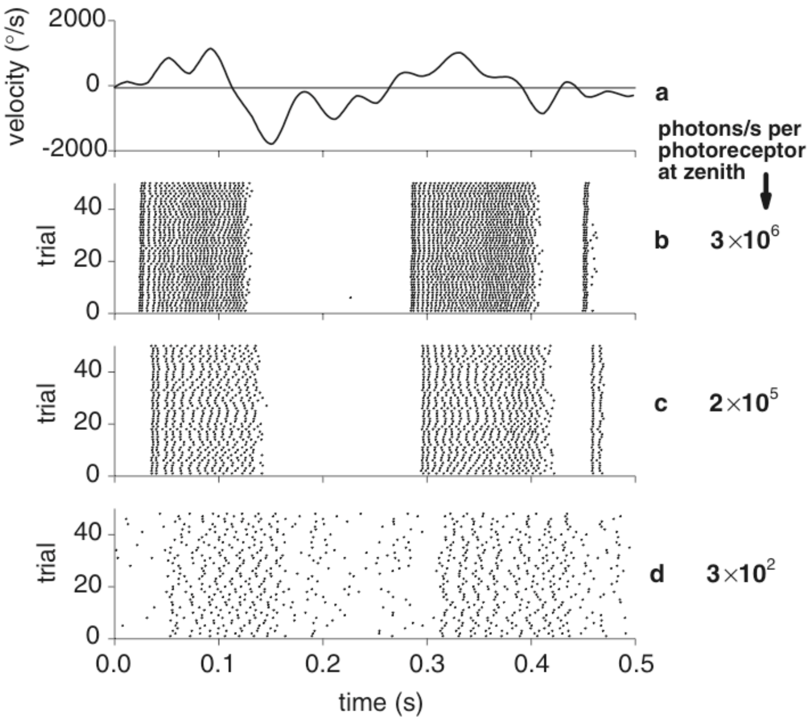


Signal shape



Zero-crossings time

Precision is limited by physical noise sources



(Lewen, et al 2001)

$T = 6 \text{ ms}$

$\tau = 0.2 \text{ ms}$

$1.1 \cdot 10^6 \text{ ph/(s} \cdot \text{rec)} \pm 3\%$

$I^+ - I^- = 0.0204 \pm 0.0108 \text{ bits}$

$p = 6\% \text{ (and much smaller)}$

The torture is over.