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

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William Bialek (Princeton)
Rob de Ruyter van Steveninck (Indiana)


| Home | Agenda | Registration | Hotel and Transportation | CNLS Home Page |
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## 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:

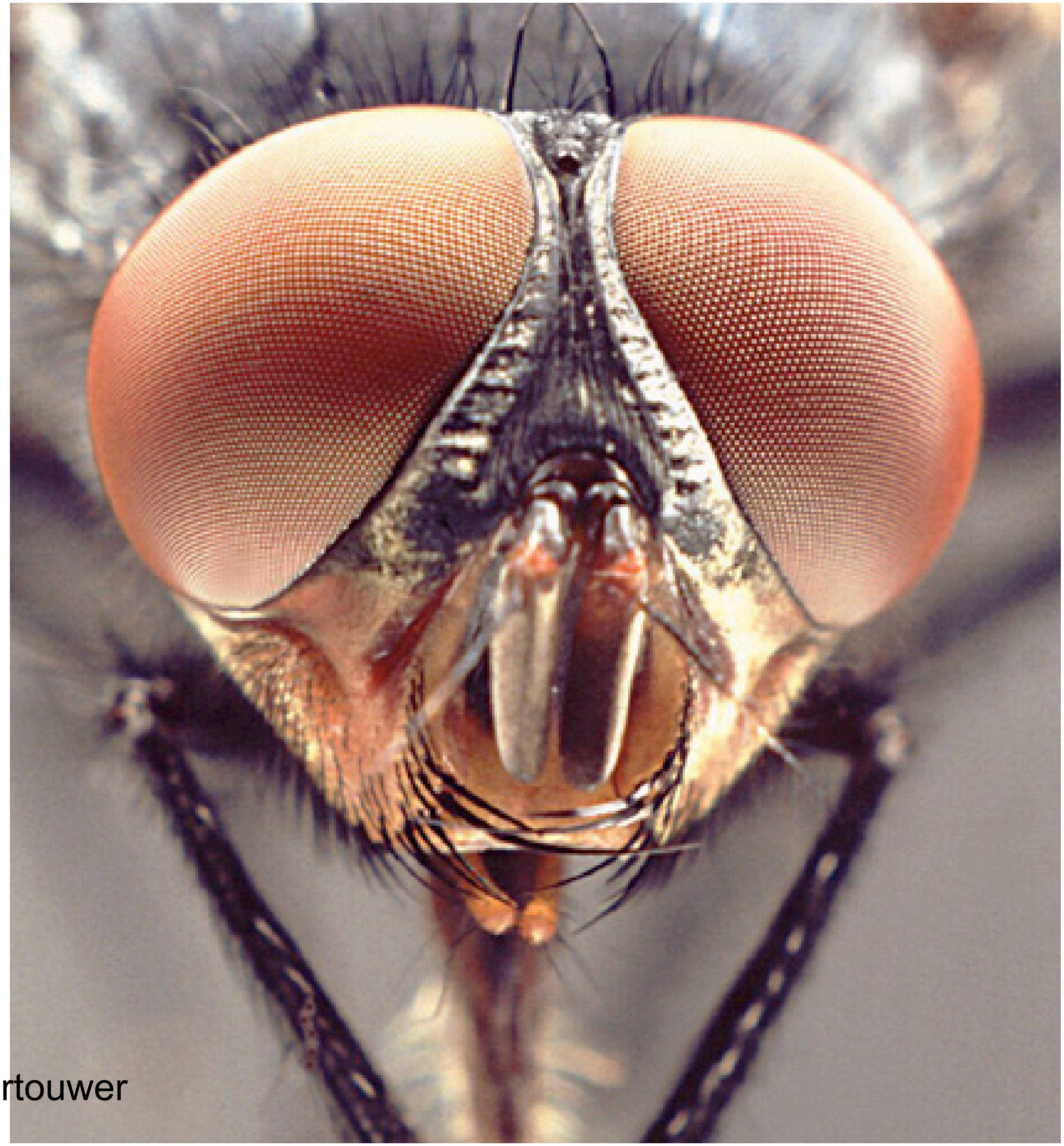
**H. Abarbanel**
University of California, San Diego
**W. Bialek**

## 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/



H. L. Leertouwer

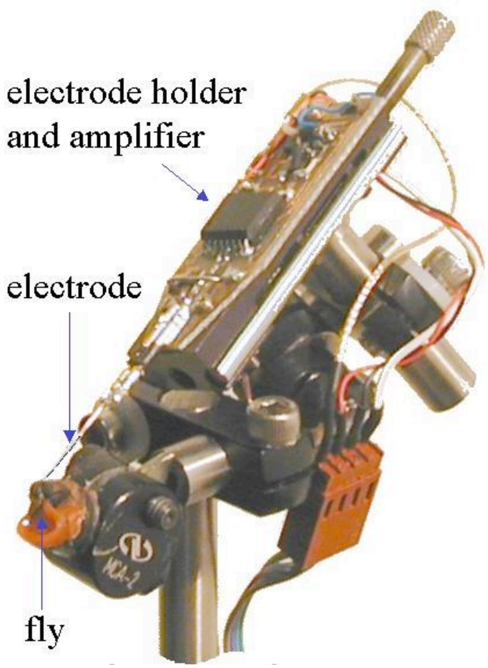
# Why fly as a neurocomputing model system?

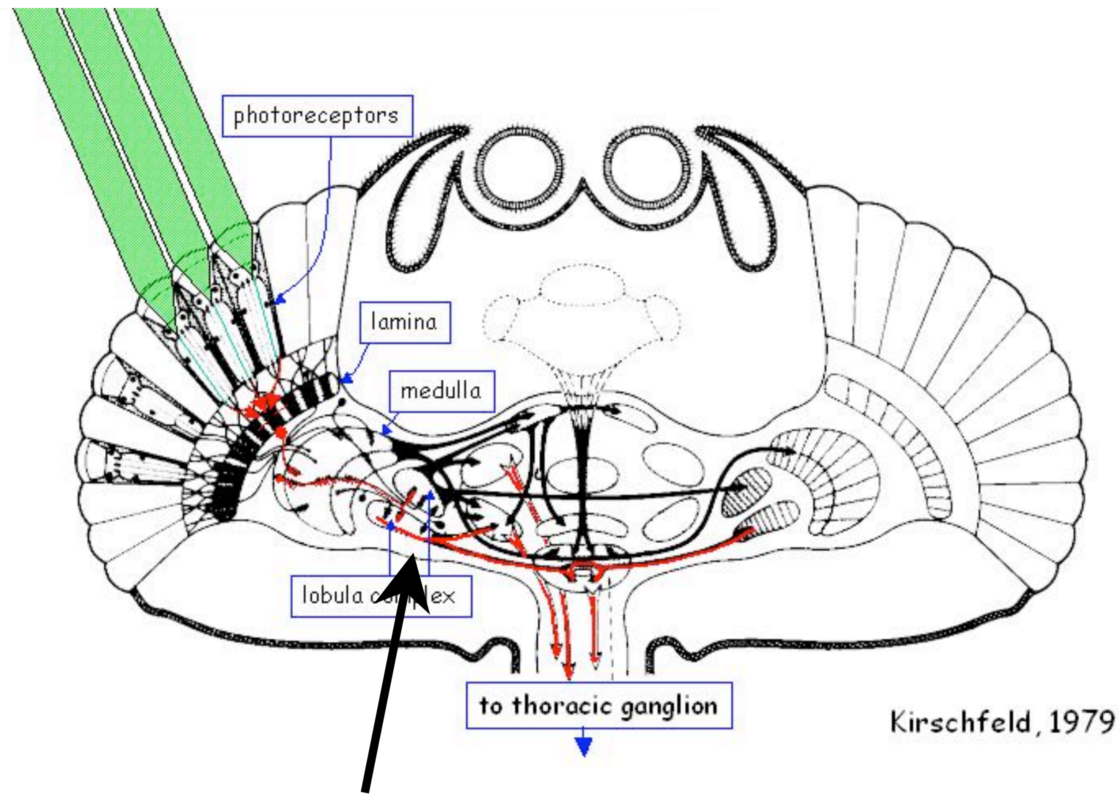
- Can record for long times
- Named neurons with known functions
- Nontrivial computation (motion estimation)
- Vision (specifically, motion estimation) is behaviorally important
- Possible to generate natural stimuli

# 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?

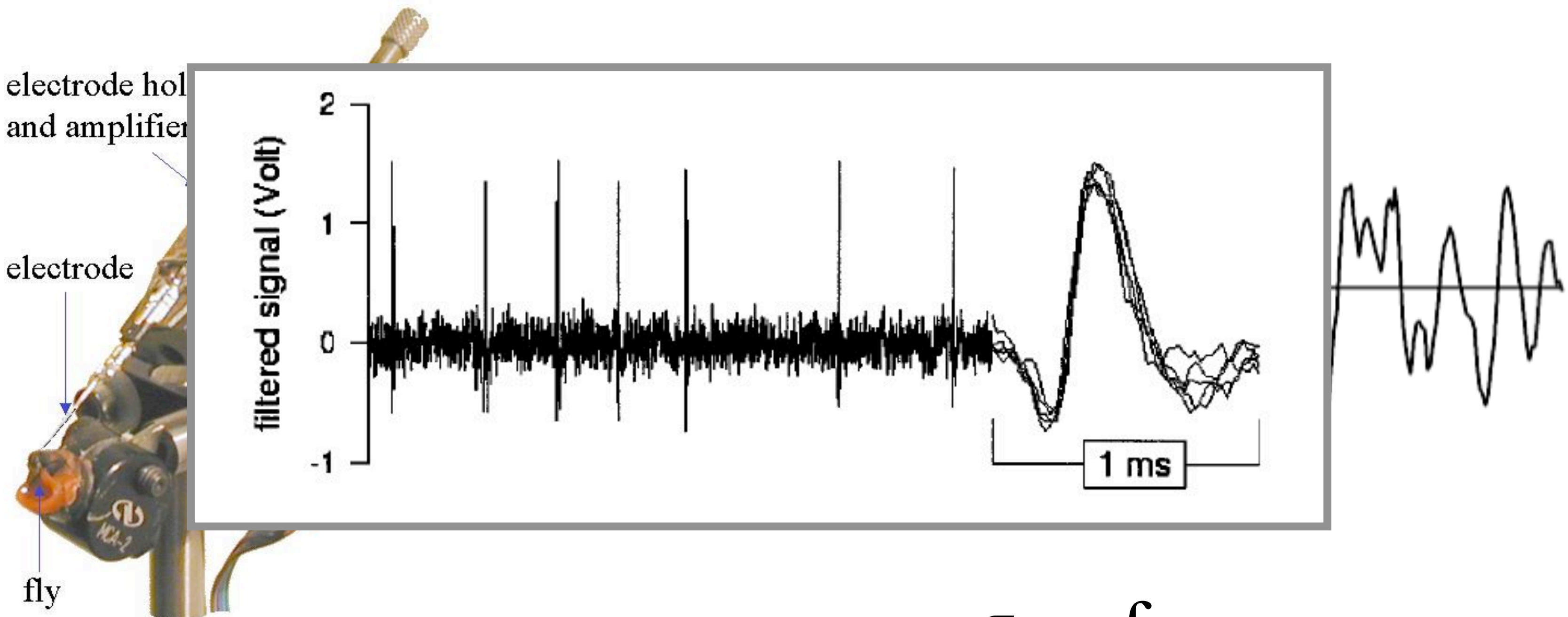
# Recording from fly's H1




record

# Motion estimation in fly H1



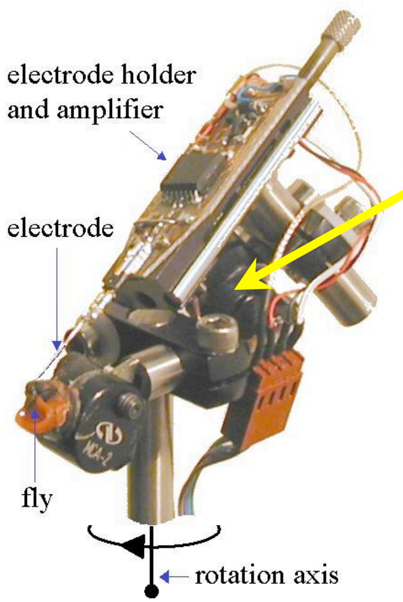

$$\tau = \text{ few } ms$$

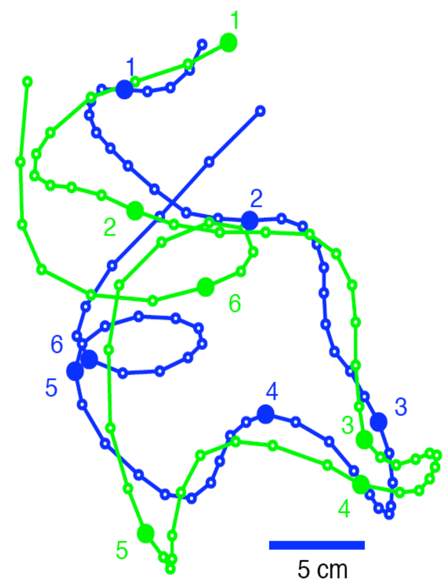
(Strong et al., 1998)

# 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?

# Natural stimuli

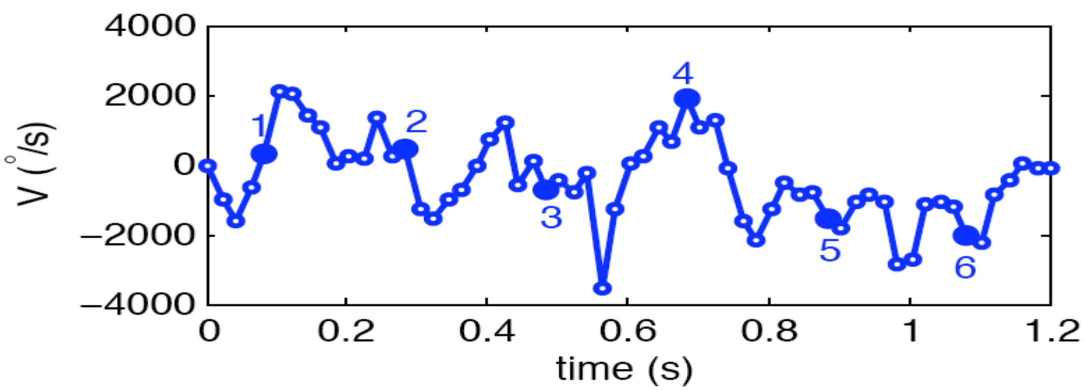



Land and Collett, 1974

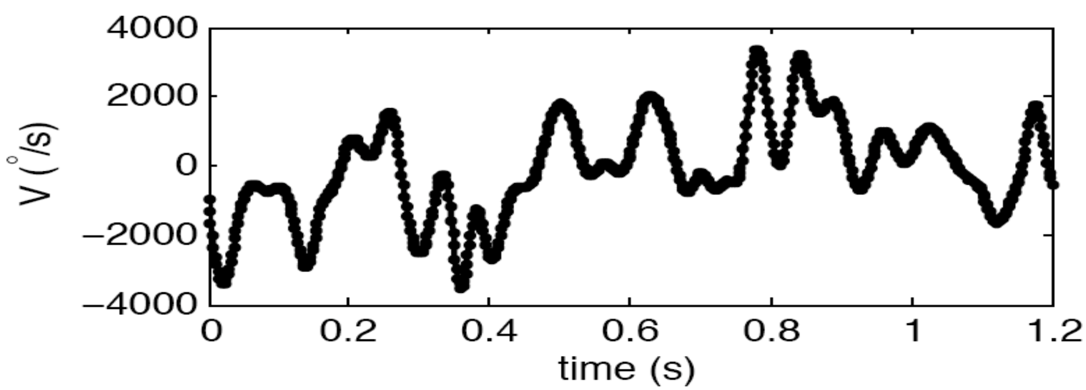
(fastest response 30 ms)

# Natural stimuli



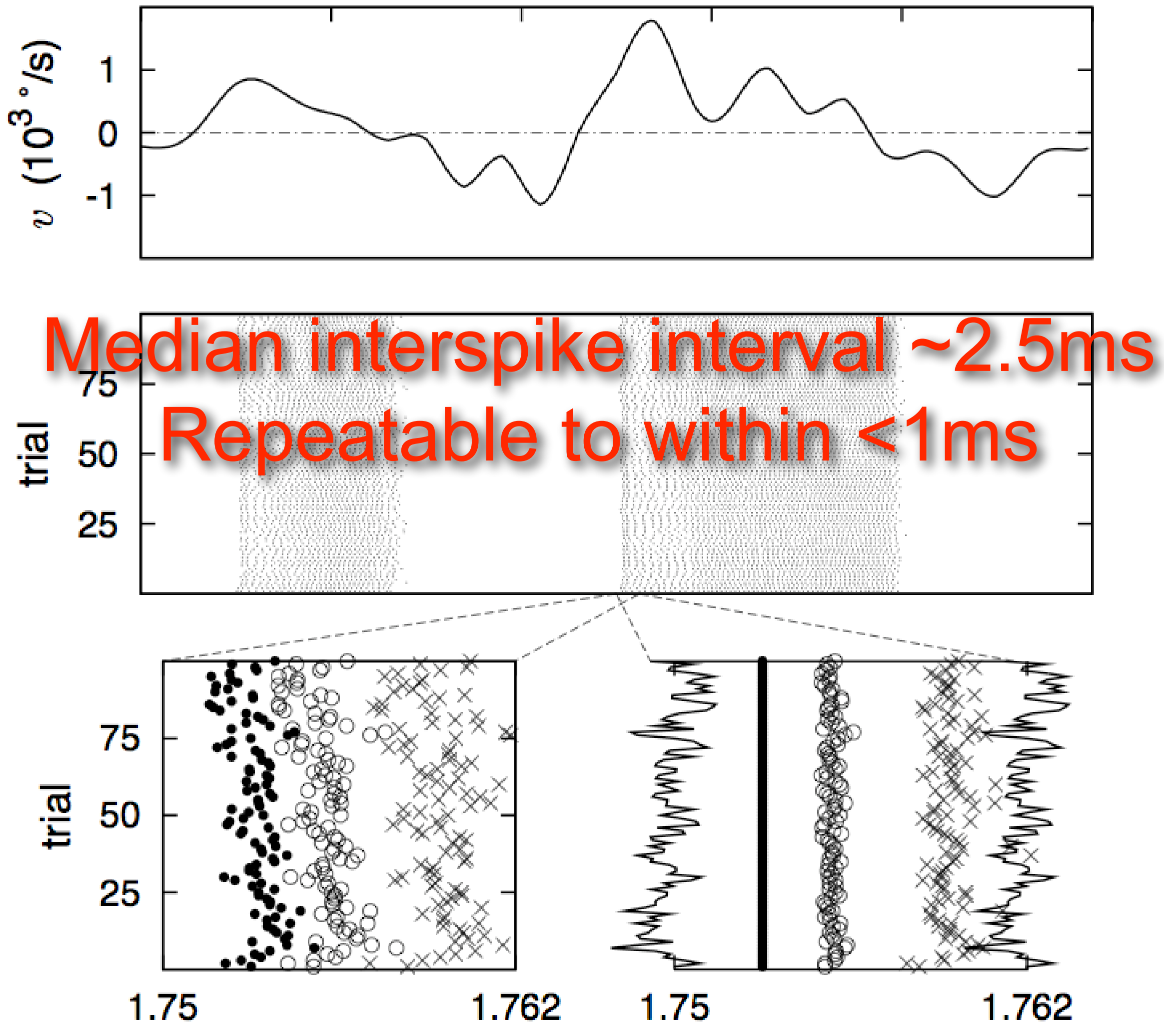

LC stimulus

$\tau = 60\text{ms}$
>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:

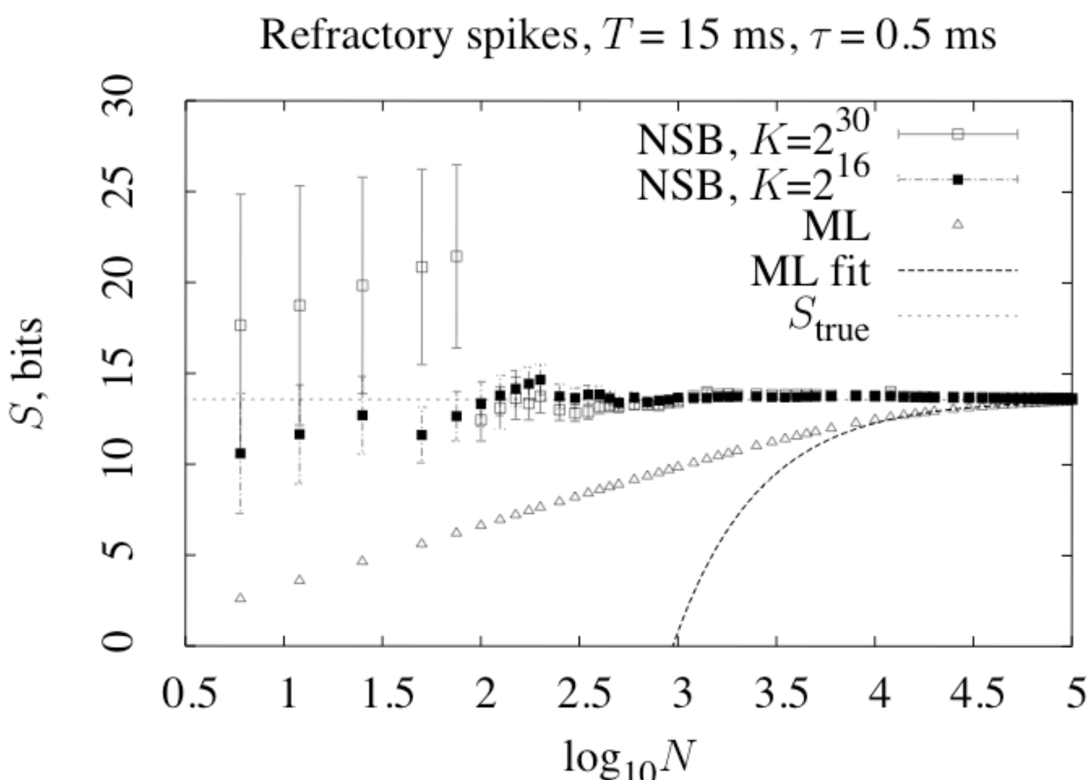
- Present long non-repeated stimulus (i.e., what is H1's vocabulary?)
- Present repeated stimulus (i.e., how much noise is in H1's responses?)
- Discretize responses (0/1 -- no/yes spike) and study stimulus-response mutual information as a function of discretization (down to <1ms)
- Do this for longer 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). http://nsb-entropy.sf.net

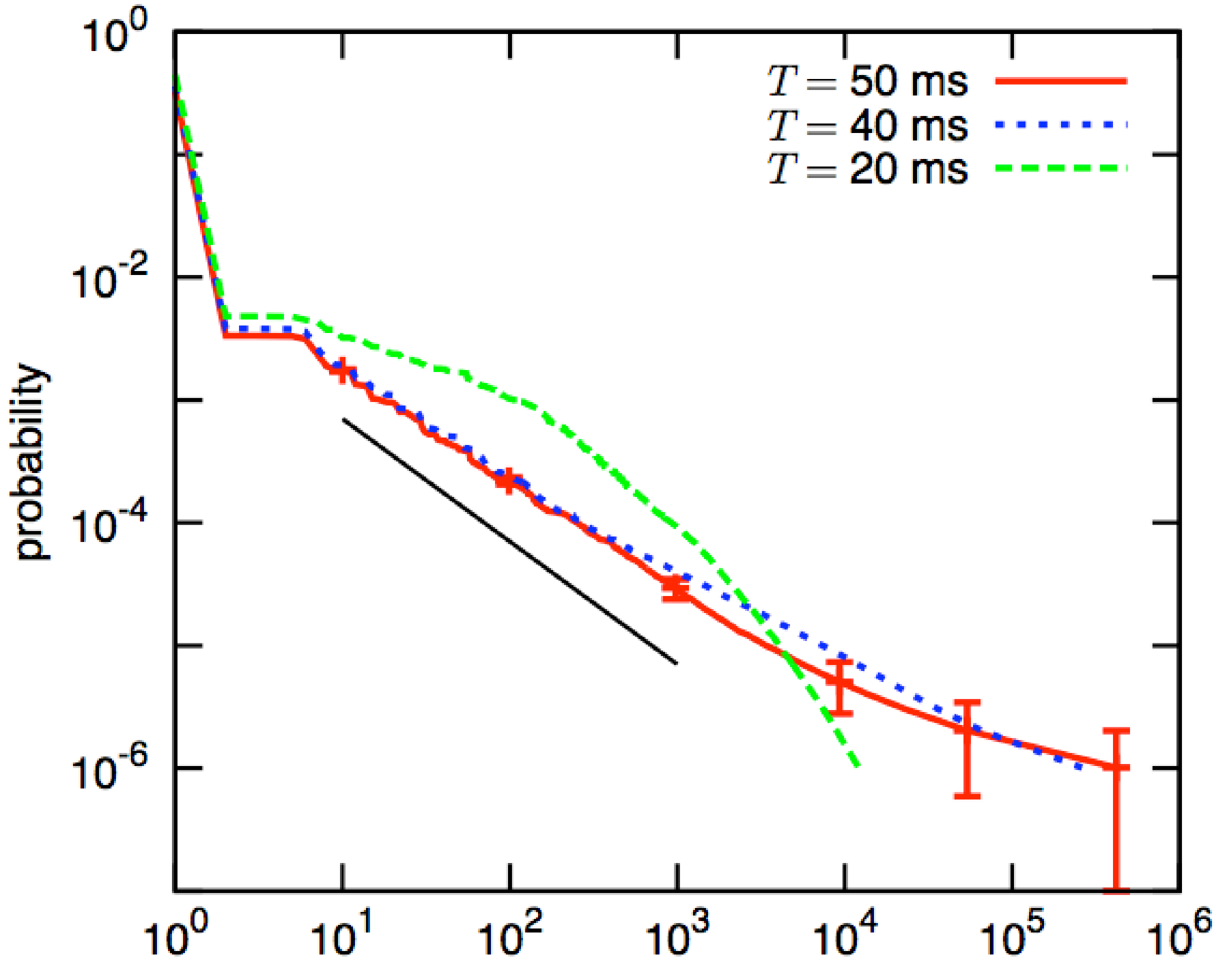
# Synthetic test
# (same for natural data)

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



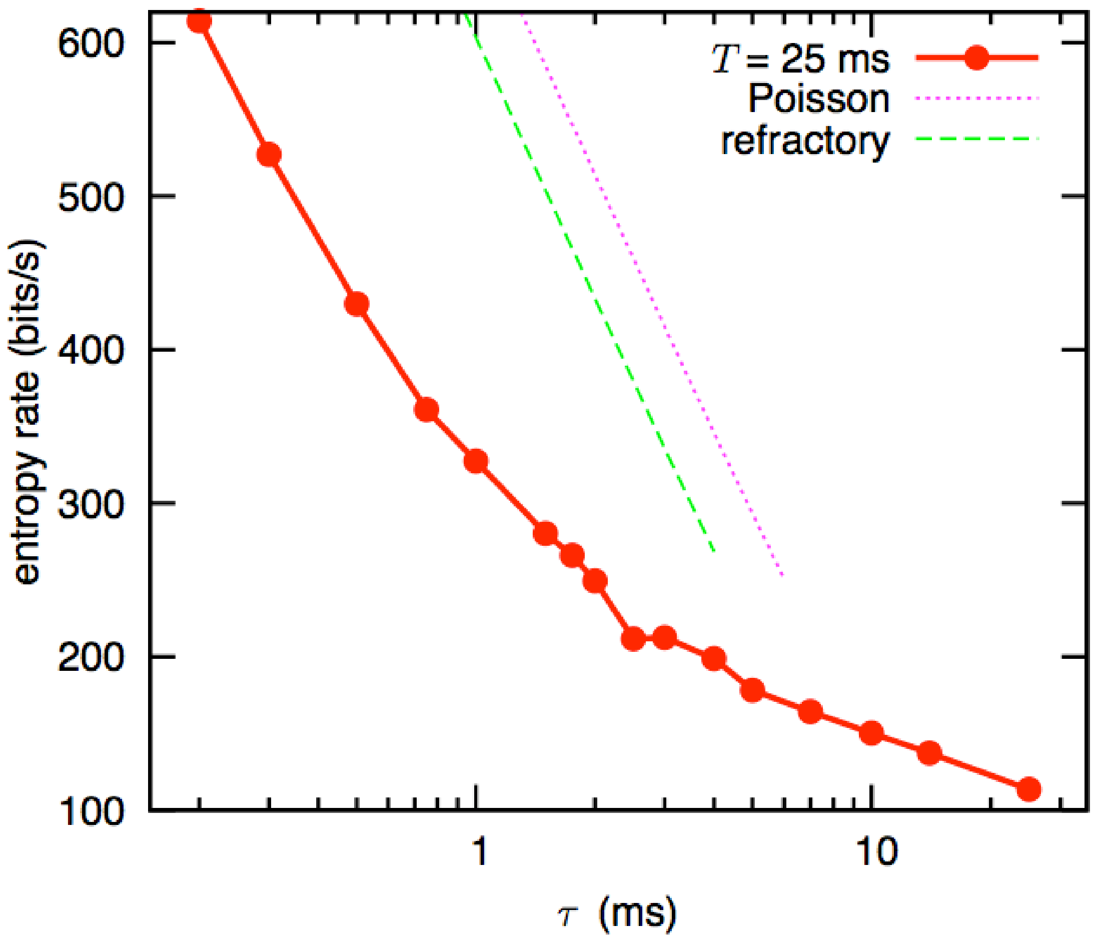

(Nemenman et al. 2004)

# Exploring the code: long Zipf tails
## *An intelligent fly? Or complex world?*



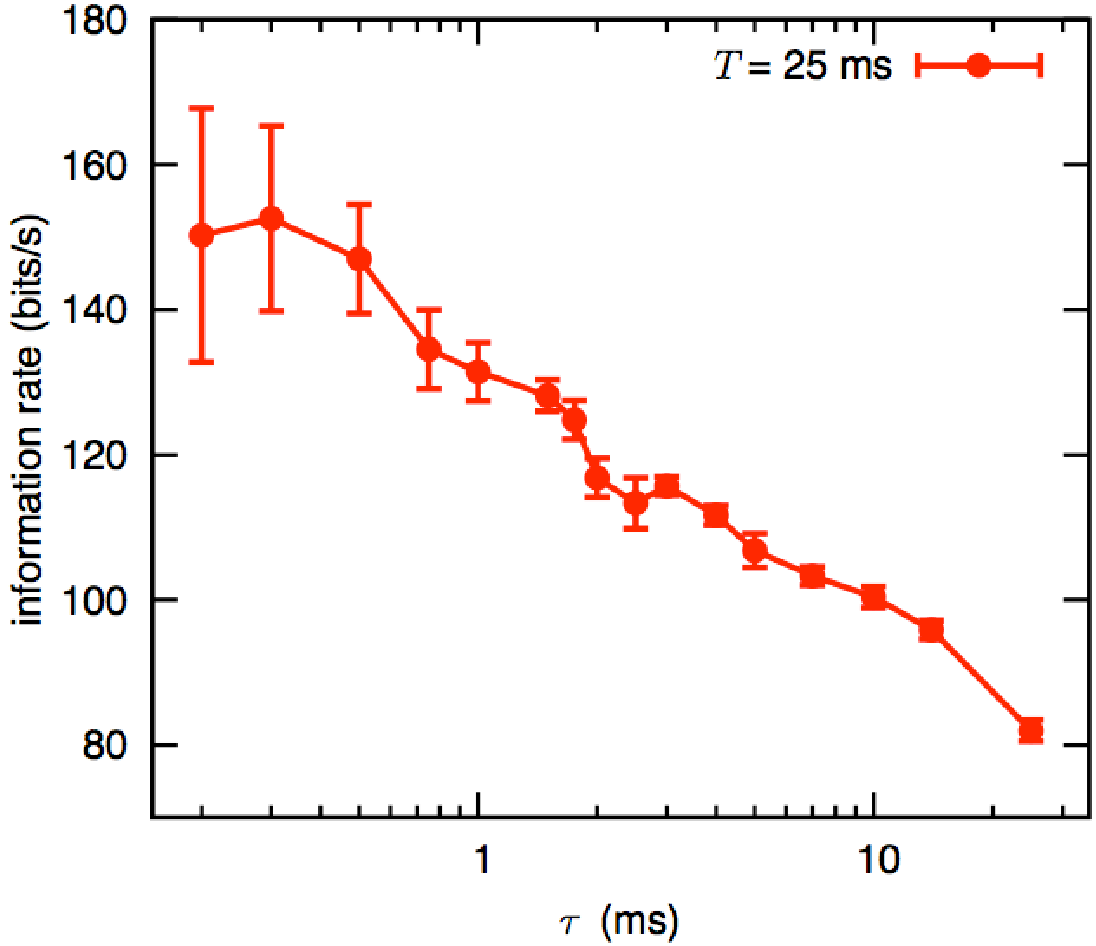

This causes complications

# Exploring the code: high entropy



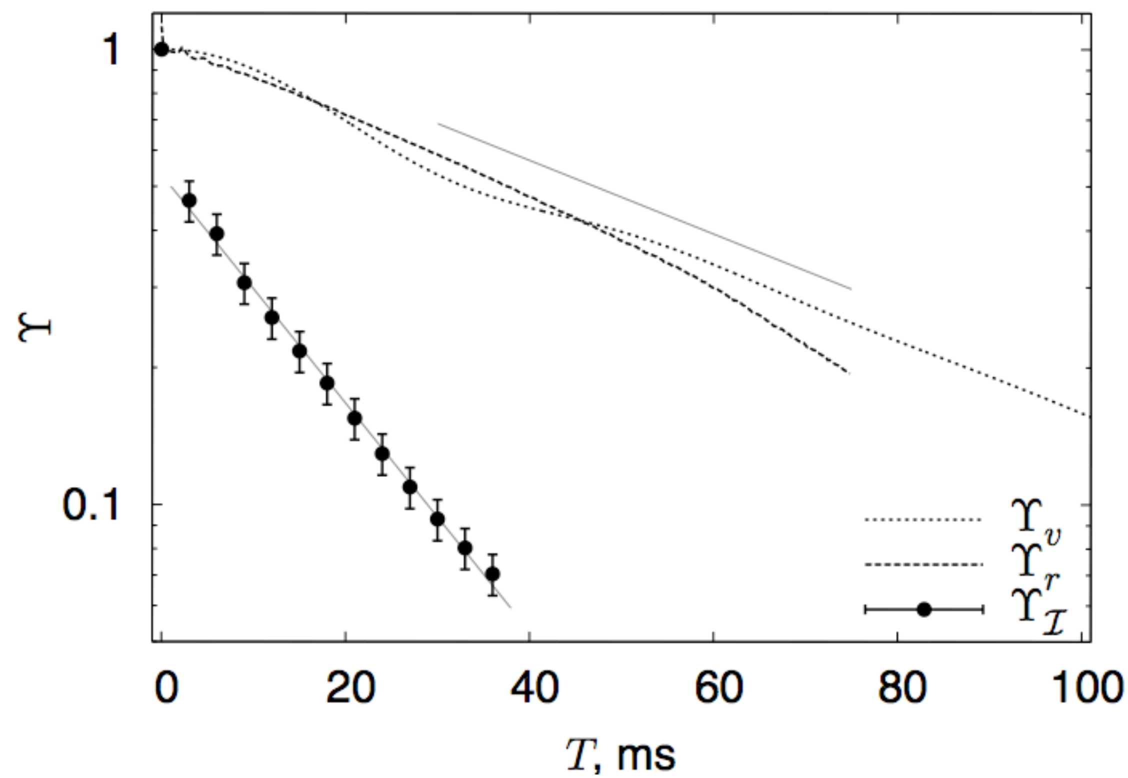

But is all this entropy used in coding?

# 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.

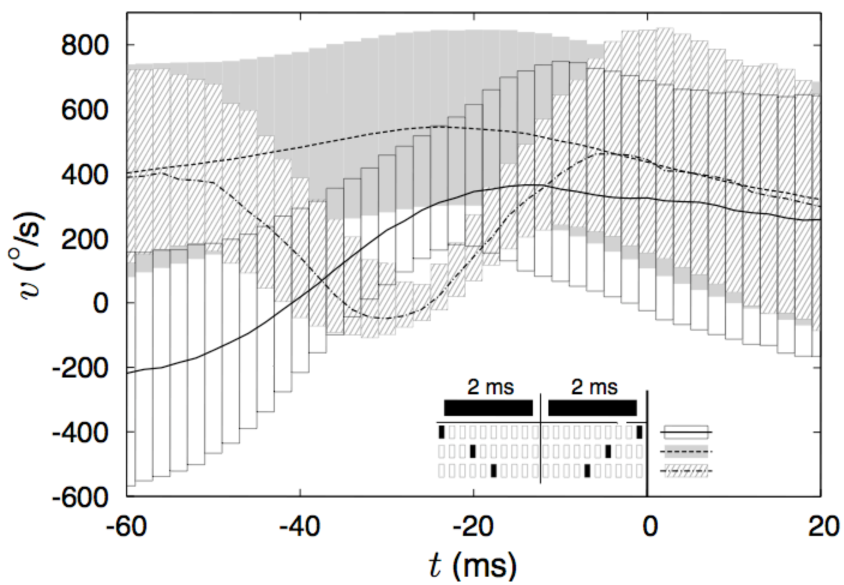
# New bits: Decorrelation in the time domain
## *Predictive coding?*



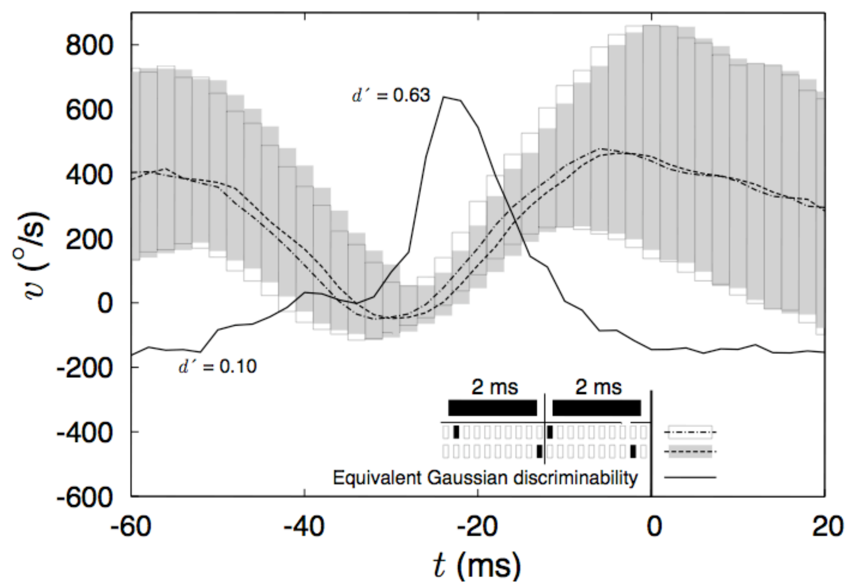

- Corr. func. at half its maximum value (for stimulus and rate), but fly gets new bits every 25 ms
- Not a simple delta-code
- Behaviorally optimized code
- Pretty amazing!

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

# Information about…

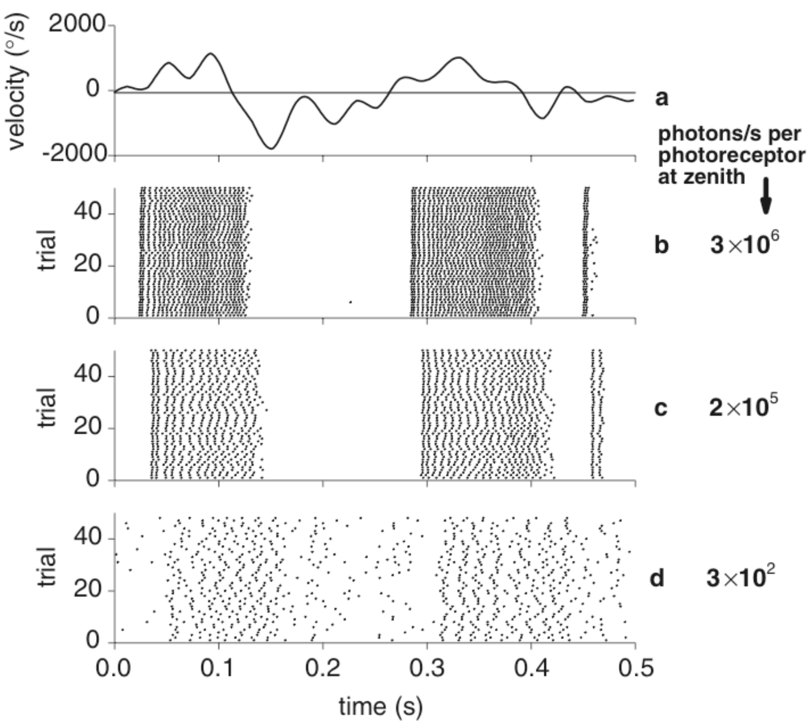



Signal shape




Zero-crossings time

# Precision is limited by physical noise sources




(Lewen, et al 2001)

$$T = 6 \text{ ms}$$

$$\tau = 0.2 \text{ ms}$$

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

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

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

# Puny fly, keen memory