Firing rates & spike time precision

The link to membrane characteristics

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Outline

- Many results on spike time precision: theoretical, *in vitro*, and *in vivo*
- With constant stimuli & noise, precision is low;
- Rapidly varying stimuli can be very precise
- Precision is tied to background level of excitation
- This can be related to the PRC by treating the neuron as a generalized oscillator
Neurons code via rate & timing

What is the relationship between rate and timing?
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- Rate seems to matter at high spike rates
Neurons code via rate & timing

- What is the relationship between rate and timing?
  - Rate seems to matter at high spike rates
  - Timing may be more important at low rates
Theoretical results

- Shadlen et al elegantly show that presence of input correlations destroys rate codes at low frequencies
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  - de Ruyter et al work on fly lobular plate
  - Reich et al Primary visual cortex
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- *In vitro* Mainen & Sejnowski show cortical neurons respond reliably to fast stimuli
How does the neuron multiplex?

Slowly changing inputs are coded with rate code and fast inputs with spike timing.
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- **Strategy**: Use dynamics of action potential initiation to study the role of frequency on spike timing
Canonical models

- Most cortical neurons are type 1
  - All or none action potentials
  - Arbitrarily low frequencies
  - Square root (instantaneous) or linear (steady state) F-I curve
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- Ermentrout et al extended to include SFA:

  \[
  I(t) = I_0(t) - g_m z \quad \frac{dz}{dt} = f(\theta)(1 - z) - z/\gamma
  \]
Intuitive picture
With adaptation

Low SFA

High SFA
Precision

- Background noise plus baseline depolarization plus stimulus.
- Measure spike time histogram over many repeated trials.
Jitter

- ... is a diffusion process when the cell is oscillating

- ... but not when bias is low
Generic behavior

What determines the temporal sensitivity?
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- Can we understand this precision from the dynamics of excitability?
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- Use the theta model with adaptation – all class I models are equivalent.
The Phase-response curve

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- Tells how timing of inputs affect the time of next spike
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- Tells how timing of inputs affect the time of next spike
- Easily computed for models and for experiments
Application to coding

Stimulus consists of a slow DC bias
Application to coding

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- plus phasic terms from inputs (fast and synchronous)
Application to coding

- Stimulus consists of a slow DC bias
- plus phasic terms from inputs (fast and synchronous)
- Thus PRC informs us when the neuron will fire
Experiment & theory

- first spike
- second spike
- theta+adapt
Firing rate & sensitivity

Low adapt

High adapt

At low frequencies - very sensitive
With much adaptation, a coincidence detector
At high frequencies - low sensitivity; “integrator”
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Consequences

- At low firing rates, inputs have a greater effect on spike timing than they do at high rates.
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