Perceptual Uncertainty

• What is it?
• Can instances of perceptual uncertainty help us understand something?
• How can the brain overcome uncertainty?
• What sorts of confusion occur when the brain simply cannot overcome uncertainty?
Rice and Munger (1986)
J. Comp. Neurol.
Texture discrimination acuity with the whiskers is equivalent to humans with the fingertip.

How is this achieved?

There was a great quest for the answer, 2003-07.
Neuronal basis for perception of whisker vibrations
Ehsan Arabzadeh

Schematic model for texture discrimination: the kinematic “signature” of whisker vibrations is encoded by neurons. In this scheme, vibrations take the simplest possible form, sinusoidal waveforms.
But what features of a vibration can a rat really feel?

Adibi, Diamond, Arabzadeh
Nose-poke → Stimulus presentation → Choice and Reward

Delay

S- → S+

Amplitude

$A$, $2A$ → $S^+$

$A$, $2A,f$ → $S^-$

Frequency

$A,f$, $A,2f$ → $S^+$

$2A,f$, $2A,2f$ → $20$ ms, $20$ μm
What we have, then, is perceptual uncertainty.

Rats can discriminate between two vibrations provided they differ in Af.

If they do NOT differ in Af, they cannot be distinguished.

This tells us something to look for in neuronal coding. Two stimuli can be distinguished only if they produce in the brain two different representations. The prediction, from the uncertainty expressed by behavior, is that neurons can encode A and f, but cannot encode differences in vibrations 1 and 2 if A1f1 = A2f2.
stimulus set for measuring cortical encoding of vibration
Onset response
barrel cortex encoding of vibration velocity at stimulus onset

Peak 5-ms spike density
Coding of vibration frequency $f$ and amplitude $A$ ...  

... and the resulting uncertainty

**a**  frequency coding  

**b**  amplitude coding

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<th>Stimulus frequency (Hz)</th>
<th>Spikes/s.</th>
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<th>Stimulus amplitude (µm)</th>
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For a sinusoidal function characterized by amplitude $A$ and frequency $f$, mean speed (abs velocity) across an integer number of cycles is proportional to the product $Af$.

Barrel cortex firing proportional to $Af$
decoding barrel cortex activity to mean whisker speed
No sign of temporal code
decoding barrel cortex activity to mean (across cycles) whisker speed
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Bounded integration –
Leading model for perceptual decision making with uncertain evidence... but model built from primate visual system.
• They typically execute 1–6 touches before withdrawing.

• How does the rat decide whether to initiate another contact or else to turn toward a reward spout? Two hypotheses:
  o Motor Program (open loop)
  o Evidence Accumulation (closed loop)
Evaluation of evidence

Closed loop: 100 ms per cycle

Open loop
invatiant quantity of evidence per trial at time of choice

Local curvature \( = \frac{1}{R} \)

Local angle difference \( = \text{abs}(\frac{1}{R_1} - \frac{1}{R_2}) \)

Local angle difference (WF3)

Local curvature (WF1)

Local curvature velocity (WF5)

Head axis

Base angle

Base angle (WF4)

Base angle velocity (WF8)

Base angle acceleration (WF9)

Local curvature difference \( = \text{abs}(\frac{1}{R_1} - \frac{1}{R_2}) \)

Local curvature difference (WF2)

Local curvature diff velocity (WF6)

Local angle difference velocity (WF7)
We exploit kinematic signatures of textures to DECODE (make prediction) of texture based on kinematic features of single touch.

Bayesian multivariate linear discriminant analysis finds optimal linear combination of 9 features.

Similar analysis to decode texture from neuronal firing in primary (vS1) and secondary (vS2) vibrissal somatosensory cortex.
whisker kinematics and neuronal firing provide correct signal on correct trials
whisker kinematics and neuronal firing provide equally strong signal, whether choice correct or incorrect.
A strong, correct signal on single touch leads to correct choice.
a strong, incorrect signal on single touch leads to incorrect choice
• Rats’ choices follow from the texture signals carried by whisker kinematics and neuronal firing (that is, we identified the right form of evidence).

• They typically execute 1–6 touches before withdrawing.

• How does the rat decide whether to initiate another contact or else to turn toward a reward spout? Two hypotheses:
  o Motor Program (open loop)
  o Evidence Accumulation (closed loop)
Motor program hypothesis

greater number of contacts means greater quantity of kinematic signal available thus better performance

Evidence accumulation hypothesis

performance independent of the number of contacts per trial
Motor program hypothesis

probability of decision independent of single-touch signal

Evidence accumulation hypothesis

contact providing no evidence can never cause threshold crossing.

probability of decision positively correlated with quantity of signal.
Motor program hypothesis

quantity of signal per touch independent of the number of touches executed in that trial

Evidence accumulation hypothesis

when individual touches provide little evidence, the rat requires more touches: inverse relationship
**Motor program hypothesis**

no serial order effect in the quantity of signal across multiple contacts

**Evidence accumulation hypothesis**

quantity of signal non-random across touches

Signal **not** independent across touches: multi-touch trials (4, 5, 6 touches) tended to begin with low-signal touches.

Also, the final touch (same as the first touch on 1-touch trials) tends to carry the greatest signal.

6-touch trial

3-touch trial

invariant quantity of evidence per trial at time of withdrawal
Vibrissal signal

Neuronal signal

decision boundary (B) visible only by exponential primacy