Are There Quantum Effects in Human Perception?

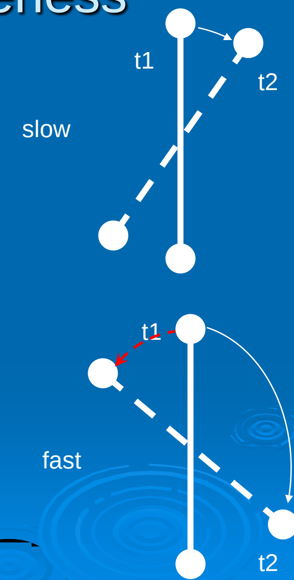
Ranxiao Frances Wang
University of Illinois at Urbana-Champaign

Outline

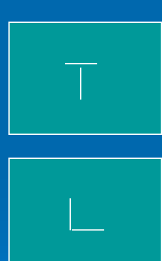
- Quantum-like perception
  - Is perception discrete or continuous?
    - Motion perception
    - Reaction time studies
  - Quantum Zeno effects
    - Multi-stable perception
    - Quantum vs conventional explanations
- Test QM using human as detector
  - Visual threshold
- Provocative statements

I. Temporal Discreteness

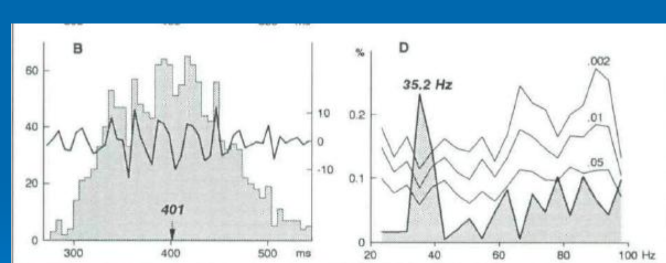
- Wagon-wheel illusion
  - Perceive reversed motion or stand still
- Why?
  - Can't happen if perception is continuous
- The explanation
  - Motion detection is inherently based on discrete "snapshots"
    - Resulting ambiguity: infinite possibilities
  - Need to use built-in heuristics to infer the most plausible cause
    - e.g., shortest distance principle
  - Motion perception determined by sampling rate relative to stimulus temporal frequency



- Discrete reaction time (Dehaene, 1993)
  - Detect visual or auditory signal
  - Reaction time distribution shows oscillation at ~40 Hz
  - Perception or action is discrete



Stimuli

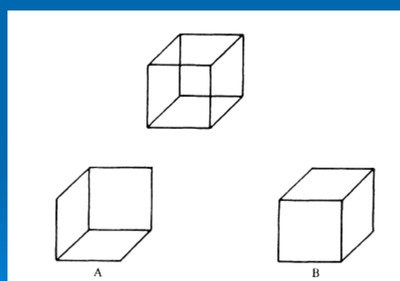


RT histogram

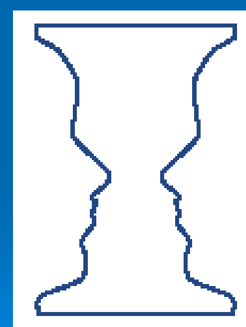
FFT of RT histogram

II. Quantum Zeno Effects

- Multi-stable perception
  - Ambiguous figures

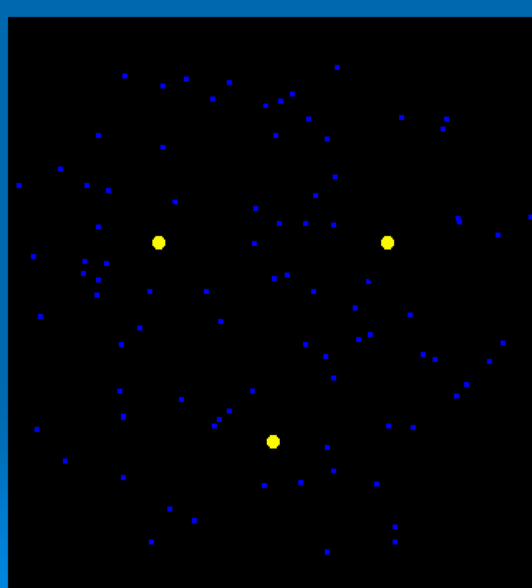


Necker cube



Face-vase illusion

Motion Induced Blindness

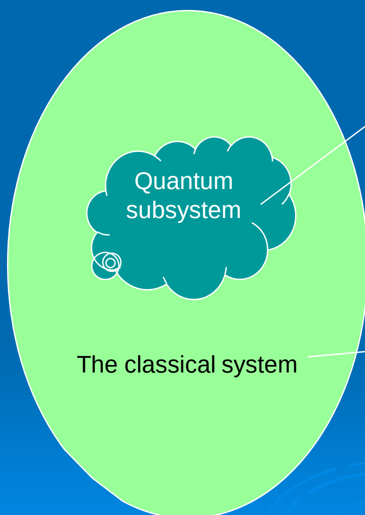


Binocular Rivalry

Quantum-like Properties

- Co-existence of multiple potential states (superposition)
- Only one perceptual state is “realized” (collapsing by measurement)
- Dominance time is affected by relative salience of the two images (probability coefficients)
- One percept persists for a period of time, then switches (Zeno effect)
  - Atmanspacher, 2003; Manousakis, 2007

The Quantum Model (Manousakis, 2007)



Quantum state:

$$|\psi\rangle = a|1\rangle + b|2\rangle$$

Time evolution:

$$|\psi(t)\rangle = \hat{U}(t)|\psi_0\rangle$$

$$\hat{U}(t) = e^{i\int_0^t dt'\hat{\omega}(t')}$$

If initial state is |1>:

$$|\psi_t\rangle = \cos(\bar{\omega}t)|1\rangle - i\sin(\bar{\omega}t)|2\rangle$$

Perception = measurement
Probability seeing |1>:

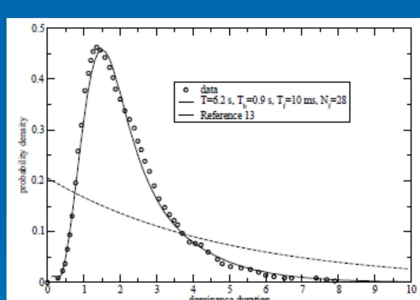
$$\langle\psi_t|\hat{Q}|\psi_t\rangle = \cos^2(\bar{\omega}\delta t)$$

Zeno effect:

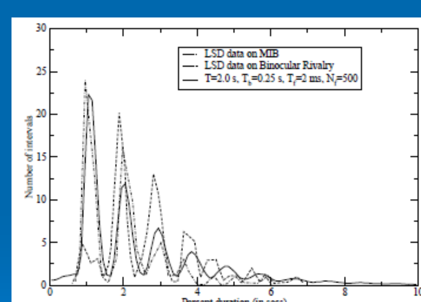
$$\delta t << T/4$$

Simulation Results

With 3 free parameters can explain diverse human data



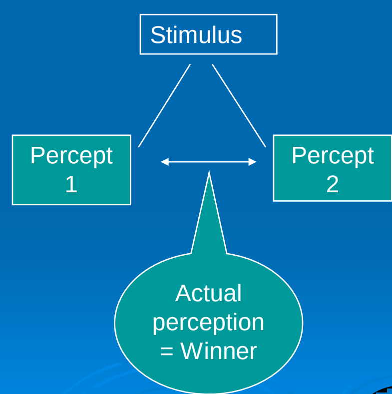
Simulating human data on mean dominance duration distribution



Simulating human data under hallucinogen

Conventional Model

- Competition / fatigue model



Same or Different Models?

	Quantum model	Conventional model
State	Potential conscious vs conscious percept	Unconscious vs conscious processes
Evolution mechanism	Schrödinger eq.	Inhibition & neural fatigue
Outcome by	Measurement	Competition winner
Discreteness	inherent	Additional assumption
Causation	Conscious percept → neural state	Neural state → conscious percept
Explain all data	?	?

- If different, which is better?

Human Single Photon Studies

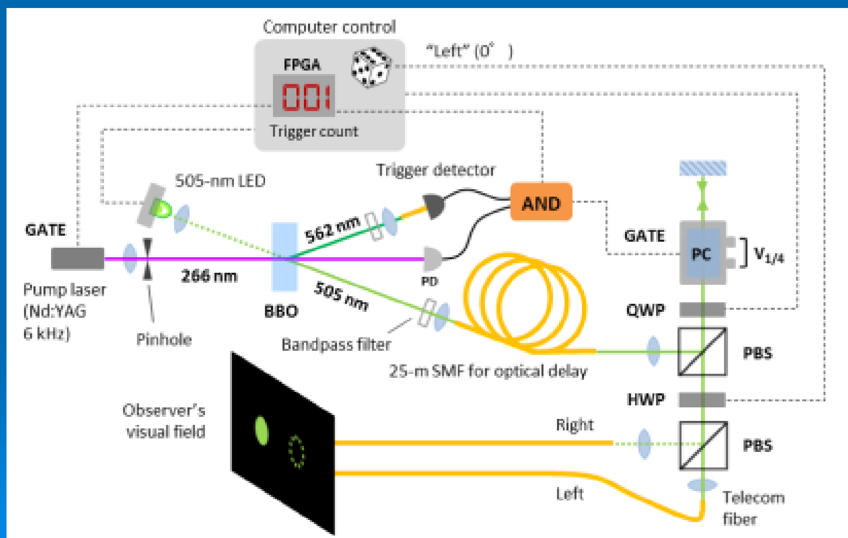
(with Rebecca Holmes, Paul Kwiat & Tony Leggett)

- *Goal: to test quantum effects directly via the human visual system, using precise (single) photon sources*
  1. Testing the validity of QM in perceptual systems using human observers by looking for differences between superposition and mixed quantum states (Ghirardi,1999)
  2. Testing quantum nonlocality with one of the photon detectors replaced by a human observer.

The Critical Issue

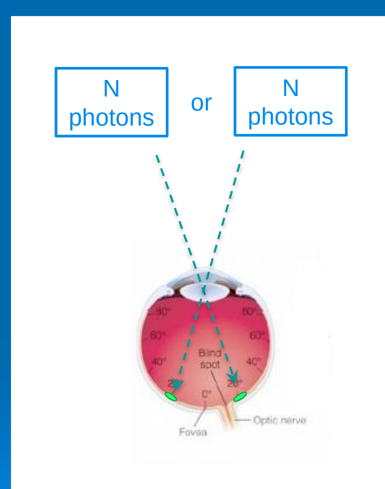
- Can humans see a single photon?
- Common answers
  - ~100
  - ~6 (Hecht et al, 1942; Brunner et al., 2008)
  - 1~2 (Sakitt, 1972)
  - 1 (Doan et al, 2006)
- The caveats
  - Cornea vs retina
  - Criterion of "seeing"
  - Photoreceptor vs perception
  - Conscious vs un-conscious perception
- Q: un-conscious perception of single photon at cornea?

Single Photon Source



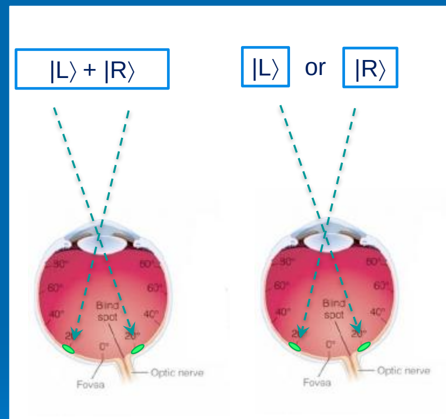
Exp 1: Visual Threshold

- Methods
  - **N** photons delivered to Left or Right test spots randomly across trials
  - Observer judges whether the light was on Left or Right
  - Measure accuracy, confidence of judgment, and reaction time
- Data analysis
  - If accuracy is statistically above 0.5, then humans can see N photon(s)



Exp 2: Superposition

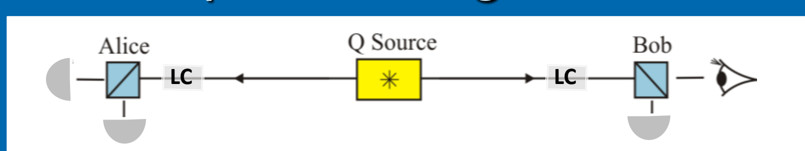
- Methods
  - Two conditions
    - Superposition condition: 1 photon at |L⟩ + |R⟩ state
    - Mixed condition: 1 photon at |L⟩ or |R⟩ with equal probability
  - Observer judges whether a light was present on Left and on Right separately
- Data analysis
  - If the detection rates are different in the two condition, then standard QM is violated



Superposition condition

Mixed condition

Exp 3: Entanglement



- Design
  - Standard EPR experiment
  - One detector replaced by a human observer
- Theoretical analysis
  - Optimal condition to detect a violation of the inequality
    - Prediction of QM: P_obs = 0.07
    - Prediction of LRT: P_obs ≥ 0.28
  - If the human detection rate suggests that p_obs <0.28, then violation of inequality is demonstrated

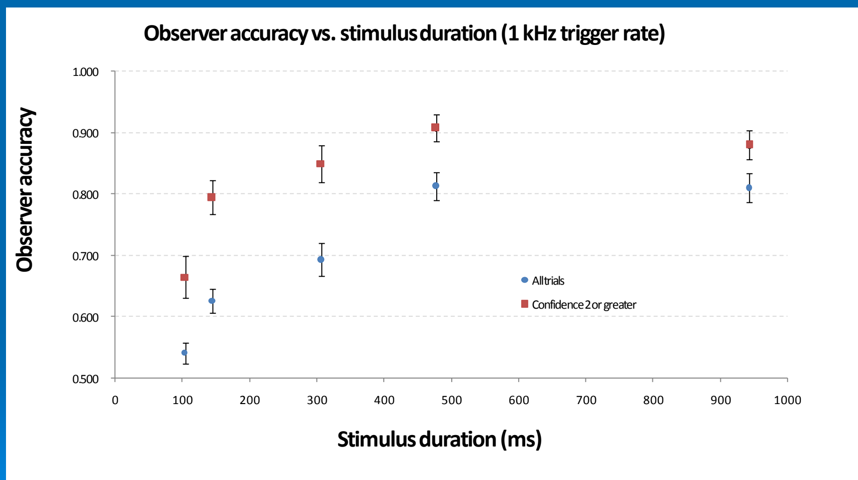
Preliminary Results

- The efficiency estimation
  - Single photon generator: ~30%
  - Eye (cornea → rod): 3~10% (actually 2~6%)
  - Rod → percept: ??? (< 10%?)
  - Total: < .18%
  - Trials needed: ~500K → 3500 hrs
- Visual threshold
  - For mean N=30, 54% correct

Temporal Integration Window

- Visual system integrates stimuli over a period of time to form a single percept
  - How long?
- Design
  - Constant rate (1 photon / ms)
  - Varying duration (100 ms ~ 1 sec)
  - Accuracy should increase until duration outside integration window

Results



Integration window = 500 ms

Theoretical Questions

- Is perception classical or quantum?
  - Perception itself is better described as a quantum system
    - May not result from quantum properties of the microscopic elements
- Do fundamental laws of QM apply to perceptual system?
  - Not necessarily, needs experimental verification