A quantum-markov open systems model of Preference accumulation

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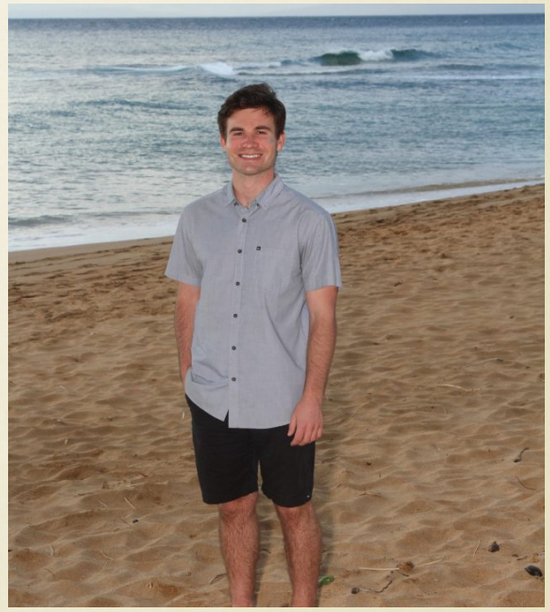


WHAT IS THE GOAL OF QUANTUM COGNITION AND DECISION?

- Not a physical/neurobiological theory of the brain
- Not a theory of consciousness
- It is a mathematical theory about human behavior
  - Specifically judgments and decisions

1. Quantum theory is a general Axiomatic theory of probability

- Human judgments and decisions are probabilistic
- These probabilities do not obey the Kolmogorov axioms
- Quantum theory provides a viable alternative

2. Non Commutativity of measurements

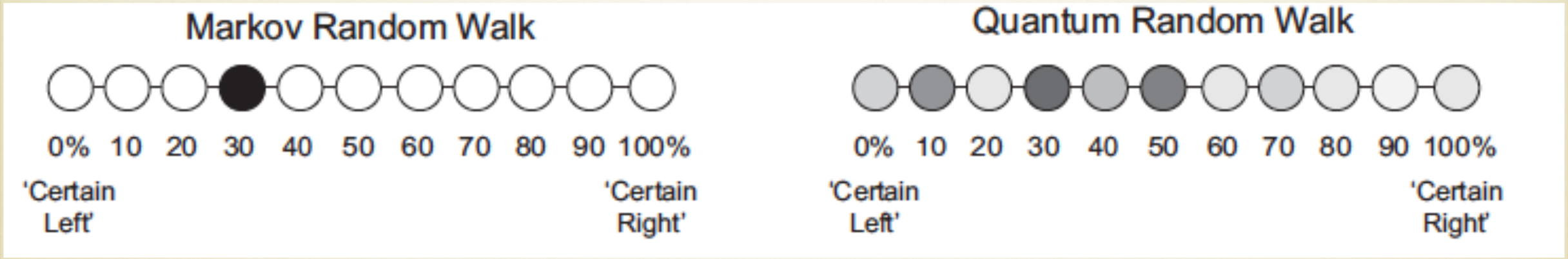
- Measurements change psychological states producing context effects
- Principle of complementarity was borrowed by Niels Bohr from William James

3. Vector space representation of probabilities

- Agrees with multidimensional space models of cognition

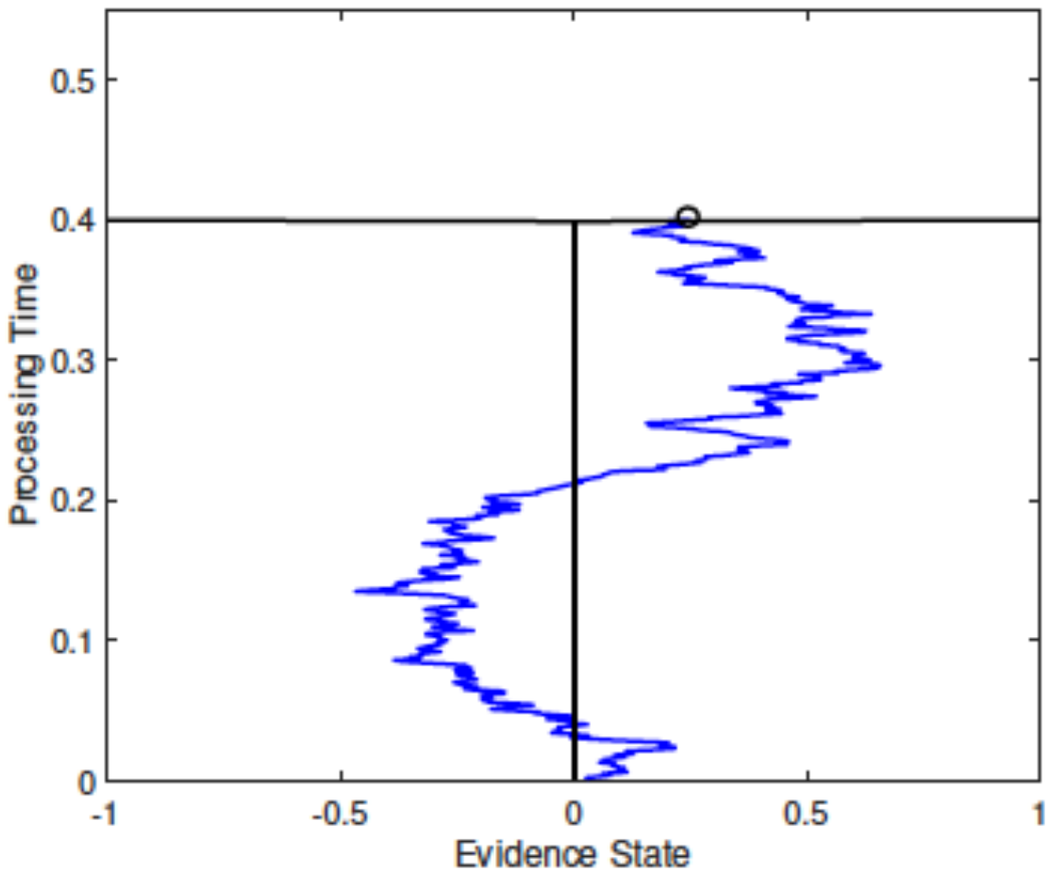
Example of Preference Accumulation during Decision Making

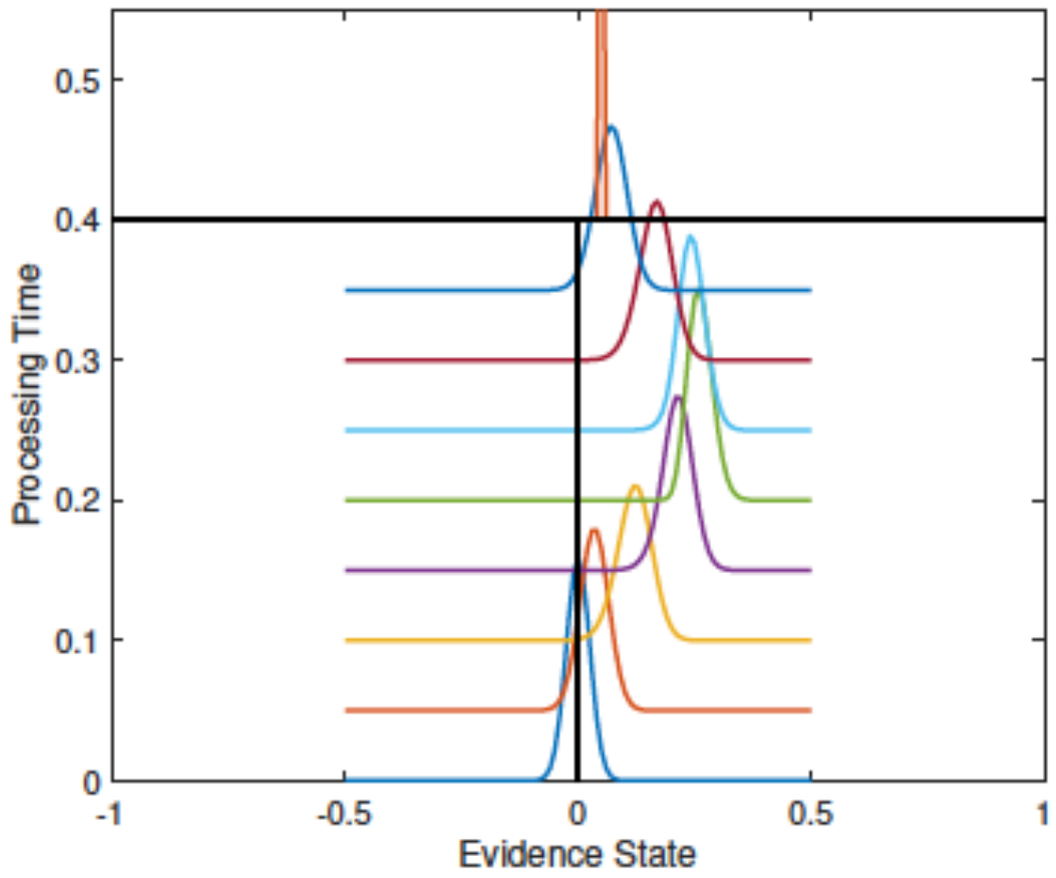
Which Motor Cycle to Buy?



- Precisely located at each time point

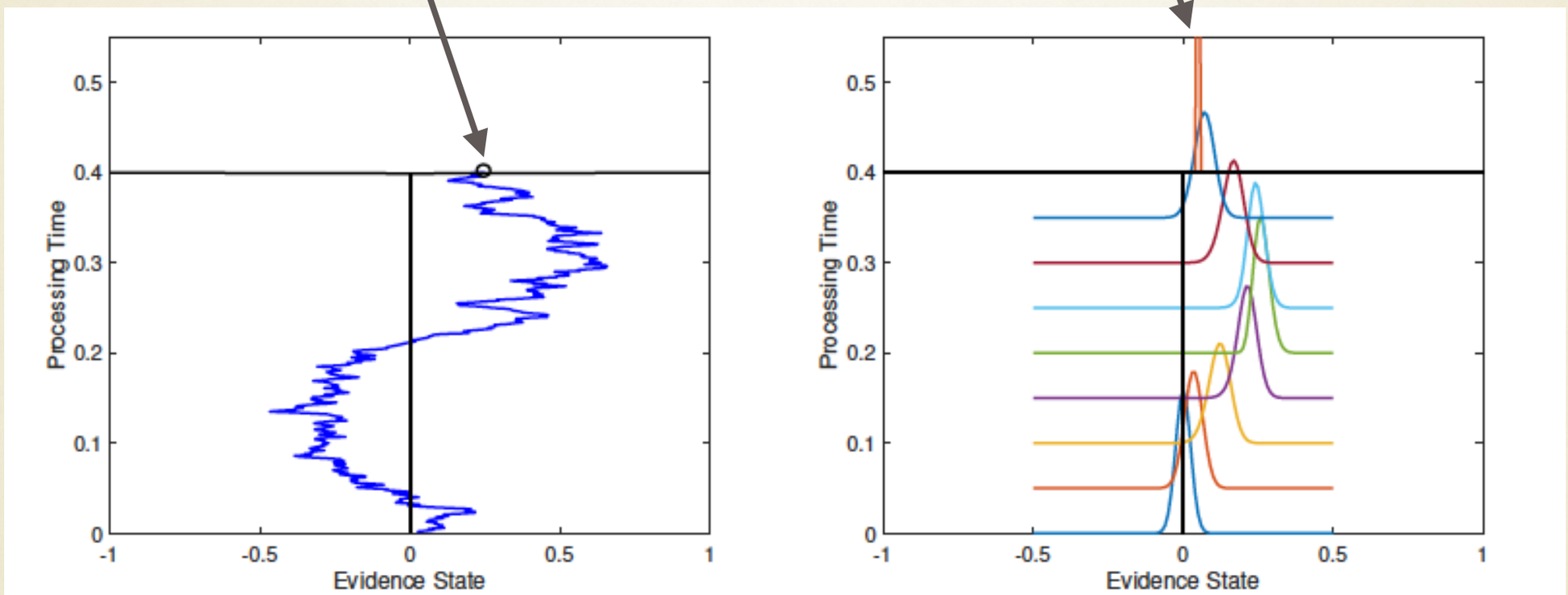
- Dispersed at any each time point





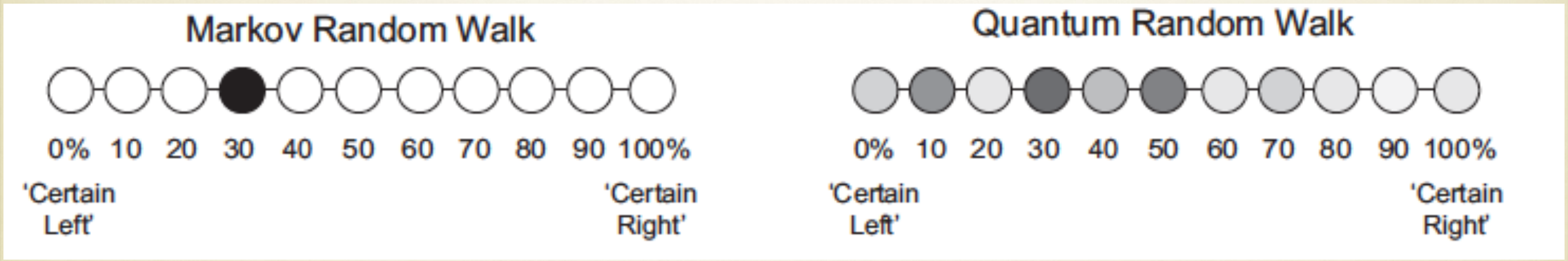
- Location moves across time tracing a trajectory

- Dispersion moves like a wave across time



- Measurement records existing location

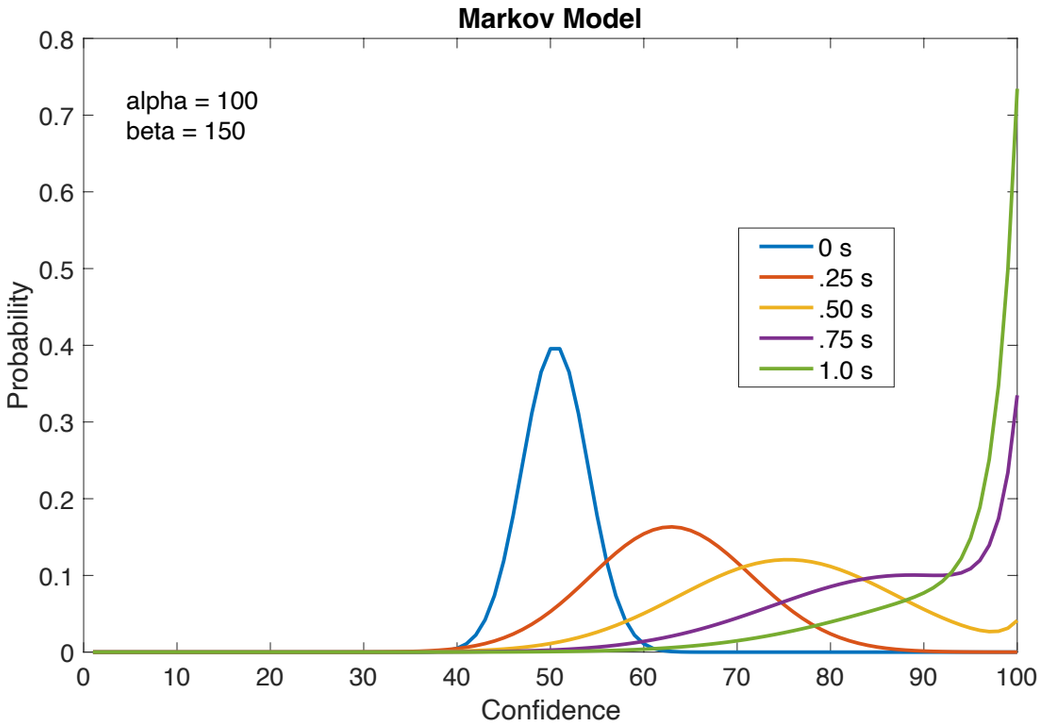
- Measurement creates a location



- Probability refers to observer's uncertainty about a person's existing location

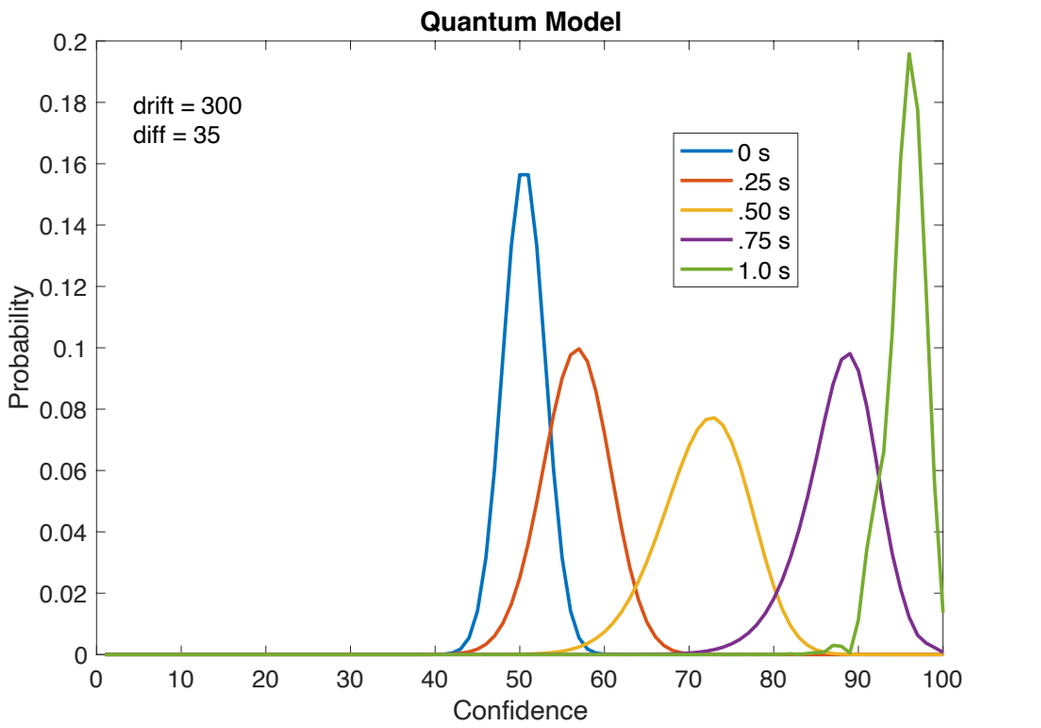
- Probability refers to person's internal uncertainty regarding location

Markov Probability Evolution



Like wind blowing sand up against the right wall forming an equilibrium

Quantum Probability Evolution



Like wind blowing water up against the right wall, splashing off to oscillate

Quantum-Markov Open System Model

Busemeyer, J. R., Zhang, Q., Balakrishnan, S. N., Wang, Z. (2020) Application of Quantum—Markov Open System Models to Human Cognition and Decision. *Entropy,* 22, 990; e22090990

Open systems master equation

$$\frac{d}{dt}\rho(t) = -i\cdot(1-w)\cdot[H,\rho(t)] + w\cdot\sum_{i,j}\gamma_{ij}\cdot\left(\left(L_{ij}\cdot\rho(t)\cdot L_{ij}^{\dagger}\right) - .5\cdot\{(L_{ij}^{\dagger}\cdot L_{ij}),\rho(t)\}\right).$$

Density Matrix

Quantum Dynamics

Lindblad (Markov) Dynamics

$\rho = \sum p_i\left(\psi_i\cdot\psi^{\dagger}{}_i\right)$ Density contains both epistemic (p_i) and ontic ψ_i uncertainty

$L_{ij} = |i\rangle\langle j|$ Transition operator from state j to state i

$\gamma_{ij} =$ Probability to transit from state j to state i

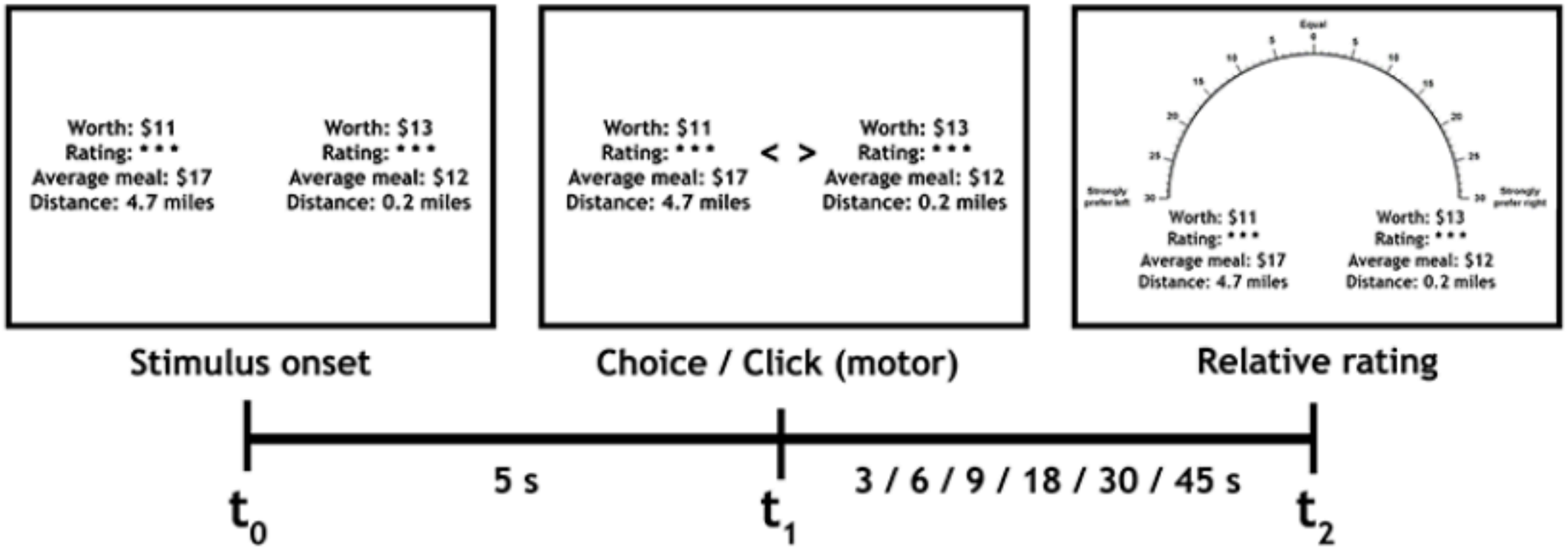
Current Research

An open system model of decision-making and temporal oscillations in preference strength

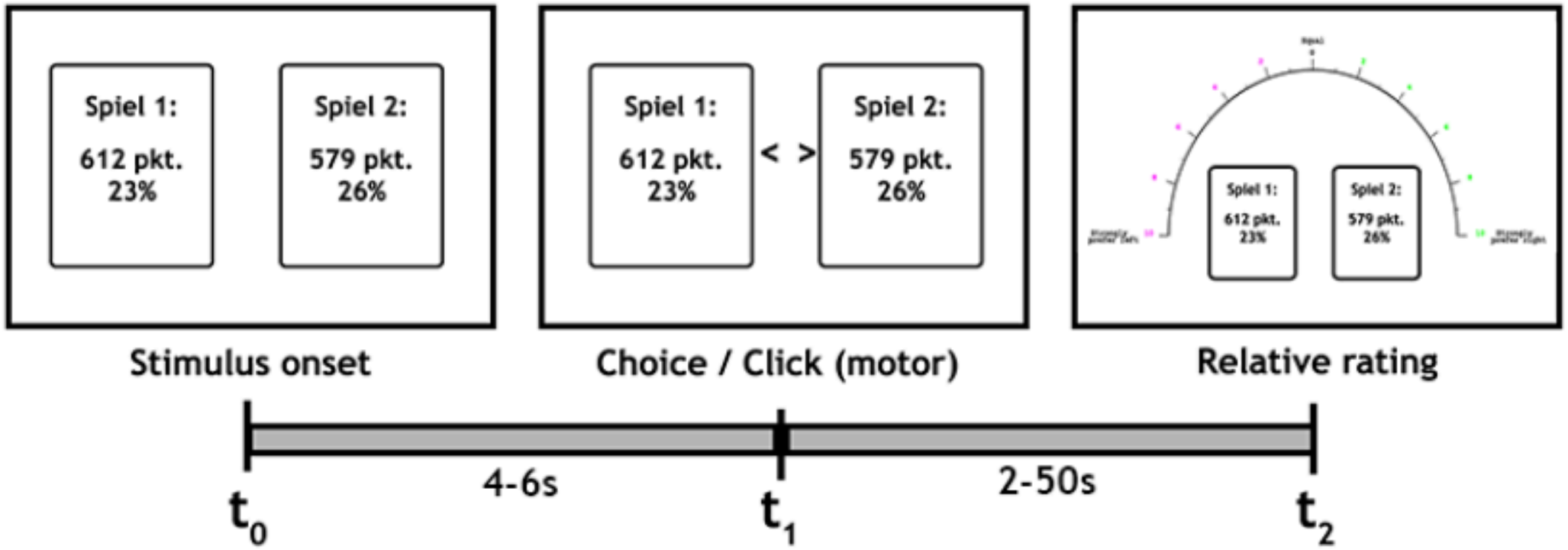
Peter D. Kvam[1,*], Jerome R. Busemeyer[2], & Timothy J. Pleskac[3]

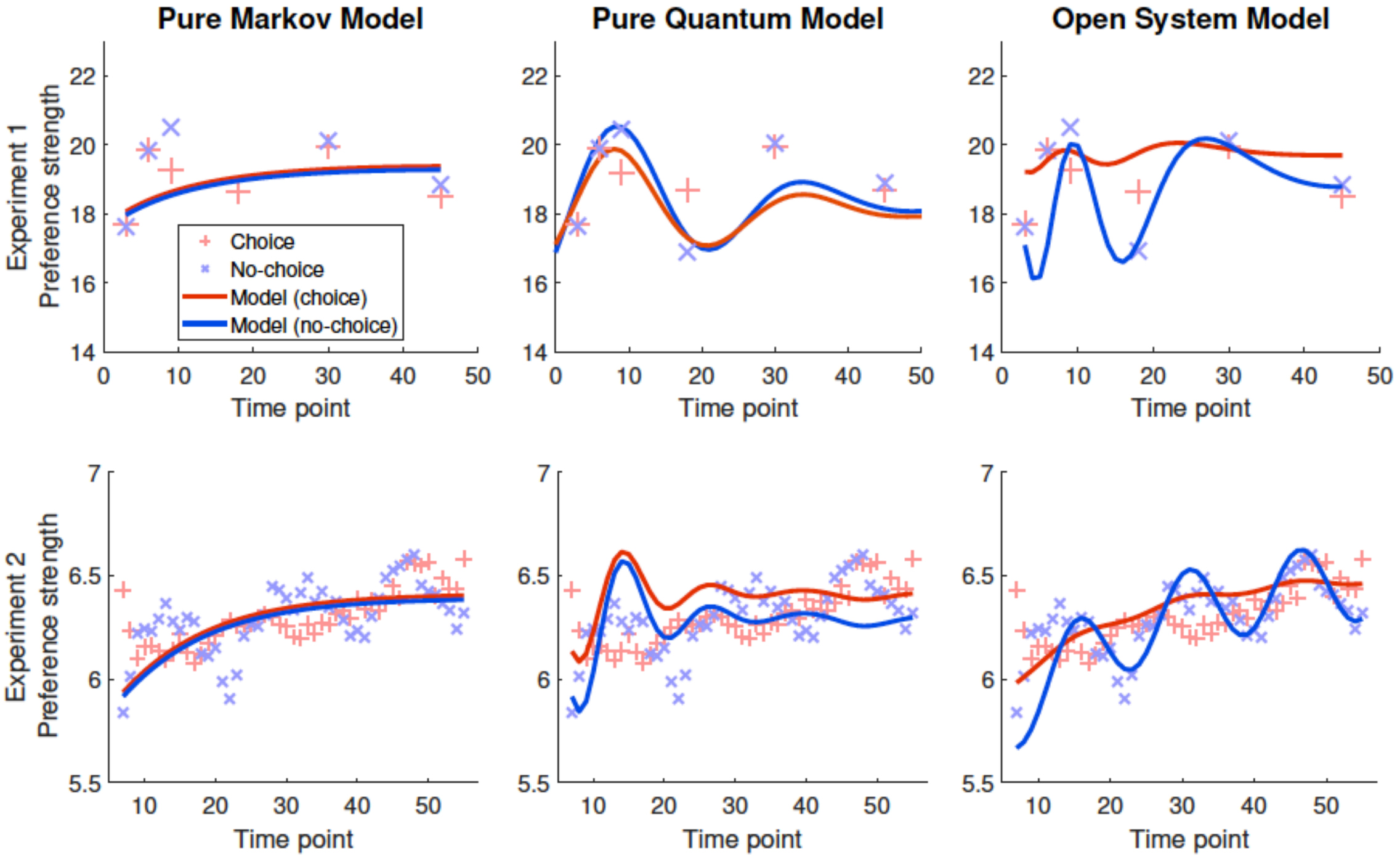
Scientific Reports, 2021,11(1),1-15

Experiment 1



Experiment 2




Pure Markov Model
Pure Quantum Model
Open System Model
Experiment 1
Preference strength
Experiment 2
Preference strength
Choice
No-choice
Model (choice)
Model (no-choice)
Time point
Time point
Time point
Time point
Time point
Time point

Conclusions

- **Markov models have a strong track record for predicting choice and response time in past research, but there is empirical evidence that Markov models are not the complete story**
- **Evidence for quantum dynamics comes from interference effects and oscillations across time**
- **It isn't necessary to choose one versus the other because the open system model provides an elegant integration and a parameter that describes the contribution of each type of dynamic**
- **Evidence and preference evolution seems to have both epistemic and ontic sources of uncertainty**

"Mathematical models of cognition so often seem like mere formal exercises. Quantum theory is a rare exception. Without sacrificing formal rigor, it captures deep insights about the workings of the mind with elegant simplicity. This book promises to revolutionize the way we think about thinking."

Steven Sloman
Cognitive, Linguistic, and Psychological Sciences, Brown University

"This book is about why and how formal structures of quantum theory are essential for psychology - a breakthrough resolving long-standing problems and suggesting novel routes for future research, convincingly presented by two main experts in the field."

Harald Atmanspacher
Department of Theory and Data Analysis, Institut fuer Grenzgebiete der Psychologie und Psychohygiene e.V.

<FURTHER ENDORSEMENT TO FOLLOW>

Much of our understanding of human thinking is based on probabilistic models. This innovative book by Jerome R. Busemeyer and Peter D. Bruza argues that, actually, the underlying mathematical structures from quantum theory provide a much better account of human thinking than traditional models. They introduce the foundations for modeling probabilistic-dynamic systems using two aspects of quantum theory. The first, "contextuality," is a way to understand interference effects found with inferences and decisions under conditions of uncertainty. The second, "quantum entanglement," allows cognitive phenomena to be modeled in non-reductionist way. Employing these principles drawn from quantum theory allows us to view human cognition and decision in a totally new light. Introducing the basic principles in an easy-to-follow way, this book does not assume a physics background or a quantum brain and comes complete with a tutorial and fully worked-out applications in important areas of cognition and decision.

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Busemeyer and Bruza **Quantum Models of Cognition and Decision**

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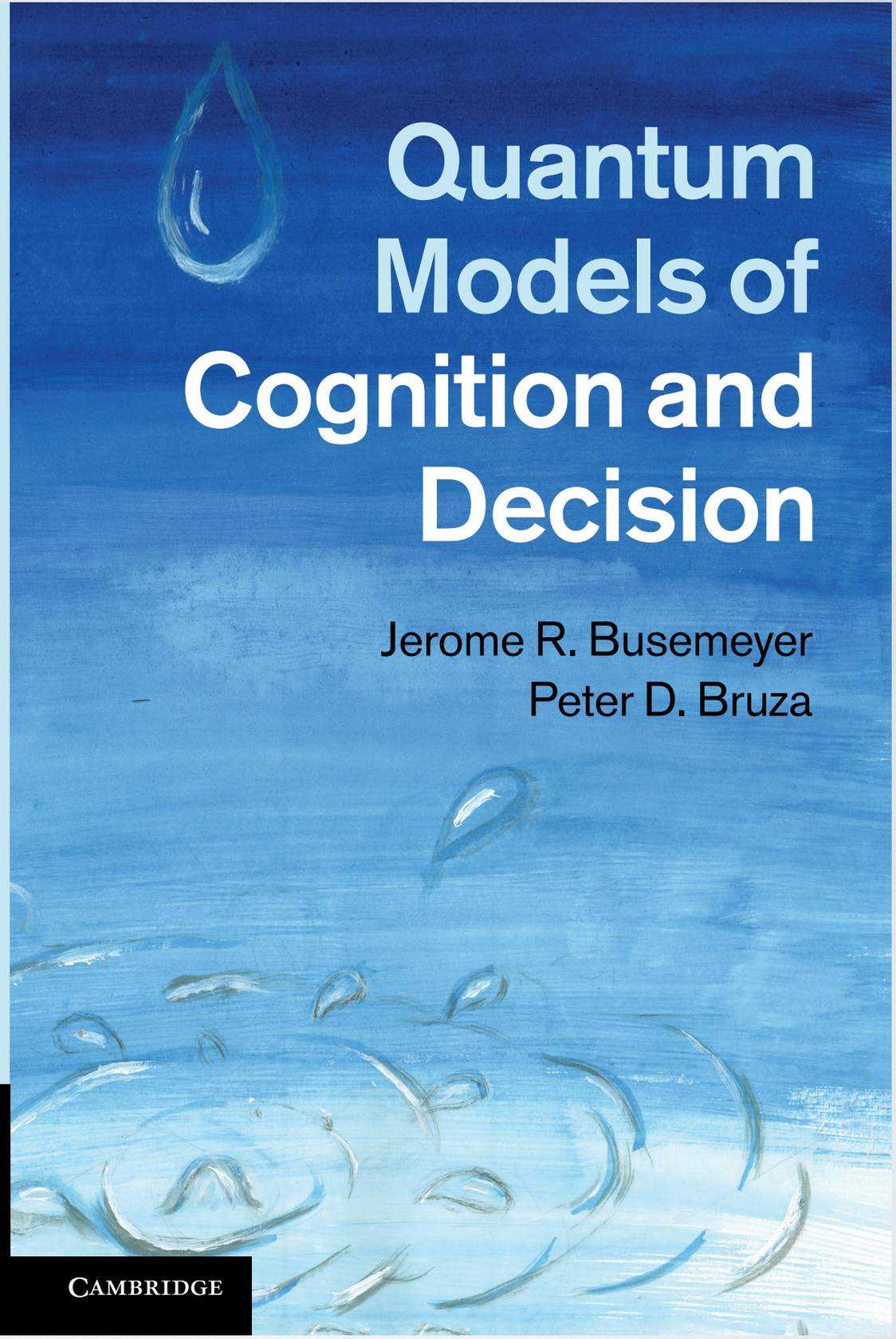
Quantum Models of Cognition and Decision

Jerome R. Busemeyer
Peter D. Bruza



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