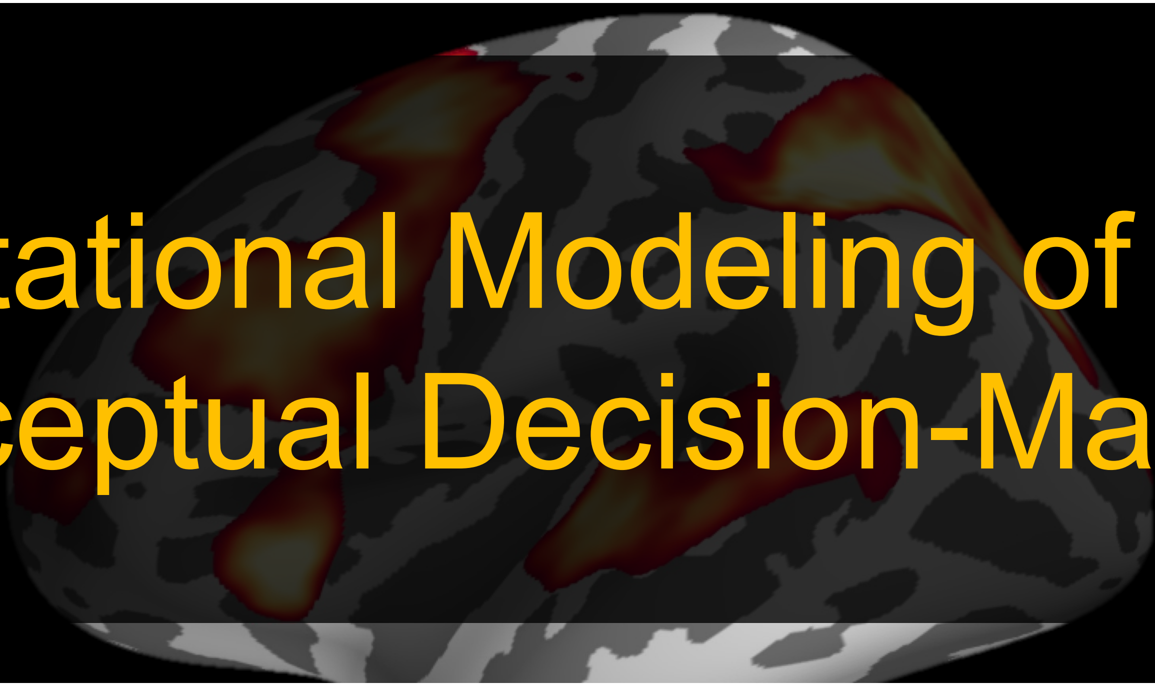
Computational Modeling of Human Perceptual Decision-Making



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Institute of Psychology and Behavioral Sciences
Shanghai Mental Health Center
2022/12/10

上海交通大學
SHANGHAI JIAO TONG UNIVERSITY

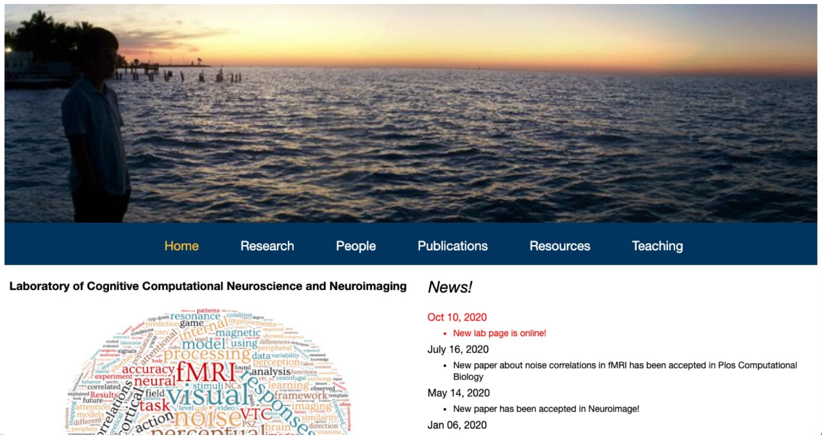
Who am I ?

- 2006–2010, B.S., Psychology and Computer Science, Peking University.
- 2010–2016, Ph.D., Brain&Cognitive Sciences, University of Rochester.
- 2016–2020, Postdoc, Center for Magnetic Resonance Research, University of Minnesota at Twin Cities.
- 2020.01-09, Postdoc, Section on Functional Imaging Methods, NIMH, NIH.
- 2020.09-present, Associate Professor, Shanghai Jiao Tong University

Who am I ?

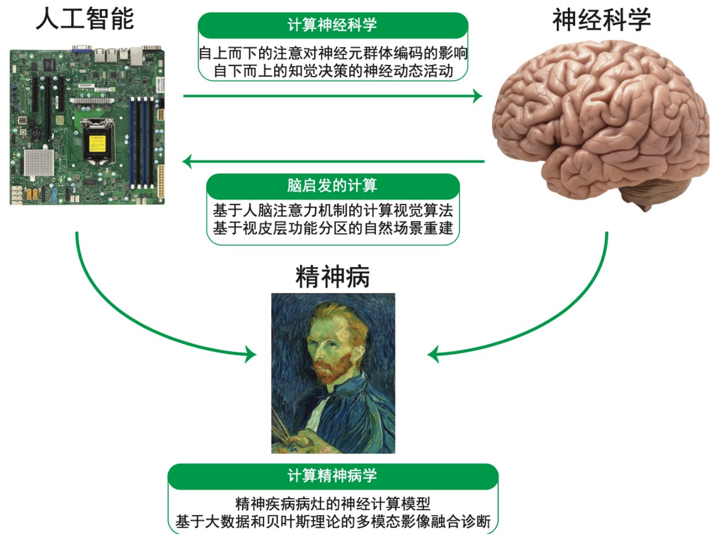
Associate Professor, Principal Investigator

Laboratory of Cognitive Computational Neuroscience and Neuroimaging
https://ruyuanzhang.github.io



Research directions

- Cognitive Computational Neuroscience
- Deep Learning and Human Vision
- Computational Psychiatry



Perceptual Decision-Making

- Goal: hands-on model fitting practice on perceptual decision-making

- Content:
  - Section 1: modeling a simple perceptual choice
  - Section 2: modeling perceptual choice and reaction time

Section 1

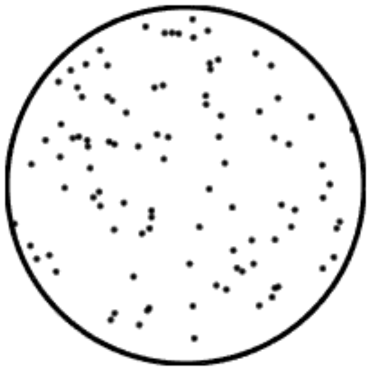
Modeling a simple perceptual choice

Section 1

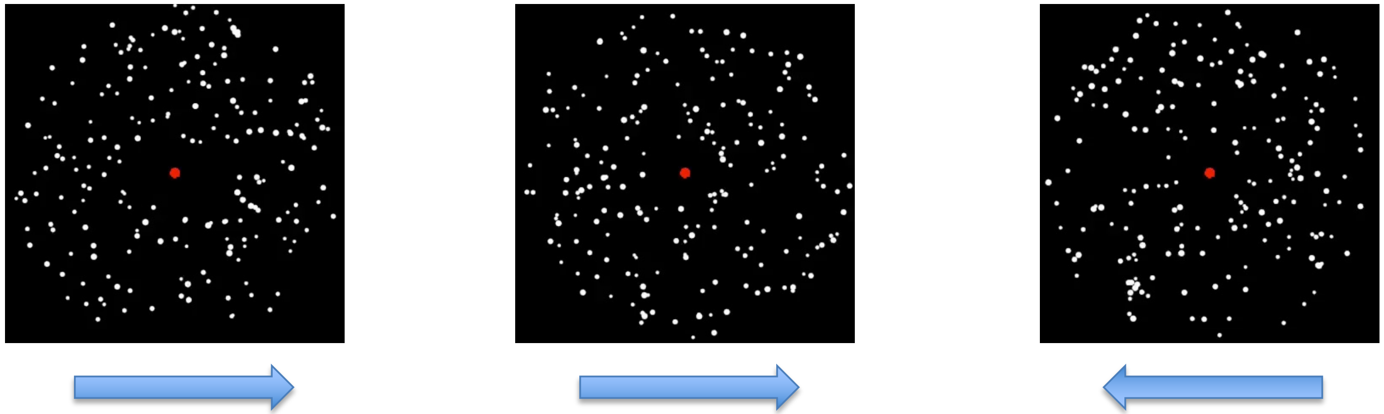
- Simple perceptual decision making

Coherence Level: fraction of dots coherently moving to one direction

Random dot motion (RDM)



100% | 50% | 10%



Right | Right | Left

Easy → Hard

Perceptual Decision-Making

Michael Shadlen

https://zuckermaninstitute.columbia.edu/michael-n-shadlen-md-phd/

A computational analysis of the relationship between neuronal and behavioral responses to visual motion

MN Shadlen, KH Britten, WT Newsome… - Journal of …, 1996 - Soc Neuroscience

We have documented previously a close relationship between neuronal activity in the middle temporal visual area (MT or V5) and behavioral judgments of motion (Newsome et al., 1989; Salzman et al., 1990; Britten et al., 1992; Britten et al., 1996). We have now used numerical simulations to try to understand how neural signals in area MT support psychophysical decisions. We developed a model that pools neuronal responses drawn from our physiological data set and compares average responses in different pools to …

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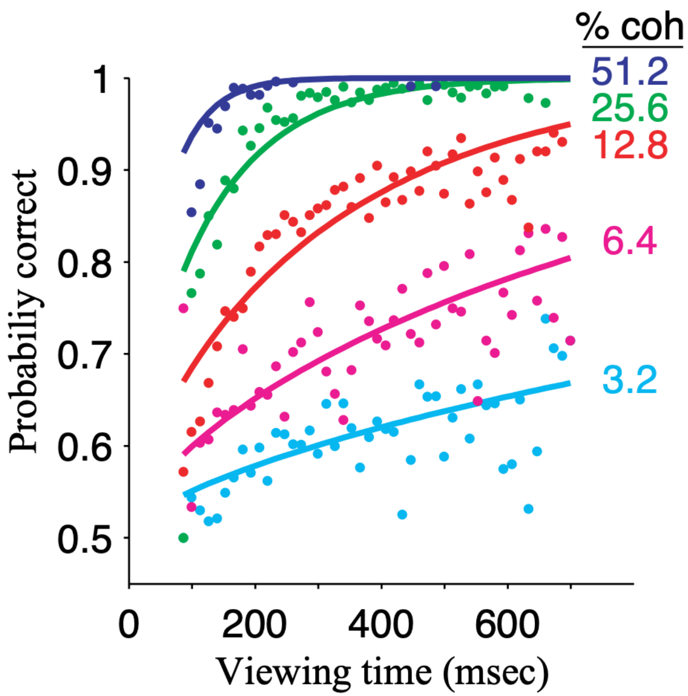
Perceptual Decision-Making



- Higher coherence, higher accuracy
- Longer duration, higher accuracy

Perceptual Decision-Making

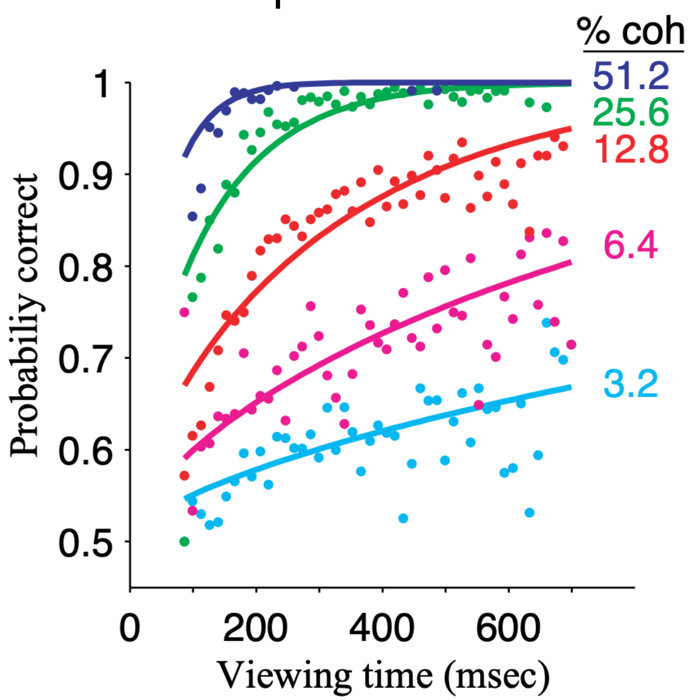
How can we model such a simple perceptual effect??

Perceptual Decision-Making

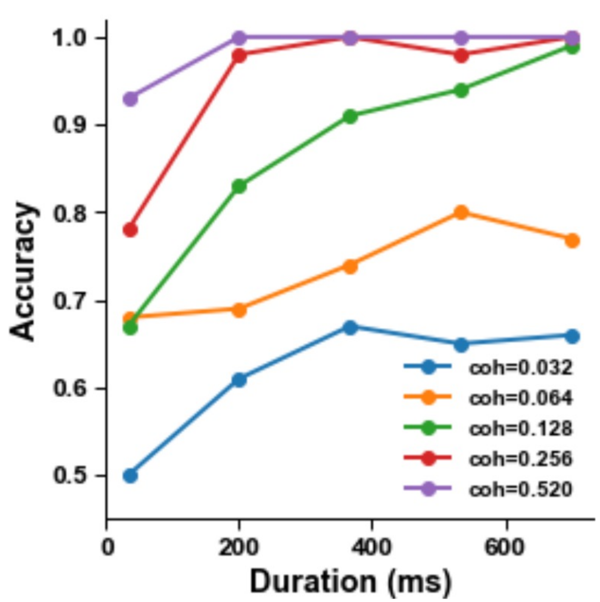
A simple model of perceptual decision-making
(pdm1.ipynb)

Perceptual Decision-Making

Empirical data



A simple perceptual model



- Higher coherence, higher accuracy
- Longer duration, higher accuracy

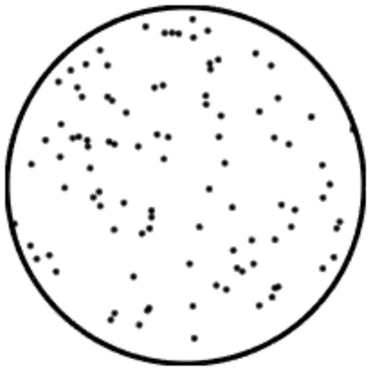
- The subject makes a decision by counting dots moving to left/right
- In real experiments, we test many coherence levels and many stimulus durations in many trials

Section 2

Modeling perceptual choice and reaction time

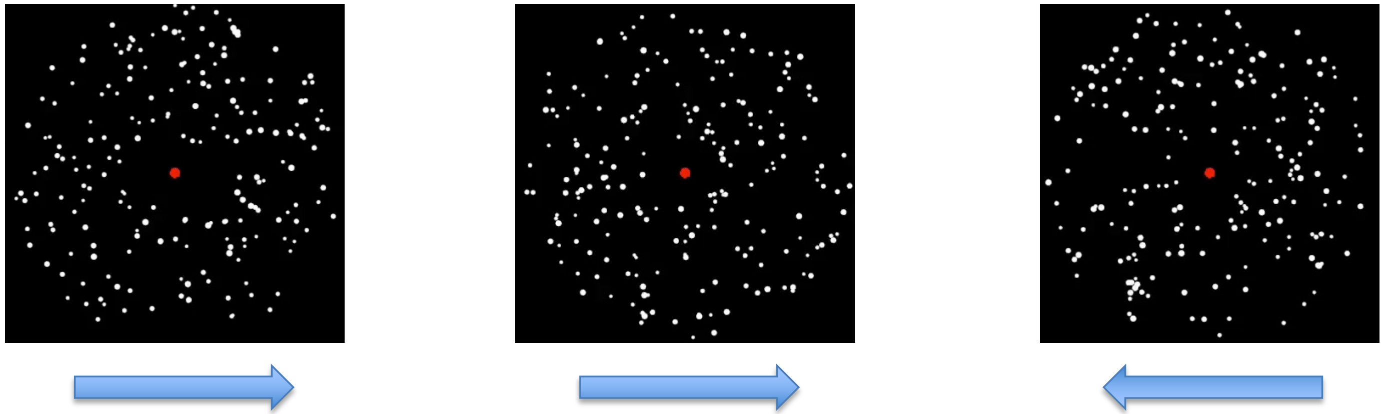
- Simple perceptual decision making

Random dot motion (RDM)



Coherence Level: fraction of dots coherently moving to one direction

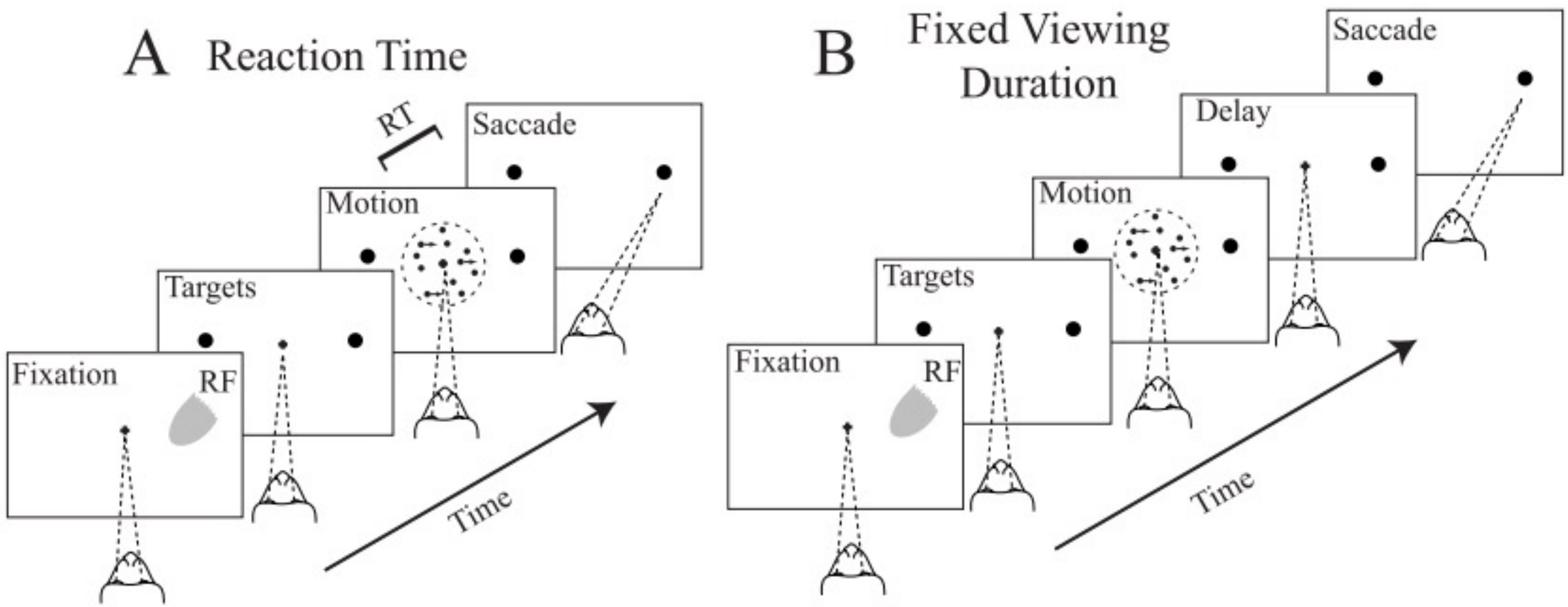
100% 50% 10%



Right Right Left

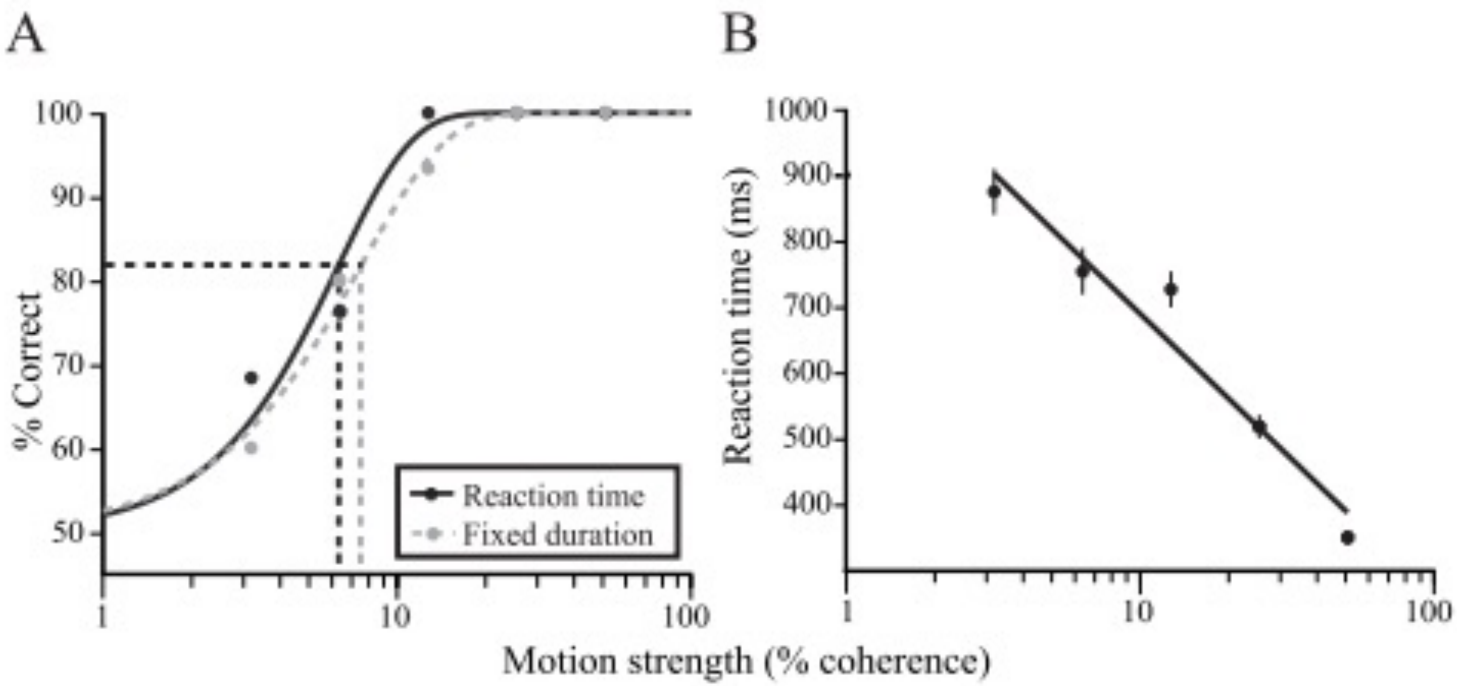
Easy → Hard

Perceptual Decision-Making



Roitman&Shadlen, *J. Neurosci.* 2002

Perceptual Decision-Making



Roitman&Shadlen, *J. Neurosci.* 2002

Perceptual Decision-Making

- Drift diffusion model (DDM)

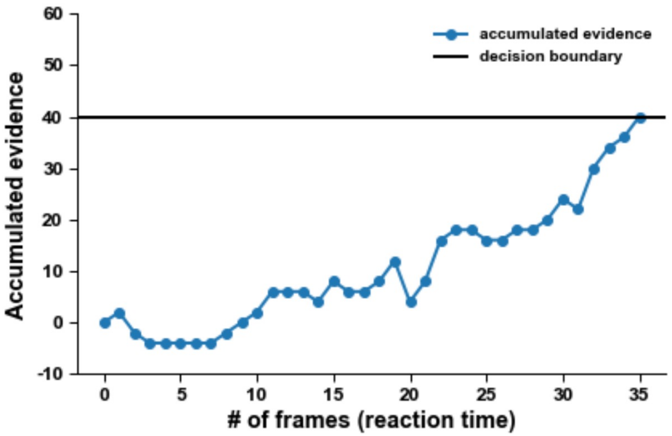
- DDM is one of the most frequently used models in perceptual decision-making

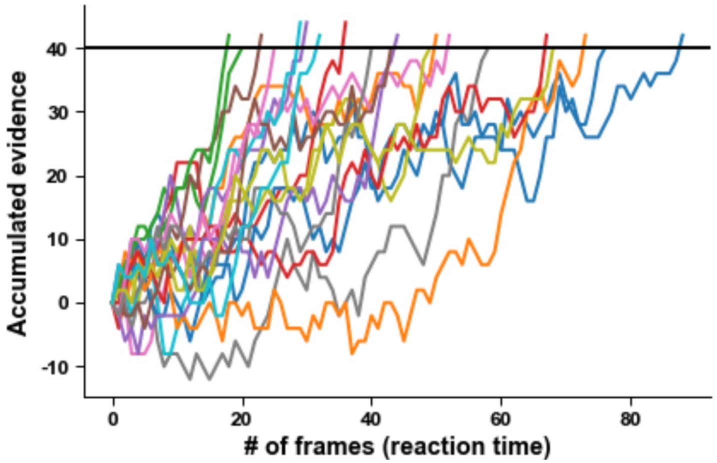
What is drift-diffusion?

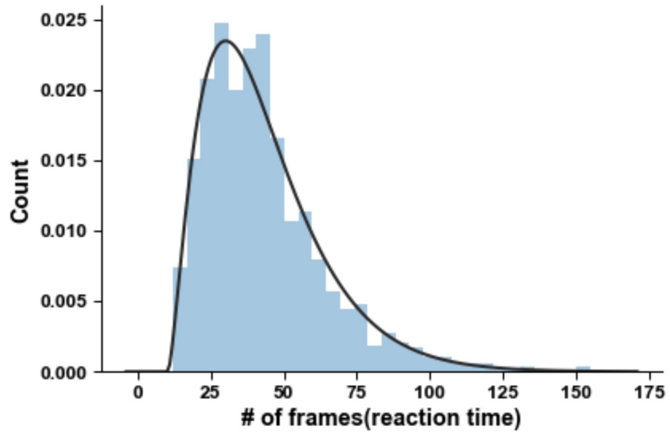
- Evidence accumulation
- Drift-diffusion
- Decision boundary

A simple illustration of the drift-diffusion process
(pdm2.ipynb)

drift-diffusion models

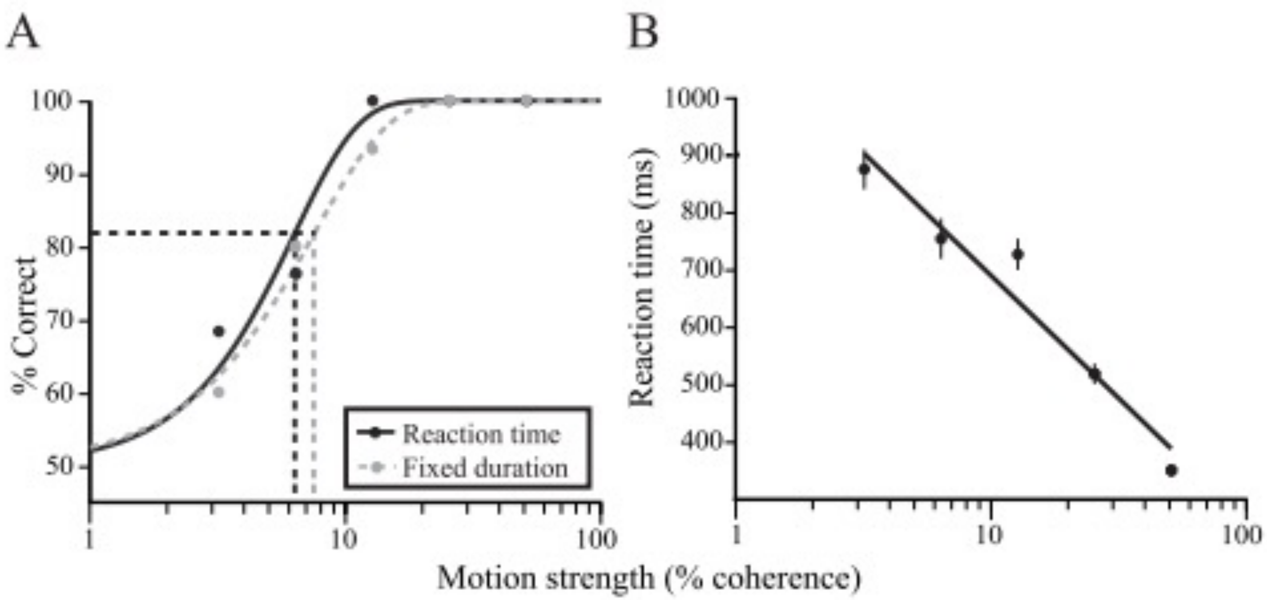






Summary
- We calculate sensory evidence in each frame
- The over sensory evidence accumulates as a drift-diffusion process
- A choice is triggered when accumulated evidence reaches a fixed decision boundary
- The reaction time distribution bears strong resemblance to the empirical reaction time data

Speed-accuracy trade-off



Higher coherence, Higher accuracy, shorter reaction time

Accuracy and reaction time are negatively correlated

Speed-accuracy trade-off

- Conservative decision-maker
  - High accuracy but long reaction time

- Impulsive decision-maker:
  - Short reaction time but low accuracy

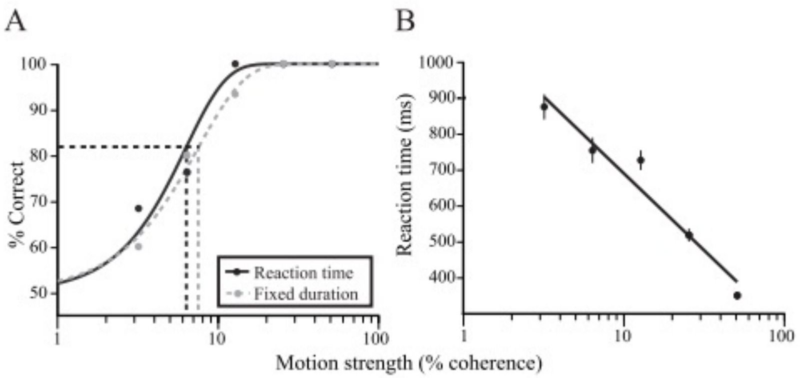
Speed-accuracy trade-off !!!

Can drift-diffusion model account for speed-accuracy trade-off?

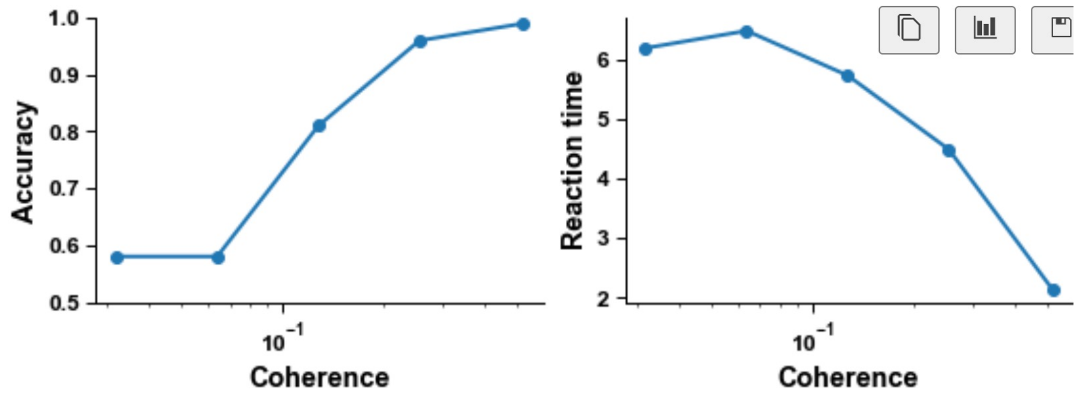
(pdm3.ipynb)

Speed-accuracy trade-off

Empirical data



Our drift-diffusion model



Section 2-Summary

- We calculate sensory evidence in each frame
- The overall sensory evidence accumulates as a drift-diffusion process
- A choice is triggered when accumulated evidence reaches a fixed decision boundary
- The reaction time distribution bears strong resemblance to empirical reaction time data
- Drift-diffusion models can well account for the speed-accuracy tradeoff in perceptual decision making
- Decision impulsivity is associated with decision bounds
    - impulsive = low decision bound
    - conservative = high decision bound

Section 2-real data

- How can we perform drift-diffusion modeling on real data?

(PDM4.ipynb)

Applications-consumer decisions

Consumer decisions

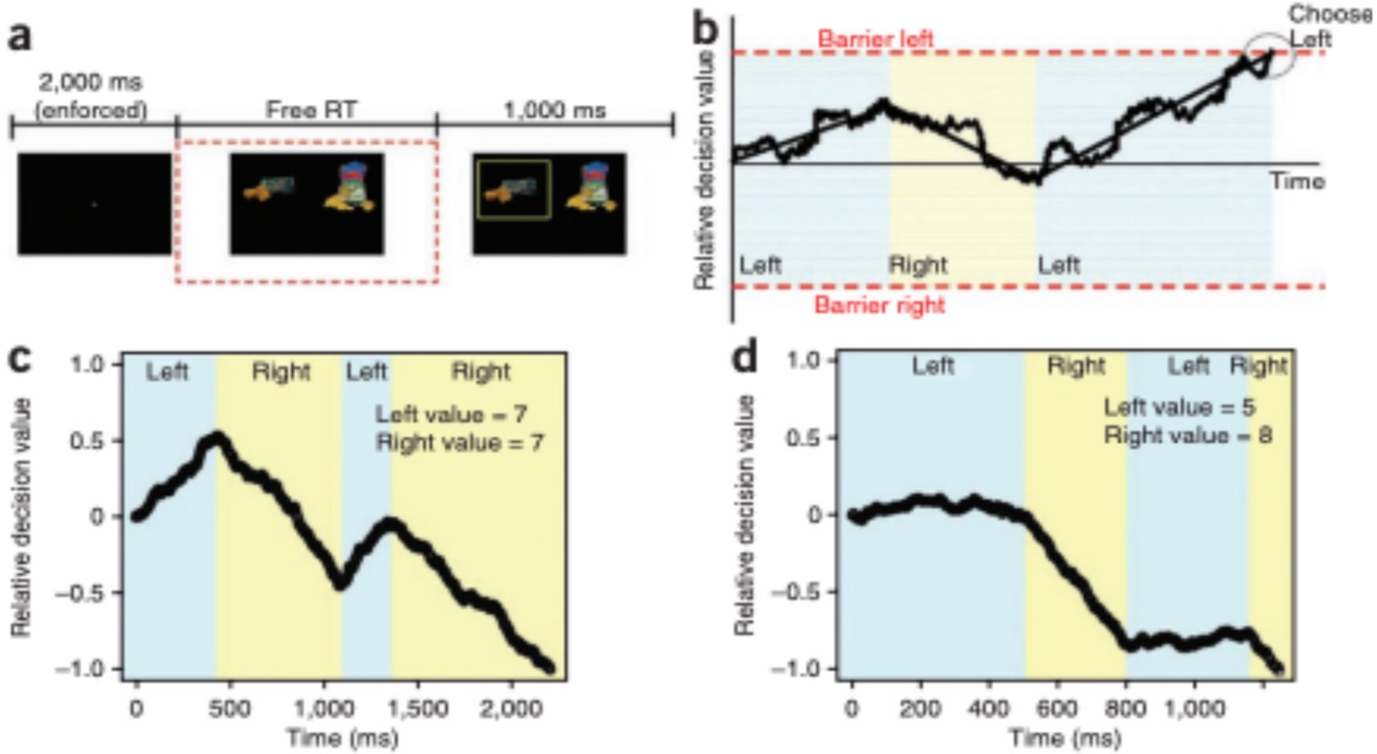
ARTICLES

nature neuroscience

Visual fixations and the computation and comparison of value in simple choice

Ian Krajbich[1], Carrie Armel[2] & Antonio Rangel[1,3]

Applications-consumer decisoins



Applications-social decisions

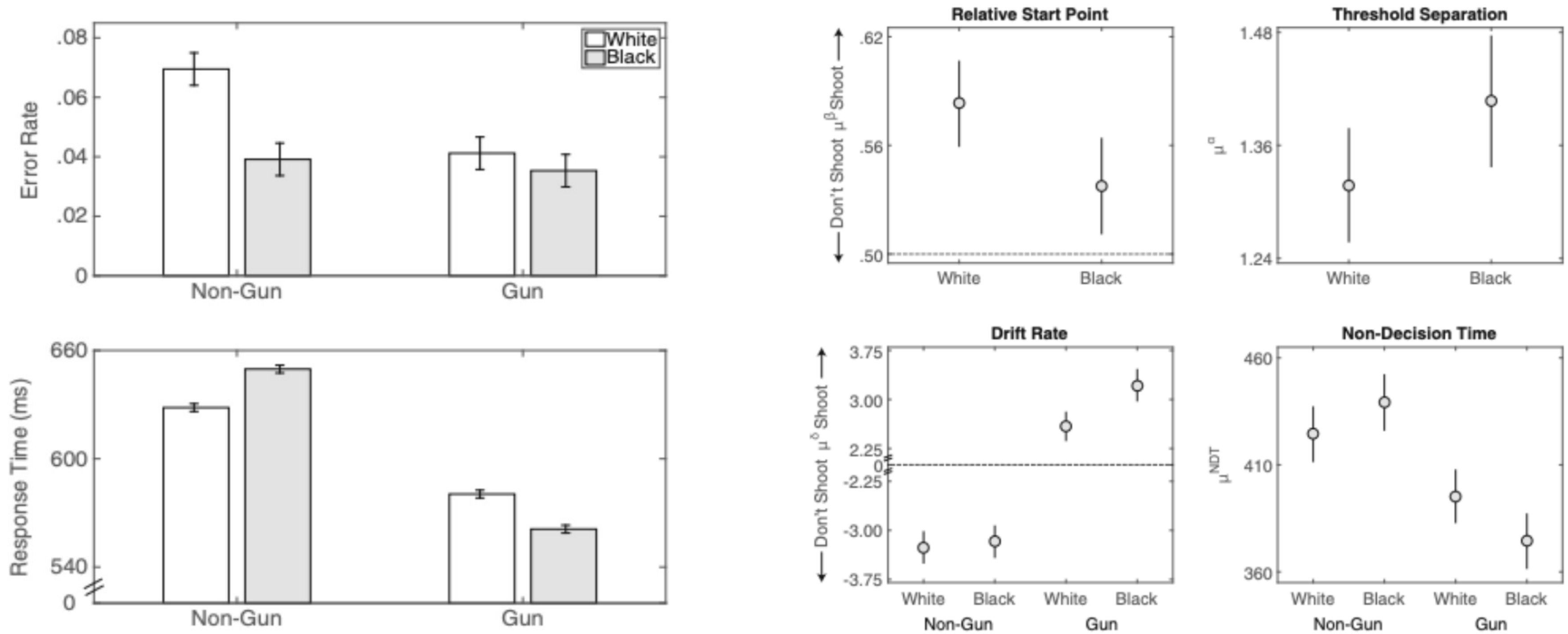
Psychon Bull Rev (2018) 25:1301–1330
https://doi.org/10.3758/s13423-017-1369-6

THEORETICAL REVIEW

How race affects evidence accumulation during the decision to shoot

Timothy J. Pleskac[1] · Joseph Cesario[2] · David J. Johnson[2]

Applications-social decisions



Perceptual Decision-Making

- Section 1: modeling perceptual choice
  - The subject makes a decision by counting dots moving to left/right
  - In real experiments, we test many coherence levels and many stimulus durations in many trials

- Section 2: modeling perceptual choice and reaction time
  - We calculate sensory evidence in each frame
  - The overall sensory evidence accumulates as a drift-diffusion process
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  - Drift-diffusion model can well account for the speed-accuracy tradeoff in perceptual decision making
  - Decision impulsivity is associated with decision bounds
    - impulsive = low decision bound
    - conservative = high decision bound

Advanced materials

- Multi-subjects hierarchical drift-diffusion modeling
- A easy-to-use docker image

Running title: Bayesian HDDM with docker

A Hitchhiker's Guide to Bayesian Hierarchical Drift-Diffusion Modeling with dockerHDDM

Hu Chuan-Peng[1], Haiyang Geng[2], Lei Zhang[3, 4, 5], Alexander Fengler[6], Michael J. Frank[6], Ru-Yuan Zhang[7, 8]

[1] School of Psychology, Nanjing Normal University, Nanjing 210024, China
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[3] Social, Cognitive and Affective Neuroscience Unit, Department of Cognition, Emotion, and Methods in Psychology, Faculty of Psychology, University of Vienna, Vienna, 1010, Austria
[4] Centre for Human Brain Health, School of Psychology, University of Birmingham, Birmingham B15 2TT, UK
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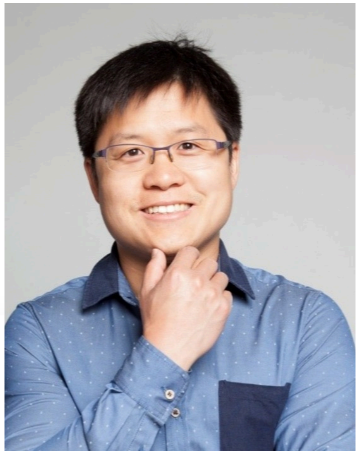
[6] Department of Cognitive, Linguistic and Psychological Sciences, Brown University, Providence, United States
[7] Shanghai Mental Health Center, School of Medicine, Shanghai Jiao Tong University, Shanghai 200030, China.
[8] Institute of Psychology and Behavioral Science, Antai College of Economics and Management, Shanghai Jiao Tong University, Shanghai 200030, China.

Preprint: https://psyarxiv.com/6uzga

Github: https://github.com/hcp4715/dockerHDDM

dockerhub: https://hub.docker.com/r/hcp4715/hddm



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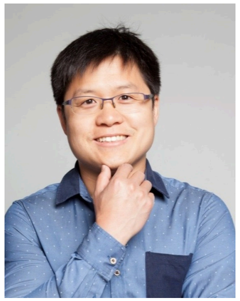
Nanjing Normal University

Acknowledgments

- Teaching Materials
  - Prof. Robert Wilson (U Arizona): http://u.arizona.edu/~bob/web_NSCS344/
  - Prof. Brenden Lake (NYU): https://brendenlake.github.io/CCM-site/

- Collaborators



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Concluding remarks

- This tutorial: https://github.com/ruyuanzhang/20221210_CITUWORKSHOP
- Lab page: https://ruyuanzhang.github.io/
- We hire Postdoc!
    - Cognitive neuroscience, computational neuroscience, neuroimaging