

Computational Modeling of Human Perceptual Decision-Making

Ru-Yuan Zhang(张如源)

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 ?



上海交通大学
SHANGHAI JIAO TONG UNIVERSITY

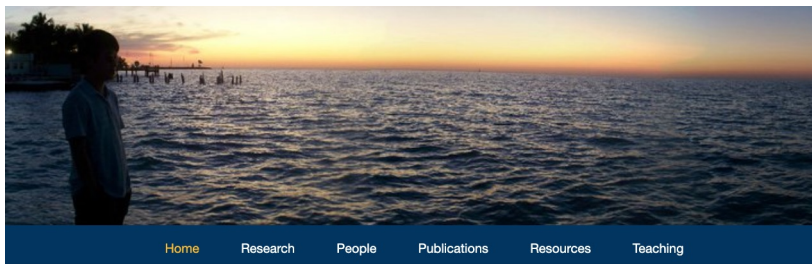
心理与行为科学研究院
Institute of Psychology and Behavioral Science



Associate Professor, Principal Investigator

Laboratory of Cognitive Computational Neuroscience and Neuroimaging

<https://ruyuanzhang.github.io>



Laboratory of Cognitive Computational Neuroscience and Neuroimaging

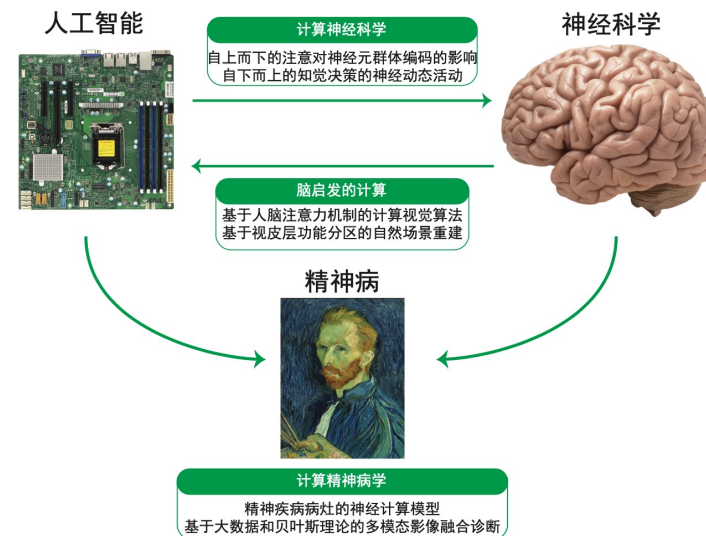
News!

- Oct 10, 2020
 - New lab page is online!
- July 16, 2020
 - New paper about noise correlations in fMRI has been accepted in Plos Computational Biology
- May 14, 2020
 - New paper has been accepted in Neuroimage!
- Jan 06, 2020



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

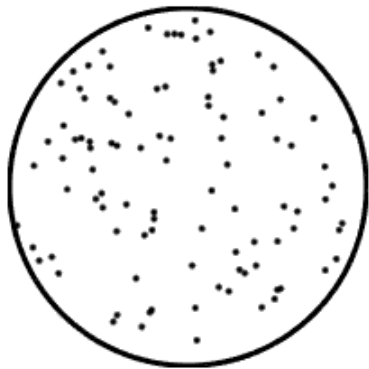
Modeling a simple **perceptual choice**

Section 1

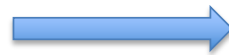
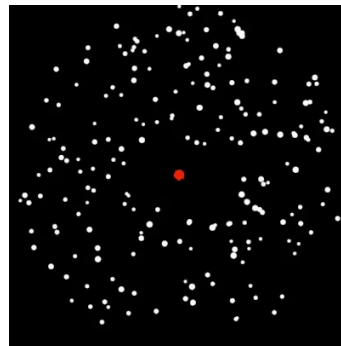
- Simple perceptual decision making

Coherence Level: fraction of dots coherently moving to one direction

Random dot motion (RDM)

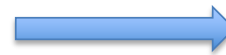
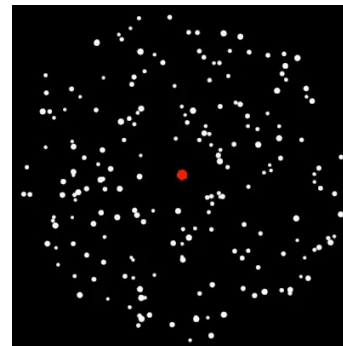


100%



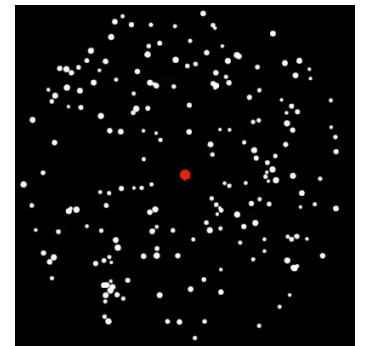
Right

50%



Right

10%



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

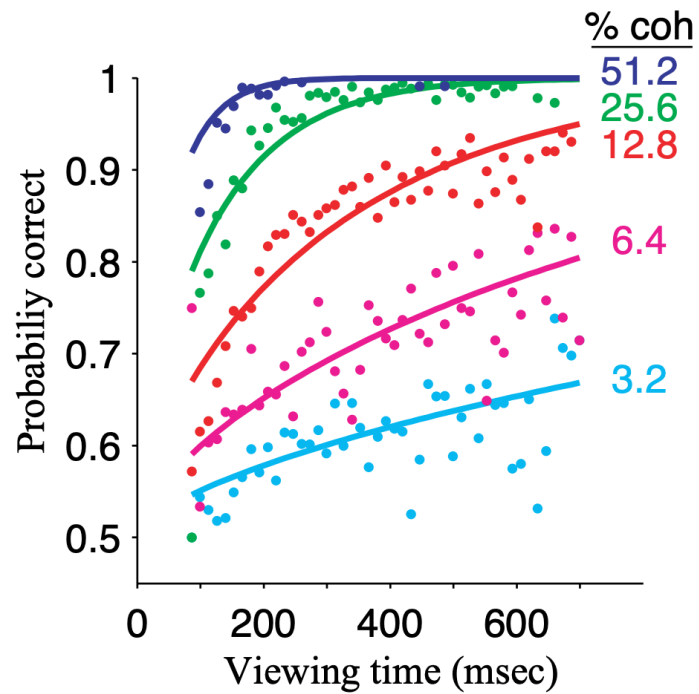
[MN Shadlen](#), [KH Britten](#), [WT Newsome](#)... - Journal of ..., 1996 - Soc Neuroscience

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

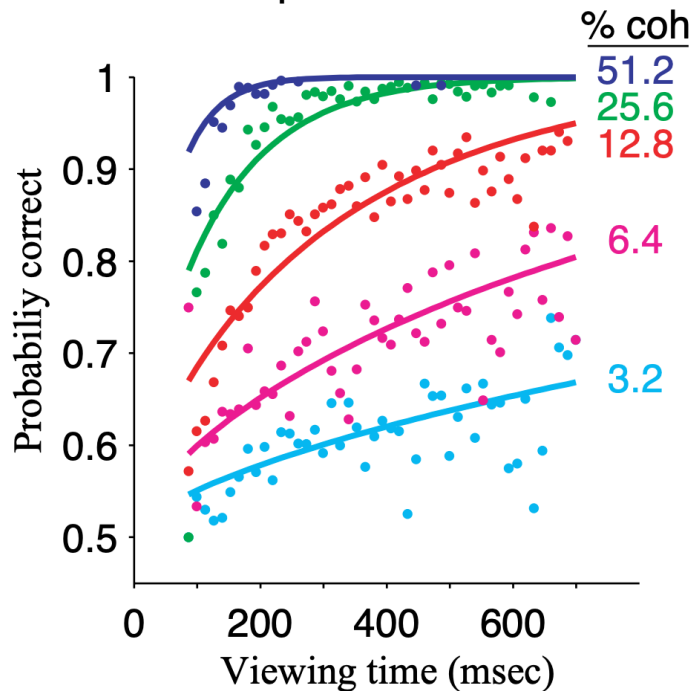
How can we model such a simple perceptual effect??

Perceptual Decision-Making

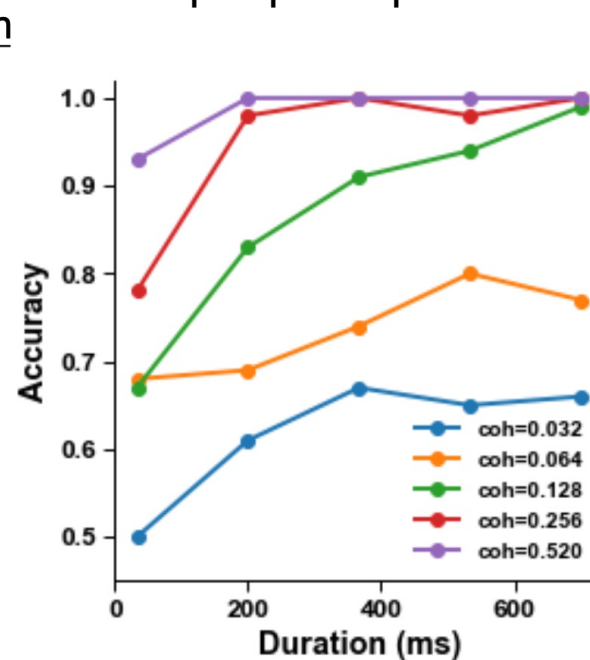
A simple model of perceptual decision-making
(pdm1.ipynb)

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

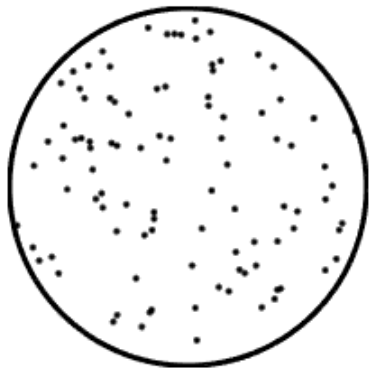
Modeling **perceptual choice** and **reaction time**

Section 2

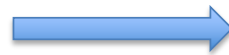
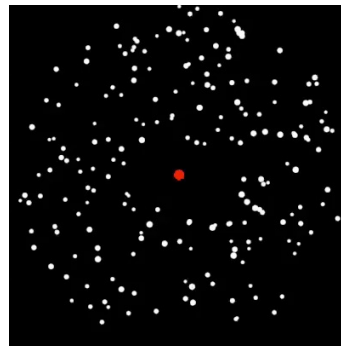
- Simple perceptual decision making

Coherence Level: fraction of dots coherently moving to one direction

Random dot motion (RDM)

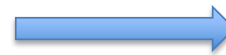
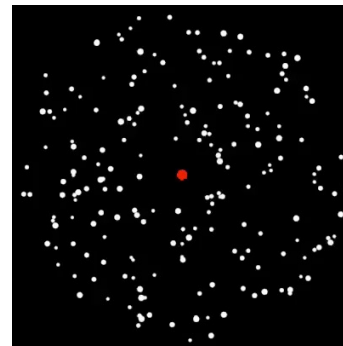


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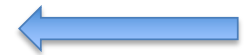
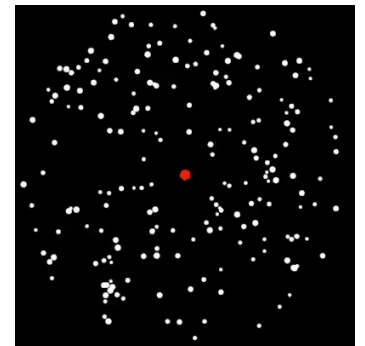
Right

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Right

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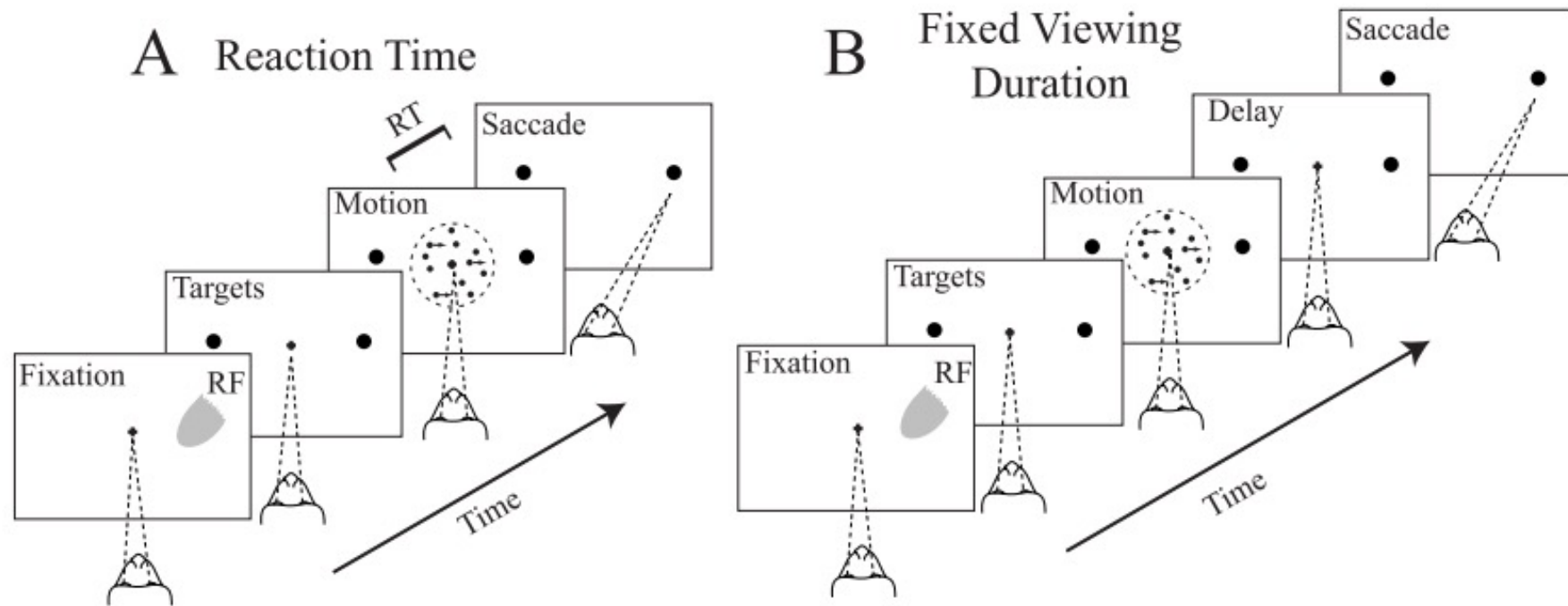


Left

Easy

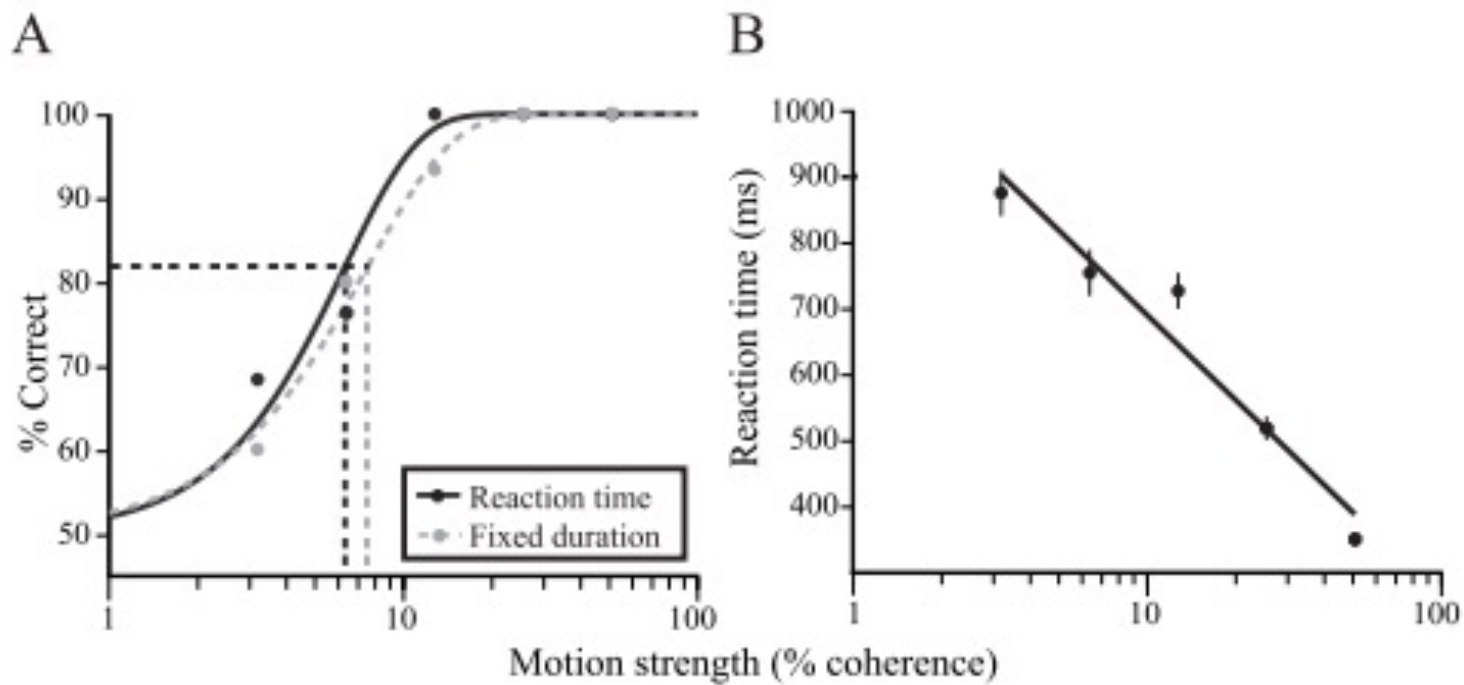
Hard

Perceptual Decision-Making



Roitman&Shadlen, *J. Neurosci.* 2002

Perceptual Decision-Making



Roitman&Shadlen, *J. Neurosci.* 2002

Perceptual Decision-Making

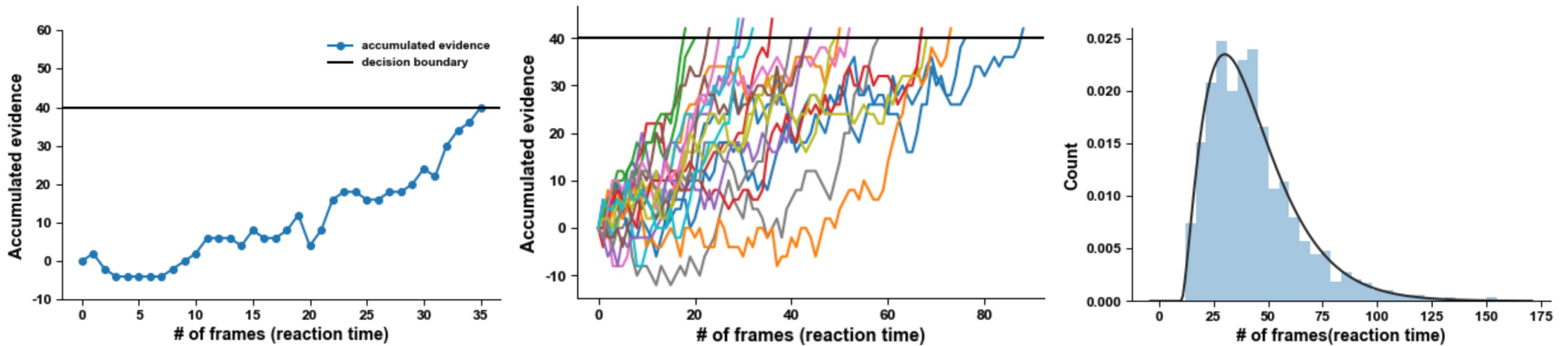
- Drift diffusion model (DDM)
- DDM is one of the most frequently used models in perceptual decision-making

What is drift-diffusion?

- Evidence accumulation
- Drift-diffusion
- Decision boundary

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

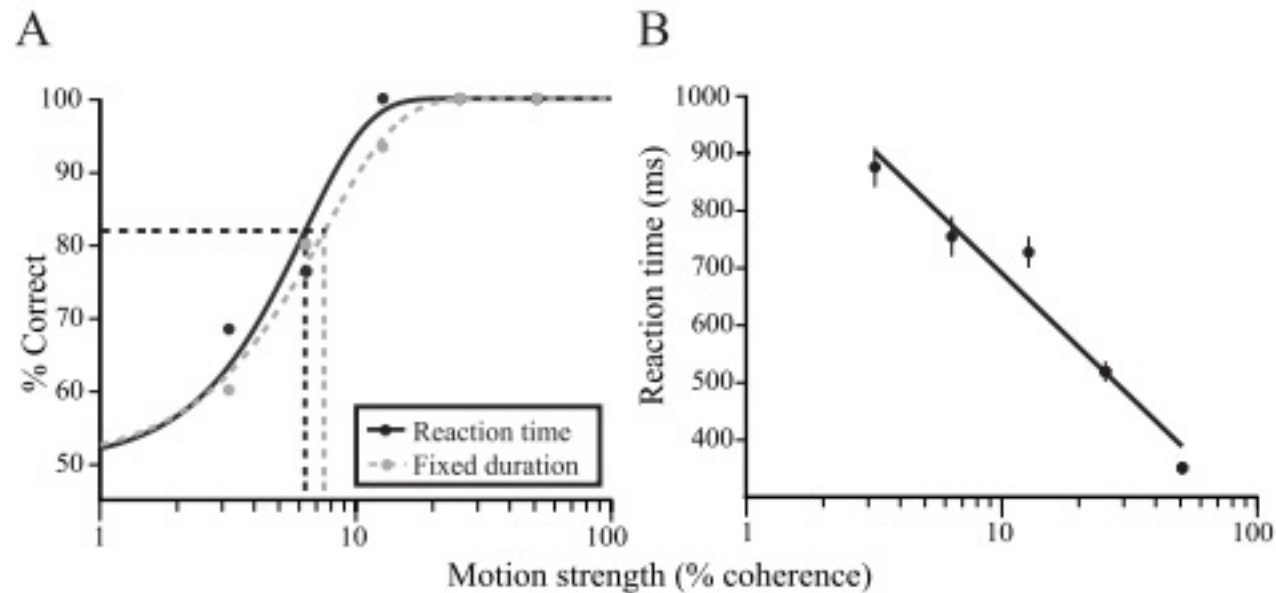
drift-diffusion models



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

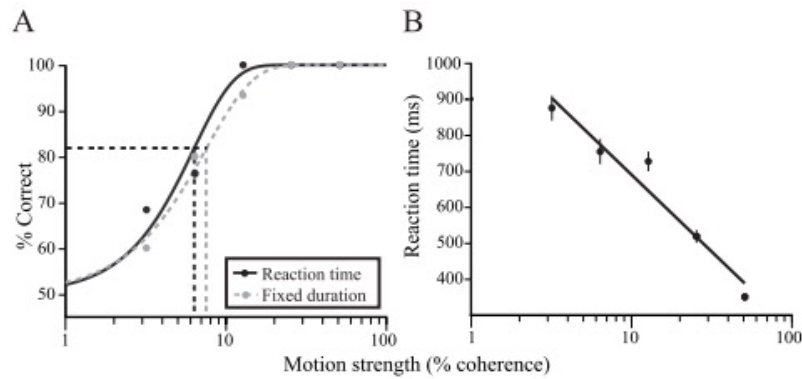
Speed-accuracy trade-off !!!

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

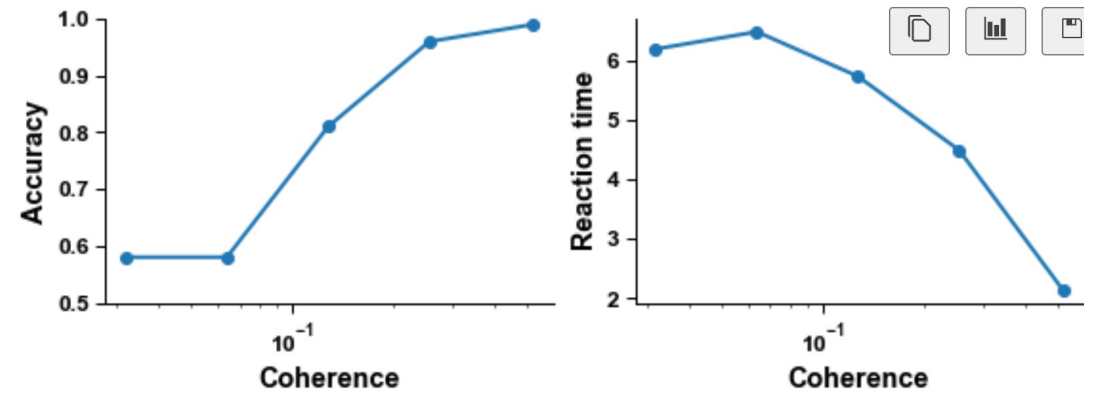
(pdm3.ipynb)

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

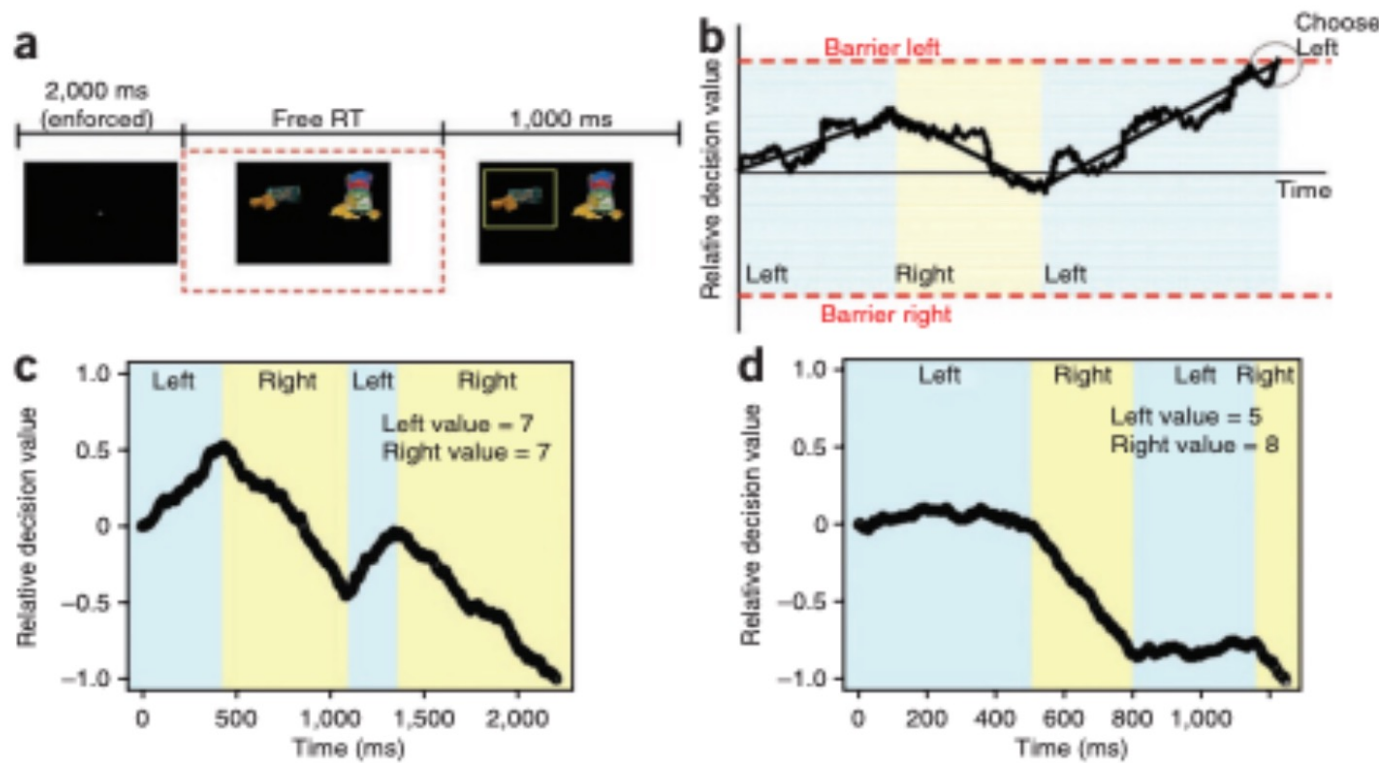
ARTICLES

nature
neuroscience

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

Ian Krajbich¹, Carrie Armel² & Antonio Rangel^{1,3}

Applications-consumer decisions



Applications-social decisions

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

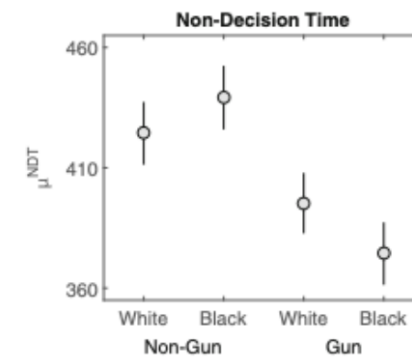
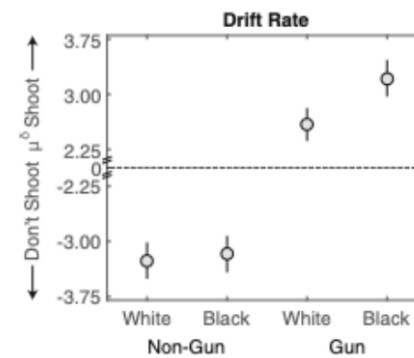
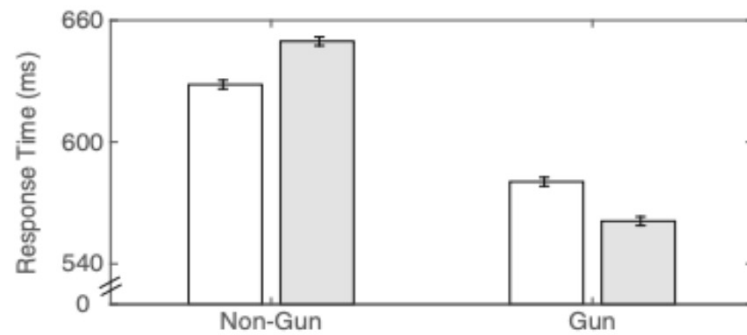
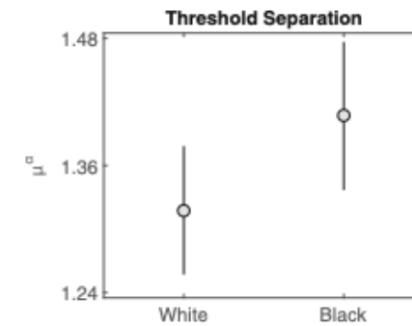
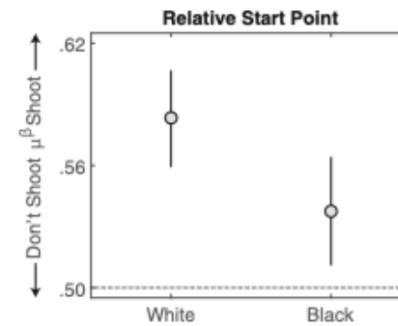
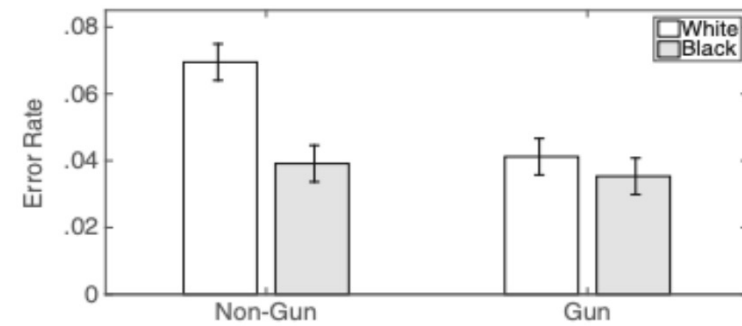


THEORETICAL REVIEW

How race affects evidence accumulation during the decision to shoot

Timothy J. Pleskac¹ · Joseph Cesario² · David J. Johnson²

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
 - A choice is triggered when accumulated evidence reaches a fixed decision boundary
 - 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

1 Running title: Bayesian HDDM with docker

2
3 **A Hitchhiker's Guide to Bayesian Hierarchical Drift-**
4 **Diffusion Modeling with dockerHDDM**

5
6 Hu Chuan-Peng¹, Haiyang Geng², Lei Zhang^{3,4,5}, Alexander Fengler⁶, Michael J. Frank⁶, Ru-
7 Yuan Zhang^{7,8}

8
9 ¹ School of Psychology, Nanjing Normal University, Nanjing 210024, China

10 ² Tianqiao and Chrissy Chen Institute for Translational Research, Shanghai, China

11 ³ Social, Cognitive and Affective Neuroscience Unit, Department of Cognition, Emotion, and
12 Methods in Psychology, Faculty of Psychology, University of Vienna, Vienna, 1010, Austria

13 ⁴ Centre for Human Brain Health, School of Psychology, University of Birmingham,
14 Birmingham B15 2TT, UK

15 ⁵ Institute for Mental Health, School of Psychology, University of Birmingham, Birmingham
16 B15 2TT, UK

17 ⁶ Department of Cognitive, Linguistic and Psychological Sciences, Brown University,
18 Providence, United States

19 ⁷ Shanghai Mental Health Center, School of Medicine, Shanghai Jiao Tong University, Shanghai
20 200030, China.

21 ⁸ Institute of Psychology and Behavioral Science, Antai College of Economics and Management,
22 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>



Chuan-Peng Hu, Professor
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



Chuan-Peng Hu
Nanjing Normal
University

2022/12/10



Lei Zhang
Univ. Birmingham



Haiyang Geng
TCCI



Alexander Fengler
Brown



Michael Frank
Brown

Concluding remarks

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

Home Research People Publications Resources Positions

Laboratory of Cognitive Computational Neuroscience and Neuroimaging

News!

Nov 11, 2022

We are pleased to announce our preprints recently released. I started this projected two years ago during COVID-19 pandemic. It is finally out.

- Cheng, Z.-J., Zhang, W.-H., **Zhang, R.Y.***. Representational geometries reveal differential effects of response correlations on population codes in neurophysiology and functional magnetic resonance imaging. [bioRxiv](#)

Nov 11, 2022

We are pleased to announce several preprints recently released.

- Hu, C.P.*, Geng, H., Zhang, L., Fengler, A., Frank, M.J., Zhang, R.Y.*. A Hitchhiker's Guide to Bayesian Hierarchical Drift-Diffusion Modeling with dockerHDDM. [PsyArXiv](#) [PsyArXiv](#)
- Tomoko Kishimoto, Sun, L., Wang, C., Xu, H., Fu, Y., Cheng, Z.J., Jin, J., Zhang, R.Y*. Psychophysical and Computational Signatures of Visual Working Memory Deficits in Adolescents with Anxiety Disorder. [PsyArXiv](#)

April 29, 2022

- 10.5T paper "Ultra-high field (10.5T) diffusion-weighted MRI of the macaque brain" published in Neuroimage [Link](#)

March 29, 2022

- Comment article "Promoting computational psychiatry in China" is online in Nature Human Behavior. We argue that development of computational psychiatry can greatly benefit confronting mental health problems in China. [Link](#)

March 03, 2022

We are recruiting undergraduate research assistants and graduate students!!! Let me know if you are interested in Cognitive Science, Computational Psychiatry, and Neuroimaging. See details in [Resources section](#)