

# **Cognitive Neuroscience Studies of Decision Making in a Social Context:**

## **Overview of Princeton Team Activities**

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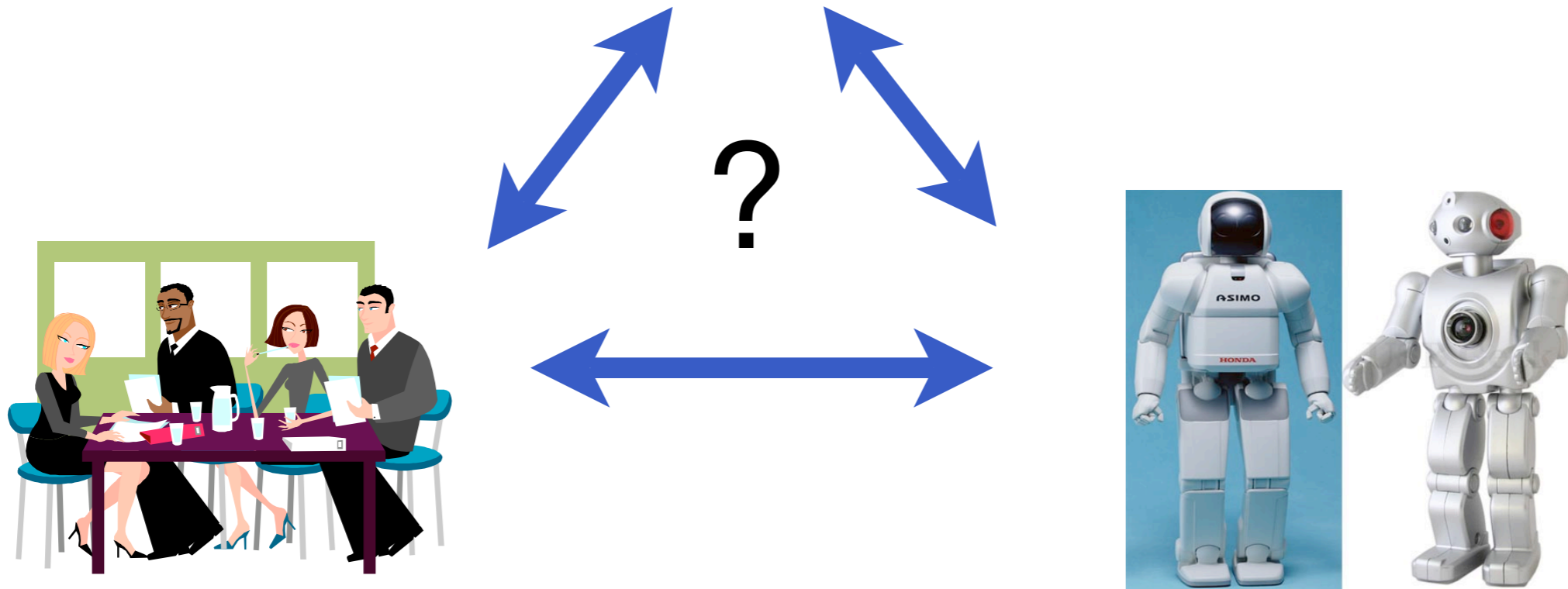
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# Mixed Human/Robot Decision-Making Teams

## Complex Task



Challenge: How can mixed teams of humans and robots best jointly contribute to decision-making?

Profitable integration should take advantage of strengths of human and robotic decision-makers.

# Princeton Team Members

## Faculty:

Jonathan Cohen, Psychology and Princeton Neuroscience Institute

Philip Holmes, Mechanical & Aerospace Engineering, Applied & Computational Mathematics, and Neuroscience

Naomi Leonard, Mechanical and Aerospace Engineering

Deborah Prentice, Psychology

## Post-Docs:

Ioannis Poulakakis, Mechanical and Aerospace Engineering

Damon Tomlin, Psychology and Neuroscience

Ming Cao, Mechanical and Aerospace Engineering (now Assistant Professor at University of Groningen)

Luca Scardovi, Mechanical and Aerospace Engineering (now Assistant Professor at Technical University of Munich)

## Graduate Students:

Emily Chakwin, Psychology

Andrea Nedic, Electrical Engineering

Andrew Stewart, Mechanical and Aerospace Engineering

Michael Todd, Psychology and Neuroscience

George Young, Mechanical and Aerospace Engineering

Benjamin Nabet, Mechanical and Aerospace Engineering (graduated with PhD, September 2009)

## Undergraduate Student:

Chris Baldassano, Electrical Engineering (now graduate student at Stanford)

## Research Staff:

Laura DeSouza, Psychology

Peter Foster, Psychology



# Interaction Among Team Members

Regular team meetings twice per month.

More frequent meetings among smaller (multidisciplinary) teams of people.

Exchanges between psychologists, neuroscientists and engineers/applied mathematicians have been central to our research activities and have provided a valuable model for our interdisciplinary training programs



# Collective Decision Dynamics: Research Areas

In human-in-the-loop systems, humans often faced with making repeated choices among finite alternatives in response to observations of evolving system performance (**sequential decision making**).

- human supervisory control of multiple UAV's where choices to be made between attending to targets and ensuring safe return of vehicles.
- human flight control operators face choices, e.g., whether or not to ground each of many vehicles in bad weather.
- human allocation control of foraging vehicles where choices to be made between surveillance and interrogation role for each vehicle.

In order to design humans into such systems, we pursue development of a **systematic description** of human decision making in social contexts.

We derive systematic descriptions of human decision making from **behavioral experiments** further supported by **neural evidence**.



# Selected Publications

Nedic, Tomlin, Holmes, Cohen and Prentice (2008) A simple decision task in a social context: experiments, a model and preliminary analysis of behavioral data, *Proc. IEEE CDC*.

Cao, Stewart and Leonard (2008) Integrating human and robot decision-making dynamics with feedback: Models and convergence analysis, *Proc. IEEE CDC*.

Scardovi and Leonard (2009) Robustness of aggregation in networked dynamical systems, *Proc. ROBOCOMM'09*, Odense, Denmark.

Nabet, Leonard, Couzin and Levin (2009), Dynamics of decision making in animal group motion, *J. Nonlinear Science*, vol. 19, pp. 399-435.

Stewart, Cao and Leonard, Steady-state distributions for human decisions in two-alternative choice tasks, *Proc. 2010 ACC* (in review).

Young, Scardovi and Leonard, Robustness analysis of consensus protocols, *Proc. 2010 ACC* (in review).

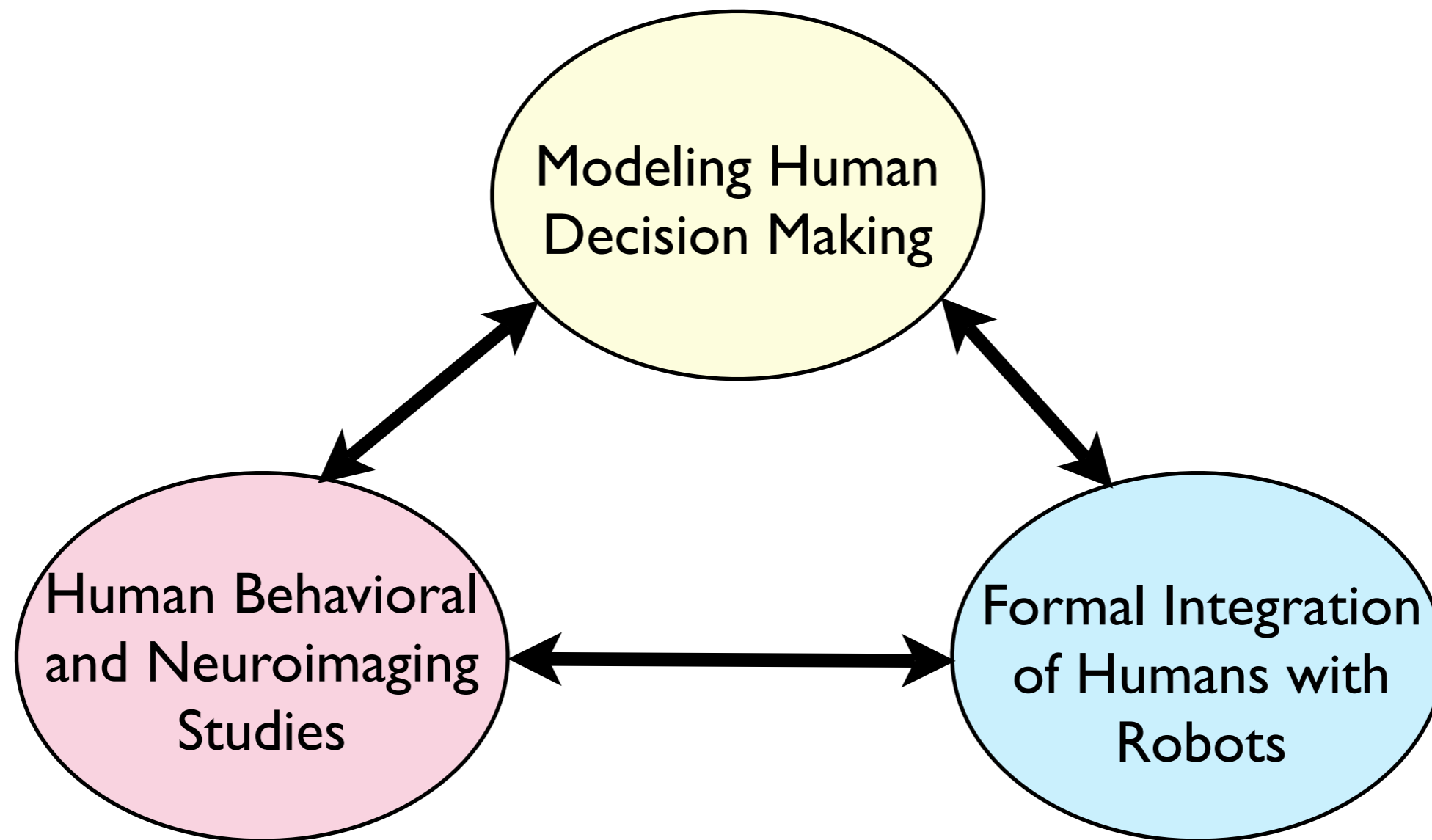
Poulakakis, Scardovi and Leonard, Coupled stochastic differential equations and collective decision making in the two-alternative forced-choice task, *Proc. 2010 ACC* (in review).

Cao, Stewart and Leonard, Convergence in human decision-making dynamics, *Sys. Control Letters* (in review).

Holmes, Nedic, Tomlin, Prentice and Cohen, A decision task in a social context: behavioral experiments, models and analyses of behavioral data (in preparation).



# Collective Decision Dynamics: Multidisciplinary Approach



# Human Behavioral and Neuroimaging Studies and Modeling Human Decision-Making

Cognitive neuroscience research as it applies to decision dynamics of teams of humans and robots.

First formal cognitive neuroscience model of multiple human decision makers with social interactions.

Data-driven modeling of interactions among individual decision makers

- Aided by data analysis, modeling techniques from engineering/applied mathematics.

Leverage access to the brain

- Seek more proximal measures of underlying mechanisms to parameterize models.
- Make more accurate predictions of behavior.

Understand conditions that produce observed collective behaviors, e.g., herding

- When does social interaction help/hurt decision-making performance?



# Formal Integration of Humans with Robots

Analyze human decision dynamics using empirically fitted models of human decision making and insights from human behavioral and neuroimaging studies. Use models to explore strengths and weaknesses of human decision-makers with and without social interactions.

Study and prove convergent behavior, sensitivity to parameters, influence of interactions, comparison to optimal benchmarks.

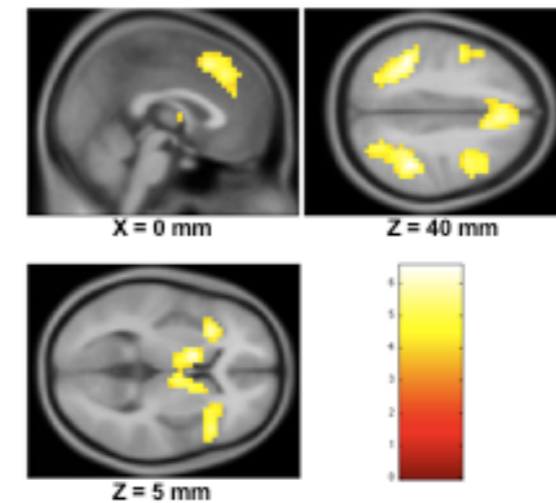
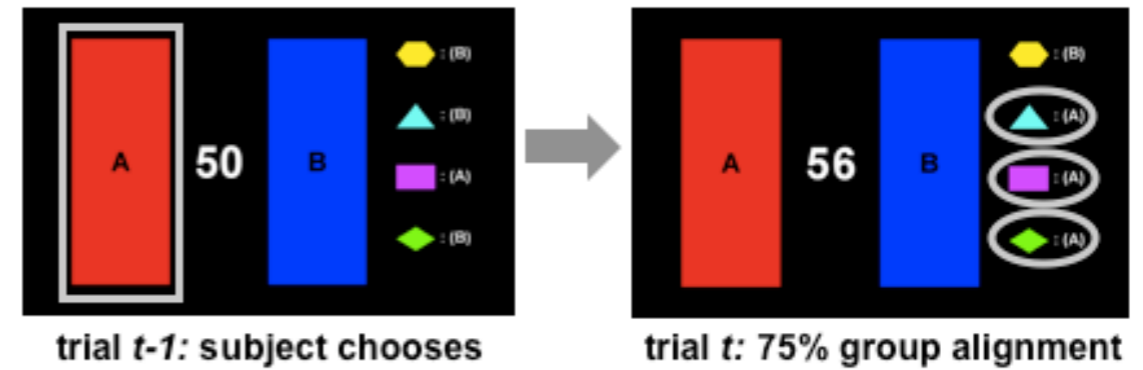
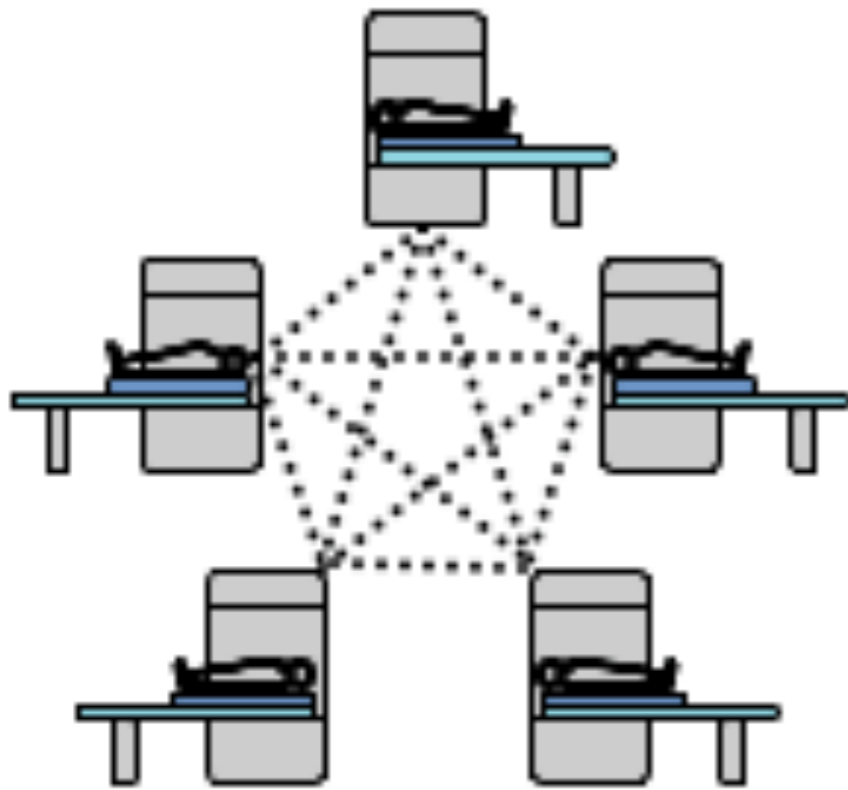
Investigate conditions in which human subjects are sufficiently representative of human operators/collaborators performing complex tasks.

Use analysis results to design strategies for making best joint use of humans and robots in challenging decision making tasks.

- Consider human as supervisor to robot teams.
- Consider humans and robots with common models for joint decision making.



# Research Highlights

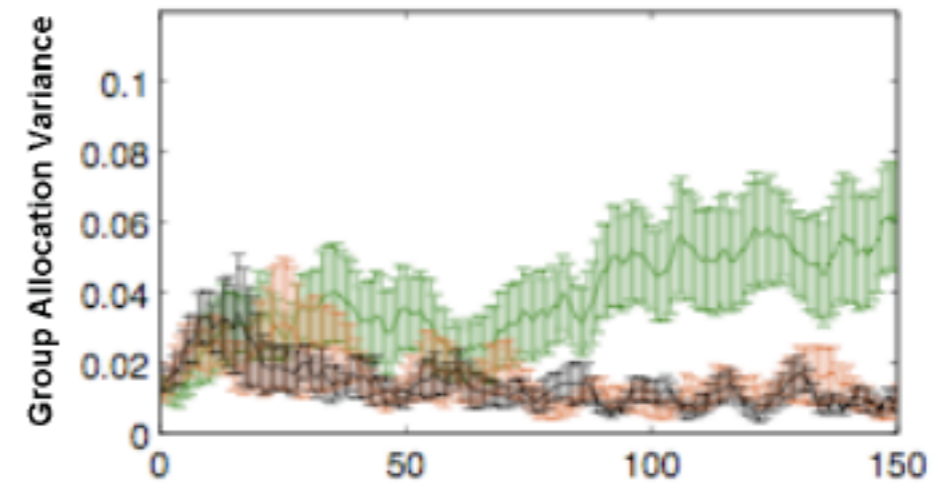
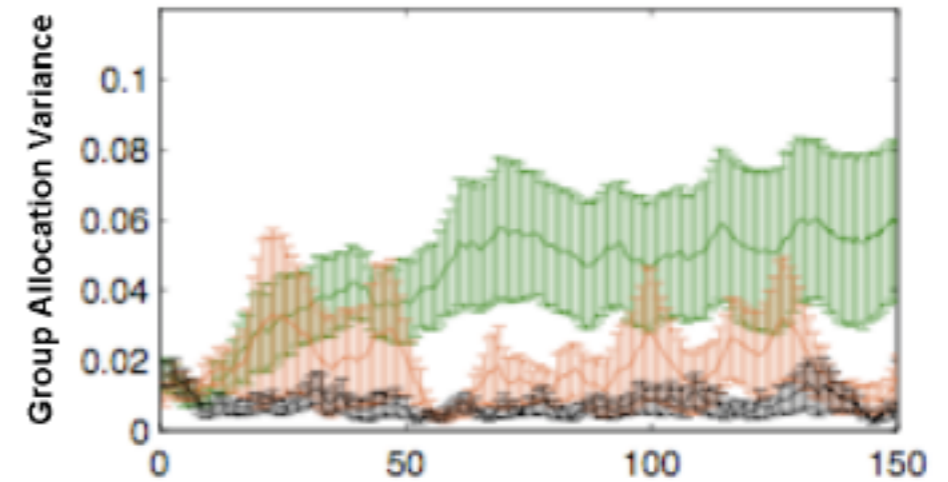
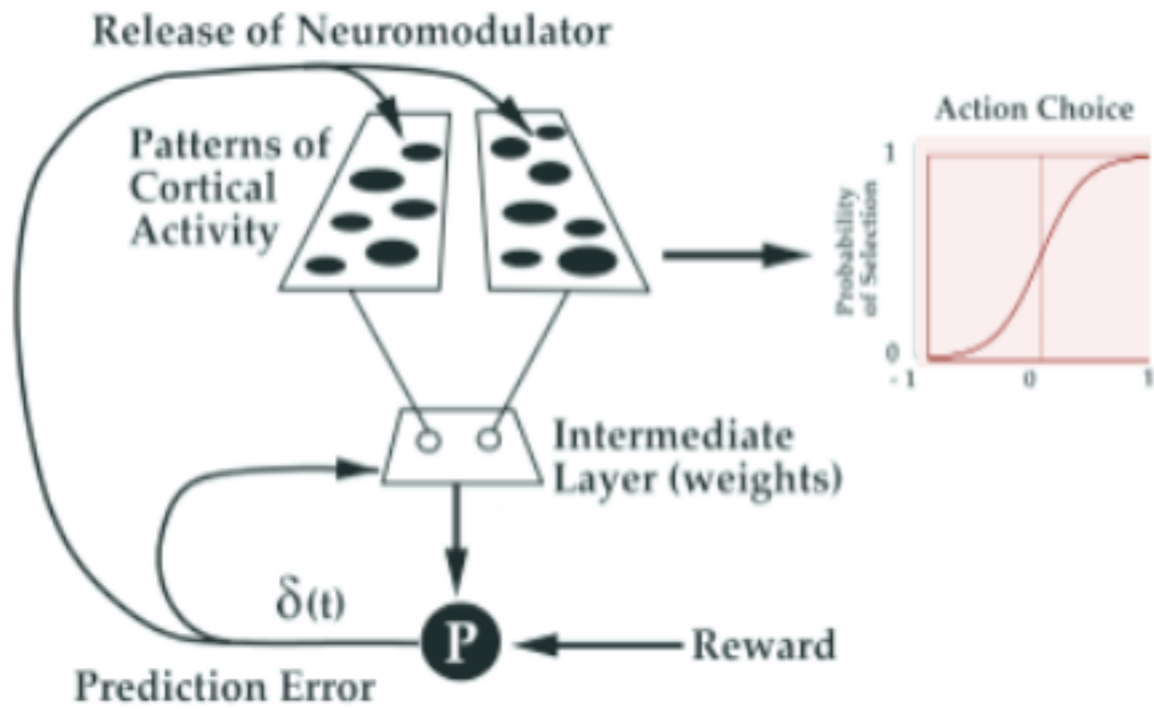


Simultaneous neuroimaging of five human subjects performing decision-making tasks in a social context

Combination of neuroimaging and social information predict behavioral performance better than social information alone.



# Research Highlights

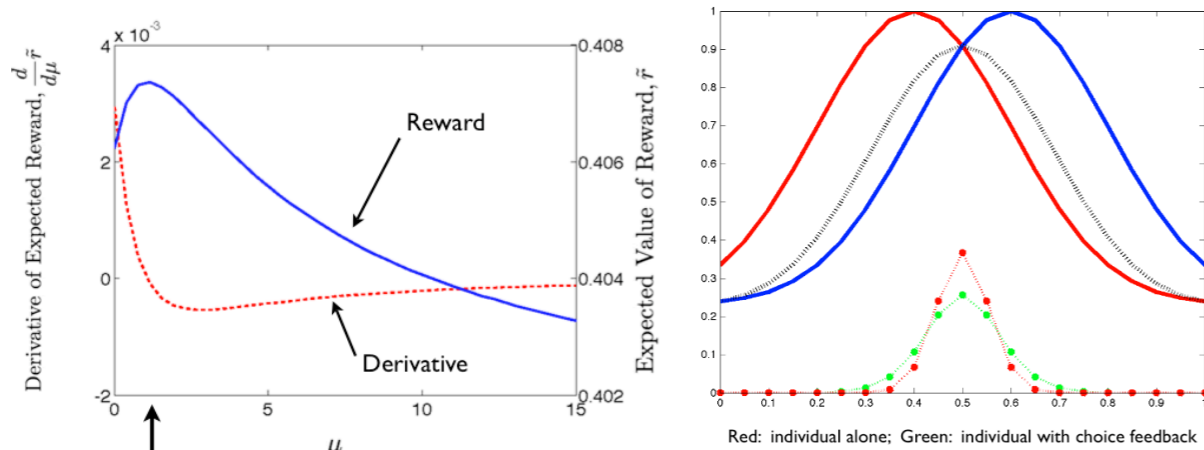


Individual choice model informed by neurobiologically based learning studies. Social feedback models parameterized by behavioral data.

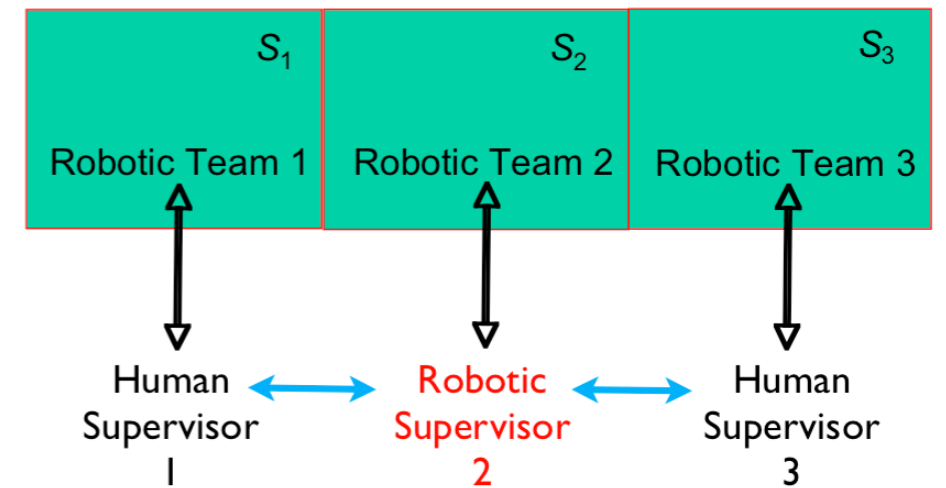
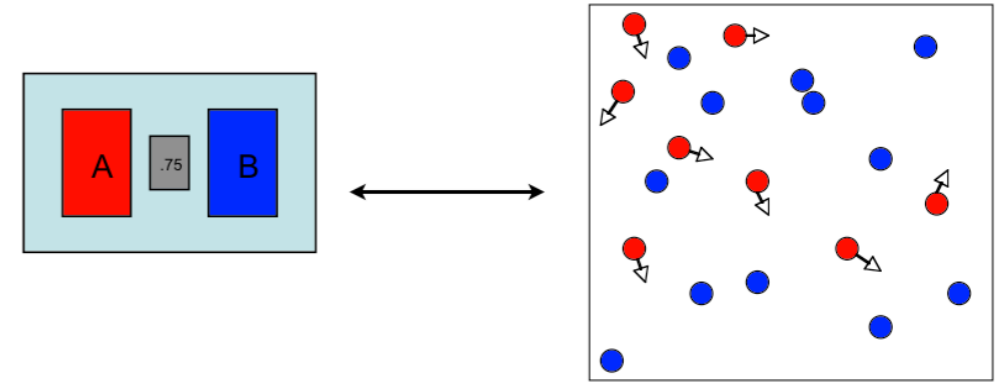
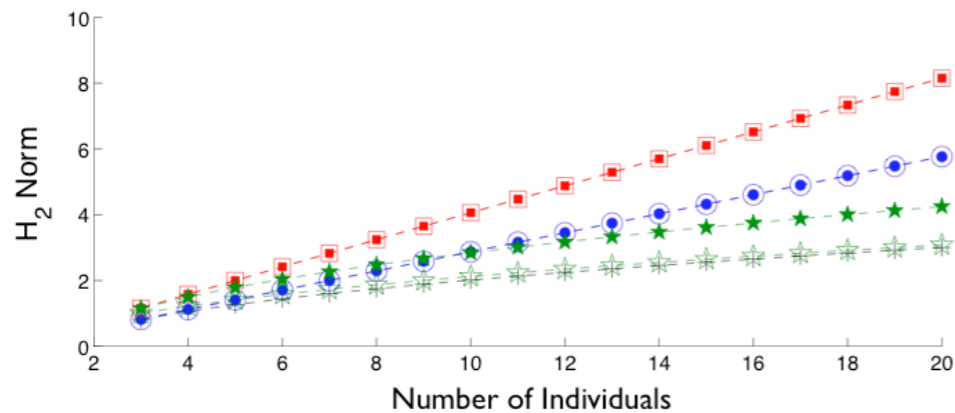
Comparison of choice behavior in social context with model predictions.



# Research Highlights



+ Complete ○ Directed Cycle ● Undirected Cycle □ Directed Path ■ Undirected Path ☆ Directed Star ★ Undirected Star



Model analyses reveal sensitivity of performance to characteristics of decision makers. Interconnection topology affects robustness to uncertainty.

Integrated design uses map from human subjects to human supervisors and common models for human and robot collaborators.



# Plans through MURI Option Years

Improve predictive behavioral models, especially by use of neuroimaging data.

Leverage individual neuroimaging results via model parameter fits to further elucidate underlying mechanisms.

Conduct and study experiments with variations on environment and available information.

Formalize mechanisms for managing exploration and exploitation.

Analyze coupled decision-making models with increased complexity for parametric sensitivities and comparison to optimal benchmarks.

Investigate role of interconnection topology in sequential decision making.

Design and implement strategies for mixed teams of humans and robots with humans as collaborators and as supervisors.



# Additional Princeton Interactions

## With others at Princeton:

Collaboration with Prof. Iain Couzin (Ecology and Evolutionary Biology, Princeton) on collective decision-making in schooling fish (communication through action).

Pat Simen (Post-doc, Psychology/Applied Math., Princeton)

Stephanie Goldfarb (Graduate student, Mechanical and Aerospace Engineering, Princeton)

KongFatt Wong-Lin (Post-doc, Psychology/Applied Math., Princeton)

## With other MURI team members:

Interactions with Boston University

- Design of experiments with humans and robots
- Explore versus exploit paradigm in resource collection tasks

Interactions with University of Washington

- Results of human behavioral studies
- Convergence analysis of human decision-making models.

Interactions with University of California, Santa Barbara

- Sequential Probability Ratio Test (SPRT) algorithms and drift diffusion models.

Interactions with Prof. Emilio Frazzoli (MIT, AFOSR funded center)

- Integration of humans with robots

