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## Developmental and computational perspectives on infant social cognition

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Adults effortlessly and automatically infer complex patterns of goals, beliefs, and other mental states as the causes of others' actions. Yet before the last decade little was known about the developmental origins of these abilities in early infancy. Our understanding of infant social cognition has now improved dramatically: even preverbal infants appear to perceive goals, preferences (Kushnir, Xu, & Wellman, in press), and even beliefs from sparse observations of intentional agents' behavior. Furthermore, they use these inferences to predict others' behavior in novel contexts and to make social evaluations (Hamlin, Wynn, & Bloom, 2007).

Inspired by this work, computational modelers have in the last few years begun to formalize the knowledge and inference mechanisms underlying infants' social reasoning (Baker, Saxe, & Tenenbaum, 2009; Lucas, Griffiths, Xu, & Fawcett, 2009; Ullman et al., 2010). Many of these models share deep similarities, explaining social inference in terms of an intuitive understanding of how an agent chooses among actions. For instance, the principle of rational action, suggested in seminal work on infant social cognition (Gergely, Nádasdy, Csibra, & Biró, 1995), states that agents will select the best action to achieve their goals, given the constraints of their environment – or in a more sophisticated version, given their beliefs about the environment. This principle has been formalized using notions of planning and decision-making from economics and computer science. It underlies models that make accurate quantitative predictions of the social inferences of adults and young children in a variety of experimental tests.

The goal of this symposium will be to bring together developmental psychologists and computational modelers in a dialogue on the social inferences made by young infants, the mechanisms by which these inferences work and become more sophisticated in older children. The first talk of the symposium (Baker et. al) will briefly survey now-classic work on infants' understanding of goals and beliefs, and will introduce a general computational framework for modeling these social inferences based on intuitive principles of rational action. Next will be two pairs of developmental and computational talks, focusing on recent advances where there has been important exchange between empirical work and models. Kushnir, et al, and Lucas, et al, will describe work on understanding of others' preferences. Hamlin, et al, and Ullman, et al, will describe attribution of "prosocial" goals (such as helping). The symposium will conclude with a discussion led by Spelke, highlighting gaps in our understanding of infant social cognition, areas where more computational work is needed, and where computational ideas might suggest new areas for developmental experiments.

Close interaction and collaboration between developmentalists and computational modelers studying infant social cognition is a fairly recent trend, yet it has already proven fruitful, as the talks in this symposium hope to demonstrate. Previously, the research to be presented here has been discussed primarily at conferences on computational modeling (e.g., NIPS) or developmental psychology (e.g., the Cognitive Development Society), or in small workshops bringing together modelers and experimentalists. The Cognitive Science Conference would be an ideal venue for a broad symposium on this emerging, interdisciplinary subfield, due to its tradition of bringing together theorists and experimentalists from a broad array of disciplines. We expect the symposium will interest a wide audience and lead to new research directions and collaborations engaging different segments of the Cognitive Science audience.

## Probabilistic models of belief-desire psychology

**Baker, Goodman & Tenenbaum** We propose a computational

framework for modeling how humans interpret intentional actions in terms of the mental states that cause behavior: chiefly, beliefs and desires. The framework represents a schema for intentional action using rational models of belief- and goal-based planning from economics and computer science known as partially observable Markov decision problems. Agents' beliefs and desires are inferred by inverting this model of rational planning using Bayesian inference, integrating the likelihood of the observed actions with the prior over mental states. This approach formalizes in precise probabilistic terms the essence of previous qualitative approaches to infant action understanding, (*e.g.* Gergely et al., 1995). We will present results showing that our models account for infants' and adults' social judgments from a body of experiments, from simple inferences about goals, to joint inferences of preferences and beliefs. We will also consider how a set of alternative, heuristic-based models compare to our account.

### Young children use statistical sampling to infer the preferences of others

**Kushnir, Wellman & Gelman**  Psychological scientists use statistical information to determine the workings of fellow humans. We argue so do young children. In a few years, children progress from viewing human actions as intentional and goal-directed to reasoning about the psychological causes underlying such actions. Here we show that preschoolers and 20-month-old infants can use statistical information – namely, a violation of random sampling – to infer that an agent is expressing a preference for one object over another. Children saw a person remove 5 items of one type from a container of objects. Preschoolers and infants only inferred a preference for that type of object when there was a mismatch between the sample and population. Mere outcome consistency, time spent with and positive attention toward the objects did not lead children to infer a preference. The findings provide an important demonstration of how statistical learning could underpin the rapid acquisition of early psychological knowledge.

### A rational model of preference learning and choice prediction by children

**Lucas, Griffiths, Xu & Fawcett**  We present a rational model of preference learning that explains the behavior of children in several recent experiments, as well as a developmental shift in which children come to understand that people have distinct preferences. We first show that a simple econometric model can account for young children's use of statistical information in inferring preferences and their ability to generalize others' preferences from one category to another. We then consider the question of how children begin to treat other individuals as having preferences that can differ from their own, showing that such a transition is consistent with Bayesian inference, given a model in which all people share preferences and one in which preference can vary as possibilities. Finally, we discuss novel predictions made by our model concerning preference understanding and the developmental shift.

### The enemy of my enemy is my friend: Infants interpret social behaviors in context

**Hamlin, Wynn & Bloom**  Recent research suggests that young infants prefer prosocial to antisocial individuals (Hamlin et al., 2007). While a preference for those who help others is certainly adaptive, there are potentially situations in which unhelpful behavior is more appropriate (*e.g.* punishing others for their wrongdoing) or more socially diagnostic (*e.g.* "The enemy of my enemy is my friend," Aronson & Cope, 1968). This talk examines whether infants always prefer those who are prosocial, in contexts in which antisocial behavior could be seen as punishment, or in which an individual's antisocial behavior may be an indication that he or she shares a negative opinion toward a disfavored other. Results suggest that even in the first year of life, infants evaluate behaviors not only in terms of their valence, but also in terms of certain qualities of their recipients.

### Help or hinder: Models of social goal inference

**Ullman, Baker, Goodman & Tenenbaum**  Everyday social interactions are heavily influenced by our snap judgments about others' goals. Even young infants can infer the goals of intentional agents from observing how they interact with objects and other agents in their environment: e.g., that one agent is 'helping' or 'hindering' another's attempt to get up a hill or open a box. We propose a model for how people can infer these social goals from actions, based on inverse planning in multiagent Markov decision problems. The model infers the goal most likely to be driving an agent's behavior by assuming the agent acts approximately rationally given environmental constraints and its model of other agents present. We also present behavioral evidence in support of this model over a simpler, perceptual cue-based alternative.

### Discussion: Open challenges and future directions

**Spelke**  The closing discussion will draw out gaps in our current understanding of infant social cognition, areas where more computational work is needed, and places where computational ideas might suggest new areas for developmental experiments.

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