8   Design for Learning: The Case of Chasing

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Abstract

Often, mental development is viewed as resulting either from domain-general learning mechanisms or from highly specialized modules containing substantial innate knowledge. However, an evolutionary developmental perspective suggests that learning and specialization are not necessarily in opposition. Instead, natural selection can favor learning mechanisms that rely on information from the environment to construct adaptive phenotypes, exploiting recurrent properties of fitness-relevant domains. Here we consider the possibility that early action understanding is centered on domain-specific action schemas that guide attention towards domain-relevant events and motivate learning about those domains. We examine chasing as a case study. We report studies (1) exploring the mechanisms that guide infants' attention to chasing events and (2) examining the inferences and judgments that children and adults make. We argue that these findings are consistent with the possibility that natural selection has built "islands of competence" in early action understanding that serve as kernels for future learning and development.

Introduction

The nature-nurture debate has mostly died in biology, but it is still actively discussed in the social sciences. The reason it has largely disappeared from discussions of biology is that progress in our understanding of human development has revealed that the whole of ontogeny is an adaptive process in which "nature" cannot be teased apart from "nurture." Instead, phenotypes are actively constructed through interactions between the genotype (including genes and gene regulatory systems) and internal and external environments. This view renders distinctions such as innate versus acquired, and nature versus nurture, of limited use. Instead, a more useful concept is *design for development*, which holds that developmental systems are shaped by natural selection to produce adaptive

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outcomes via interactions with recurring features of developmental environments. Developmental systems are sensitive to specific aspects of the environment and structure their interactions with these elements in adaptive ways (Frankenhuis & Panchanathan, 2011); therefore, the developmentally relevant environment and its interactive effects, rather than being factors separate from the developmental system, are a function of the design features of the developmental system itself (Barrett, 2007; Oyama, Griffiths, & Gray, 2001). In this chapter, we suggest that the same view will be useful for understanding the development of psychological phenotypes as well.

Adaptations are misunderstood in psychology to the extent that they are viewed as inflexible, isolated from other mechanisms, and incompatible with learning (Buller, 2005). Adaptations include systems for learning (Gould & Marler, 1987; Greenough, Black, & Wallace, 1987), such as inferential systems for estimating environmental parameters (e.g., the location, value, and abundance of resources; Dukas, 2008), mechanisms for assessing one's own attributes relative to other individuals (e.g., relative body size, social status; Maynard Smith & Harper, 2003), and networks that selectively form associations between particular objects and events (e.g., foods and nausea; for a review, see Seligman, 1970). Adaptations also include perceptual and motivational biases for attending to fitness-relevant objects, such as animate events (New, Cosmides, & Tooby, 2007). These biases ensure that organisms process environmental information relevant to (1) current decision making (e.g., an approaching predator) and (2) long-term developmental trajectories (e.g., in environments estimated to be dense with predators, organisms may develop specialized morphology and behavior for avoiding predators; Benard, 2004; Harvell, 1990).

Many animals use psychological adaptations to predict future events, including the locations, trajectories, and actions of other agents, who may have conflicting interests (Barrett, 2005). Consider a gazelle spotting a pride of lions. Depending on the pride's predicted trajectory (e.g., Are they moving closer or farther away?), the gazelle may relax or increase its vigilance levels. If the lions are moving closer, but their gaze is averted, the gazelle may estimate it hasn't been detected and freeze, hoping it remains unseen. However, if the lions are fixating on her, the gazelle may flee. This could trigger a chase, in which the lions and gazelle quickly and continuously predict each others' locations and trajectories. What psychological systems enable such behavior prediction? How do these mechanisms evolve and how do they develop?

Inference Based on General Concepts

Developmental psychologists tend to believe that human infants rely on a small set of general concepts to understand and predict the behavior of others. For instance, according to one influential view—known as the "teleological stance" or infants' intuitive theory of "rational action" (Gergely, 2010; Gergely & Csibra, 2003)—infants expect agents to choose ACTIONS consistent with achieving their GOAL in the most efficient manner possible given environmental CONSTRAINTS. Having such a model of rational action would afford infants inferences about how others will behave. For instance, knowing that an agent has the goal of catching another agent, one might predict the chaser's action to be the shortest path to its victim as allowed by environmental constraints (Gergely, Nádasdy, Csibra, & Bíró, 1995). The principle of rationality can also be used to infer goals (Csibra, Bíró, Koós, & Gergely, 2003): if an agent takes the shortest path to a moving object, one might infer that the agent has the goal of gaining proximity to this object. Finally, if one agent has the goal of catching another and takes the shortest path toward the victim except at a particular point, one could infer a constraint at this location (Csibra et al., 2003). Thus, according to the rationality principle, infants interpret and predict the behavior of other agents using a small set of general concepts—GOAL, ACTION, and CONSTRAINT—interconnected by an assumption of efficiency.

Since its inception, the teleological stance perspective has generated novel and unique predictions that—through systematic testing—have resulted in groundbreaking discoveries (for reviews, see Gergely, 2010; Gergely & Csibra, 2003). The approach has clearly made major contributions to the study of developmental science. Nonetheless, we argue that this theory of infants' inferential capacities, while correct in the domains where it has been tested, might in fact be too broad. Although we agree that "rationality" principles are likely to be engineered into infants' early-developing behavior prediction abilities, we suggest that these abilities might consist of a larger number of narrower inference abilities and not a single, broad, teleological stance (Barrett, 2005). According to this proposal, each of these more specific abilities includes teleological principles for understanding the behavior of others, but covers a narrower scope of behavior than does the assumption that agents pursue the most efficient means to their goals. We call these smaller teleological abilities *islands of competence*, to distinguish them from the more continental view of a "stance" (see figure 8.1).

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Rational Action Theory

efficient action,
given constraints

Perception ⟶

⟶ Behavior
prediction

Islands of Competence

avoid   dominate

Perception ⟶   help   chase   hinder   ⟶ Behavior
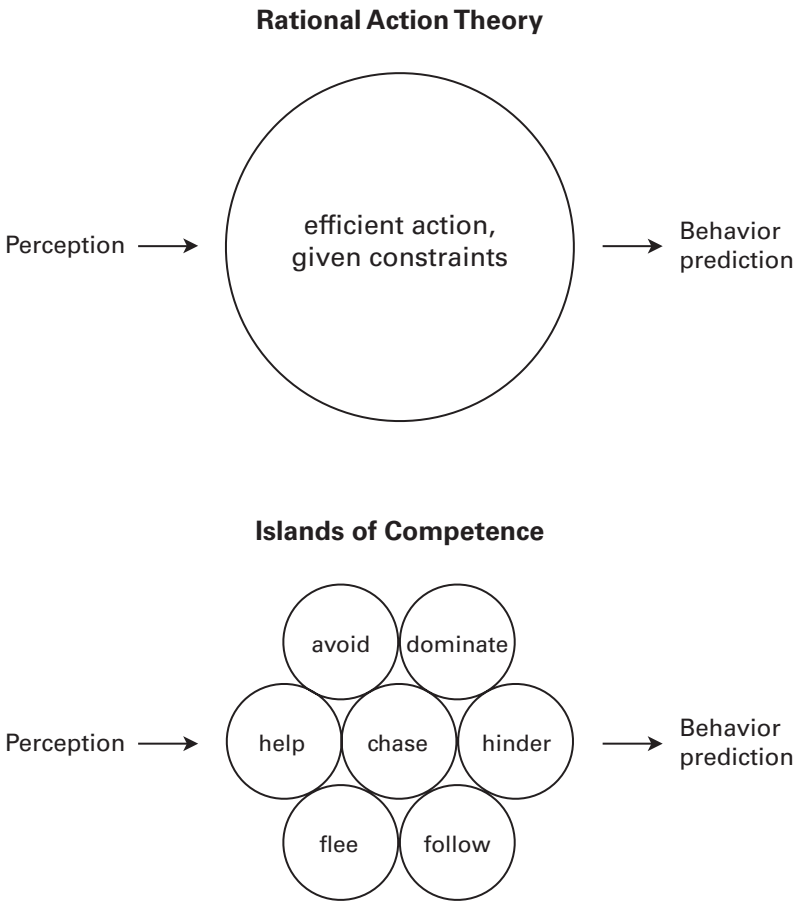prediction

flee   follow

Figure 8.1
The rational theory of action versus islands of competence.

The reason for our view is that while concepts like GOAL, ACTION, and CONSTRAINT may be useful for psychologists in individuating *types* of concepts in the mind, they would not by themselves be useful to infants as *tokens* of concepts that could be used to predict actual behavior. General concepts, by themselves, don't sufficiently constrain prediction space. For a behavior prediction system to evolve via natural selection, it must enable infants to make effective predictions about behavior. For example, to make predictions about the behavior of a cat chasing a mouse, an infant must do more than apply a general principle of rationality; he or she must understand the logic of *chasing*, in which the goal of one agent is to catch

another agent, and the goal of the second agent is to not be caught. For this reason, we suggest that infants' early-developing action prediction abilities are centered on *action schemas* (e.g., chasing, following, grasping, dominating, searching, etc.), which, while obeying a teleological logic, use a larger set of more specific concepts to do so (Barrett, 2005). The relevant concepts are expected to be different for different domains, but might include agent concepts such as PREDATOR, PREY, MOTHER, and HELPER, goal concepts such as CHASE, ESCAPE, APPROACH, SIGNAL, PROTECT, and constraint concepts such as BARRIER, PATHWAY, CONTAINER, LINE OF SIGHT, and so on. From an evolutionary point of view, the virtue of such specific concepts is that, when properly combined, they can yield more precise predictions about behavior by reducing degrees of freedom in prediction space. Their drawback, of course, is that they yield behavior prediction skills that are patchy, endowing infants with islands of behavior-prediction ability within a much larger sea of *possible* inferences about rational action that, because they don't have the relevant action schemas, infants can't make. However, if a function of early-developing action schemas is learning, we expect action schemas to become more elaborate over the course of an infant's development through (1) refinement of input conditions, (2) learning of new concepts, (3) fine-tuning of inferential processes, and (4) interaction with other knowledge structures, which we will discuss in greater detail below.

Our view predicts that infants will develop action schemas at those ages at which those schemas become fitness-relevant (or became fitness-relevant across evolutionary time). Other schemas that are equally rational may await later development. For example, the logic of chasing might be useful for young infants both because of its role in enabling children to understand chase play—a common form of play that may train adult abilities of pursuit and evasion (Pellegrini, Dupuis, & Smith, 2007; Steen & Owens, 2001)—and because it might enable infants to perceive when something is stalking them or predict the trajectory of animate objects the infant is trying to grasp. Abundant evidence exists for the logic of such action schemas as affiliative approach, grasping, and searching for inanimate objects (such as food or a toy) (Csibra, Gergely, Bíró, Koós, & Brockman, 1999; Gergely et al., 1995; Hamlin et al., 2007; Kuhlmeier et al., 2003; Thomsen et al., 2011; Woodward, 2009; Woodward & Sommerville, 2000). However, there are other action logics, such as those associated with mating and reproduction (e.g., courtship, jealousy) as well as other goals pursued in adulthood (e.g., political maneuvering), which do not develop until later.

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The teleological stance is not the only case in which infants might possess islands of competence that only later grow to span a larger conceptual space. The literature on Theory of Mind, too, holds that children reason using a small stock of extremely abstract and general concepts, including BELIEF and DESIRE. However, like GOAL and ACTION, these concepts by themselves would not be sufficient to predict actual behavior without plugging in specific contents—specific beliefs and desires—only some of which children might understand at a given age. GOALS can include things that infants understand, such as chasing and approach, but can also include things that infants don't understand, like becoming wealthy, achieving checkmate in chess, and committing adultery. Similarly, BELIEFS can include things that infants understand, such as beliefs about where food is hidden, and things that infants don't understand, like belief in God or beliefs about the power of free markets to heal ailing economies. When combined with principles of rational action, these beliefs could be used to predict behaviors (like going to church or voting Republican). However, most research on early-developing abilities to predict an agent's behavior is limited to such cases as predicting where an agent will look for food or some other desired object (e.g., a caterpillar looking for an apple or a piece of cheese; Surian, Caldi, & Sperber, 2007). Without looking at the specific belief contents that infants are able to track and the contexts in which they can do so, we risk concluding that a more domain-general ability has developed than actually exists. In other species, research has shown that abilities thought to be general, such as knowledge tracking, are closely tied to certain contexts, such as competition over food (Hare, Call, & Tomasello, 2001). It is possible that children's early-developing abilities in many domains are similarly targeted toward contexts that are useful for the child.

In our view, then, looking at the specific content and contexts that babies are able to understand is just as important as looking at the more abstract features of their conceptual structure. Moreover, we suggest that early-developing action schemas serve as kernels for future learning, including the acquisition of more general concepts. Thus, where many scholars hold that infants start out with general concepts and construct specific understandings later, in this chapter, we propose the opposite.

In the following section, we first provide details about how action schemas might be instantiated in infants' minds in terms of perceptual inputs, cognitive rules, and behavioral outputs, as well as their role in shaping learning. We then discuss chasing as a case study and review empirical work conducted with infants, children, and adults. We will illus-

trate that existing evidence is consistent with an islands of competence view. In the discussion section, we suggest how our view can be distinguished empirically from other current perspectives. Finally, we also point to several psychological domains, other than chasing, where our model can be tested.

Domain-Specific Action Schemas

A virtue of early-developing islands of competence is that action schemas can help solve frame problems that would be faced by more domain-general systems: that is, action schemas would avoid churning through many possibilities of what might count as "rational" by specifying specific actions that are rational in a given context. In chasing, for example, roles can be assigned to chaser and evader based on their behavior (approach and avoidance, respectively). These in turn lead to predictions about what is rational: for the chaser, systematically reducing the distance to the evader, and for the evader, doing the opposite. Similarly, cues to mutual approach could activate a different schema, an approach schema, in which the goals of agents are to (1) come into contact with each other and (2) find the shortest path in order to do so. In each case, the output of the system is a prediction or expectation that can be measured using, for example, violation of expectation or preferential looking techniques.

Like all evolved specializations, islands of competence evolve under trade-offs. For example, islands of competence may solve frame problems for infants by generating specific expectations in particular cases, but will be less likely to do so effectively outside their domain of application (Barrett & Kurzban, 2006; Cosmides & Tooby, 1994; Frankenhuis & Ploeger, 2007). We would expect such schemas to be in place at the ontogenetic stage at which they resulted, across evolutionary time, in fitness benefits to children. These fitness impacts could come in at least two ways: (1) Benefits of immediate predictions (e.g., predicting where a predator, prey, or conspecific will run, or how a parent might move in response to the child's crying) and (2) learning benefits (note that this is not a strict dichotomy, as predictions about behavior can have learning consequences).

Trade-offs in the Evolution of Domain-Specific Developmental Designs

How many action schemas should we expect there to be? Here, at least two factors are important. The first is to what extent a particular action schema has a fitness impact on the child at various life stages. For young children, for example, a chasing schema might have more fitness benefits

than a mate-competition schema. A second factor has to do with the scope of the schema: how broad or narrow, in spanning possible interaction space, we might expect islands of competence to be. For example, chasing shares much in common with leading and following, both in terms of goals (e.g., staying close to the target) and perceptual properties (e.g., a chaser and evader tend to move in the same direction, as do a leader and follower). However, the goals of the leader (in a following event) and an evader (in a chasing event) are different: The evader is trying to lose the chaser, whereas a leader may want to be followed. Similarly, chasing and playing show perceptual overlap—for instance, play often involves bouts of chasing (Barrett, Todd, Miller, & Blythe, 2005)—yet their goals are different and involve different expectations about behavior—for instance, just how "rational" it is for the evader to allow himself to be caught.

A relevant principle is the principle of functional incompatibility, which was originally developed in thinking about the evolution of multiple memory systems (Sherry & Schachter, 1987). Consider two adaptive functions, X and Y. We might imagine a single mechanism, such as a single action schema, that evolved to handle both functions—for example, making predictions for both chasing and leading/following. Or there could be two mechanisms—one specialized to handle chasing and one for following. In evolutionary terms, the principle of functional incompatibility can be stated as a heuristic: All else being equal, natural selection should favor multiple systems when the net fitness benefit of having multiple systems is greater than the net benefit of having a single system that handles both functions. These benefits will depend on such factors as the costs of building and maintaining multiple systems and the magnitude of the marginal benefit of having multiple systems over a single one (Cosmides & Tooby, 1994). We would expect this marginal benefit to depend on the extent to which different schemas entail different goals. For example, though chase-play and predator-prey interactions often show high degrees of perceptual overlap, their fitness-relevant goals are vastly different; effectively distinguishing them and deriving adequate inferences is crucial. Hence, we might expect infants to be sensitive early on to cues that distinguish cases of chase-play from cases that involve genuine aggression (Smith & Lewis, 1985; Steen & Owens, 2001).

As we mentioned, some of the fitness benefits of early-developing action schemas could come from the generating of immediate expectations about how others will behave. This might be especially true in cases where the child herself is one of the agents in the interaction. For example, cues to hostile approach could prompt the child to cry, thereby avoiding possible

harm (e.g., by eliciting parental help). Cues to friendly approach, however, could prompt the child to initiate approach to the other agent. These two responses can have quite different consequences for fitness, and so there are many cases where forming detailed expectations about what another agent will do could benefit even small children.

Islands of Competence May Facilitate Learning

Action schemas can also provide learning benefits; this is true even in the case of interactions in which the child herself is not taking part. For example, by watching predator-prey interactions from a distance, useful information can be gleaned about predator and prey behavior. In general, by watching others, babies can learn the social structure of their world, including who is dominant over whom (Thomsen, Frankenhuis, Ingold-Smith, & Carey, 2011), who is nice and who is nasty (Hamlin, Wynn, & Bloom, 2007; Kuhlmeier, Wynn, & Bloom, 2003), how to interact appropriately with artifacts (Gergely, Bekkering, & Király, 2002), the nuances of local norms of social interaction (Rakoczy, Warneken, & Tomasello, 2008), and more.

Action schemas can facilitate learning in at least two ways. First, they can help guide the infant's attention toward fitness-relevant objects and events. Events can be worth attending to when the behavior of agents satisfies the infant's action predictions, but also in cases where agents' behavior violates the infant's expectations, as this may help tune the underlying action schema by teaching the infant its boundary conditions and exceptions. Second, action schemas can help the child to parse behavior into appropriate categories, which is critical for learning. For example, in order to learn about predation as a separate category of behavior from affiliative interactions, it is important not to blend knowledge gained from watching affiliative approaches between parents and offspring (e.g., a parent approaches a child with goal of helping it) with knowledge gained from watching leopards stalk gazelles (e.g., a leopard approaches a gazelle to kill it).

If our conjecture is correct, and infants' early-developing understanding of behavior is organized around specific islands of competence, then the stock of action schemas that infants initially posses is clearly not the only set of schemas they will ever develop. Surely, adults understand many more contexts of interaction, and make much more nuanced distinctions, than children do. Infants might begin with, for example, relatively simplistic, stereotyped, and separate schemas of chasing and social dominance. At first, they might treat all cases where A approaches B and B flees as the

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same kind of event—chasing—and all cases where one individual defers to another (e.g., stepping out of the way to let them pass) as dominance (Thomsen et al., 2011). However, by attending to details of interactions, infants can begin to notice fine-grained distinctions between types of actions that might, ultimately, cause them to bifurcate into multiple schemas: for example, one schema for predation-related chasing and another for chasing after a moving inanimate object; one schema for deference out of fear and another for deference based on respect (Henrich & Gil-White, 2001). In some cases, the ability to represent new goal states may develop when behavior is observed that cannot be assimilated into an existing schema, which may result in the spawning of a new schema (Jacobs, 1997). There are many ways in which the development of more sophisticated knowledge can emerge from infants comparing real-world, observed behavior to simpler schemas they already possess (for examples outside the domain of chasing, see Carey, 2009; Gelman, 1990; Mandler, 1992).

Finally, the islands of competence view suggests that rather than observing stage-wise conceptual shifts, such as a shift from a desire-based psychology to a belief-based psychology across all domains, one might see something more akin to Piaget's notion of décalage (Piaget & Inhelder, 1951). At an early age, children might not have a domain-general understanding of belief or a general ability to track beliefs. Rather, they might have narrow competences of belief tracking, such as an ability to track an agent's belief about where a valued object, such as food, is hidden (Onishi & Baillargeon, 2005; Surian et al., 2007). The ability to track other beliefs, such as a person's belief about his mate's fidelity, may appear later. If early-developing skills are organized around islands rather than broad domains, competences that are sometimes viewed as part of the same domain (e.g., interpreting the behavior of other agents teleologically) may actually develop at different points during ontogeny. We now turn to the case of one particular action schema for which we and others have gathered evidence: a chasing schema.

Psychological Design for Chasing

What motion features are characteristic of chasing events, and what mechanisms in humans leverage these properties to interpret and predict behavior? Psychologists have long known that infants are sensitive to motion. For instance, even though the neonate's visual field ranges only 15 to 20 degrees to either side for static stimuli (when the head is still), it can be

wider and the distance greater for moving objects (Tronick, 1972). More-over, infants are especially attuned to biological motion (e.g., Bertenthal, 1993; Fox & McDaniel, 1982). When neonates are presented with two displays side-by-side—one depicting a point-light display of an animal walking and the other depicting nonbiological motion—they tend to navigate their gaze toward the biological motion (Simion, Regolin, & Bulf, 2008). But among the many types of motion infants might attend to, is there anything special about chasing?

Early Development of Perceptions of Chasing

Computational analyses suggest a number of properties that distinguish chasing from other kinds of animate motion. One simple yet effective cue appears to be absolute velocity. Blythe, Todd, and Miller (1999) trained a neural network on three hundred examples of motion trajectories from six intentional categories—pursuing, evading, courting, being courted, fighting, playing—which had been generated by humans controlling a computer mouse (for details, see also Barrett et al., 2005). After training, the network correctly categorized 82 percent of the trajectories in terms of their intention. Out of seven cues, absolute velocity yielded the most accurate categorization, followed by relative angle, relative velocity, relative heading, relative vorticity, absolute vorticity, and relative distance. Given the discriminatory power of absolute velocity, we may expect an early-developing chasing schema to include sensitivity to this cue. (This is not to say that high velocities correlate exclusively with chasing; see below.)

Adults judge faster motion as more animate, whether faster speed results from accelerations (Tremoulet & Feldman, 2000; see also Scholl & Tremoulet, 2000) or from faster constant speed (Szego & Rutherford, 2007), and animacy judgments increase when entities move in a direction that violates gravity (e.g., upward; Szego & Rutherford, 2008). Further, it is easier for adults to detect a chasing event among distracter stimuli when the chaser moves relatively fast; that is, a depiction of a lamb following its mother is more difficult to detect than a depiction of a wolf chasing its prey (Dittrich & Lea, 1994). We recently explored whether infants, too, are sensitive to accelerations. We presented four- and ten-month-old infants with two displays side-by-side, each depicting two moving discs, but in one display, one of the discs would sometimes accelerate. By a substantial margin, nearly all infants looked longer at the accelerating motion (Frankenhuis, House, Barrett, & Johnson, 2012). We note that this finding does not imply that infants perceive accelerations as animate in the way that adults do. Although this is conceivable, our experiment was not designed

to test this (for recent reviews on infants' perceptions of animate motion, see Frankenhuis, Barrett, & Johnson, in press; see also chapter 11 of this volume).

Accelerations are an integral part of chasing events: one agent approaches another, the other accelerates away (possibly triggering the chaser to accelerate as well). Thus, sensitivity to acceleration is consistent with an attentional system designed to orient toward chasing events. However, there are various reasons that accelerations might occur, including accelerations due to gravity (a rock falling) and accelerations due to self-propelled motion (chasing). To the extent that the adaptively relevant (or formal) properties of different stimuli overlap and demand a similar response (e.g., attention-orientation), selection might not produce two distinct mechanisms. On the flip side, to the extent that stimuli *do* require different responses (e.g., continued monitoring may be appropriate for agents, but not for inanimate objects), selection would be expected to favor different responses to these stimuli.

In addition to high velocities and accelerations, at least two relational properties are also characteristic of chasing: attraction (one agent pursuing another, sometimes called "heat-seeking") and fleeing (the evader tries to get away). Rochat, Morgan, and Carpenter (1997) investigated whether three-month-old infants are sensitive to these properties. Infants watched two displays side-by-side, each depicting two discs (blue and red) moving across the screen. The motions of the red and blue discs were identical in both displays, with the exception that in one display the discs would be chasing each other, while in the other they were moving independently. The results showed that three-month-old infants looked longer at the chasing display (although this discrimination was observed only in infants with relatively long attention spans). In the displays used by Rochat and colleagues (1997), two kinds of contingencies in the chase could have generated the infants' preferential looking. First, the chaser took the shortest path to the evader (attraction); second, when the chaser came close, the evader accelerated away (fleeing). Both attraction and fleeing allow for the prediction of one agent's behavior based on the motions of the other agent. It is unclear whether the infants in the study attended to attraction or fleeing, or to both.

We recently gathered data relevant to this question. In our experiment, four- and ten-month old infants watched displays showing attraction without fleeing. Looking times indicated that boys in both age groups preferentially attended to attraction without fleeing over a control display; however, girls did not (Frankenhuis et al., 2012). These results raise the

possibility that boys and girls may be differentially sensitive to different properties of chasing (or even of animate motion in general). Another question of interest is: Why did girls preferentially attend to Rochat's contingent display, but not to ours? His displays combined both attraction and fleeing; ours isolated only the former. It is possible that at the ages we tested, girls are sensitive to fleeing without attraction, but unlike boys, not to attraction without fleeing. Future studies might explore infants' perception of fleeing without attraction.

We have thus far discussed the perceptual inputs that orient the visual system toward chasing, focusing on high velocities and accelerations, and two forms of social contingency: attraction and fleeing. In addition, we want to know whether infants, like adults, interpret dynamic motion displays in goal-directed terms (Bassili, 1976, Heider & Simmel, 1944; Michotte, 1963). Rochat, Striano, and Morgan (2004) used a habituation paradigm to investigate whether infants perceive social contingency as goal directed. They showed four- and nine-month-old infants a video of one disc chasing another (e.g., red chasing blue) until looking times decreased. If infants had habituated to the perceptual features of the event, they should have remained uninterested if a role reversal occurred (blue chasing red), since this was perceptually similar to what they had seen before. However, if infants had assigned different goals to the chaser and the evader, they should have regained interest in response to a role reversal, because the agents had changed their goals. When shown the role reversal, infants in the younger age group (four-month-olds) did not regain interest; however, infants in the older age group (nine-month-olds) did increase their looking time, which suggests that they had assigned different goals to the chaser and the evader.

When do infants begin to use inferred intentions to predict a chaser's future trajectory? Csibra and colleagues (2003) presented nine- and twelve-month-old infants with an animation of a large ball moving in the direction of a small ball in a heat-seeking manner, always taking the shortest path toward it. The small ball then moved through a hole in a barrier too small for the large ball to pass through. The large ball would move around the barrier. In the test phase, infants were presented with two different endings: Either the large ball "caught" (contacted) the small ball, or the large ball would slide past the small ball and come to a halt. The results showed that twelve-month-old, but not nine-month-old, infants expected the large ball to contact the small ball (see also Wagner & Carey, 2005). This work shows that by at least twelve months of age, infants can infer the intention to capture another agent based on motion cues alone, and

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use the inferred intention to predict the trajectory and future locations of a chaser.

Finally, several studies have looked at older children's ability to verbally categorize or describe animate motion displays based on goals. Berry and Springer (1993) showed three-, four-, and five-year-old children four different versions of a chasing display. The first version was identical to the chasing display used by Heider and Simmel (1994). In the second version, form was preserved but motion disrupted, so that children watched static frames from the original tape, sampled at two-second intervals, with each frame lasting two seconds. In the third version form was disrupted but motion preserved, such that the objects were not triangles and a circle anymore, but rather mosaic shapes blending into their background. In the fourth version, both motion and form were disrupted. Children of all age groups tended to interpret the displays in anthropomorphic terms when motion was preserved; however, they did not when motion was disrupted, irrespective of disruptions of form. The same pattern of results was obtained with adults—although adults did provide more anthropomorphic descriptions overall than children (Berry, Misovich, Kean, & Baron, 1992).

Barrett and colleagues (2005) showed three-, four- and five-year-old German children four motion displays (chasing, following, fighting, and playing) that were identical to those used by Blythe and colleagues (1999). Children watched one display at a time and were asked which of two intentions was depicted on the display (e.g., chasing or following), with one intention always being the correct one. Results showed that four- and five-year-old German children were above chance at categorizing the four types of intentional motion, but three-year-old children were not. Interestingly, children were not above chance for one motion category, chasing—probably, the experimenters surmise, because the experiment used a word for chasing that most German three- to-five-year-olds don't know (*verfolgen*), given prior results showing that children understand chasing from an early age (Csibra et al., 2003; Rochat et al., 2004). These results suggest that language skills used to describe and categorize motion trajectories may develop later than the relevant perceptual and conceptual abilities.

Fine-tuning and Elaboration of the Chasing Schema across the Life Span
How does our understanding of chasing develop into adulthood? As we have mentioned, we believe that an early-developing chasing schema's primary learning function is to orient infants' attention to instances of chasing, thereby allowing them to learn about instances of chasing via input from the world; this is similar to the role that an early-developing

face schema or template might play in the development of face perception (Morton & Johnson, 1991). Thus, adults' knowledge of chasing will not be the same as that of infants. It will, in a broad sense, be richer because it is informed by experience. However, there are several ways that adults' inferential structures related to chasing might have narrowed compared to infants' and several ways in which they might have broadened. This is because some kinds of learning entail elaboration of existing knowledge structures and skill sets, which is done by constructing new categories, developing richer interpretations, and so on. Other kinds of learning, however, can entail various kinds of "pruning" (e.g., Kuhl, 2004; Pascalis, de Haan, & Nelson, 2002): Input conditions for activating a schema might become narrower, properties of objects and events might be forgotten, concepts or connections between concepts might erode, and information previously used in decision making might become muted. For example, among many American city-dwellers, an encounter with any spider, whether dangerous or not, might cause an aversive reaction because experience has not yet narrowed the category to just those spiders that are dangerous. Among those who live in spider-rich environments such as the Amazon rainforest, on the other hand, an initially broad category of fearful objects might become narrowed by experience to include just those that merit a fearful reaction. Similarly, in juvenile rhesus macaques, predator alarm calls are initially generated for a larger variety of objects than is appropriate, but this category of objects is gradually narrowed to include only the appropriate set of targets (Cheney & Seyfarth, 1990).

Pruning processes may also play a role in the development of contingency detection. We previously mentioned our finding that boys preferred to attend to "attraction without fleeing" over two discs moving independently (Frankenhuis et al., 2012). We also presented these stimuli to adults, and they did not rate the contingent display as more animate. There could be several reasons for this. Adults might have perceived the motion as contingent, but not as animate. If so, this would not support the idea that adults have narrower input criteria for detecting contingencies in motion; it would just mean that our stimuli do not fit the criteria for being categorized as animate. It is also possible, however, that the input criteria of action schemas' contingency detectors become narrower across development; this narrowing could be the result of real-world experiences (in this case, experiences with actual chasing events). Such perceptual narrowing has been demonstrated in several other areas of perceptual development, in particular phoneme perception (Kuhl, 2004) and face perception (Pascalis et al., 2002).

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Prior work has shown that adults tend to judge and describe some kinds of displays of moving objects as animate (Heider & Simmel, 1944; Morris & Peng, 1994; Rimé, Boulanger, Laubin, Richir, & Stroobants, 1985)—even displays showing only a single geometrical shape (Michotte, 1963; Szego & Rutherford, 2007, 2008; Tremoulet & Feldman, 2000)—and researchers have investigated the range of parameters that lead to judgments of animacy and specific categories of animate motion. For instance, Gao, Newman, and Scholl (2009; see also chapter 9 of this volume) explored how objective chasing (the degree to which one shape, the wolf, actually pursues another shape, the sheep) relates to perceived chasing (the degree to which participants detect this behavior). Gao and colleagues found that objective chasing is readily perceived as chasing when the wolf pursues the sheep in a perfectly heat-seeking manner, always moving in the exact direction of the sheep. However, when the wolf's motion deviates even slightly from perfect heat seeking (e.g., it moves in the general direction of the sheep, but not directly toward it), chasing is more difficult to detect—even when the wolf *is* efficient at reducing its distance to the sheep. Percepts of chasing are further impacted by the direction in which the wolf is orienting. When the wolf faces the direction in which it is moving, the detection of chasing is enhanced. In contrast, when the wolf's orientation is random with respect to its trajectory, or when it is surrounded by distracter shapes that also face the sheep, detection of chasing is impaired (Gao, McCarthy, & Scholl, 2010; see also Gao & Scholl, 2011 and chapter 9 of this volume).

Action schemas might also develop as a result of processes such as elaboration of information structures, formation of new connections between knowledge domains, discovery of new properties of objects and events relevant to a particular decision problem, bifurcation of one concept into several more fine-grained ones, and so on. One way in which an island of competence for chasing might grow is through expansion of the scope of knowledge (both contextual and general) that is brought to bear on inferences about intentions, goals, and behavior prediction. For instance, adults have been shown to segment an action stream not only based on bottom-up processing of distinctive sensory characteristics, but also based on top-down effects of knowledge structures, including information about actors' intentions (Zacks, 2004; see also chapter 13 of this volume). So, an adult may know that a chaser might mislead an evader by averting its gaze; the adult might then predict that a chasing event is not over, even though an averted gaze suggests this to the child. Compared to infants, adults in general are likely to use a larger repository of background knowledge (e.g.,

properties of the predator and prey) and contextual information (e.g., relevant features of the ecology) in making predictions about the outcome of a chasing event (e.g., who will win), often resulting in more accurate behavior prediction.

In their landmark paper from 1944, Heider and Simmel proposed that knowledge might exert top-down influences on intention judgments. Toward the end of their animation, the big triangle (T) chases the small triangle (t) and the disc (c) twice around the house. Participants nearly universally interpreted these movements as chasing. However, when the animation was played in reverse, most participants did not interpret this as t and c chasing T. Heider and Simmel suggest that this difference might result from knowledge of the story line, which shaped the participants' interpretations of intentions. Specifically, they suggest that a history of antagonism between T and the pair t and c, combined with T being stronger than t and c, facilitates interpretations of chasing in the forward animation (p. 254). In contrast, in the reverse animation this combination of features is absent; this absence inhibits the uniform percept of chasing and results in more diverse interpretations. The percept of T being stronger may derive from an earlier part in the animation in which T pushes t backward, as well as from T being physically larger than t and c. Subsequent work has shown that interpretations of agent characteristics (e.g., whether T is viewed as aggressive or not) can be manipulated by providing participants with information about the characteristics of *other* agents in the animation (Shor, 1957).

Conclusion

We have reviewed a variety of data consistent with the development of a chasing schema early in childhood that (1) uses perceptual cues of pursuit and evasion to orient infants' attention toward chasing events and (2) enables infants to make predictions about the behavior of agents engaged in chasing. In our view, this evidence is consistent with the idea that infants' abilities to understand and predict intentional action are centered on certain islands of competence, which only later in development are fleshed out into other areas of rational action understanding. Despite the fact that domain-general models of rational action can account for much of the existing data, we have argued on theoretical grounds that, by themselves, general concepts (such as BELIEFS, DESIRES, and CONSTRAINTS) do not allow effective behavior prediction. Although we have not reviewed the evidence here, we think that developmental studies also

point to other islands of competence for action understanding, including an approach schema (e.g., Csibra et al., 1999; Gergely et al., 1995), a grasping schema (e.g., Woodward, 2009; Woodward & Sommerville, 2000), a helping schema (Hamlin et al., 2007; Kuhlmeier et al., 2003), and a dominance schema (Thomsen et al., 2011). Of course, there are likely to exist other schemas as well.

We conclude with several caveats to the claims we have made here. First, there exist several pieces of evidence that challenge the view that action understanding is centered on domain-specific action schemas. For example, a recent study by Southgate, Johnson, & Csibra (2008) suggests that infants can make predictive inferences about goals even in a case that appears to be outside the boundaries of interactions that would have occurred over evolutionary time: namely, in a case where a rubbery arm stretches and bends through a maze in order to grasp an object. Consistent with the teleological stance framework, infants expect this bendy arm to bend only when it is forced to do so by the walls of a maze, but not when the barriers are removed: efficient action toward a goal, under constraints. We acknowledge that this is a surprising result, consistent with the teleological stance theory, and a challenge for the islands of competence view since bendy arms are presumably not within the proper evolutionary domain of any such competence. However, we suggest that it is possible that even this display might satisfy the input conditions of either a single evolved schema (e.g., resource search) or some combination of schemas (resource search plus grasping). What is remarkable about the result is that infants are not surprised at seeing an arm bend when they have never seen a real-world arm bend before (the infants in the study were not shown the bendy arm in habituation conditions). Although we would not have predicted that infants should fail to be surprised by this, it is still the case that the *path* the arm takes is the path one would expect using a schema such as chasing or approach. A stronger test of the islands of competence view, perhaps, would be to use some perceptual array where goal satisfaction directly contradicts the predictions of an evolved schema such as chasing or approach. However, we recognize that bendy arms are a challenge for evolved schema theory, and further work is required to address the issue.

Similar concerns might arise from other "unnatural" aspects of laboratory stimuli—such as squares, triangles, and blobs—that generate consistent predictive intuitions in infants, as well as from the fact that overhead views of motion—as in Heider and Simmel (1944), Barrett and colleagues (2005), and others—appear to yield better recognition of intentions than

do side-view displays (McAleer & Pollick, 2008). If action understanding is centered on evolved schemas, then why are these schemas activated by evolutionarily novel stimuli?

Again, we can offer only a *post hoc* response, but we suspect that the answer lies in the fact that evolved mechanisms are designed to take certain *relevant* cues as inputs, but not *all* cues. For example, research on early face perception suggests that infants' attention is drawn to facelike stimuli that share only minimal features with real faces, such as the organization of extremely schematic features and, possibly, even just patterns of shading (Morton & Johnson, 1991). Although some would see this as evidence that these early templates are not adaptations for detecting faces (e.g., Nelson, 2001), the use of minimal yet reliable cues is consistent with an evolutionary view. If schemas have a learning function, as we have suggested, then one would not expect them to be endowed with complete knowledge of their target domain. Indeed, such knowledge is what they are designed to acquire. Instead, one would expect them to use a subset of cues that index their target with high cue validity. Consistent with this idea, the use of frugal, high-validity cues appears common in nature, from eyespots to the extremely coarse imprinting rules of baby geese (in essence, imprint on the first large, moving object you see), to frogs' sensitivity to small, dark objects that enter the visual field, stop, and move around intermittently (Lettvin, Maturana, McCulloch, & Pitts, 1959).

What this means is that for chasing, the most predictive cues that a chasing event is occurring do not have to do with the shapes or properties of the chasing objects themselves: it is motion, not the identity of the mover, that makes something a chasing event. If infants are built to *learn* what kinds of things are predators and what kinds of things are prey, for example, it would make sense to equip them with motion detectors that allow them to first recognize the goal of predation and then learn about the features of predators and prey through observation. Similarly, if motion parameters indicative of targeted approach serve as inputs to such a system, and overhead views of motion afford a better view of those parameters, then overhead views might better satisfy the input conditions of the system than, for example, a horizontal view of a predator chasing prey with both moving directly away from the viewer and appearing to be fused in a single unmoving point.

A final caveat, which we wish to stress again, is that the predictions generated by an action schema view are highly overlapping with those of a teleological stance view of action understanding. In essence, everywhere

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that the action being observed entails the rational, efficient pursuit of goals under constraints—which includes the majority of naturally observed animal behavior—the predictions of both theories overlap. This means that the most informative tests between the theories would involve looking at more studies similar to the bendy arm case, where the action is "rational" under some construals but not expected to fall within the domain of one or multiple evolved action schemas (though this expectation assumes, perhaps unrealistically so, that evolved action schemas would include a full understanding of the anatomical limits of human arms). As it happens, the vast majority of research on infants' understanding of action has looked at cases where the action is not only "rational," but also the kind of action one would expect that an infant might understand—from looking for hidden food, to chasing, to helping someone up a hill, to grasping desired objects. This is not surprising, because developmentalists typically design experimental stimuli to match what they believe infants can understand (as researchers will search for positive findings, not negative ones). However, in order to understand how specific or general cognitive skills are, we need to look not just at prototypical cases where infants are likely to succeed, but also at the boundary conditions where they might fail.

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