Lessons from Cognitive Ethology: Animal Models for Ethological Computing

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Abstract

Computers may be "smart" in terms of brute processing power, but their abilities to learn are limited to what can easily be programmed. A computer can indeed learn to solve new problems, but only ones that are quite similar to those it has already been programmed to solve. Computers cannot yet form new abstract representations, manipulate these representations, and integrate disparate knowledge (e.g., linguistic, contextual, emotional) to solve novel problems in ways managed by every normal young child. Even the Grey parrots (*Psittacus erithacus*) I study, with their evolutionary distance from humans, succeed on such tasks. How can parrots, with walnut-sized brains, succeed where a computer cannot? The birds' success likely arises for two reasons. First, a parrot, like a young child, does not rely exclusively on conditioned responses or simple associative learning, but has a repertoire of desires and purposes that cause it to form and test ideas about the world and how it can deal with and function in the world; these ideas, unlike simple associations or conditioned responses, can amount to representations of cognitive processing. Second, I hypothesize that their learning processes resemble those of young children because I have found that a *social interaction* paradigm is necessary to train the birds to communicate with us using the sounds of English speech. Because learning occurs more slowly in birds than humans, and is thus easier to study, I suggest that by deepening our understanding of the social processes whereby nonhumans advance from conditioned responses to representation-based learning we will uncover rules that can be adapted improve the ability of nonliving computational systems to perform advanced learning.

1. Introduction

The goal of many workers in robotics is to design an intelligent learning machine. Not one that, like "Deep Blue", is programmed to solve one particular problem with stunning success (e.g., Campell, 1997), but rather one that actually learns in a broad manner, that is, that can integrate new and existing knowledge to solve novel problems, that takes knowledge acquired in one domain to solve problems in another, that can form and manipulate representations to attain concrete goals. Attempts to design such machines have not yet succeeded. Even within the most elegant attempts, which involve some form of programming by example, the extent to which the computer learns is limited (e.g., Lieberman, 2001; Weng et al., 2001).

In general, most computers are presently analogous to living systems trained in conditioned stimulus-response or simple associative learning paradigms: Given a specific set of input parameters (that can, of course, be quite significant in diversity and number), the computer will quickly and efficiently produce the predetermined, correct output. But if the input is novel and the output not already known, such programming fails to produce an appropriate response, both in computers and in living systems that are similarly "programmed" (Woodard & Bitterman, 1972).

Specifically, the kind of trial-and-error, stimulus-response, conditioned learning that can fairly easily be mathematically modeled for machine learning fails to involve extended generalization. The system, animal or computer, may exhibit a savings in learning closely related tasks (Rumbaugh & Pate, 1984), but never shows the insightful behavior that characterizes human or some forms of animal intelligence (Pepperberg & Lynn, 2000). Animals unable to learn more quickly in the wild than through such trial-and-error would not survive, and human learning is rarely structured in such a manner. How can we determine what processes are involved in *optimal* learning—for both animals and humans? And can we adapt and model these processes for robotic intelligence? My research begins to answer the first question, and I will describe my results in detail, focusing on those processes involved in acquisition of communicative competence (not language). For now, I leave the second question to the robotics experts; after examining my data, I hope that their answer is affirmative.

2. Animals, Learning and Cognitive Processing

To begin answering the questions posed above, two more issues must be addressed. First, what differentiates advanced types of cognitive processing from the more primitive associative learning and conditioned (S/R) responses? Second, why should animals be our models?

Associative/Conditioned Learning vs. Advanced Learning/ Cognitive Processing

What is so important about the kind of advanced learning or cognitive processing in which humans and some animals engage, compared to the conditioning paradigm that is often used for programming computers? I propose that advanced learning is an ethological adaptation whereby social creatures acquire information and actions from one another that improve their fitness and allow flexible responses to a changing environment. Such learning involves the ability to choose the set of rules, among many learned possibilities, from which the appropriate response can be made, and the creativity to build upon learned information to devise novel solutions to a problem. In contrast, the more primitive conditioned learning is limited in scope in that it does not allow construction of the insight that enables immediate transfer across domains, nor even the ability to alter behavior quickly based on the immediate past, much less allow flexibility to respond to changing conditions. Conditioned learning appears to be implicit and unconscious (Damasio, 1999), and to be stimulus driven, even within learning sets. Thus a monkey that learns to pick the odd object of a set of three, no matter what objects are given (which means it has learned some level of transfer), still cannot quickly learn to alter its behavior to pick one of the two objects that are the same (King, 1966).

The point is *not* that associative/conditioned learning is irrelevant: It exists, it is a basis for learning, it can be seen as basic to the programming language of learning… but it is not the appropriate overall *program* for learning, because it does not engender generalization, transfer, or insightful behavior. Rather, the simple initial association of stimulus and response may be what is first linked in memory in humans, but repeated interactions in the real world both sharpen and broaden the connections (Bloom, 2000); what results is a *representation*. Advanced learning derives from the manipulation of such representations. What is needed to devise an intelligent learning machine thus is not to program it more efficiently to take a stimulus as input and use various rules to produce an expected response, but to take that stimulus and use creativity, reasoning, and decisions based on context to produce an appropriate, adapted, adaptive behavior. Some might argue that the latter behavior requires language, but whether the representations necessary to produce such behavior precede language or are formed by language isn't precisely the issue; the representations could be imagery-based. Human biases, however, cause us to focus on communication both as a descriptor and measure of cognitive processing, and thus I will concentrate on communicative competence.

Animal Models

Animal models are important for learning that involves communication. The processes in nonhumans and humans demonstrate striking parallels (Pepperberg, 1999; Savage-Rumbaugh et al., 1993), but proceed more slowly in animals. Children's language acquisition is so fast that after 30 years of study, researchers are still perplexed by the process (Brown, 1973; Hollich et al., 2000). Using animals, however, enables us to examine how a subject learns (a) differently under different levels of affect; (b) to see and use others as an information source, so that guided learning can occur; (c) to integrate knowledge from disparate domains; (d) to develop and manipulate representations; and (e) to relate new information to old knowledge to build concepts for generalization. Too, animals allow researchers to perform experiments that significantly vary the type of input given (Pepperberg, 1999; Pepperberg et al., 1998, 1999, 2000)—something not ethically possible with human infants.

Studies on Grey Parrots

Grey parrots (*Psittacus erithacus*) are especially good subjects for such studies. Grey parrots, like children and computers, can detect/represent speech segments in terms of phoneme probabilities, chunk speech into syllable-like units, produce phonemes, visually detect items, represent shape and color, and attend to and remember co-occurring auditory (speech) and visual representations of items (Pepperberg, 1999). Parrots, like computers and unlike children, are not predisposed to learn human language, but like children and unlike current computers, have a repertoire of desires and purposes that cause them to form and test ideas about the world and how they can deal with the world; these ideas are likely representations of cognitive processing that are open to investigation and modeling.

For almost 25 years, my students and I have been training Grey parrots to use the sounds of English speech to communicate with humans; we then use this two-way communication code to examine their cognitive processing (Pepperberg, 1999). Our oldest subject, Alex, labels over 50 exemplars, 7 colors, 5 shapes, quantity to 6, 3 categories (material, color, shape), and uses "no", "come here", "wanna go X" and "want Y" (X, Y are appropriate location or item labels). He combines labels to identify, classify, request, or refuse ~100 items and alter his environment. He processes queries about concepts of category, relative size, quantity, presence or absence of similarity/difference in attributes, and shows label comprehension; he semantically separates labeling from requesting. He processes conjunctive, recursive queries to tell us the material or of one object, among seven, that has a particular color and shape, or the number of, for example, green blocks from a collection of green and blue blocks and balls. He understands hierarchical categories, that is, that specific attributes that are labeled "red", "green", etc. are subsumed under a category labeled "color", whereas attributes of "3-corner" and "4-corner" are subsumed under a category labeled "shape"; if shown a novel item and told that its "color" is "taupe", he understands how a second novel object of that hue is to be categorized. He also forms new categories readily. He transferred his knowledge of absence of similarity and difference to respond correctly, without training, the first time he was given two objects of equal size and asked to label the one that was bigger (Pepperberg & Brezinsky, 1991). He thus exhibits capacities once presumed limited to humans or apes (Premack, 1978, 1983). He is not unique: Other Greys replicate some of his results (Pepperberg, 1999). The important questions then are: (1) How does a creature with a walnut-sized brain that is organized completely differently from that of mammals (e.g., Jarvis & Mello, 2000; Streidter, 1994) learn these elements of human language? and (2) How does he solve complex cognitive tasks that require generalization and concept formation?

The specific answer as to "how" his brain functions to accomplish these feats of intelligence remains to be discovered. What my students and I have discovered, however, is the type of input he needed in order to learn the elements of human language, that is, the tools that may have enabled him to transition from simple associations to advanced forms of learning (Pepperberg, 1999; Pepperberg & McLaughlin, 1996; Pepperberg et al., 1998, 1999, 2000).

The Model/Rival (M/R) Technique

I was not the first researcher to attempt to establish two-way communication with avian subjects. In the 1940s and 1950s, Mowrer (1952, 1954), using standard conditioning techniques, failed to teach English speech to several psittacids. He used procedures such as the following to teach a bird to produce "Hello" upon the appearance of its trainers (Mowrer, 1969). First, a bird received food and water only in the presence of its trainers. Next, trainers produced "certain characteristic noises" (p. 264), for example, "Hello", followed by a positive action such as a trainer appearing from behind a screen or uncovering the cage. The noise would then be considered a signal (in the parlance of the behaviorists, a 'conditioned stimulus') for subsequent appearance of the positive action (a reward, or 'primary reinforcer'). According to the behaviorists, moreover, the sound itself becomes reinforcing, if only secondarily (the 'secondary reinforcer'), because of what it predicts (Mowrer, 1954). If a bird began to produce the sound itself, the bird received this secondary reinforcement. Production of the sound would, theoretically, increase more quickly if an additional reward occurred for vocalizing (another 'primary reinforcer', such as a favorite food). Thus another association would be formed, between vocalizing and a lessening of hunger, and a bird would be expected to produce the sound with increasing frequency. (The comparison with simple neural nets is obvious.) Mowrer introduced several different words and phrases, but the reward for all vocalizations was food. The idea was that, after a bird emitted vocalizations with some frequency, it could be trained to produce the utterance only in the appropriate context (on the appearance of the trainer) by receiving food only when the vocalization was emitted in such a situation.

Mowrer's birds acquired few vocalizations. His use of food rewards that directly related neither to the task being taught nor the skill being targeted (such as saying "Hello" when the trainer appeared) probably delayed or possibly prevented learning: Most likely, birds confounded the label of the object or action to be taught with that of the unrelated food reward (review in Pepperberg, 1999). That is, his birds apparently connected reproduction of human sounds with the inevitable appearance of food (a salient object to a hungry bird) rather than with their actual referents, for example, "Hello" and the appearance of the trainer. Birds clearly did not realize that a trainer's appearance was the relevant stimulus for producing "Hello". Attempts to obtain food by producing "Hello" when a trainer was already in place would eventually fail: The trainer would consider that the vocalization had been used inappropriately and provide no reward; a bird's production of the strange sound ("Hello") would then lessen (in behaviorist terms, 'be extinguished'). Moreover, because a bird received food for whatever it produced, it may have stopped learning after acquiring one or two utterances that were sufficient for decreasing its hunger.

Some researchers, possibly believing that Mowrer's social setting was responsible for his failure, attempted to train mimetic birds under more rigorous operant conditions, using sound isolation boxes and tapes of human voices; they achieved little success (Ginsburg, 1960, 1963; Gossette, 1969; Gramza, 1970; Grosslight & Zaynor, 1967; Grosslight et al. 1964). Clearly, use of techniques based on conditioned association failed to teach any level of communicative competence.

In contrast, Grey parrots that observed two humans interactively model specific vocal dialogues (Todt, 1975) acquired targeted speech patterns. Todt developed the model/rival (M/R) technique in which humans assume roles played by psittacine peers in the wild. Humans thus demonstrate to a bird the types of interactive vocalizations to be learned. In Todt's procedure, one human is the exclusive principal trainer of each parrot, asking questions and providing increased visual and vocal attention for appropriate responses. Another human is the exclusive *model* for the parrot's behavior and simultaneously the parrot's *rival* for the attention of the principal trainer. So, for example, the trainer says "What's your name?"; the human model/rival responds "My name is Lora." Such human interchanges are similar to duets between parrots in large aviaries (Mebes, 1978). Todt's parrots learned the model/rival's response often in less than a day, in striking contrast to the slow and sparse acquisition in operant paradigms.

The rapidity with which Todt's birds acquired human speech was impressive, but the phrases he used did not allow him to show if a bird understood their meaning; that is, words and phrases did not refer to specific items or actions, such as "tickle", to which an experimenter could respond by scratching a bird's head. Thus Todt's birds may have learned a human-imposed form of antiphonal duetting (i.e., an elaborate form of contact calling for interacting with social peers; Thorpe, 1974; Thorpe & North, 1964) or a conditioned response (e.g., Lenneberg, 1971, 1973). Too, Todt's parrots vocally interacted solely with their particular trainer and learned only the phrase or sentence spoken by the model/rival, never that of the principal trainer. Todt's intent, however, had not been to train birds to communicate meaningfully with humans, but only to determine optimal learning conditions.

My students and I adapted Todt's procedure: adding *reference* so that words and phrases did refer to specific objects and actions, adding *functionality* so that the bird saw that the purpose of learning the odd humans sounds was to obtain desired interactions or objects, and *exchanging roles* of model/rival and trainer, so that the bird saw that the process was interactive, and that one individual was not always the questioner and the other the respondent. The extensive *social interaction* between trainers and between the trainers and the bird also involved different forms of affect: positive for correct responses, negative for errors. The results of our work were described above (Pepperberg, 1999). Interestingly, the ape that appears to be the most proficient in symbolic communication, Kanzi (*Pan paniscus*), initially learned to use computer keys to label and request objects by watching his mother's training sessions (Savage-Rumbaugh et al., 1993); that is, via a form of M/R training. But acquisition of our data on referential use of speech was just the beginning: What was it about our modeling technique that made it so successful? Could it be the basis for a new learning paradigm? We embarked upon a series of experiments to answer that question.

How Aspects of M/R Training Affect Learning

We asked what would happen if we began to remove various aspects of input from M/R training: reference, functionality, social interaction, and modeling. Table 1 depicts the various types of tasks we gave our birds, showing what aspect of input was lacking in each case. In the study ~~Jt~~-Atten, we tested the effects of joint attention. Here a student sat with her back to the bird, talking about an object that was within the bird's reach (Pepperberg & McLaughlin, 1996). She did not attend to the object nor interact directly with the bird. When children were placed in such a situation, they failed to acquire the object label (Baldwin, 1995). The HAG-dual study (HAG= "Human-Alex-Griffin") tested the effects of using an already talking conspecific, Alex, as an additional trainer of a younger bird, Griffin; the M/R procedure was thus expanded to include a third trainer, although not one with full competence. In HAG-solo, Alex was paired with only one of the human trainers in the M/R procedure; because he did not question Griffin directly, some of the normal interaction was missing (Pepperberg et al., 2000). In HG-solo (HG="Human-Griffin"), one student simply conversed with the bird about the object in question, maintaining joint attention, but eliminating modeling and thus some functionality (Pepperberg et al., 2000). In the video training, parrots watched a video of Alex's sessions on a particular label; they experienced various levels of interaction with a single human, from having no human present (social isolation) to having a human who would label, point to, and exhibit the object that Alex was receiving in the video (Pepperberg et al., 1998, 1999). In audio sessions, the birds, placed in isolation, simply heard the audio portion of the videotapes (Pepperberg, 1994). The final column shows that when *any* aspect of the basic M/R procedure was missing, the birds failed to learn, with the intriguing exception of latent learning in the HG-solo situation: After 50 sessions of solo training, the bird had not uttered the label a single time. When we immediately switched labels trained in this manner into M/R format, however, the bird began to produce the label after only 2 or so sessions, unlike the 20 or so M/R sessions that are generally needed. Thus, when functionality was not demonstrated, the bird apparently learned the label, but not what to *do* with it.

Table 1: Effects of Training Method

Method	Ref?	Function?	Interaction?	Model?	Learning?
M/R	Y	Y	Y	Y	Y
~~Jt~~-Atten	Y	N	partial	N	N
HAG-dual	Y	Y	Y	Y	Y
HAG-solo	Y	Y	partial	Y	Y-slow
HG-solo	Y	partial	Y	N	latent
Videos	Y	partial	N/some	not live	N
Audio	N	N	N	N	N

These data showed that M/R training gave birds the tools to learn new labels and concepts, but actually was not the entire story. First, we found that, like children (e.g., Hollich et al., 2000), our parrots' initial learning of labels was still slow and difficult although not stimulus-bound; and, like children, later label acquisition was much faster and involved interesting types of transfer and concept formation. Second, we found that considerable learning was occurring outside of sessions, and that some of this learning was initiated by the birds, much like children playing the "naming game" (Brown, 1973).

3. Progression to Advanced Processing

The point is that we observed a transition from learning that is slow and difficult to learning that is relatively fast, that involves complex processing and that is self-initiated —and that this transition is not limited to humans. How this transition occurs even in humans is not understood, but such understanding (a) is critical if we are to develop intelligent learning machines and (b) may be explored with animal models.

Parallels with Children

For both our parrots and for children, first labels are qualitatively different from later labels. First labels may be acoustically biased by and based on prenatal (DeCasper & Spence, 1986; Querleu et al., 1981) or prehatching exposure to sounds (e.g., Gottlieb, 1982), and have a clear, probably evolutionarily based, predisposition to refer to whole objects: For birds and monkeys, a 'hawk' alarm call initially doesn't necessarily refer to the specific predator or some aspect of a bird, but simply some big object overhead with a general type of shape (e.g., Cheney & Seyfarth, 1990). These first labels are often mimetic, indexical in that they may refer to a specific item rather than a class, and may lack true meaning and communicative intent (de Villiers & de Villiers, 1979).

Nevertheless, at least for humans—and I suspect for my parrots—first labels are still not based on simple associations. If that were true, children could be as easily trained to use tones rather than labels (Colunga & Smith, 2000), or to void the whole-object concept—and they can't (Macnamara, 1982; Markman & Wachtel, 1988). And my birds easily transfer to related objects—without training, "paper" referred to an old-fashioned huge sheet of computer output as well as a piece of an index card used as the original exemplar. Even so, some of my birds' earliest utterances lacked full reference; thus, for example, one bird began to say "Hello" each time any phone rang.

What seems to be lacking in the functionality of first labels is the use of representation. Subjects might not be able to hold images in memory long enough to form a representation, or might not be able to sort early labels into categories used to form representations. Conceivably, both these issues might be involved.

In terms of memory, studies have shown that children under a year lack full object permanence; that is, if an object disappears for more than a few seconds before the child is allowed to search for it, the child has considerable difficulty in retrieval (Diamond, 1985). The rationale for such failure is that the child is not able to store a representation of the object. Whether this ability is dependent upon neural development (Chukani, 1999; Diamond, 1990) or some other effect (Wellman et al., 1986; Pepperberg et al., 1997) is unclear.

In terms of categorization, we know that adults use images of basic categories for a representation: When we hear 'car', we generally do not think of some other vehicle (e.g., a truck), nor do we think of the jalopy that we first owned (Rosch, et al., 1976). Children—and probably birds—initially seem to lack these basic categorical images; for them, 'turtle' is specifically (and solely) the squeak toy in the bath. But later these underextensions and sometimes the specific labels are completely lost. For children, "ur-ul" then refers to the class of critter (de Villiers & de Villiers, 1979) and for birds, "key" can now be any color, shape, or material.

What is occurring as the label-learning process continues in children (Hollich et al., 2000)—and I believe in my birds—is that they begin to process information within an entirely different context that arises through their understanding of social systems; quite likely various levels of neural development underlie such understanding. What is apparent to an observer, however, is only the overt behavior: Although learning is still appears to be self-directed in the sense of being driven by a need to influence others and to have basic needs met, learning now advances because the subject is able to attend to the intentions of others and recognizes others as information sources separate from self. Let's explore how such advances might occur and then lead to concept formation, representation, and complex cognitive processing.

What Mediates the Transition from Early to Later Labeling?

Interestingly, most studies that involve both labeling and concept formation deal with older children (18-24 mos, e.g, Bloom, 2000; Tomasello, 2001); only a few studies attempt to examine the transitional stages either in humans (Hollich et al., 2000) or animals (Cheney & Seyfarth, 1990; Pepperberg, 1999). At 18 months, a child can be playing with one toy, notice that an experimenter is playing with another and giving that toy a label, and then will change its focus to view the experimenter's toy when it hears the experimenter's label, rather than continue to be absorbed with the one that has captured its own interest. But at about 12-14 months, the child is so self-centered that, in the same situation, it will prefer to look at its own toy when it is given a choice between toys and hears the experimenter's label (Hollich et al., 2000), and at about 10 mos is actually likely to associate the experimenter's label with its own toy (Hirsh-Pasek et al., 2000). Thus, during only a brief period, a transition occurs in which the child begins to lose its completely self-centered bias.

And even more interesting is the finding that it is at this transitional stage that autistic behavior and its lack of communication often becomes evident in humans (Tager-Flusberg, 2000)—that is, at the point at which self-awareness and the need to understand self as separate from others and others as information sources becomes critical for learning. Some autistic children never move beyond the 10 mo old stage in terms of associating labels and objects (Baldwin & Tomasello, 1998)

Given that many researchers argue against any level of consciousness or full self-awareness in animals but for extensive cognitive processing (Blumberg & Wasserman, 1996; Heyes, 1993), what level of awareness might be necessary and how might it develop to allow for the kind of abilities that we see in Grey parrots? Possibly, most creatures learn how to generalize and make the initial separation of self from other by first categorizing and generalizing emotions with respect to environmental events (Humphrey, 2000) and then inter-subject interactions (Damasio, 1999). Damasio argues that "core" consciousness (the basic form that involves total awareness of the present, but not the future or past) emerges when we interact with an object (including other beings), and is a feeling that accompanies the making of a mental image—even one that is retained for less than a minute. His theory might explain why social interaction so handily assists learning. The mental image allows for categorization of emotions and events with respect to their emotional content, then, in intact individuals, eventually leads to categorization of involved objects and actions. Note that a child, for example, initially does not label an emotion, but talks about objects about which it cares and expresses the emotion by displaying positive or negative affect (Bloom, 2000). How these categorizations lead to a representation of objects and actions that can be manipulated to allow for advanced learning is still unclear. But at some basic level, self-hood (not necessarily full consciousness), which begins in the *emotional* domain, before the emergence of language, seems to lead to the ability to categorize, which then leads to understanding and use of representation. We can examine our parrots' behavior for clues as to how the transition to advanced learning might arise as they begin to recognize others as sources of information.

Parrot Transitions: Referential Mapping, Sound Play

Evidence for our birds' transitions away from self-centered learning comes from three forms of vocal actions that they use in very similar ways. First, although our birds' new labels usually appear in sessions initially in a modified, rudimentary pattern—first as a vocal contour, then with vowels, and finally with consonants—birds occasionally utter completely-formed new labels after minimal training and without overt preliminary 'practice'. Second, our birds—like young children, Kuczaj, 1998)—often engage in a form of sound play outside of sessions, in which they spontaneously recombine labels or label parts. In both cases, these labels quickly become part of their repertoire if we provide a corresponding object. Thus after learning "grey", one bird produced and was rewarded for "grape", "grate", "grain", "chain", and "cane" (Pepperberg, 1999). Another bird, after learning "spoon" produced "spool" and "school". "Spool" remained in the repertoire because it could easily be rewarded; "school" dropped in frequency because it could not. What appears to happen in both cases, and also in the third (see below) is that the birds begin to test out the possibility that humans are indeed good information sources for the reference for these novel labels. They see humans in this context during training; they then take the situation a step further: In the third form, they not only play with label phonetics, but take a label that they have seen used in a very specific context, such as "wool" for a woolen pompon, and pull at a trainer's sweater while uttering that label. The probability of such action happening by chance is slim; at that stage the bird usually has at least 3 and usually 4 other labels. The birds—like children (Brown, 1973)—seem to be testing the situation. And our responses in all three cases—of high affect and excitement, which stimulate the birds further—show them the power of their utterances and reinforce their early attempts at categorization. Even if the birds err in initial categorizations, they still get positive reinforcement, in that we provide a correct, new label for something; for example, we tell them that the almond isn't a "cork", but suggest the term "cork nut" (Pepperberg, 1999).

What is important to remember is that what we have is a form *not* of trial-and-error learning, but of guided invention (Lock, 1980), from the initial label mapping to the generalization to the imaginal syntax: Parrots, like children, have a repertoire of desires and purposes that drive them to form and test ideas in dealing with the world; these ideas can amount to the first stages of representation (categorization) in cognitive processing. And manipulation of representations is a syntax of imagery, which Damasio insists requires some level of self-awareness.

Do procedures exist to foster such emergent behavior? Preliminary data on children with various dysfunctions, including autism, suggest that they are also sensitive to the elements of input of the M/R protocol (Pepperberg & Sherman, 2000). Although children in these studies have not yet achieved fully age-appropriate behavior patterns, their communication abilities improve significantly after M/R training. Work in progress (Sherman, pers. comm.) suggests that children with particularly severe disabilities may need training to prepare them to accept M/R input. Data from such studies may provide additional understanding of the transitional processes.

Of course, one might argue that sensitivity to input and separation of self from others is not the cause but only the outcome of brain maturation; that is, that the transition to advanced learning occurs simply because of a certain level of neural development. Many neural connections we have at birth die off early (Changeux & Danchin, 1976); are systems used in early, simple label learning what die off? Are they the ones we have been modeling for our computers? Many new connections are formed in the first few years of life; given that neural categorization occurs when a neural ensemble provides the same output from different inputs, is this type of connectivity that which is almost absent in year-old babies and grows in older ones? Is the failure to form the new connections as the old ones die off what is connected to or is responsible for emergent autistic behavior? Possibly (see Chugani, 1999). But if the shift in behavior and the transition to a different form of learning does indeed result from changes in neural connections, such neural reorganization is unlikely to be *specific to humans* because it also occurs in parrots, and parrot brain architecture differs significantly from that of humans (Medina & Reiner, 2000).

4. Conclusion: The Future

Much is still to be determined—for birds as well as children—but I again suggest that animal models will provide a succinct way to understand the processes involved in transitioning between simple and complex learning. To understand the transition, we must learn more about emergent processes: How do the birds form representations and their syntax of imagery? How important is interaction/guidance? How important is emotional interaction? Will generalization occur without feedback? What is the role of M/R training? What is the role of awareness? Is awareness necessary for the formation and manipulation of representations? How can a computer, which is not a social creature, does not yet assess emotion or affect, does not have a sense of itself versus others, be programmed to learn to generalize? Must we build self-aware computers before we can build ones that have advanced learning? Clearly, we must first understand this transition to advanced cognitive processing in living creatures before we can model it for computer learning. Perhaps we need to explore ways in which a computer can *become* a social creature in some sense, so that the M/R paradigm can be usefully applied. Clearly, we are at the beginning of a new area of research.

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