Can Development Be Designed? What We May Learn from the Cog Project*

Julie C. Rutkowska
Cognitive & Computing Sciences,
UniversityCog

a historical process must be a necessary component of the construction of a system that is to become capable of survival in our normal environment. Engineering methods are at the heart of a 'design' approach to building robots, attempting to pre-specify component behaviors that are required and the mechanisms through which they can be implemented. Brooks's insect-like Creatures (1986, 1990, 1991a & b), based on a subsumption architecture with layered control, provide elegant and successful examples of this strategy. Exponents of evolutionary robotics see this kind of hand-design as simply too hard to be feasible at any but a toy scale, however ingenious the experi-

2 From Creatures to Cog

The Cog Project is at an

1971), the origins of whose developmental stages it purports to explain, insofar as he considers stages as evidence for levels of knowledge that are neither observers' discriminations map straightforwardly onto demarcations in our subjects' mechanisms. Certainly, the selection and interpretation of behaviors for such a design plan

- Observing changing behaviors in a domain of activity, using the relative position of a behavior within a sequence to constrain its interpretation.

3 Behavioral Interpretation Through Development

The developmental strategy can be illustrated by looking at infants' changing performance on a simple visual tracking task that presents them with a moving object, part of whose path is hidden by an occluder (Rutkowska, 199 , 1994a & c). Their looking behavior is generally assumed to index knowledge of the object and of its motion ('success' = look to exit as/before the object reappears; 'failure' = look elsewhere). Even very young infants will sometimes succeed in 'anticipating' the object's emergence from behind the occluder in an operational sense, by looking at the exit side as or before the object comes back into view. Should we therefore conclude, depending on theoretical preference, that infants come equipped with visual procedures for solving the problem of object search or 'believe' that objects continue to exist while out of sight? Considering the details of this behavior in the context of others displayed by -, 6- and 9-month-old infants makes such interpretations extremely implausible. Three aspects of the data are notable:

- The behavior pattern of fixations and head and eye movements that sometimes leads -month-olds to be looking at the object's reappearance point before it comes into view is quite different from the pattern through which 9-month-olds attain the same outcome. While -month-olds simply continue tracking as the object disappears from view, sometimes tracking as far as the reappearance point, 9-month-olds characteristically pause as the object disappears from view, then make a single head and eye movement to the reappearance side of the occluder, which they fixate until the object returns to view.

- Although -month-olds' continued tracking has the appearance of functional search for the disappeared object, its frequency declines rather than increasing with age. Nor is it simply replaced by a corresponding increase in the 'entry-exit' fixation pattern found in 9-month-olds, despite infants getting faster and faster at turning to refixate the reappearing object, from wherever they do happen to be looking, as it comes into peripheral vision. 6-month-old subjects exhibit less of either form of 'successful' anticipation than - or 9-month-olds, demonstrating the kind of U-curve that characterizes many instances of development.

- What does increase are behavior patterns involving attention to the object's disappearance point. The one most characteristic of 6-month-olds can be described as backtracking: as the object disappears, the infant continues tracking, but then turns head and eyes sharply back to fixate the object's disappearance point. This is a strange observation as far as attempts to interpret backtracking in isolation are concerned, since those generally assume the infant must have noticed some change in the reappearing object and be looking back to the disappearance point where the original object was last seen. Here, however, a single object moving at constant speed is involved, and is generally still out of view when the infant turns back.

These and other aspects of the data suggest the observer-labelled tracking task is not initially a

Emergent functionality is central to the Cog Project's attempt to maintain behavioral organization through layered control, and it may be developmentally advantageous in two ways, at least as far as the early stages of acquiring novel abilities are concerned (cf. Rutkowska, 1994a & c).

Firstly, emergent functionality could support an initial organization of independent sensorimotor coordinations, such as the visual following featured in the preceding section, that is neither a *tabula rasa* nor a blanket prewired solution to problems that will be encountered. This would offer preadaptation without rigid predetermination. Interactions between preadapted abilities of such a system and the environment in which it finds itself could enable it to 'tune in' sensorimotor coordinations, and sequences of such coordinations, that prove viable in the individual's experience. Novel coordinations (e.g. locomotion by scooting) would not be precluded in case of altered environmental conditions and/or properties of the subject (e.g. physical-motor disability).

Secondly, within the developmental process, the phenomenon of scaffolding can be viewed as a form of supervised learning in which emergence of function is temporarily engineered to establish the developmental space within which viable patterns of activity can be stabilized. Scaffolding, as originally viewed in social terms, marks the process through which more able humans manipulate the infant's transactions with the environment so as to foster novel abilities (e.g. Valsiner, 1987; Wood, Bruner & Ross, 1976).

The process begins with sensory and motor processes that are not coordinated by the infant but are set in alignment with the environment by adults. For example, if an infant's head is moved to look at someone leaving a room and simultaneously his/her hand is moved up and down, whatever the infant is doing, initially s/he is not waving goodbye. Key features are: customizing or simplifying the environment; reducing the number of degrees in the target task; directing attention by marking critical attributes; and enabling repeated experience of the end, outcome or goal of an activity that the infant would be unable to seek voluntarily. This sets up the possibility of serendipitous learning by the infant, that is of an accidental (i.e. unplanned) yet fortunate discovery of possibilities for effective action, in which the balance of behavioral control shifts from the environment to the subject.

The ubiquitous nature of such phenomena has been seen as evidence for all aspects of human development being socially and culturally guided, but adults may be exploiting and directing inbuilt processes that also operate in infant's spontaneous interactions with the environment. For example, in the previous section's account of the development of visual tracking, initial serial ordering of behaviors emerged from ongoing interaction with the environment; it was not governed by a goal or plan directed at finding the disappeared object. Spatio-temporal properties of the infant's interactions with the environment supported recurrent sequences of sensory and motor processes, most notably attention to kinetic occlusion followed by turning to refixate (and hence to experience 'finding') the reappearing object. In principle, such processes may share the main properties of social scaffolding, provided

is worth emphasizing that, to the extent that they 'model' anything, it is constraints on effective action rather than an external 'world' in which action takes place. Developmental psychology and cognitive

- No 'bit' of action mechanisms is 'the' internal representation. The capacity for successfully locking onto the environment and anticipating the consequences

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