Developing Concepts from Robot Behaviour

Christopher Willmot **Stefan Wermter** **Christo Panchev**
University of Sunderland, Hybrid Intelligent Systems (www.his.sunderland.ac.uk)
School of Computing and Technology, Sunderland, SR6 0DD, United Kingdom

Abstract

This paper describes an approach to developing concepts from robot actions using dynamically growing self-organising networks. A robot explores the difference between objects with different properties, e.g. rollable and pushable shapes. We use an assimilation mechanism to build robot analogs of Piaget's first sensory-motor circular reactions. Motor schemes are accumulated in a growing self organizing network according to the Interactivist grounding hypothesis. The structures which form are similar to (very primitive) Kellyan personal constructs and provide potential distinctions for the accommodation process. The purpose is to demonstrate emergence of these internal structures which indicate separable clusters of "experience". In this way we show how grounded, pre-linguistic "concepts" might develop from a robot's interaction with its environment.

(Bickhard, 2000) suggests that knowledge can be grounded in the response to the question, "*If I do this, will it work?*" Implied in this question are (a) an initial environmental state; (b) an action and (c) an anticipated state. Although it is simpler for mechanical systems to learn from specifics to produce generalisations, we prefer a more biologically realistic direction, progressing from the general to the specific. We do this by growing and adapting the context-dependent, partial representations of action-based knowledge suggested by (Mareschal et al., 2007). Like them, we adopt a Constructivist stance in the tradition of Genetic Epistemology (Piaget, 1953) and Personal Construct Theory (Kelly, 1955). Also, to accrue the philosophical benefits of modelling from an Interactivist perspective (Bickhard, 2003), our data avoid static representations in favour of process-based (Stojanov and Kulakov, 2003).

Actions that are 'innate' to the robot are a random walk, avoiding walls and approaching coloured objects. Following (Piaget, 1953), assimilation is aggressive in accumulating the expressions of these 'reflex' primitives according to the current knowledge structure, which is initially undifferentiated. This results in the build up of *sequences* of *events*, which comprise initial state, action and resulting state. Prototypical sequences are recorded and added to the pool of potential actions. Each sequence is an implicit hypothesis – that the string of actions will transform one state into another. Where the actions from a sequence are carried out by the robot, and the predicted state transformation is reflected in what actually occurred, the hypothesis is confirmed and the chance of replaying this sequence in future is increased.

Our experiment has a khepera robot moving freely within an enclosure containing balls, boxes, pyramids and cylinders. We expect interactions with rollable and pushable objects to form distinct regions in the network. These "experiences" are not merely accumulated randomly, but purposefully shaped and selected. So we expect to see clusters appear faster in the experimental condition, utilising the mechanisms described here, compared with the control, where the robot in the same physical environment can only draw on 'innate' actions.

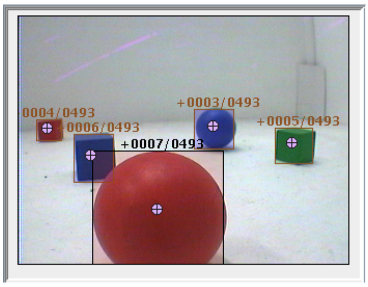
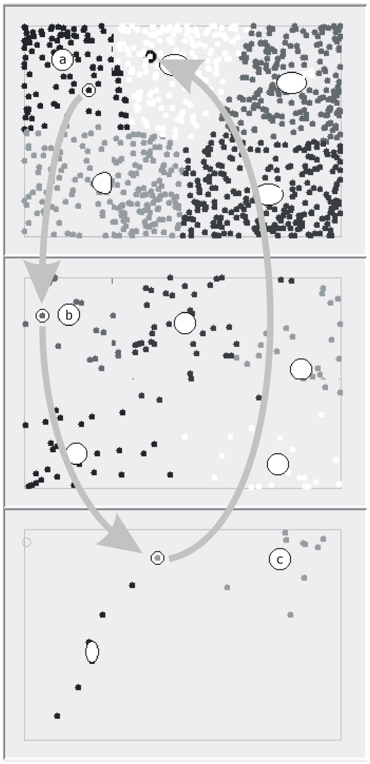


Figure 1: Collecting action sequences

Piaget's first circular reactions may be seen in the robot's behaviour as it repeats the same activity in the same manner, becoming "ingrained". Also, the confirmation of the hypothesis implicit in each *sequence* is itself a grounded knowledge primitive (Bickhard, 2000), so the robot system is acquiring a dynamical representation of world knowledge.

Perceptual input is recorded in separate (Gärdenfors, 2000) conceptual spaces (GCS) for odometry, infra-red sensors, object appearance and object movement. The data for each GCS goes through an incremental, hierarchical dynamic clustering system (Fig. 2) based on (Shen and Hasegawa, 2005). Initially there is only one cluster per set, but the number of clusters grows to reflect the perceptual variation in that place in the hierarchy. The *event* which is appended to the currenly active *sequences* doesn't use raw input, but the cluster vectors. Thus the *sequences* represent segments of experience constructed from the system's perception at this point in its developmental history.



This illustrates one branch through the event cluster hierarchy. The top panel shows all initial states. In the middle are all actions from state cluster 'a'. All result states from action cluster 'b' are at the bottom. Raw initial, action and result vectors for one event are ringed. These are transformed into a perceived event *comprising the vectors for 'a', 'b' and 'c'. Of course the result of this event is the start of the next one. In this example, the next event's initial vector will be taken from the neighbouring cluster tree (not shown).*

Figure 2: Dynamic clustering of events

Sequences are entered into a self organising network such that similar trajectories are close together. If the *sequence* has been tested and its implicit hypothesis proved correct, it is promoted to an *hypothesis*. The relationships between *hypotheses* produces "concepts" as distinguishable neighbourhoods. *Hypotheses* are compared in triads as in Kelly's repertory grid technique (Bannister and Fransella, 1989). A concept is identified where two *hypotheses* are more similar to each other than to a third.

In modelling Piaget's first circular reactions, we use a similar approach to the Petitagé simulator (Stojanov, 2001), collecting and replaying action sequences. However, our system works in the real world in real time and aims for representations that are more Interactivist (Stojanov and Kulakov, 2003). Where Petitagé used grid directions and required a static environment, our system uses unconstrained actions, a continuous multi-dimensional state space and can handle changes resulting from its own interactions. (Stojanov, 2001) recorded the circular reactions themselves and used representations of these as proto-concepts. We see circular reactions as the *outcome*, not the learning itself, and consider it more Interactivist for the concept representation to refer to the *hypotheses* themselves.

Like Piaget, we believe cognitive systems *actively* seek understanding. Our robot augments its programmed activity with sequences of previously experienced actions. Successful tests become grounded atomic knowledge recorded as actions, not states, as Bickhard suggests.

The self organising network architecture is still under development, using similarity measures inspired by (Victor et al., 2007) and the partial, distributed representations suggested by (Mareschal et al., 2007). We hope to report experimental results when that is completed.

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