Control Mechanisms for Spatial Knowledge Processing in Cognitive / Intelligent Systems

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Why Control in Spatial Knowledge Processing?

Crucial characteristics of cognitive systems, may they be *robots*, (*software*) *agents*, or *humans* are (a) spatial knowledge processing and (b) mechanisms for control of information processing. Without the former, cognitive systems would not be able to act in as well as reason and communicate about a world which is inherently spatial. Without the latter, all the reasoning faculties and activities of the system would be employed solitarily leading, in the end, to a failure of the system. Consequently, over the last decade(s), there has been a growing interest in the understanding and realization of both aspects in all three types of cognitive systems. Despite the substantial research effort devoted to control mechanisms and spatial knowledge processing as such, control mechanisms for spatial knowledge processing have virtually been neglected.

Control Mechanisms

Regarding control mechanisms both the field of AI and the field of cognitive science have focused on comparable problems. One important topic, for instance, has been whether and how top-down and bottom-up influences can be and are integrated to achieve control of information processing in artificial and natural cognitive systems. In AI it now seems to be generally accepted that to implement satisfactorily flexible and at the same time intelligent information processing it is necessary to take into account both top-down influences like goals and bottom-up influences like environmental stimuli triggering certain processing steps (Murphy 2000). Similarly, research in cognitive science has shown that control mechanisms in humans can be conceived as being implemented as the interaction of intentions / goals and environmental influences (Monsell & Driver 2000). A second fundamental question in both fields of research is whether the top-down influences are to be conceptualized as being instantiated by a single component of the cognitive system: in cognitive science as well as in AI some approaches argue for a central controller (i.e., a central executive (Baddeley & Logie 1999)) whereas others favor the view that control emerges—maybe even heterarchically—from the interplay of several functional components (Broersen *et al.* 2001).

Spatial Knowledge Processing

With respect to spatial knowledge processing, research has focused on the type of representations employed and the processes working on them. Whereas AI research aims at devising new representations and respective processes to most efficiently reason about some particular spatial problem, cognitive science research tries to reveal and discover the representations utilized in human spatial knowledge processing. Significantly, the representations identified by both strands of research are comparable regarding important characteristics. More precisely, representations for spatial knowledge processing are characterized in both fields as being (a) qualitative (i.e., distinguishing conceptual categories rather than measures (Cohn 1997)), (b) fuzzy / imprecise, and (c) analogous (i.e.,—at least some of—the relations holding between the constituting parts of the representation are analogous to the relations that hold between the entities denoted by those parts (Sloman 1975)). Adhering to these characteristics a number of different types of representations for different kinds of spatial knowledge processing have been proposed in modeling and implementing cognitive systems.

Control in Spatial Knowledge Processing: Open Issues

Although spatial knowledge processing as well as control mechanisms in information processing have thus been considered in close detail, they have been considered mostly only independently of each other. Therefore, results about and conceptions of control mechanisms in spatial knowledge processing are hardly available. Open questions are, for example:

- How is the construction of spatial representations controlled?
- How is processing that makes use of spatial representations controlled?
- Given several existing spatial representations, how is the selection of one or more of them for processing controlled?
- Can different spatial representations be combined? How is such a combination controlled?
- Are control mechanisms used in spatial knowledge processing the same as in other domains? If not, what are the differences?
- What are efficient ways to realize control in spatial knowledge processing?

The goal of the AAAI spring symposium documented in this report was to give first answers to these and related questions by bringing together researchers from AI and cognitive science.

Control in Spatial Knowledge Processing: Approaches

This collection assembles several approaches to answer the above and related questions. Though these approaches differ in their specifics, some general trends can be observed.

Methods

Two main approaches to tackle the questions stated above are computational cognitive modeling and building spatially able robot systems. Regarding the former, the contributions by Ragni & Steffenhagen, Gunzelmann & Lyon, Bertel, and Chandrasekaran & Kurup present computational approaches concerned with the mechanisms of control in human spatial knowledge processing and possible applications of such computational approaches. Regarding the latter, proposed approaches span the range of improving visual perception of spatial configurations by top-down control (Birk), enabling robots to autonomously learn control laws (Modayil & Kuipers), and control mechanisms for building maps of the environment (Zender & Kruijff).

Generality

One issue addressed—at least implicitly—by several contributions in this report is the question whether control mechanisms in spatial knowledge processing are the same as in other domains or not. Most prominently, the approaches by Chandrasekaran & Kurup and Gunzelmann & Lyon propose that control in spatial cognition can accurately be modeled by the general control mechanisms as implemented in the cognitive architectures of ACT-R (Anderson *et al.* 2004) or Soar (Newell 1990), respectively. A similar stance is taken by Bojduj & Kurfess as well as by Ragni & Steffenhagen. Bojduj & Kurfess present an approach where the selection of appropriate spatial representations is controlled using classical case-based reasoning. Ragni & Steffenhagen assume a central executive like proposed by, for instance, Baddeley and Logie (1999) in their general working memory conception as the controlling entity in spatial reasoning. Thus, there seems to be a inclination by researchers to presume general control mechanisms being also at work in spatial knowledge processing.

Controlling Representations and Representing Control

Another central concern seems to be the mutual dependencies of (constructing) spatial representations and control. On the one hand, as mentioned above, controlling the construction of spatial representations is an important aspect for every cognitive system. In accord with this, Yeap as well as Lovett, Dehgani & Forbus introduce their thoughts on how such control might be realized in general and when constructing spatial representations from hand-drawn sketches, respectively. On the other hand, the contributions by Tellex & Roy and Hommel & Klippel suggest how representations might underlie certain control abilities. In both contributions it is assumed that control information either in the form of spatial routines (Tellex & Roy) or in the form of object-action complexes (Hommel & Klippel) is part of the spatial representation and, thus, activating a particular representation triggers certain control schemas.

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