Multimodal Systems as Multirepresentational Systems

Unmesh Kurup, B. Chandrasekaran

Rensselaer Polytechnic Institute, The Ohio State University
110 8th St, Carnegie 013, Troy, NY 12180
DL 591, 2015 Neil Ave, Columbus, OH 43210
kurupu@rpi.edu, chandra@cse.ohio-state.edu

Abstract
In earlier work, we have shown how a cognitive architecture can be augmented with a diagrammatic reasoning system to produce a bimodal cognitive architecture. In this paper, we show how this bimodal architecture is also bi-representational (multi-representational in the general case) by describing a desiderata for representational formalisms and showing how the diagrammatic representation in biSoar satisfies these requirements.

Introduction
In earlier work, we have shown how a diagrammatic reasoning system (DRS) can be added to an existing architectural framework (Soar) to construct a bimodal cognitive architecture (biSoar) that can represent and reason about knowledge in both linguistic and diagrammatic forms as appropriate. In this paper, we place this work in the context of the current symposium – namely, we show how and why this bimodal architecture is multi-representational. We describe desiderata for representations (in a cognitive architecture context) and show how the diagrammatic representation in biSoar meets these requirements.

Systems can be multi-representational along multiple dimensions – based on their content, their form or some combination of both. The distinctions between form and content are not always clear and every form imposes restrictions on the content that can be represented using that form. Every formalism at its lowest level can be reduced to a set of primitives and a set of rules to combine these primitives into representations. This compositionality is a key feature that allows the formalism to represent a potentially infinite number of sentences. Finally, non-trivial formalisms also provide for a set of processes that operate on these representations. The output of these processes may be expressions themselves in the same formalism or, in a multi-representational system, they can be expressions in a different formalism. These processes have both formalism-level and domain-level characterizations that capture the intended semantics of the system. Figure 1 represents the components of a non-trivial representational formalism. The desiderata for a formalism then is as follows – it should describe the primitives of the representation and give rules of composition that allow for expressions in the representation to be formed. It should also describe a set of processes that modify the existing representation and create new representations.

The traditional representational formalism for high-level reasoning is predicate-symbolic – where the world is represented in terms of entities in the world (symbols) and relations that hold between them (predicates). Figure 2 shows the components of the predicate-symbolic formalism and provides examples of the primitives, various rules of composition and processes. More recently, there have been proposals that call for a greater role for perceptual and action systems in high-level cognition (Chandrasekaran 2006). These proposals call for cognition to be multi-modal with the modality-specific components of cognition contributing modality-specific representations and processes.
biSoar is a bimodal cognitive architecture constructed by augmenting the cognitive architecture Soar with a diagrammatic reasoning system (DRS). (Kurup and Chandrasekaran 2007) gives a more detailed description of the system and how it can reason by interleaving linguistic and diagrammatic representations as appropriate. One of biSoar’s representations is Soar’s native representation which is predicate-symbolic and obviously satisfies the requirements of representational formalism. Here, we focus on the diagrammatic representation – the DRS (Chandrasekaran et. al. 2004) – and show how it too satisfies the desiderata for a non-trivial representational formalism.

**Primitives.** The DRS representation recognizes three types of primitives – points, curves and regions. Point objects only have location (i.e., no spatial extent), line objects only have axial specification (i.e., do not have a thickness), and region objects have location and spatial extent.

**Rules of Composition from Entities to Diagrams.** The only rule of composition for entities is that they have a spatial location within the grid. In the case of curves and regions, the location may refer to any intrinsic point of the entity (end points, mid point, center-of-gravity) or simply an arbitrary point of the entity.

**Processes.** There are two types of processes (called routines) in DRS – perceptual routines and action routines. Perceptual routines are used to extract relations and recognize emergent objects from a given diagram. The output of a perceptual routine can be a predicate-symbolic expression (relation extraction) or a diagrammatic expression (as in the case of emergent object detection). For example, the perceptual routines Left(a, b, d) check to see if object a is to the left of object b in diagram d and return the symbol true. Action routines are used to create, remove and modify entities within a diagram and their output is a new diagram. For example, an action routine to create a new object b to the right of a, modifies the diagram to add b to the right of a.

Fig 3 shows corresponding component hierarchy for the DRS representation.

**Discussion**

A diagram in the DRS consists of point, curve and region entities which are combined to form diagrams. This compositionality allows a potentially infinite number of diagrams to be constructed from a potentially infinite number of entities. Thus DRS satisfies the requirements for a representational formalism. In the general case, the diagrammatic representation may be extended along same principles to include other modalities as well, making the system multi-modal. In conjunction with the predicate-symbolic representation, DRS allows biSoar’s representational system to be multi-representational.

**A Note about the Semantics of Diagrams.** A key aspect of diagrams and diagrammatic entities is that they are independent of any domain theory. That a point refers to a tank, or that a curve refers to a river or a region to a blast radius is imposed by the problem solver depending on the problem being solved. This independence allows the DRS to represent and reason about diagrammatic entities irrespective of the domain in which they may be used.

**References**

