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GUEST EDITORIAL

Representing and reasoning about three-dimensional space

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In any field, it may be all too easy to overlook the invisible background practices taken for granted when working within it. The design of any physical object or environment naturally takes on board a series of assumptions about three-dimensional (3-D) space, the seemingly unproblematic background that serves to define geometry, to measure relations between objects, and to provide the field for action. These relationships among shape and form, structure and function, and behavior and semantics are among the most fundamental questions studied by science and engineering. The ways in which we represent and reason about 3-D space has undergone increasing discussion in recent decades, as the variety of different tasks and requirements are made explicit. The growing reliance on computer-aided design systems for integrated communication of large, international design teams on more complex projects has necessitated the development of better standards by which we can represent space and the objects within it. At the other extreme, approaches such as those in "embodied" robotics avoid representation altogether, and use "the world as its own best model" (Brooks, 1991).

Computational approaches in computer-aided design seem to fit naturally with a Cartesian representation of geometry in relation to a single origin, with objects defined as symbolic primitives. This is powerful and ubiquitous, but many alternative representations of space may be desirable for various other applications and forms of analysis. Relationships between geometry, such as adjacency, interior versus exterior, convexity of spaces, which may be self evident and important to designers require significant additional computation. Parametric and topological alternatives, graph-based representations, and distance metrics all play a role across a variety of disciplines from cognitive and perceptual modeling to virtual reality. Spatial reasoning techniques from artificial intelligence and robotics have found utility in motion and assembly planning, whereas procedural and grammar-based representations are increasingly common in architecture, engineering, and construction. The choice of representation affects the process of design and should be understood prior to the creation and use of intelligent computational applications.

This special issue focuses on 3-D space itself as the one unifying factor across all domains of engineering and design. The way in which it is represented and understood is fundamental to a diversity of fields. In architecture and urban design, space is the product of design. In the engineering of smaller artefacts it is the context in which their parts relate to one another. In manufacturing it is the environment in which control systems must operate physical processes. It is hoped that such an issue could contribute to the dialogue across a number of disciplines and application areas.

One way to approach this is through formalisms, schemata, and protocols: the development of standards is one of the aims of those working in almost any domain. Pieter Pauwels et al. address the issue of different kinds of representations head on, and are specifically concerned with communication. Even if file formats such as .dxf, .dwg, and .obj cannot be merged, they still ostensibly refer to the same 3-D geometry, and it should be possible to translate between them because they have the same semantic content. Semantic web technology is shown to be a useful means for doing so.

Such an approach is less about the particular representation as it is about providing our computational tools with the capacity for reasoning in 3-D space in a way that is effortless for the human operator. In contrast, there are tasks thrown up by computational approaches that have been intrinsically difficult, and therefore limiting for us. Design approaches such as shape grammars have potentially been limited by this, an issue that Frank Hoisl and Kristina Shea take on in their paper. Shape grammars are often implicitly taken as a standard formalism. Perhaps unintentionally, a set of formal rules seems to imply a unique representation for a given corpus of work. As a means to explore certain commonalities, this has been fruitful, but to date there have been few implementations of such rules that have been adopted by designers. Hoisl and Shea acknowledge a criticism that is likely to be at the root: the rule sets are relatively inflexible and time consuming to produce. They propose an interactive approach that improves the user interface by relying on geometric relationships among primitives, from which the symbolic rules can be abstracted. This is parametric, and can be adjusted

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with real values to tune and alter the rule set as needed. The use of parametric tools has now become commonplace, with popular adoption in recent years. It may be approaches like this that fit closely with the new workflow that will help to realize the potential of grammar and rules-based design methods.

If the first two papers can be said to address the topic of spatial reasoning in machines and humans, the second two suggest a means of representation for spaces in which actions (movement, navigation) take place. Ermal Shpuza draws on work that is typically fully embodied in an environment, sightlines, movement, wayfinding, and so forth (which need the full representation of spatial geometry to calculate at any point), and distills two concise measurements as representation. The application goals here are for improved visualization, virtual reality and 3-D interaction. For Ata A. Eftekharian and Horea T. Ilieş, movement is not the source but the aim, and they are driven by motion planning and physics-based simulation problems. They propose a representation that captures the relevant structure so that this can be easily computed without the full representation of space.

As we design the systems within which we design, issues of our perception of space and how it is mediated by the interface become more evident. There are important differences between psychology of our own perception and any of these modes of representation. Our every daily action takes place in a 3-D space to which we relate unproblematically via a suite of behaviours and conventions practiced for our whole lives, and it is perhaps for this reason that Michael Glueck and Azam Kahn draw on their own work in designing computer-aided design systems at Autodesk, as well as current industry standards, to review the current state of our interaction with the virtual environment. They propose that intellection and navigation, which can too easily be considered distinct, are intimately related to one another, and should be considered together. They identify a suite of perceptual cues that may be leveraged by human–computer interaction and interface designers to give us a better and more effortless perception of space, scale, and movement within the virtual space in which we must operate. It may be hoped that such an improved understanding of our natural perceptual abilities may be a road to better tools, and set the stage for further research.

The stated theme of 3-D space is superficially precise, but it may be evident from this issue's contents alone that the topics covered were broad. The guest editors gratefully acknowledge the team of anonymous reviewers from a wide range of diverse fields for their insight and sometimes quite varied opinions. We also express our thanks to Professor David Brown, Editor in Chief of *AI EDAM*, for his advice and help in editing this issue of the Journal.

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