Chapter 16
Reasoning about Space, Actions, and Change:
A Paradigm for Applications of Spatial Reasoning

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ABSTRACT

Qualitative spatial conceptualizations provide a relational abstraction and interface to the metrical realities of the physical world. Humans, robots, and systems that act and interact, are embedded in space. The space itself undergoes change all the time, typically as a result of volitional actions performed by an agent, and events, both deterministic and otherwise, which occur in the environment. Both categories of occurrences are a critical link to the external world, in a predictive as well as an explanatory sense: anticipations of spatial reality conform to commonsense knowledge of the effects of actions and events on material entities. Similarly, explanations of the perceived reality too are established on the basis of such apriori established commonsense notions. The author reasons about space, actions, and change in an integrated manner, either without being able to clearly demarcate the boundaries of each type of reasoning, or because such boundaries do not exist per se. This chapter is an attempt to position such integrated reasoning as a useful paradigm for the utilization of qualitative spatial representation and reasoning techniques in relevant application domains. From a logical perspective, the author notes that formalisms already exist and that effort need only be directed at specific integration tasks at a commonsense conceptual, formal representational, and computational level.

INTRODUCTION

The field of Qualitative Spatial Reasoning (QSR) investigates abstraction mechanisms and the technical computational apparatus for representing and reasoning about space within a formal, non-metrical framework (Freksa, 1991b; Cohn & Renz, 2007). Logical formalizations of space and tools for efficiently reasoning with them are now well-established (Renz & Nebel, 2007). Similarly, temporal calculi, in a minimalist sense of the interval-interval relations of Allen (1983), and other more elaborate formal methods in reason-

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ing about change provide the general mechanisms required to handle various aspects such as continuity, concurrency, causality and the fundamental problems resulting therefrom (Shanahan, 1997; Davis & Morgenstern, 2004; Mueller, 2006). Developments in this latter field, generally referred to as Reasoning about Actions and Change (RAC) (Van Harmelen, et al., 2007), have primarily been motivated by some of the fundamental epistemological problems that arise in reasoning about actions and their effects, e.g., the *frame* (McCarthy & Hayes, 1969), *ramification* (Finger, 1987), and *qualification* (McCarthy, 1977) problems. Within RAC, efforts have resulted in formal calculi such as the Situation Calculus (McCarthy & Hayes, 1969), Event Calculus (Kowalski & Sergot, 1986), and Fluent Calculus (Thielscher, 1998), and other more specialized formalisms also similarly grounded in mathematical logic (Davis & Morgenstern, 2004). In contrast to the field of RAC, QSR has acquired its present status as a sub-division within Artificial Intelligence (AI) only relatively recently (Stock, 1997), and has its most direct origins in the work on Qualitative Reasoning in the late 80s and early 90s (Weld & de Kleer, 1989).

With the aim of realizing practical applications of *logic-based* reasoning about space and spatial change, this article poses the question of the integration of formal methods in qualitative spatial representation and reasoning on the one hand, and general commonsensical approaches to represent and reason about action and change on the other. The question is posed within the context of a certain class of application scenarios, and ensuing computational requirements therefrom, which inherently require the ability to model and reason about changing spatial datasets. In a rather specific sense, this posits the question of the integration of qualitative spatial theories encompassing one or more aspects of space with calculi of action and change such as the Situation Calculus, Event Calculus and Fluent Calculus; the range of available specialized formalism for modelling commonsense reasoning, and reasoning about action and change being rather extensive (Davis & Morgenstern, 2004; Van Harmelen, et al., 2007).

Why is Integration Necessary?

The integration of qualitative spatial representation and reasoning techniques within general commonsense reasoning frameworks in AI is an essential next-step for their applicability in realistic (relevant) domains, e.g., in the form of spatial control and spatial planning in cognitive robotics, for spatial decision-support in intelligent systems and as explanatory models in a wide-range of systems requiring the formulation of hypothesis, e.g., diagnosis, event-based geographic information systems, robotic control scenarios. It is also imperative that the intended integration be achieved at uniform ontological, representational and computational levels, or aptly, a paradigm such as *Reasoning about Space, Actions, and Change* (RSAC) is needed. Indeed, if 'spatial reasoning,' both qualitative and otherwise, and commonsense notions of space and spatial change are to be embedded or utilized within practical or larger application scenarios in AI, for instance to model the qualitative spatial reasoning abilities of a robot, their integration with formal calculi and tools to model change in general needs to be adequately investigated in a fundamental manner. Furthermore, it is necessary that the integration and the supported computational mechanisms therefrom be generic/applicable in a wide-range of application domains, such as the ones highlighted in this chapter.

Integration and Sub-Division in AI

The proposed integration is also closely related to the general problem pertaining to the sub-division of endeavours (McCarthy, 1977), such as spatial reasoning, in artificial intelligence in general. Within the context of the formalisation of common-sense knowledge, McCarthy (1977)