Chapter 1
Region-Based Theories of Space: Mereotopology and Beyond

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ABSTRACT

This chapter focuses on the topological and mereological relations, contact, and parthood, between spatio-temporal regions as axiomatized in so-called mereotopologies. Despite, or because of, their simplicity, a variety of different first-order axiomatizations have been proposed. This chapter discusses their underlying ontological choices and different ways of systematically looking at them. The chapter further gives an overview of the algebraic, topological, and graph-theoretic representations of mereotopological models which help to better understand the model-theoretic consequences of the various ontological choices. While much work on mereotopologies has been primarily theoretical, the focus started shifting towards applications and domain-specific extensions of mereotopology. These aspects will most likely guide the future direction of the field: How can mereotopologies be extended or otherwise adjusted to better suit practical needs? Moreover, the integration of mereotopology into more comprehensive and maybe more pragmatic ontologies of space and time remains another challenge in the field of region-based space.

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1. INTRODUCTION

The very nature of topology and its close relation to how humans perceive space and time make mereotopology an indispensable part of any comprehensive framework for Qualitative Spatial and Temporal Reasoning (QSTR). Within QSTR, it has by far the longest history, dating back to descriptions of phenomenological processes in nature (Husserl, 1913; Whitehead, 1920, 1929)—what we call today ‘commonsensical’ in Artificial Intelligence. There have been plenty of other motivations to study the topological and mereological relations of space—as an appealing alternative to set theory or point-set topology, or as an region-based alternative to Euclidean geometry. Even beyond QSTR, mereotopology is fairly universal and can be applied to various other fields, where the spatial or temporal character is not its primary purpose.

Mereotopology also often serves for testing and exploring techniques of building qualitative spatial reasoning frameworks. Likewise, central issues of knowledge representation can be tested within it—building reusable, generic ontologies, constructing upper ontologies, testing specification and validation of formal semantics for ontologies and not least, coming up with general mathematical frameworks to systematically compare ontologies model-theoretically or axiomatically.

Without doubt, we can say that within QSTR mereotopology encompasses some of the most advanced and best understood spatial theories. This chapter gives a high-level overview of the early and more recent advances in the field, what mathematical tools and techniques are successful, how the theories vary, and what are the challenges remaining within and beyond the field.

The quest for region-based theories of space as alternatives to classical point-based geometry is often driven by the human cognition: how humans perceive their spatial and spatio-temporal environment. An urge for common-sense representations and reasoning systems is given by work on naïve physics (Hayes, 1978; Hayes, 1985b; Smith & Casati, 1994) and naïve geography (Egenhofer & Mark, 1995b). Theories of space and time will be a major component of any common-sense representation of geographic or physical space. For common-sense reasoning, region-based theories of space (and time) are more promising than point-based theories since they are able to draw commonsensical topological or mereological conclusions even in the absence of exact data, or as Egenhofer and Mark (1995b, p. 9) put it: “topology matters, metric refines.” Not least, the study of region-based theories contributes towards the understanding of the nature of points—they actually have structure that is not evident in Euclidean geometry (Eschenbach, 1994). Through the inclusion of qualitative models of space, common-sense reasoning but also the next generation of Geographic Information Systems (GIS) and other spatial reasoning software can at least partially bridge the gap between rigid computational models of space and less rigid users that freely navigate between quantitative and qualitative and between low-level and high-level conceptions of space.

1.1. Scope and Structure

Upfront a few words on the scope of this chapter. There have been a few overviews of mereotopology in the context of qualitative spatial reasoning (Bennett, 1997; Casati & Varzi, 1999; Cohn & Hazarika, 2001; Cohn & Renz, 2008; Cohn & Varzi, 2003; Donnelly, 2001; Eschenbach, 2007; Vieu, 1997). We do not simply aim to extend these summaries with more recent work, but we hope to compile a more comprehensive account of mereotopology paying respect to the whole breadth of the field. Overviews covering mereotopology just as one amongst many qualitative spatial reasoning frameworks (Cohn & Hazarika, 2001; Cohn & Renz, 2008) have been unable to allocate sufficient space to cover the many different approaches towards mereotopology. More