面向过程的时空现象建模方法

PROCESS ORIENTED MODELLING APPROACH FOR SPATIO-TEMPORAL PHENOMENA

徐爱功　[斯里兰卡]A.H.拉克曼　著

测绘出版社

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测绘出版社

·北京·

Published and distributed
By Surveying and Mapping Press
50 Sanlihe Lu
Xicheng, Beijing 100045
China

Process Oriented Modelling Approach for Spatio-temporal Phenomena
787mm × 1092mm 9.5 Printed sheets
1st Edition 1st Impression Dec 2013
ISBN 978-7-5030-3223-3 CNY 32.00

图书在版编目(CIP)数据

面向过程的时空现象建模方法：英文／徐爱功，（斯里）拉克曼（Lakmal, A. H.）著. —北京：测绘出版社，2013.12

ISBN 978-7-5030-3223-3

Ⅰ. ①面… Ⅱ. ①徐… ②拉… Ⅲ. ①地理信息系统－数据模型－模型建立－英文 Ⅳ. ①P208

中国版本图书馆 CIP 数据核字(2013)第 241255 号

责任编辑 吴 芸 **封面设计** 李 伟 **责任校对** 董玉珍 **责任印制** 喻 迅

出版发行	测绘出版社	**电　　话**	010－83543956(发行部)
地　　址	北京市西城区三里河路 50 号		010－68531609(门市部)
邮政编码	100045		010－68531363(编辑部)
电子信箱	smp@sinomaps.com	**网　　址**	www.chinasmp.com
印　　刷	北京京华虎彩印刷有限公司	**经　　销**	新华书店
成品规格	169mm × 239mm		
印　　张	9.5	**字　　数**	235 千字
版　　次	2013 年 12 月第 1 版	**印　　次**	2013 年 12 月第 1 次印刷
印　　数	001－500	**定　　价**	32.00 元

书　　号 ISBN 978-7-5030-3223-3 /P · 676
本书如有印装质量问题，请与我社门市部联系调换。

Foreword

Describing real-world evolution is a complex task. One may observe the status of entities before and after a change occurs, these are facts and consequences. An event is a set of related changes leading to a new status. Events may be observed without knowledge about the mechanisms leading to change. However, that change is postulated to happen when a set of active entities or forces transform their environment. Most of the time these transformations do not occur at random because they are constrained to previous status and obey to evolution laws. Discovering these laws is the ultimate goal of science. Process is a concept developed by scientists to understand and relate changes occurring in nature. It is an intricate mixture of facts (status of entities) and transformation mechanisms (ordered changes) that must be considered to structure knowledge about evolution, build models, and forecast future situations. Therefore, to describe processes in a data model while keeping the information needed to test hypotheses about evolution mechanisms, evidence must be accumulated that a set of entities are linked into an active system of transformations that is consistent in both space and time.

This book addresses the technical issues of process management in a dynamic model within the perspective of spatio-temporal. Technologically, neither commercial nor operational process model could be able to manage these complex phenomena. Therefore, two issues have been taken up in this research basically, i. e. the management of process with its behaviours and the design and simulation of an entire process model. In the past, many problems and obstacles have been arisen for both process management and simulation of process model, e. g. the concept of time and changes as a process, concept of space and changes as a process, spatio-temporal process modelling, nature of the interaction of spatio-temporal process with spatial process and temporal process, interaction between concurrent or sequential process within the phenomenon, integration of processes, algorithms, architecture, technological development and spatio-temporal queries, etc. Some issues are application-dependent, such as, interaction between concurrent or sequential process within the phenomenon, and integration of processes, while others are more fundamental and relevant to any generic to process models.

The authors of this book appreciate contribution from our colleagues and students, Ji Changdong, Ji Huifeng, Xu Xinchao, Xu Zongqiu, Sui Xin, Zhu Huizhong, Sun Huasheng, Sun Wei, Zheng Tao, Che Lina, Ren Dongfeng, Zhao Guiling, He Xiaojun, Wang Chunyan, Wu Jiaqi, Wang Daxue, Yang Huan, Li Lei, Gao Meng, Ghasem Askari, Bao Yong, Wang Dongyan, Xu Tao, and Liu Hongfei, etc.

The research results of this book is supported by the Natural Science Foundation of Liaoning Province (201102087), Program for Liaoning Excellent Talents in University (LR201018), and the Ph. D. Program Research Foundation from MOE of China (20122121110007).

Contents

Chapter 1 Introduction

Geography has moved beyond chorology, beyond describing the location of geographic things and their properties. Nor, in contrast to Kant (Watkins, 2007), is geography the science of space. Geography deals with processes, spatio-temporal phenomena that are with spatial and temporal references. Geographical processes involve entities and changes that are located in both space and time. Therefore, building taxonomy of spatio-temporal processes (STP) implies an analysis of the representation of facts and events within a space-time framework. According to Peuquet (1994), scientists retain two complementary ontological views to define space-time structures. The absolute approach (introduced by Newton) (Rynasiewicz, 2004), identifies space as a collection of points and time as a set of instants that exist by themselves. Those dimensions allow the objective measure of entity locations within an independent space-time framework. In contrast, the relative space-time approach (introduced by Leibniz) (Zalta, 2000), focuses on real-world entities and uses their mutual relationships to define a subjective space-time canvas. For space, this leads to the distinction between Euclidean geometry (absolute location) and topological properties (relative position). For time, it makes the difference between measured time (absolute chronology) and ordered events (historical sequences). These two complementary paradigms are mandatory to enable the full potential of spatio-temporal geographic information system (STGIS) framework (Yu et al, 2008), so that many researchers applied it in several spatio-temporal human related modelling techniques, such as accessibility (Kwan, 1998; Kwan et al, 2003; Miller, 1999a; Neutens et al, 2008; Schwanen et al, 2008), human travel (Kwan, 2000; Laube et al, 2007) and transportation demand modelling (Banerjee et al, 2009; Miller, 1999b; Wang et al, 2001), or have extended the framework in mathematical manner (Milner, 1980). In addition, some other researchers have used the framework in case oriented problems such as deriving rules from activity diary data and measuring similarity between geospatial lifelines (Arentze et al, 2001; Sinha et al, 2005; Tabesh et al, 2010). Similarly, the framework also applied for real-world phenomena studies (Claramunt et al, 1996; Flewelling et al, 1992; Floyd, 1967; Langran, 1992; Yuan, 1996a). Even though, the framework has the potential to be used in various aspects of human modelling behaviour (Marj et al, 2009; Nouri et al, 2010) , dynamic phenomena (Vafaeinezhad et al, 2010) can hardly be presented on it.

Describing real-world evolution is a complex task. One may observe the status of entities before and after a change occurs, these are facts and consequences. An event is a set of related changes leading to a new status. Events may be observed without knowledge about the mechanisms leading to change. However, that change is postulated to happen when a set of active entities or forces transform their environment. Most of the time these transformations do not occur at random because they are constrained to previous status and obey to evolution laws (causal relationships) (Miller, 2005). Discovering these laws is the ultimate goal of science (explanation).

Process is a concept developed by scientists to understand and relate changes occurring in nature (e. g. soil erosion, organic, growing processes). It is an intricate mixture of facts (status of entities) and transformation mechanisms (ordered changes) that must be considered to structure knowledge about evolution, build models and forecast future situations. Therefore, to describe processes in a data model while keeping the information needed to test hypotheses about evolution mechanisms, evidences must be accumulated. So that, a set of entities are linked into an active system of transformations that is consistent in both space and time. During the data-gathering step, there is no immediate need to identify the causal relationships linking events (why). However, one must stay at the experimentation levels and records which entities (active and passive) are involved in the transformation, what are the differences between their previous and final status (changes), where (absolute location or relative position) and when (measured time or historical sequence) these changes occur and if possible the mechanisms involved (how). All these facts are clues for scientists in their attempt to understand evolution (test hypotheses, formulate theories and discover the evolution laws). Therefore, it is here argued that if process is considered as the basic organizing concept of geography, as theoretically salient and tenable, then pure process model must be developed based upon this concept.

Processes may be modelled using a top-down or a bottom-up approach (Meijler et al, 2006). Users may describe evolution using high semantic level concepts based on a priori taxonomy of processes that is application or domain dependent (e. g. meteorological processes). For instance, they identify a global process (e. g. warm front) and relate it to specific events (rain, thunderstorm, etc.). However, process definitions and laws must be provided by system designers to permit this deductive modelling approach. On the other hand, the bottom-up procedure leads to inductive analysis. In this context, theoretical requirements are kept minimal and users provide only a description of observed evolution. Typically, they want to accumulate data about changes and transformation mechanisms to permit statistical and systemic analysis of spatio-temporal patterns. The ultimate goal being to test hypotheses, the data gathering procedure must avoid any priori taxonomy that can introduce some bias in the analysis.

The objective of this research is to develop a modelling approach that takes this notion of reference, in the form of process, as its modelling primitive. Such an approach attempts to build a model from bottom-up, where a method of modelling geographic phenomena will be derived from appropriate theories of geographic phenomena and process calculus. As Couclelis has stated, "the technical question of the most appropriate data structure for the representation of geographic phenomena begs the philosophical question of the most appropriate conceptualization of the geographic world" (Couclelis, 1992).

However, the author does not intend to enter into any form of metaphysical debate. Rather, it is recognized that our observations of constant change in the "things" studied recommend an approach to process modelling that is based on phenomenon, which takes change as its core.

The significance of this work comes from the recognition that object orientation is not the panacea to modelling spatio-temporal phenomena (Worboys, 2001), as the underlying theories and conceptualizations have not changed; the recent advances in dynamic modelling such as Cellular Automata and Agent Based Modelling continue to reify these theories; the divide between the spatiality of geographic information systems (GIS) and the temporality of traditional modelling software remains (Clarke et al, 2001). Therefore, this dissertation presents an alternative framework that is grounded in process and is inherently spatio-temporal. Within the methodology developed, geographic processes are modelled as processes rather than inferred from system or object states.

Consequently, it is important to draw apart the technological limitations of representational systems, such as GIS or agent based modelling environments, from the theoretical limitations of the representational system (Raper, 2000). The specification of a geographic process model is critical due to the limitations of current tools to query and analyze the dynamic subject of geographic research, in particular, spatially continuous processes (Clarke et al, 2001). Rather than using concepts developed in different disciplines for different purposes, a modelling theory must be developed specifically for spatially dynamic phenomena to capture the unique nature of these processes appropriately. What is needed is a bottom-up approach based on a solid theoretical foundation, rather than a top-down approach where the tools selected and applied (typically from a narrow range of options) were not developed with geographic phenomena in mind. As was evident in the social critique of GIS more than a decade after its widespread use within academia (Pickles, 1995), it is often not until much later that the fundamental assumptions and theory inherent in such tools are considered or questioned.

§1.1 Scope of the Research

This research addresses two problems, emerging from the technological front (design of spatio-temporal process model) and the application end (spatio-temporal phenomenon). Such technological aspects are dealt with as a design of purely spatio-temporal process model (STPM) and the architecture for spatio-temporally extended process calculi. From the application perspective, spatio-temporal issues of a real world phenomenon and its dynamism are investigated. The research focuses on the core issue in spatio-temporally extended process calculi and the dynamism of a particular phenomenon, i. e. the modelling of real world phenomenon by spatio-temporal process model. To cover these two aspects, following fundamental considerations are taken into account:

(1) The research aims to design conceptual and logical schemata for a spatio-temporal process model by taking into account the critical factors associated with each level of modelling, i. e. a uniform states and transition structures to treat their respective process uniformly, support two spatial process instances and at least two temporal process instances, support spatio-temporal process instance etc. Handshake is an integral part of spatio-temporal process model, among phenomenon, space, and time, which can play the vital role in this model.

(2) Spatio-temporally modelling in process-based systems is the focus of this research, where the incorporation of time and space processes to a phenomenon (as a process) increases the complexity of the process structure. The process-based approach is more appropriate for the pure process model of the world: everything is process. Philosophical discussions of space and time also necessitate in this phase.

(3) The aim of the research is to design each schema by employing standard, yet powerful tools at various stages of modelling, such as process calculi. At the conceptual level, it is the aim to utilize solid syntaxes and semantics of process calculi. The syntax

phases provide a sound basis for defining space and time, which may provide an unambiguous definition of a process model for implementation and a basis for further development (modelling as a process) of space and time. Semantic concepts facilitate the advancement of individual processes and interaction between processes in a modular and systematic manner.

(4) Since the STPM is subject to dynamic applications, modelling each application is indispensible. These applications assort into four different dynamic categories. The aim is to identify, design, and model each fundamental dynamic category as a case study.

(5) The data collection is not primarily the aim of this research. However, real world phenomenon is utilized to demonstrate the applicability of the model by developing a conceptual prototype.

(6) At the logical level, the goal is to design a spatio-temporal model by employing existing commercial modelling software and exploiting the strength and functionalities of these systems.

(7) Development of the model from logical level to implementation level (physical level) is critical. Considering the issues of spatio-temporally extended process calculi in the programming environment from the programmer's perspective are essential. The aim is to construct a technical guideline that containing previously mentioned issues and follow-ups. That would be an additional benefit when developing this logical model up to physical model.

It is the aim of the research not to address in detail:

(1) Spatial indexing to optimize the performance.

(2) Performance issues including the performance of algorithms in terms of space and time.

(3) 4D visualization of space and time as objects.

(4) Spatio-temporal query languages.

(5) Any other point that has not been listed explicitly in the scope of the research.

§1.2 Objectives

The main objective of the research is to design and implement a process-oriented spatio-temporal model based on sound mathematics and state-of-the-art process calculi, where time and space as processual entities. The secondary objective is to document the need of the spatio-temporal process model for real world phenomena. The model will be exemplified by a prototype, which will demonstrate how model can represent phenomenon as processes in consistent manner, by preserving the characteristics of process and spatio-temporal topology. Final objective is to discuss the further development of the conceptual spatio-temporal process model. Therefore, the detailed objectives can be outlined as follows:

(1) Review and relate the important theoretical foundations of spatio-temporal data modelling.

(2) Define a theory of process that considers the dynamic nature of geographic phenomena as its central construct.

(a) Develop a concept, which is based on theory of process.

(b) Specify this conceptualization in an unambiguous manner, forming the basis for implementation.

(3) Develop a general modelling approach that applies the theory developed in the main objective.

(4) Test the general theory and methodology, developed in the main objective, with the appropriate case studies.

(5) Verify the applicability of the model, developed in secondary objective, with the real world application.

(6) Improve the conceptual level model up to logical level model.

(7) As a co-aspect of final objective, illustrates the pathway to the implementation level (physical model) of this model.

From these objectives, the structure of this book is developed.

§1.3 Research Questions

This research asks three formal research questions. The first question is on spatio-temporal phenomenon and the second question is on process modelling approach of the phenomenon. Final question is on nature of the spatial and temporal references in the phenomenon. These three questions are interrelated; the process modelling approach should be designed to inherit the references through the components of phenomenon and references support to the individual components and process model and their progressions. The following paragraphs state the research questions respectively.

(1) How can the spatio-temporal phenomenon be decomposed into divergent components?

Defining the spatio-temporal phenomenon as a single process is not sufficient for a good process modelling approach. Phenomenon may involve complex interactions between outside environments and time is subjected to dynamical representation objectives. Therefore, the phenomenon and its intrinsically tied components need to be able to analyze flexible decompositions of the process and consider interactions between them.

Three-domain model (Yuan, 1994) provides a systematic and scientific decomposing technique and uses that technique, it is more convenient to represent the dynamical linkage among components. This technique is applied to decompose the spatio-temporal phenomenon into divergent components.

(2) What is the process modelling approach that is appropriate for constructing spatio-temporal phenomenon?

The process calculus, is the calculus thatallows processes to be explicitly represented by Milner and others (Hennessy, 1988; Langran, 1992; Milner, 1980; Stirling, 2001), are concerned primarily with computational occurrents machine processes, represented by the actions of collections of automata, for example. In order to make this work relevant to real-world occurrences, these computational processes should be firmly embedded in space and time.

The modelling approach should be general to support process construction and advancement activities, scalable to support complex constructions, and flexible to allow consideration of alternatives and future improvements.

This research question has two parts:

(a) What are the basic construction process elements to leverage process models?

From the ontological perspective, it is obvious that, as an initial division of entities that exist in the world of entities, continuants that endure through time and entities, occurrents that happen or occur and are then gone. Grenon and Smith (2004), call temporal sequence of object configuration or the "entities existing at a time" called SNAP ontology and the processual view or the "entities extended in time" called SPAN ontology.

These process elements should be such that, given a process model of the finished facility and parameters describing each decomposed component, it should be possible to perform the model and visualize the results directly. However, the process elements should not depend on a specific component representation.

(b) How can the individual divergent components be modelled?

Complex processes of each divergent component may be constructed using algebraic combinatory operations acting on a base collection of atomic actions. The term action here is that traditionally used in process calculi. In computational processes, as with the real world occurrences, a fundamental notion is one occurrence followed by another (Hoare, 1985).

These actions as being performed by agents and in here, the agent is a computer on which the action is executed.

(3) What kind of transmission technique is required to describe and analyze the nature of spatial and temporal references?

It is not possible to distinguish the connection links from the phenomenon to its divergent component, though they tie intrinsically. These types of links, virtual links (Milner, 1999), can also consist of radio connection, linkage between airplane and control tower in an air-traffic control system, etc. In systems with transient links have mobile structure, those transient links are able to transmit messages among the phenomenon and its components.

These transmission links should have handshake relation between local process (phenomenon) and a remote process.

This research question also has two parts:

(a) How can the references be transmitted to the phenomenon?

Messages passing through channels are the transmission media of references. A channel is an abstraction of the communication link between two processes. Processes interact with each other by sending and receiving messages over channels.

Different kinds of messages are used for different kind of transmission techniques, either send or receive.

(b) How can this model be functioned and analyzed?

Functions of the model depend on the single process execution and interactions between each other collection of processes. Queries are the good analyzing tools for the model.

Relevant theoretical background is provided by syntax and semantics of process calculus.

§1.4 Motivation

Change is inevitable. Almost all objects in the world change as a time process. It happens either by natural phenomena or due to human activities. It is because of this, time occupies a very important aspect in our life.

Since GIS plays an important role in the solution of the real world problem, it is almost impossible to find the system that does not contain the time component as important part. However, it can be argued that the lack of efficient management of time is an issue that needs an immediate attention. Currently, most of the applications do not cater all types of the geographic movement in the system.

This research attempts to make a discussion regarding the way of upgrading the real world occurrences to an equal statue with processes in dynamic geographic representations, and suggests the way of doing this by a novel spatio-temporal model. It develops a pure process theory of space and time, and demonstrates its applicability with dynamic phenomena in the real world. Importance of this research is as a guideline for managing and visualizing geographic movement application for helping in decision-making process.

Chapter 2 Theoretical Review

§2.1 Introduction

The time element plays a vital role in the dynamic world. Dynamic models are utilized to understand the dynamic status of this real world. Current models (even though declared as dynamic models) are not sufficient to address the dynamic nature of the world because they lack the time component. Spatio-temporal dynamic modelling demands different techniques to capture and model the real world phenomena. There have been persistent calls in the GIS literature for new spatio-temporal ontologies and new theoretically grounded process models (Peuquet, 2001; Worboys, 2001), to accomplish this mission. The significance of developing a process conceptualization and ontology based on apposite theory is in its potential interoperation between process models developed upon the same foundation, its ability to communicate the modelling constructsclearly, and its basis for methodological advances in analyzing (to be discussed in Chapter 3 and Chapter 4).

This chapter delves into the chronicle of spatio-temporal modelling, digging for theories of space, time, space-time, processes and change, what the fundamental constituents of spatio-temporal models are and how such things are conceptualized as the foundations of models. Further components of spatio-temporal GIS (STGIS), i. e. spatial, temporal and spatio-temporal components, are discussed in their own domains. The spatial component describes the space, attribute, and spatial relations; the temporal component recapitulates the time and temporal operations; and the space-time component defines the nature of phenomenon, its relations and progression. Therefore, the objective of this chapter is to review the primary conceptualization of process in the literature and contend for a more apposite theory of process for modelling geographic processes. This theory is based on ideas that have been developed within philosophy, namely four-dimensionalism, process philosophy and mobility.

This book does not discuss how reality, or geographic processes occurring therein, is perceived or conceptualized directly; this is in contrast to naive geography, which emphasizes principles from artificial intelligence. Nor are natural language or common sense descriptions of processes of interest here. Rather, the focus is on the scientific