CONCEPTUAL FRAMEWORK FOR SPATIO-TEMPORAL PROCESS MODEL[1]

Xu Aigong
A. H. Lakmal
School of Geomatics, Liaoning Technical University
47 Zhonghua Road, Fuxin, Liaoning Province, 123000, China,
Tel/Fax: +86-418-3350145
xuaigong@lntu.edu.cn

Abstract

Geographical phenomena involve entities and changes that are located in both space and time. Therefore, it is not an unjust germane to declare each geographical phenomena as spatio – temporal phenomena. As a result of that, building a taxonomy of spatio – temporal phenomena implies an analysis of the representation of facts and occurrences within a space – time framework. While the absolute approach represents the space - time framework as a set or a collection of points and time instances, the relative approach has a view of mutual relationships between real world entities for this purpose. This paper addresses to development of the conceptual modeling phase of spatio-temporal phenomena. It is necessary develop new techniques to accommodate the peculiarities of the combined spatial and temporal information that take their outset in existing techniques and minimally extend them. As a foundation of spatio-temporal domain, covering concepts such as objects, attributes, and relationships can be present according to the objective. Based on this foundation, the paper then proposes a small set of constructs aimed at improving the ability to conveniently model spatio-temporal information at the conceptual level. These constructs may be included in a wide range of existing conceptual data models as well as event models, improving their modeling capabilities without fundamentally changing the models. New modeling approach, which based on π – Calculus, to represent and manipulation these message transmissions, is proposed. The representation model consists in describing how a message evolves in the course of time and space. We co-operate syntax and semantics of π – Calculus to define, reductions and manipulations of processes. Process calculi provide a tool for the high-level description of interactions, communications, and synchronizations between a collection of independent agents or processes. The aim of the π - Calculus is to be able to describe concurrent computations whose configuration may change during the computation. π – Calculus can play two distinct roles as a model of networking in the broad modern sense and as a model of computation. Passing message capability from site to site through Channel is the outstanding characteristic of π – Calculus. This model is capable to recover eight different situations from temporal,

1 The research is supported by Liaoning Province University Innovation Team Programmes (2007T072, 2008T85) and Liaoning Province University Key Laboratory Programme (2009S049) in Liaoning Province, Peoples' Republic of China.

spatial and spatio-temporal domains and their combinations. Those situations are highly co-related with the static and dynamic behaviors of spatio-temporal phenomena.

1 INTRODUCTION

Describing real – world phenomena in space – time framework is a complex task. One may observe the statues of entities before and after a change occurs, these are facts and consequences. Providing an efficient system to operate simultaneously on absolute and relative views of space and time implies that geographical [where] and temporal [when] components are implemented using a homogeneous data models (Armstrong 1988; Langran 1988; Peuquet 1995). Because it relates where and when predicates in a common time dependant structure, the event based spatio temporal data model [ESTDM] (Peuquet 1995) triad framework can handle complex queries about geo-historical facts and changes. It tracks evolution and describes their consequences. Despite its powerful capabilities this framework does not carry explicit information on how and why changes happen. It records temporal and location facts that can be used to analyze spatio-temporal patterns and infer underlying processes and relationships. However, it does not provide mechanisms to explicitly describe events and processes and relate changes of one specific entity to actions of other known entities. Though, it is a raster based model, ESTDM may receives the honor for the first model with dynamic perspective.

Process is an essential component in dynamic mechanism. A process is a concept developed by scientists to understand and relate changes occurring in nature (e.g., soil erosion, organic, growing processes). Process is not an isolated term in the dynamic perspective. It has widespread ontological arguments for its individual behaviors. Process is one of the ontological arguments among them. Recognize of the spatio – temporal world is a crucial fact in defining the term "Process". The entities which stand to *Process* termed as Processuals entities. Processuals are occurrents or happenings which depend upon their participants and located both in spatio – temporal and temporal regions. The self connected Processual entities together, define as a *Process*. *Events* are the instantaneous boundaries of processes and instantaneous transitions within processes (Grenon & Smith 2004). *Action* is a different kind of occurrents than *Process* and *Events* which is initiated and sometimes terminated by human or non – human agents (Worboys 2005). It is better to use the real world example of "Billiard tournament" for further elucidation the terms of *Process*, *Event* and *Action*. Billiard tournament has a specific boundary such as, start time, end time, date and venue etc. So, billiard tournament is a good example for an *Event*. Meanwhile, main scope of the event, billiard tournament is playing billiards and it is a *Process*. During the process of playing billiards player may strike the billiard ball by cue and with that strike can declare as an *Action*.

In this paper, we propose a different spatio temporal model called Spatio Temporal Process Model (STPM) which has high correlations with the concepts of where, when,

process and action. Unlike other models, STPM is highly compatible for concurrent process modeling via π – Calculus (Milner 1999). It is capable to model the spatio - temporal changes with the context of either location or process.

The rest of the paper is organized as follows. Section 2 the architecture of STPM with its concepts and in Section 3 modeling behavior of the real world phenomena through STPM as case study. Final Section, section 4 expresses the conclusion and further developments of the STPM model.

2 ARCHITECTURE OF SPATIO – TEMPORAL PROCESS MODEL

STPM doesn't have a complex architecture. This conceptual model consists with three domains, two channels and two links. While, Domains and channels are essentials for a complete model and links are optional for it. Though this model looks like Three Domain model (Yuan 1996) at once but STPM diverse from Three Domain model as it has a different mechanism. Following diagram will make the notion of the Conceptual framework of STPM.

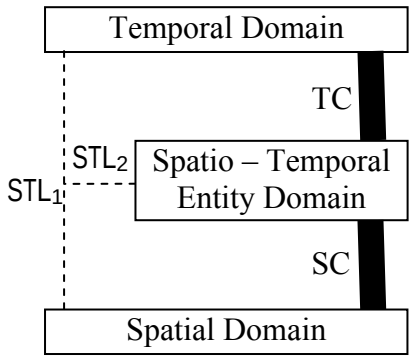

Figure 1. Spatio – Temporal Process Model (STPM)

2.1 DOMAINS AND CHANNELS

While the temporal domain represents time as a Process, the spatial domain represents the space also as a Process. Though, the notion of time as a process is not quite unfamiliar since time already represent as an event, the notion of a space as a process will be complicated. Conceptual view requires presenting the space as a *Process* perspective. Neither "Even" nor "Uneven" processes doesn't associates the space, it is also can present as two different *Process* methodologies termed either "Locations" (Worboys 2005) or "Attributes". In "Locations", represents each location as a *Process* that handshake with its neighbor locations through its adjacency relations which are act as an *Actions*. "Attributes" process concerns only the attribute changes of a particular location gone on "Action". Status of attribute represent as a *Process* and anything which cause to change the statues of attributes declare as an *Action* in "Attribute" process.

All entities which have both temporal and spatial relation can consider as Spatio – Temporal entities. Entities may have static or dynamic behaviors when going through

time. Process of an entity with static behaviors termed “Even” process which is no *Actions* happens during the *Process*. Some *Actions* happens during the *Process*, means the statues of process change by *Actions* named “Uneven” process for the Process of entity which has dynamic behaviors conversely. Multiple processes can occupy the modeling role as a sequential manner. So, both “Even” and “Uneven” processes can embed to Spatio – Temporal Entity Domain.

TC and SC are channels termed as Temporal Channel and Spatial Channel respectively. So, it is understood that each *Process* in Temporal domain should at least link with one *Process* in Spatio – Temporal Entity domain through channel **TC** and each *Process* in Spatial domain also should at least link with one *Process* in Spatio – Temporal Entity domain through channel **SC** conversely.

2.2 LINKS

Spatio Temporal Link (**STL**) is an optional link which can present the link between Temporal domain, Spatial domain and Spatio – Temporal Entity domain. When defining a predetermined trajectories or activities, this STL_1, which is between Temporal domain and Spatial domain will helpful to present the relation in between time and locations or time and attribute statues. Similarly, STL_2 also an optional link in between STL_1 and Spatio – Temporal domain, when defines a predetermined activity of a Spatio – Temporal Entity. It necessary to understand that, STL_2 bounds only with the “Uneven” process of Spatio – Temporal Entity. If the trajectory or activity is not predetermined, then no more further use with this **STL**. It is essential to keep in mind that this link can make 1:1 relations only. Modeler’s privilege to determines either **STL** is applicable or not to the model. If it is applicable then it should make with broken lines, similarly in figure 1, in the model. Otherwise, ignore it.

3 CASE STUDY - MECHANISM OF BOREHOLE MINING DRILL

Hitherto the process model construction and its theoretical background have discussed. Henceforth, we discuss the applicability of the STPM with real world Phenomena. Four (4) different applications associate for earlier discussed combinations such as “Location” process applications for “Even” and “Uneven” processes of Spatio – Temporal Entities and “Attribute” process applications also for “Even” and “Uneven” processes of Spatio – Temporal Entities. In this section we wish to discuss the Mechanism of Borehole Mining Drill as a combination of an “Uneven” and an “Attribute” process among them. The optional STLs also utilize in this model.

3.1 TEMPORAL DOMAIN – CLOCK AND TIME

Three instances of clock process termed as Cl_1, Cl_2, Cl_3 and *tick* represents the action in figure 2.

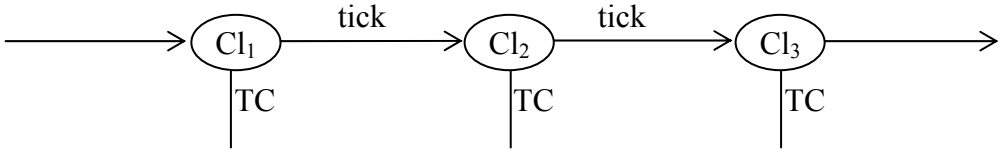

Figure 2. Temporal Process

Clock Process

$$\text{Clock} \overset{\text{def}}{=} Cl_1.Cl_2.Cl_3.....$$

Process Advancement

$$Cl_1 = \text{tick}.Cl_2 \quad (1)$$

$$Cl_2 = \text{tick}.Cl_3 \quad (2)$$

$$Cl_3 = \text{tick}.Cl_4 \quad (3)$$

Message Transmission Process T,

$$T_1(t) = \overline{TC}\langle t_1 \rangle.Cl_1 \quad (4)$$

$$T_2(t) = \overline{TC}\langle t_2 \rangle.Cl_2 \quad (5)$$

$$T_3(t) = \overline{TC}\langle t_3 \rangle.Cl_3 \quad (6)$$

Where t_1, t_2 and t_3, times are referring to instances of Clock process Cl_1, Cl_2 and Cl_3 respectively.

3.2 SPATIO – TEMPORAL ENTITY PROCESS DOMAIN

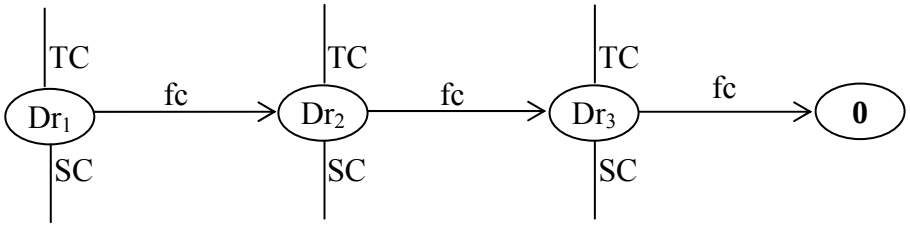

Figure 3. Spatio – Temporal Process

Where, Instance of process *Dr1*, *Dr2*, *Dr3* and **0** of Drill process. *Dr1* and **0** represent the initial and final process instances respectively. fc_1, fc_2 and fc_3 are *Actions* and no *Action* prior to *Dr1* since it is the initial instance of the process. TC and SC represent Temporal Channel and Spatial Channel respectively. Since, **0** is the final process instance, no process channels have assigned to it.

Drill Process

$$\text{Dr} \overset{\text{def}}{=} Dr_1.Dr_2.Dr_3.0$$

Process Advancement

$$Dr_1 = fc_1.Dr_2 \quad (7)$$
$$Dr_2 = fc_2.Dr_3 \quad (8)$$
$$Dr_3 = fc_3.0 \quad (9)$$

Message Receiving Process E,

$$E_1(t, l) = TC(t).SC(a).Dr_1 \quad (10)$$
$$E_2(t, l) = TC(t).SC(a).Dr_2 \quad (11)$$
$$E_3(t, l) = TC(t).SC(a).Dr_3 \quad (12)$$

3.3 SPATIAL PROCESS DOMAIN

Three (3) process instances have been used to presents the moment of "Attribute" process congeniality to the Spatio – Temporal Entity Domain with three (3) different *Actions*. *Process* and *Action* termed as "At" and "ac" respectively.

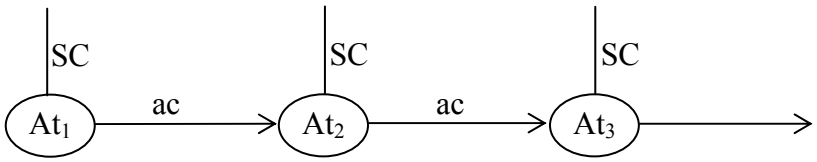

Figure 4. Spatial Process

Even the drilling process over at process instance At_3, "Attribute" process may continue due to various *Actions*. Because of this transition graph shows the continuation in figure 4.

Attribute Process

def

$$At = At_1.At_2.At_3$$

Process Advancement

$$At_1 = ac_1.At_2 \quad (13)$$
$$At_2 = ac_2.At_3 \quad (14)$$
$$At_3 = ac_3.At_4 \quad (15)$$

Message Transmission Process S

$$S_1(l) = \overline{SC}\langle a_1 \rangle.At_1 \quad (16)$$
$$S_2(l) = \overline{SC}\langle a_2 \rangle.At_2 \quad (17)$$
$$S_3(l) = \overline{SC}\langle a_3 \rangle.At_3 \quad (18)$$

3.4 SPATIO – TEMPORAL LINK (STL)

Both STL_1 and STL_2 have been used in this model, to define predetermined activities as an illustrating convenience.

3.5 SPATIO – TEMPORAL PROCESS MODEL (STPM)

Following figure expresses the overall spatio-temporal process model for case study.

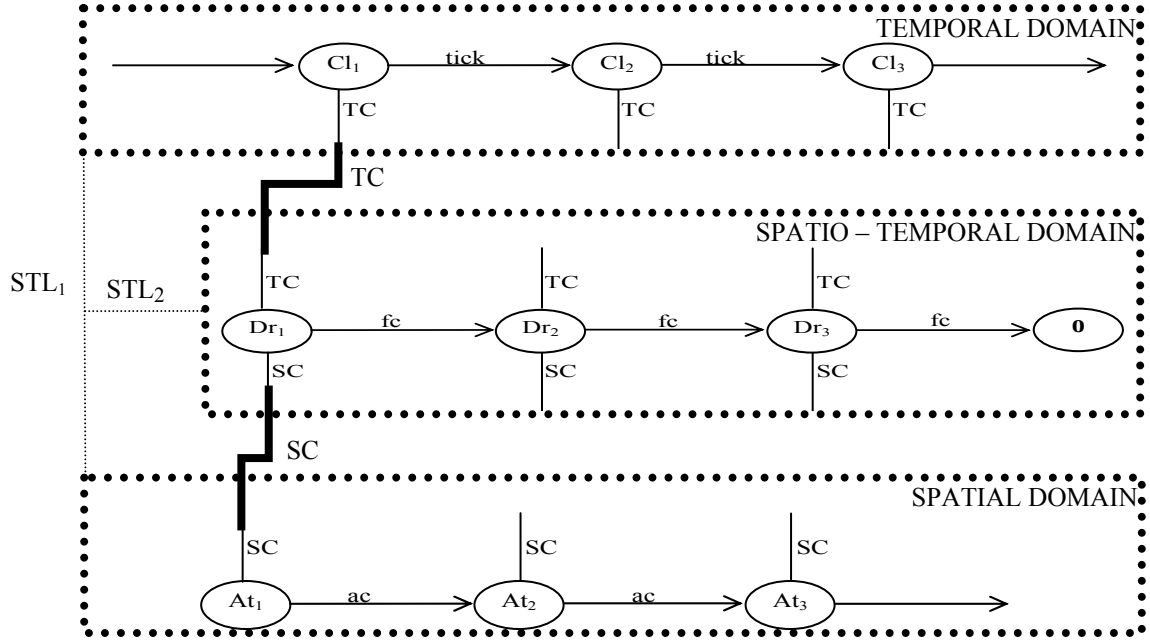

Figure 5 STPM for Case Study

Reduction semantics of STPM

It is necessary to check the bisimularity between processes prior to initiate the reduction semantics, since the Spatio – Temporal Entity process should simulates by Temporal process as well as Spatial process. If it happens only we can assume as each *Process* which behave in the same way. Therefore it is necessary to have *barbed bisimulation* between Temporal process and Spatio –Temporal Entity process $(\mathrm{Cl} \sim_B \mathrm{Dr})$ and also Spatio –Temporal and Entity process Spatial process $(\mathrm{Dr} \sim_B \mathrm{At})$. This kind simulation is not relevant to "Even" process as it is not simulates by Temporal process or Spatial process. Practice of *REACT* rule with the reactions between processes remains same.

Process Bisimulation

Temporal process and Spatio –Temporal Entity process

Table 1 implies the relations between Temporal process and Spatio –Temporal Entity process $(\mathrm{Cl}' \Re \mathrm{Dr}')$ and in addition to that following facts also presents the *barbed bisimulation*.

(1) to (3) implies the $Cl \xrightarrow{\tau} Cl'$ and $\exists Dr' : Dr \xrightarrow{\tau} Dr' \wedge Cl' \Re Dr'$ [by (9) to (11)] [Where, Cl' and Dr' represent the process instance of Clock and Drill process respectively] And $Cl \downarrow TC$ Then $Dr \downarrow TC$.
It implies that Cl and Dr are barbed bisimilar. So, $(Cl \sim_B Dr)$.

Spatio –Temporal and Entity process Spatial process
Table 1 implies the relations between Spatio –Temporal Entity process and Spatial process $(Dr' \Re At')$ and in addition to that following facts also presents the *barbed bisimulation*.

Temporal process	ST Entity process	Spatial process
Cl_1	Dr_1	At_1
Cl_2	Dr_2	At_2
Cl_3	Dr_3	At_3

Table 1. Spatio – Temporal Links

(9) to (11) implies the $Dr \xrightarrow{\tau} Dr'$ and $\exists At' : At \xrightarrow{\tau} At' \wedge Dr' \Re At'$ [by (14) to (16)] [Where, Dr' and At' represent the process instance of Drill and Attribute process respectively] And $Dr \downarrow SC$ Then $At \downarrow SC$
It implies that Dr and At are barbed bisimilar. So, $(Dr \sim_B At)$.

Messages Transmission

Reactions between Processes: Message Transmission Process T and Message Receiving Process E,
(4) and (10),

$$T \mid E \tag{19}$$

$$\overline{TC}\langle t_1 \rangle.Cl_1 \mid TC(t).SC(a).Dr_1 \tag{20}$$

Message transmission Process *S* and Message Receiving Process E″.

$$\underbrace{Cl_1 \mid \left\{ {t_1}/{t} \right\}.SC(a).Dr_1}_{E''} \tag{21}$$

Process E″and (16),

$$E'' \mid S \tag{22}$$

$$Cl_1 \mid \left\{ {t_1}/{t} \right\}.SC(a).Dr_1 \mid \overline{SC}\langle a_1 \rangle.At_1 \tag{23}$$

$$Cl_1 \mid \left\{ t_1 / t \right\}.\left\{ a_1 / a \right\}.Dr_1 \mid At_1 \qquad \text{(R1)}$$

(R4) expresses that, when starting Spatio – Temporal Entity process, Dr_1, at time instance t_1 the earth composition is a_1.

Due to the bisimulations of $Cl \sim_B Dr$ and $Dr \sim_B At$, it expresses that at the time instance t_2 Entity process changes its status to Dr_2 and the attributes process advances it's status to At_2 in accordance with Entity process.

After occurs the bisimulation the (11) can modify with (R4) as follows,

$$E_2(t, l) = TC(t_1).SC(a_1).Dr_2 \qquad (24)$$

By (5), (24) and (17),

$$Cl_2 \mid \left\{ t_2 / t_1 \right\}.\left\{ a_2 / a_1 \right\}.Dr_2 \mid At_2 \qquad \text{(R2)}$$

As a result of (R2) and process bisimulation (12) can modify as,

$$E_3(t, l) = TC(t_2).SC(a_2).Dr_3 \qquad (25)$$

Similarly (6), (25) and (18),

$$Cl_3 \mid \left\{ t_3 / t_2 \right\}.\left\{ a_3 / a_2 \right\}.Dr_3 \mid At_3 \qquad \text{(R3)}$$

Mechanism of STPM

By amalgamating (R1) to (R3) and bisimulation process, the entire mechanism of STPM express as follows. Equation order presents the sequence of STPM mechanism.

$$Cl_1 \mid \left\{ t_1 / t \right\}.\left\{ a_1 / a \right\}.Dr_1 \mid At_1 \qquad \text{(M1)}$$

$$Cl_1 = tick.Cl_2 \text{ , } Dr_1 = fc_1.Dr_2 \text{ and } At_1 = ac_1.At_2 \qquad \text{(M2)}$$

$$Cl_2 \mid \left\{ t_2 / t_1 \right\}.\left\{ a_2 / a_1 \right\}.Dr_2 \mid At_2 \qquad \text{(M3)}$$

$$Cl_2 = tick.Cl_3 \text{ , } Dr_2 = fc_2.Dr_3 \text{ and } At_2 = ac_2.At_3 \qquad \text{(M4)}$$

$$Cl_3 \mid \left\{ t_3 / t_2 \right\}.\left\{ a_3 / a_2 \right\}.Dr_3 \mid At_3 \qquad \text{(M5)}$$

$$Cl_3 = tick.Cl_4 \text{ , } Dr_3 = fc_3.0 \text{ and } At_3 = ac_3.At_4 \qquad \text{(M6)}$$

4 CONCLUSION AND FUTURE WORK

The theme of this paper is to introduce new spatio – temporal conceptual model for real world phenomena. Each phenomenon can differentiate up to three basic domains due to its structural process as temporal, spatial and spatio – temporal. Though the spatio – temporal domain is a combination of spatial and temporal domains, it has its unique identity, attributes and behaviors, since it's the only domain which can represent the real world activity. While the mechanism of the borehole drill enunciates the process of spatio – temporal domain, original domains of spatial and temporal also contribute to accomplish the mission in discussed case study.

Even though π – Calculus has an extensive coverage of message transmission, few of them can only applicable to spatio – temporal modeling. But we believe this few amount would make grate changes in process modeling. STPM is a newly design model which is totally depends on π – Calculus and concurrent processing. This model is capable to retrieve eight (8) different situations and all these situations can apparent in this case study as follows.

I. Temporal situation
II. Spatial situation
III. Attribute situation
IV. Process situation
V. Temporal transition
VI. Spatial transition
VII. Attribute transition
VIII. Process transition

It is necessary to have some further developments in this model to suite it for *asynchronous* and *asyntopic* domains. Hitherto we have been discussed all the activities only with single Spatio – Temporal Entity process either it is "Even" or "Uneven". But there may be some phenomena happen with the association of two or more Spatio – Temporal Entities. So another development of this model will be the association of multiple Spatio – Temporal Entities. Spatial and temporal topological relations are conditiones sine quibus non with multiple Spatio – Temporal Entities. So those facts also will add to this model in its further developments.

REFERENCE

Armstrong, MP (1988) 'Temporality in spatial databases' *GIS/LIS 88 Proceedings*, vol. 2, pp.880 – 889.

Grenon, P & Smith, B (2004) 'SNAP and SPAN: Towards dynamic spatial Ontology', *Journal of Spatial Cognition and Computation*, vol. 4, no. 1, pp.69 – 104.

Langran, G. & Chrisman, NR (1988) 'A framework for temporal geographic information'. *Cartographica: The International Journal for Geographic Information and Geovisualization*, vol. 25, no.3, pp.1 – 14.

Milner, R (1999) *Communicating and Mobile Systems: The π-calculus*, Cambridge University Press, Cambridge.

Peuquet, DJ & Duan, N. (1995) 'An event-based spatiotemporal data model (ESTDM) for temporal analysis of geographical data', *International Journal of Geographical Information Systems*, vol. 9, no. 1, pp. 7-24.

Worboys, MF (2005) 'Event-oriented approaches to geographic phenomena', *International Journal of Geographic Information Systems*, vol. 19, no.1, pp. 1 – 28.

Yuan, M. (1996) "Temporal GIS and Spatio-Temporal Modeling", *http://ncgia.ucsb.edu/conf/SANTA_FE_CD-ROM/sf_papers/yuan_may/may.html*.