Spatio-Temporal Abduction for Scenario and Narrative Completion

(A Preliminary Statement)

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Abstract. Hypothetical reasoning is a form of inference that is useful in many application domains within the purview of *dynamic spatial systems*. Within a spatial context, this form of inference necessitates the ability to model (abductive) explanatory reasoning capabilities in the *integrated* context of formal *spatial calculi* on the one hand, and high-level logics of *action and change* on the other.

We present preliminary results by demonstrating the manner in which this form of explanatory reasoning may be implemented within the framework of the Event Calculus, which is a high-level formalism for representing and reasoning about actions and their effects. We use an example from the domain of automatic (virtual) cinematography / story-visualization and story-boarding, where the objective is to control camera / perspectives and animate a scene on the basis of apriori known *film-heuristics* and partial scene descriptions available from discourse material. Underlying the example domain lies the ability to perform spatio-temporal abduction in a generic context.

1 Introduction

Hypothetical reasoning about '*what could be*' or '*what could have been*' on the basis of, and possibly instead of, '*what is*' is a form of inference that is useful in many applications involving representing and reasoning about dynamic spatial knowledge. Many application instances within fields such as cognitive robotics, dynamic / event-based GIS, ambient / smart environments, and spatial design may all be considered to be within the scope of a class of *dynamic spatial systems* that require hypothetical reasoning capabilities in specific, and the ability to reason about space, actions and change in an integrated manner in general [5]. Both from a representational as well as a computational viewpoint, the basic set of requirements in all these application domains remains the same. Primarily, the following may be deemed important:

1. Qualitative scene modeling: the capability to abstract from precise geometric modeling of scenes and agent perspectives (e.g., of robots, avatars) by the use of qualitative spatial representation calculi pertaining to various aspects of space such as topology, orientation, directions, distance, size
2. Static scenario inference: given partial scene descriptions consisting of sets of spatial relationships between domain entities, the derivation of complete scene models by the application of constraint reasoning algorithms that infer the implicit spatial relationships from the explicit ones by exploiting the relational properties of the spatial calculi being utilized
3. Scenario and narrative completion: this is the most general case, where given partial narratives that describe the evolution of a system (e.g., by way of temporally ordered scene observations of a robot, event-based GIS datasets) in terms of high-level positional and occurrence information, the ability to derive completions that bridge the narrative by interpolating the missing spatial and action / event information in a manner that is consistent with domain-specific and domain-independent rules / dynamics

Whereas (1) and (2) involve static scenario inference in a strictly spatial sense, (3) necessitates commonsense reasoning about space, actions / events and change in an integrated manner [5]. The underlying intuition here being that spatial configurations in both real and virtual setups change as a result of interaction (i.e., actions and events) in the environment and that the formulation of hypothesis about perceived phenomena is closely connected to the commonsensical notions of interaction (e.g., manipulation, movement) in the real world. For instance, within a GIS, spatial changes could denote (environmental) changes in the geographic sphere at a certain temporal granularity and could bear a significant relationship to natural events and human actions, e.g., changes in land-usage, vegetation, cluster variations among aggregates of demographic features, and wild-life migration patterns. Here, event-based and object-level reasoning at the spatial level could serve as a basis of explanatory analyses, for instance by abduction, within a GIS [11, 16, 36]. Similarly, within a *behavior monitoring* and/or security system for a smart environment (e.g., home, office), *recognition of dynamic scenes* from changes in pre-designated configurations of qualified spatial configurations could be used as a basis of behaviour monitoring, activity recognition, alert generation and so forth [6, 8, 15].

From a computational viewpoint, hypothetical reasoning within the class of aforediscussed *dynamic spatial systems* requires a form of abductive explanation capability that may be implemented with a formal logic of action and change. This in turn necessitates the *embedding* of qualitative spatial calculi— i.e., the high-level axiomatic constitution of qualitative calculi —within a particular logic of action and change that is intended to be utilized [3, 4, 5].

In this paper, we demonstrate the manner in which explanatory reasoning may be implemented within the framework of the Event Calculus, which is a high-level formalism for representing and reasoning about actions and their effects. Specifically, we illustrate how spatio-temporal abduction may be directly realized with the discrete version of the Event Calculus (available as a reasoning engine) in

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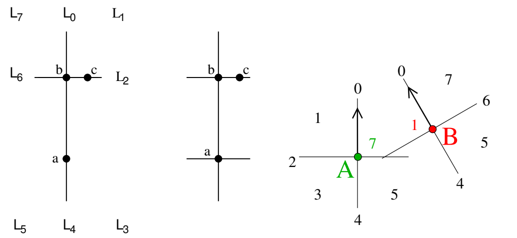


(a) $\mathcal{SCC}$ and $\mathcal{DCC}$ Partitioning (b) The $\mathcal{OPRA}_2$ relation $\vec{A}\ 2\angle^{1}_{7}\ \vec{B}$

Figure 1: Orientation Systems

the context of qualitative spatial calculi. We use an example from the domain of automatic-cinematography / story-visualization and story-boarding, where the objective is to control a camera and / or animate a scene on the basis of apriori known *film-heuristics* and partial *scene descriptions* available from discourse material.

2 Space and Change: Preliminaries

2.1 Qualitative Spatial Reasoning

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 [10]. Logical formalizations of space and tools for efficiently reasoning with them are now well-established [29]. Formal methods in spatial representation, referred to as spatial calculi, may be classified into two groups: topological and positional calculi. When a topological calculus such as the Region Connection Calculus (RCC) [28] is being modeled, the primitive entities are spatially extended and could possibly even be 4D spatio-temporal histories (e.g., in a domain involving the analyses of motion-patterns). Alternately, within a dynamic domain involving translational motion in a plane, a point-based (e.g., Double Cross Calculus [14], $\mathcal{OPRA}_m$ [22]) or line-segment based (e.g., Dipole Calculus [30]) abstraction with orientation calculi suffices.

In addition to ontological differences with respect to the nature of the primitive spatial entities, i.e., points, line-segments or spatially extended bodies, multiple viewpoints also exists with respect to the conceptualization of orientation relations themselves. In general, orientation either refers to the direction in which one object is situated relative to another, or the direction in which an object is pointing. The family of point-based orientation calculi define the direction of a located point to a reference point with respect to a perspective point [14]. Within this approach, three axes are used, one is specified by the perspective point and the reference point, the other two axes are orthogonal to the first one and are specified by the reference point and the perspective point respectively. These axes define 15 different ternary base relations.

The Single and the Double Cross Calculi [14] use points and orthogonal lines to partition the space in a finite number of locations, which could take the form of points, lines and extended regions (See Fig. 1). Similarly, Fig. 1(b) illustrates one primitive relationship for the Oriented Point Relation Algebra (OPRA) [22], which is a spatial calculus consisting of oriented points (i.e., points with a direction parameter) as primitive entities. The granularity parameter m determines the number of angular sectors, i.e., the number of base relations. Applying a granularity of $m = 2$ results in 4 planar and 4 linear regions (Fig. 1(b)), numbered from 0 to 7, where region 0 coincides with the orientation of the point. The family of $\mathcal{OPRA}_m$ calculi are designed for reasoning about the relative orientation relations between oriented points and are well-suited for dealing with objects that have an intrinsic front or move in a particular direction.

2.2 The Event Calculus

The Event Calculus is a logical language for reasoning about actions and change [20, 33]. It defines a set of predicates and axioms that provide an inference mechanism to decided "*what is true when*". In this paper we use a version of the Event Calculus, which is restricted to the domain of discrete time, referred to as the Discrete Event Calculus [23].

The (discrete) Event Calculus defines a fluent as a boolean property that represents a value that can change by direct or indirect effects of an event. Fluents can represent a numerical value of a quality, such as the temperature of a room, or a boolean proposition, such as *it is cold*. Additionally, fluents adhere to the commonsense notion of inertia, which states that a fluents value can only be changed by the effects of an event. Therefore, if some fluent is true at time-point t_0, it will necessarily be true at some later time-point t_1, unless an event occurs between t_0 and t_1 such that it effects the value of the fluent.

The Event Calculus provides a set of predicates and axioms to represent problem domains. The *HoldsAt* predicate defines when a fluents holds for a certain value; the *Happens* predicate defines when an event happen; and the *Initiates*, *Releases*, *Terminates* predicates express the effects events have on fluents. The following axioms relate the Discrete Event Calculus predicates to the properties of the calculus as described above.

$$\begin{aligned} HoldsAt(f, t+1) \Leftarrow\ & HoldsAt(f, t), \wedge \neg ReleasedAt(f, t+1) \wedge \\ & \exists e.(Happens(e, t) \wedge Terminates(e, f, t))) \end{aligned} \tag{1a}$$

$$HoldsAt(f, t+1) \Leftarrow Happens(e, t), \wedge Initiates(e, f, t) \tag{1b}$$

$$\begin{aligned} \neg HoldsAt(f, t+1) \Leftarrow\ & \neg HoldsAt(f, t), \wedge \neg ReleasedAt(f, t+1) \neg \wedge \\ & \exists e.(Happens(e, t) \wedge Initiates(e, f, t))) \end{aligned} \tag{1c}$$

$$\neg HoldsAt(f, t+1) \Leftarrow Happens(f, t), \wedge Terminates(e, f, t) \tag{1d}$$

Axioms (1a–1b) ensure the common-sense notion of inertia is enforced over fluents. (1a) states that a fluent f holds true at a time-point $t + 1$ if it held true at time-point t and that it was not released from it's inertia from the effect of an event. 1a additionally states that a fluent is true at a time-point $t + 1$ if an event occurs at t, which causes the fluent to be true. 1c and 1d describe the conditions when a fluents does not hold. A detailed discussion of the Event Calculus formalism is not necessary for this paper, but may be consulted in authoritative sources [23, 33].

3 The Domain of Automatic Cinematography

Automatic cinematography aims to derive a sequence of camera shots (i.e. the camera's perspective / orientation to the actors, camera's focus, and angle of view, etc.) from descriptions provided in a script [18] [9] [12]. In practice, most automatic cinematography involves using a knowledge-base of filming heuristics to control the perspective / placement of a camera based on contextual cues of the scene. In this context, a film can be viewed as a hierarchy [18]; the top of the film hierarchy is the script, which consists of a sequence of time-ordered narrative descriptions, referred to as scenes. Each scene, in turn, provides contextual information, in the form of actions

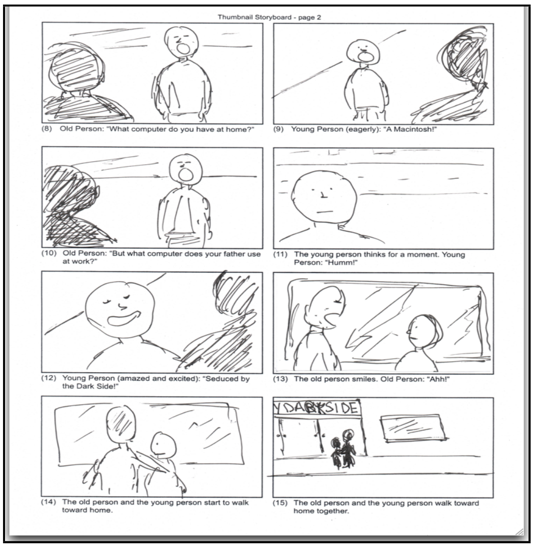


Figure 2: Artistic Impression of a Storyboard.

and events that can be used to derive a specific camera shot. The objective of each camera shot is to capture the sequence of events in a manner that is cinematically pleasing.

As an example, lets look at the simple, but common, scene in Fig. 2 depicting a group of two actors in a conversation. A storyboard, such as in Fig. 2[3], is typically an artist's impression on the basis of a film/drama script/screenplay. Within this scenario, the context of each scene is based on the current state of each actor with regards to their participation in the conversation, i.e. *talking, listening*, or *reacting*. Below is a sample script that involves two actors, Kendra and Annika, engaged in a conversation. In the example, contextual cues are provided as key words that indicate the current state of each actor, i.e. "Kendra starts to *talk*" and "Annika *reacts* sheepishly" and so forth:

```
ACT 1: Kendra and Annika
[Establishing-shot] -- Kendra and Annika
Kendra starts talking to Annika--[``dialogue'']
[Cut: mid-shot] -- Annika reacts anxiously to Kendra
Kendra continues talking to Annika
[Cut: Close-up] Annika responds to
Kendra--[``astonish'']
End.
```

As the scenes progress the states of each actor change as the conversation develops. From this information, it is the job of the (automatic) cinematographer to decide on an appropriate sequence of camera shots to properly depict the conversation. The result of this process is similar to the storyboard found in Figure 2., which shows the the perspective of the camera throughout the key moments of the scene. Because this scenario is so common in film, cinematic patterns have emerged that defined heuristics to capture this particular type of situation, referred to by cinematographers as a *film idiom* [2]. These idioms have been defined for many typical cinematic situations, such as groups of actors in a conversation, or an action sequence. In general, a film idiom can be seen as a set of declarative rules that specify a mapping between the use of camera shots to a situational context. We formally build-up on these aspects in the sections to follow.

[3] Source: `http://upload.wikimedia.org/wikiversity/en/e/e4/Mok_Thumbnail_storyboards_tiny2.png`

4 Explanation by Spatio-Temporal Abduction

Diametrically opposite to projection and planning is the task of postdictum or explanation [25, 27], where given a set of time-stamped observations or snap-shots, the objective is to explain which events and/or actions may have caused the observed state-of-affairs. Explanation, in general, is regarded as a converse operation to temporal projection essentially involving reasoning from effects to causes, i.e., reasoning about the past [31].

4.1 Narratives

Explanation problems demand the inclusion of a narrative description, which is essentially a distinguished course of actual events about which we may have incomplete information [21, 26]. Narrative descriptions are typically available as *observations* from the real / imagined execution of a system or process. Since narratives inherently pertain to actual observations, i.e., they are temporalized, the objective is often to assimilate / explain them with respect to an underlying process model and an approach to derive explanations.

In the automatic cinematography domain set-out in Section 3, narrative descriptions are (implicitly) available from linguistic descriptions about *acts* and *scenes* within a drama or film script.[4] Here, with the understanding that the progression of the script can be thought of as an imaginary evolution of the system, the symbolically grounded information from the script is equivalent to temporally ordered observations that constitute the available narrative.

$$\begin{bmatrix} \Phi_1 & \equiv & \neg HoldsAt(Talking(Kendra),\ t_1) \wedge \neg HoldsAt(Talking(Annika),\ t_1) \wedge \\ & & \neg HoldsAt(Reacting(Annika),\ t_1) \wedge \neg HoldsAt(Reacting(Kendra),\ t_1) \\ \Phi_2 & \equiv & HoldsAt(Talking(Kendra),\ t_2) \wedge \neg HoldsAt(Talking(Annika),\ t_2) \wedge \\ & & \neg HoldsAt(Reacting(Annika),\ t_2) \wedge \neg HoldsAt(Reacting(Kendra),\ t_2) \\ \Phi_3 & \equiv & HoldsAt(Talking(Kendra),\ t_3) \wedge \neg HoldsAt(Talking(Annika),\ t_3) \wedge \\ & & HoldsAt(Reacting(Annika),\ t_3) \wedge \neg HoldsAt(Reacting(Kendra),\ t_3) \end{bmatrix} \tag{2a}$$

$$[t_1 < t_2 < t_3] \tag{2b}$$

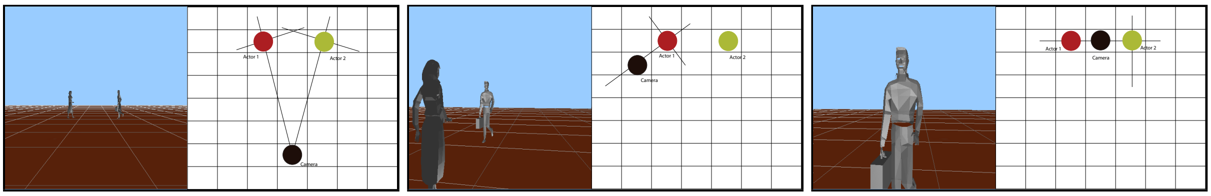
(Spatial) Narratives in the Film Domain

One of the key creative roles of a cinematographer / director or a story-boarding artist is to anticipate / visualize the scene on the basis of applicable film-idioms / heuristics (Section 3) that are suited to filming a particular scenario / narrative, such as the one exemplified in (4). For instance, in the context of the ongoing example, the applicable idioms are *EstablishingShot*, *ExternalShot* and *ReactionShot*.

$$\begin{bmatrix} \Phi_1 & \rightarrow & EstablishingShot(actor_1,\ actor_2) \\ \Phi_2 & \rightarrow & ExternalShot(actor_1,\ actor_2) \\ \Phi_3 & \rightarrow & ReactionShot(actor) \end{bmatrix} \tag{3}$$

Each of these film heuristics have a specific *structural form* that is identifiable with respect to relative orientation of the camera and the

[4] We ignore the translation from a linguistic to a symbolic/predicated form; this is beyond the scope of the objective of this paper.



(a) Establishing Shot (b) External Shot (c) Reaction Shot

Figure 3: Structural Form of Film Idioms (Automatic Cinematography: *2 Avatars and 1 Virtual Camera*)

actors involved in a scene or the applicable film idiom[5]:

$$\left[\begin{array}{l}(\forall\, t).\ HoldsAt(EstablishingShot(actor_1, actor_2),\ t)\ \rightarrow \\ \qquad\qquad HoldsAt(\phi_{scc}(camera_1, actor_1, actor_2, scc_3),\ t) \wedge \\ \qquad\qquad HoldsAt(\phi_{scc}(camera_1, actor_2, actor_1, scc_5),\ t)\end{array}\right] \tag{4a}$$

$$\left[\begin{array}{l}(\forall\, t).\ HoldsAt(ExternalShot(actor_1, actor_2),\ t)\ \rightarrow \\ \qquad\qquad HoldsAt(\phi_{scc}(camera_1, actor_1, actor_2, scc_1),\ t) \wedge \\ \qquad\qquad HoldsAt(\phi_{scc}(camera_1, actor_2, actor_1, scc_5),\ t)\end{array}\right] \tag{4b}$$

$$\left[\begin{array}{l}(\forall\, t).\ HoldsAt(ReactionShot(actor_1, actor_2),\ t)\ \rightarrow \\ \qquad\qquad HoldsAt(\phi_{scc}(camera_1, actor_1, actor_2, scc_4),\ t) \wedge \\ \qquad\qquad HoldsAt(\phi_{scc}(camera_1, actor_2, actor_1, scc_4),\ t)\end{array}\right] \tag{4c}$$

Consider the illustration in Fig. 3 for the present film domain: the world consists of three point-abstracted entities— 2 *avatars* and 1 virtual *camera*.[6] Further, suppose that container space is modeled a discrete grid world together with relative orientation relationships among the entities as per the partitioning scheme of the Single-Cross Calculus (see Section 2.1, Fig. 1). For this ongoing "*Kendra and Annika*" script, further suppose that the *camera* is the only entity that is able to move, i.e., change location from one grid-cell to another. For a scenario such as this, explanation by spatio-temporal abduction could serve as a basis of *scenario and narrative completion*, and for this particular example, the derivation of ideal *camera placements* as a side-effect of the abduction process. The general structure of such as derivation is explained next, and the ongoing example is further continued in Section 4.2.

Structure of (Abductive) Explanation

It is easy to intuitively infer the general structure of narrative completion (by abductive explanation). Consider the illustration in Fig. 4 for a branching / hypothetical situation space that characterizes the complete evolution of a system. In Fig. 4 – the situation-based history $< s_0,\ s_1, \ldots,\ s_n >$ represents one path, corresponding to an actual time-line $< t_0,\ t_1, \ldots,\ t_n >$, within the overall branching-tree structured situation space. Given incomplete narrative descriptions, e.g., corresponding to only some ordered time-points (such as in Fig. 3) in terms of high-level spatial (e.g., topological, orientation) and occurrence information, the objective of explanation is to derive one or more paths from the branching situation space, that could best-fit the available narrative information. Of course, the completions that bridge the narrative by interpolating the missing spatial and action/event information have to be consistent with both domain-specific and domain-independent rules/dynamics.

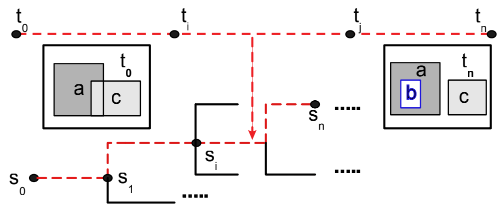


Figure 4: Branching / Hypothetical Situation Space

Many different formalizations of spatio-temporal explanation are possible, such as within a belief revision framework [1], nonmonotonic causal formalizations in the manner of [17], Situation Calculus [3, 4, 32] and so forth; this paper is a pragmatic illustration of the manner in which this may be achieved in the context of the discrete Event Calculus [20, 24].

4.2 Scenario and Narrative Completion

Figure 5 consists of a *narrative* (completion), starting with time-points t_1 and ending at time-point t_{12}: this denotes an *abduced* evolution of the system, as represented by the sequence of qualitative state descriptions for 2 stationery and 1 moving entity. For clarity, images from a 3D simulation are included together with the relational / graph-based illustrations for each of the time-points.

The narrative completion is abduced from an initial narrative description consisting of observations only of time-points $[t_1,\ t_4,\ t_6, t_8,\ \ t_{12}]$. Precisely, from the available observations, the narrative completion has been abduced on the basis of available *camera actions – pan, zoom, move* – and pre-specified knowledge or heuristics / film-idioms about desired camera placements, e.g., *establishing shot*, *external shot*, *mid-shot*, *close-up* and so forth. Needless to say, we have excluded one key representational aspect: the description so far has only focussed on the domain-specific representational aspects, and details about encoding the semantics of the spatial calculus, in this case the single-cross relations, have been excluded so far. The spatio-temporal abduction actually works on the basis of the embedding of all the high-level axiomatic aspects of the spatial calculus, together with the domain-theory of the "film world'. Without the embedding, spatial calculi— composition theorems, continuity constraints — have no semantic interpretation within the Event Calculus reasoner.

We further discuss the embedding of the spatial calculus within the Discrete Event Calculus in Section 4.3. Here, we conclude the

[5] This may be easily generalized to n actors/entities in the scene. Further, note that the formal interpretation of the spatial / structural form of an idiom is open-ended, and subject to the richness of the spatial calculi and other aspects (e.g., scene illumination) being modeled. For the purposes of this example, we restrict to an interpretation strictly in terms of orientation relationships.

[6] The third entity in the simulation is a virtual camera that records the other two entities in the scene, and hence is not visible within the 3D illustration of Fig. 3(c).

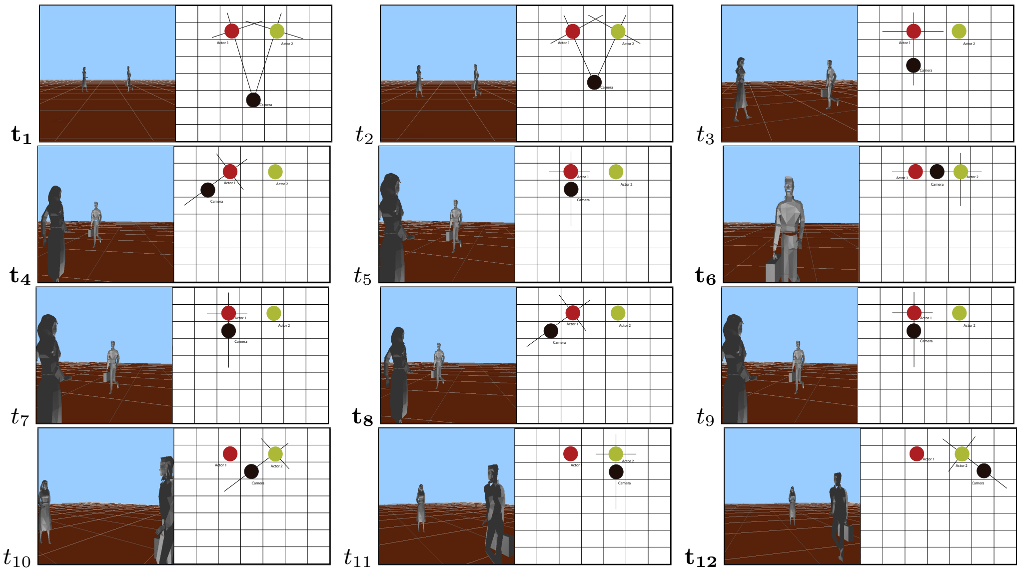


Figure 5: Scenario and Narrative Completion (by Abduction).

demonstration of the application with the remark that for this example, the resulting narrative completion is usable by a virtual reality and/or an automatic cinematography system to automatically generate animations and / or perspective visualizations for automatic storyboarding.

4.3 Embedding Spatial Calculi

In order to derive a spatio-temporal narrative completion directly on the basis of the semantics of the Discrete Event Calculus (DEC) reasoner, it is necessary to encode the high-level axiomatic aspects that determine the constitution of a qualitative spatial calculus. For the example under consideration in this paper, one only needs to encode certain key aspects of the Single/Double-Cross calculus (in addition to the domain-theory). Precisely, the following aspects need to be modelled explicitly: jointly exhaustive and pair-wise disjointness (JEPD) of the base relations, the composition theorems and the continuity constraints of the relationship space.

4.3.1 JEPD Property

Orientational spatial relations, such as those defined by the Single-Cross calculus, are jointly exhaustive, mutually disjoint and pairwise disjoint. The property of jointly exhaustive and mutually disjoint can be sufficiently expressed in the DEC using n state constraints of the form (5), where n is the number of total base relations defined by the calculus.

$$\begin{bmatrix} (\forall\, t).\ \neg[HoldsAt(\phi_{scc}(o_1, o_2, o_3, scc_0),\ t) \vee \\ \quad HoldsAt(\phi_{scc}(o_1, o_2, o_3, scc_1),\ t) \vee \\ \quad HoldsAt(\phi_{scc}(o_1, o_2, o_3, scc_2),\ t) \vee \\ \quad HoldsAt(\phi_{scc}(o_1, o_2, o_3, scc_3),\ t) \vee \\ \quad HoldsAt(\phi_{scc}(o_1, o_2, o_3, scc_4),\ t) \vee \\ \quad HoldsAt(\phi_{scc}(o_1, o_2, o_3, scc_5),\ t) \vee \\ \quad HoldsAt(\phi_{scc}(o_1, o_2, o_3, scc_6),\ t)] \equiv_{def} \\ \quad HoldsAt(\phi_{scc}(o_1, o_2, o_3, scc_7),\ t)) \end{bmatrix} \tag{5a}$$

$$\begin{bmatrix} (\forall\, t).\ \neg[HoldsAt(\phi_{scc}(o_1, o_2, o_3, scc_0),\ t) \wedge \\ \quad HoldsAt(\phi_{scc}(o_1, o_2, o_3, scc_1),\ t)]) \end{bmatrix} \tag{6a}$$

$$\begin{bmatrix} (\forall\, t).\ \neg[HoldsAt(\phi_{scc}(o_1, o_2, o_3, 1),\ t) \wedge \\ \quad HoldsAt(\phi_{scc}(o_1, o_2, o_3, 2),\ t)]) \end{bmatrix} \tag{6b}$$

Similarly, the property of pairwise disjointness can be expressed using $[n(n - 1)/2]$ ordinary constraints of the form in (6).

4.3.2 Composition Theorems

The composition theorems of the Single-Cross calculus have to represented in the DEC using state constraints. For Single-Cross, this formulation requires 8 X 8 state constraints of the form in (7).

$$\begin{bmatrix} (\forall\, t).\ [HoldsAt(\phi_{scc}(o_1, o_2, o_3, scc_0),\ t)\ \wedge\ HoldsAt(\phi_{scc}(o_2, o_3, o_4, scc_0),\ t)] \\ \quad \rightarrow\ HoldsAt(\phi_{scc}(o_1, o_2, o_4, scc_4),\ t) \\ (\forall\, t).\ [HoldsAt(\phi_{scc}(o_1, o_2, o_3, scc_1),\ t)\ \wedge\ HoldsAt(\phi_{scc}(o_2, o_3, o_4, scc_1),\ t)] \\ \quad \rightarrow\ HoldsAt(\phi_{scc}(o_1, o_2, o_4, scc_5),\ t) \vee HoldsAt(\phi_{scc}(o_1, o_2, o_4, scc_6),\ t) \\ \quad \vee\ HoldsAt(\phi_{scc}(o_1, o_2, o_4, scc_7),\ t) \end{bmatrix} \tag{7a}$$

Global compositional consistency of scenario descriptions is a key contributing factor determining the crucial commonsensical notion of the *physically realizability* [3, 4] (for model elimination) of narrative descriptions during the abduction process [7].

4.3.3 Conceptual Neighborhood

The conceptual neighborhood graph [13] for a set of spatial relations reflects their corresponding continuity structure, namely the the direct, continuous transformations that are possible among the relations as a result of motion by translation and / or deformation. Lets assume that the binary (reflexive) predicate $neighbour(\gamma_1,\ \gamma_2)$ denotes the presence of a continuity relation between qualitative relations γ_1 and γ_2.

$$\begin{bmatrix} ConceptualNeighbor(scc_0, scc_1) \\ ConceptualNeighbor(scc_1, scc_2) \\ ConceptualNeighbor(scc_6, scc_5) \end{bmatrix} \tag{8}$$

Given this, one only needs to represent one predicate per continuity link of the form in (8) as reflected by a particular partitioning of the spatial calculus being utilized, which in this case, is the Single-Cross calculus.

[7] Other factors, not relevant for the example of this paper, are *physical* and *existential* consistency [3, 4].

5 Discussion and Outlook

The logic-based integration of specialized *spatial representation formalisms* on the one hand and general logics for *reasoning about actions and change* is an initiative that defines the broad agenda of the work described in this paper. The preliminary results presented herein are guided by the proposition of integrated *Reasoning about Space, Actions and Change* (RSAC) [5], which we regard to be a useful paradigm for applications of formal methods in Qualitative Spatial Representation and Reasoning (QSR) within realistic *Dynamic Spatial Systems*.

The specific aim of this paper has been to demonstrate the manner in which *spatio-temporal abduction* may be performed with an off-the-shelf logic of action and change, namely the Event Calculus, that is available a reasoning tool. We demonstrate this in the context of an example "*automatic cinematography*" domain, which we regard to be intuitively appealing in order to communicate the often contrived idea of *logical explanation by abduction*. We emphasize that automatic cinematography is not merely a toy domain: in the entertainment industry, a wide-range of applications require the to ability to visualize complex— single agent and multi-perspective —scenes in a dynamic and real-time context. Major applications include automatic (virtual) cinematography or in general automatic story visualization and story-boarding (as addressed here), real-time perspective modeling for games, the modeling of interaction in hybrid or real–virtual environments, e.g., for e-learning, and so forth. As another emerging application, consider the domain of *spatial computing for design* [7]. Here, abductive reasoning in general plays a significant role in reasoning about hypothetical spatial structures.

From a theoretical perspective, we are presently pursuing the integration of specialized (infinite domain) spatial reasoning tools such as *SparQ* [34]and *GQR* [35] within the Discrete Event Calculus reasoner; the approach being adopted here is to ensure a separation of concerns during the satisfiability checking process (based on the *relsat solver*[8]) underlying the DEC reasoner. Experiments are also in progress to achieve a similar sort of integration of spatial reasoners with not only the *relsat solver*, but also other extensions into the answer-set programming (ASP) framework[9] [19]. The challenge here lies in maintaining the separation during the constraint solving stage between the native *relsat / ASP* solvers that underly the Event Calculus reasoner and specialized spatial reasoning tools, i.e., the objective here is not to replace SAT or ASP solvers, but rather to complement their constraint solving capabilities with the aforestated specialized spatial reasoning tools. From an application perspective, we are pursuing the application of the proposed spatio-temporal abduction mechanism in other application areas of interest, e.g., design creativity, dynamic GIS, smart environments.

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REFERENCES

[1] Carlos E. Alchourrón, Peter Gärdenfors, and David Makinson, 'On the logic of theory change: Partial meet contraction and revision functions', *J. Symb. Log.*, **50**(2), 510–530, (1985).

[2] Daniel Arijon, *Grammar of the Film Language*, Hastings House, New York, 1976.

[3] Mehul Bhatt, 'Commonsense inference in dynamic spatial systems: Phenomenal and reasoning requirements', in *23rd International Workshop on Qualitative Reasoning (QR 09), Ljubljana, Slovenia, June 2009*, eds., Ivan Bratko and Jure Žabkar, pp. 1–6, (2009). (Part 1 of 2).

[4] Mehul Bhatt, 'Commonsense inference in dynamic spatial systems: Epistemological requirements', in *FLAIRS Conference: Special Track on Spatial and Temporal Reasoning*. AAAI Press, (2010). (Part 2 of 2): to appear.

[5] Mehul Bhatt, 'Reasoning about space, actions and change: A paradigm for applications of spatial reasoning', in *Qualitative Spatial Representation and Reasoning: Trends and Future Directions*. IGI Global, USA, (2010).

[8] *relsat*: http://www.bayardo.org/resources.html

[9] *ecasp, f2lp*: http://reasoning.eas.asu.edu/f2lp/

[6] Mehul Bhatt and Frank Dylla, 'A qualitative model of dynamic scene analysis and interpretation in ambient intelligence systems', *International Journal of Robotics and Automation*, **24**, (2009). (to appear, url as of 14.11.2009).

[7] Mehul Bhatt and Christian Freksa, 'Spatial computing for design: An artificial intelligence perspective', in *NSF International Workshop on Studying Visual and Spatial Reasoning for Design Creativity (SDC'10)*, (2010). (to appear).

[8] Mehul Bhatt and Hans Guesgen, eds. *Spatial and Temporal Reasoning for Ambient Intelligence Systems (STAMI 09)*. SFB/TR 8 Spatial Cognition Report Series, No. 020-08/2009, September 2009.

[9] David B. Christianson, Sean E. Anderson, Li wei He, David H. Salesin, Daniel S. Weld, and Michael F. Cohen, 'Declarative camera control for automatic cinematography', (1996).

[10] A G Cohn and J Renz, 'Qualitative spatial reasoning', in *Handbook of Knowledge Representation*, eds., Frank van Harmelen, Vladimir Lifschitz, and Bruce Porter, Elsevier, (2007).

[11] Helen Couclelis, 'The abduction of geographic information science: Transporting spatial reasoning to the realm of purpose and design', in *COSIT*, eds., Kathleen Stewart Hornsby, Christophe Claramunt, Michel Denis, and Gérard Ligozat, volume 5756 of *Lecture Notes in Computer Science*, pp. 342–356. Springer, (2009).

[12] Steven M. Drucker and David Zeltzer, 'Camdroid: a system for implementing intelligent camera control', in *I3D '95: Proceedings of the 1995 symposium on Interactive 3D graphics*, pp. 139–144, New York, NY, USA, (1995). ACM.

[13] Christian Freksa, 'Conceptual neighborhood and its role in temporal and spatial reasoning', in *Decision Support Systems and Qualitative Reasoning*, eds., M. Singh and L. Travé-Massuyès, pp. 181–187. North-Holland, Amsterdam, (1991).

[14] Christian Freksa, 'Using orientation information for qualitative spatial reasoning', in *Proceedings of the Intl. Conf. GIS, From Space to Territory: Theories and Methods of Spatio-Temporal Reasoning in Geographic Space*, pp. 162–178, Berlin, (1992). Springer-Verlag.

[15] Antony Galton, 'Causal reasoning for alert generation in smart homes.', in *Designing Smart Homes*, pp. 57–70, (2006).

[16] Antony Galton and James Hood, 'Qualitative interpolation for environmental knowledge representation', in *ECAI*, eds., Ramon López de Mántaras and Lorenza Saitta, pp. 1017–1018. IOS Press, (2004).

[17] Enrico Giunchiglia, Joohyung Lee, Vladimir Lifschitz, Norman McCain, and Hudson Turner, 'Nonmonotonic causal theories', *Artif. Intell.*, **153**(1-2), 49–104, (2004).

[18] Li-wei He, Michael F. Cohen, and David H. Salesin, 'The virtual cinematographer: a paradigm for automatic real-time camera control and directing', in *SIGGRAPH '96: Proceedings of the 23rd annual conference on Computer graphics and interactive techniques*, pp. 217–224, New York, NY, USA, (1996). ACM.

[19] Tae-Won Kim, Joohyung Lee, and Ravi Palla, 'Circumscriptive event calculus as answer set programming', in *IJCAI'09: Proceedings of the 21st international jont conference on Artifical intelligence*, pp. 823–829, San Francisco, CA, USA, (2009). Morgan Kaufmann Publishers Inc.

[20] Robert Kowalski and Marek Sergot, 'A logic-based calculus of events', *New Gen. Comput.*, **4**(1), 67–95, (1986).

[21] Rob Miller and Murray Shanahan, 'Narratives in the situation calculus', *J. Log. Comput.*, **4**(5), 513–530, (1994).

[22] Reinhard Moratz, 'Representing relative direction as a binary relation of oriented points', in *ECAI*, pp. 407–411, (2006).

[23] Erik T. Mueller, *Commonsense Reasoning*, Morgan Kaufmann Publishers Inc., San Francisco, CA, USA, 2006.

[24] Erik T. Mueller, 'Automating commonsense reasoning using the event calculus', *Commun. ACM*, **52**(1), 113–117, (2009).

[25] C. S. Pierce, *The Collected Papers of Charles Sanders Peirce*, Harvard University Press, 1935.

[26] Javier Pinto, 'Occurrences and narratives as constraints in the branching structure of the situation calculus.', *J. Log. Comput.*, **8**(6), 777–808, (1998).

[27] D. Poole, R. Goebel, and R. Aleliunas, 'Theorist: A logical reasoning system for defaults and diagnosis', in *The Knowledge Frontier*, eds., N. Cercone and G. McCalla, 331–352, Springer, New York, (1987).

[28] David A. Randell, Zhan Cui, and Anthony Cohn, 'A spatial logic based on regions and connection', in *KR'92. Principles of Knowledge Representation and Reasoning: Proceedings of the Third International Conference*, 165–176, Morgan Kaufmann, San Mateo, California, (1992).

[29] Jochen Renz and Bernhard Nebel, 'Qualitative spatial reasoning using constraint calculi', in *Handbook of Spatial Logics*, 161–215, (2007).

[30] C. Schlieder, 'Reasoning about ordering', in *Proc. of COSIT'95*, volume 988 of *Lecture Notes in Computer Science*, 341–349, Springer, Berlin, Heidelberg, (1995).

[31] Murray Shanahan, 'Prediction is deduction but explanation is abduction.', in *IJCAI*, pp. 1055–1060, (1989).

[32] Murray Shanahan, 'Explanation in the situation calculus.', in *IJCAI*, pp. 160–165, (1993).

[33] Murray Shanahan. The event calculus explained, 1999.

[34] Jan Oliver Wallgrün, Lutz Frommberger, Diedrich Wolter, Frank Dylla, and Christian Freksa, 'Qualitative spatial representation and reasoning in the sparq-toolbox', in *Spatial Cognition V: Reasoning, Action, Interaction: International Conference Spatial Cognition 2006*, eds., Thomas Barkowsky, Markus Knauff, Gerard Ligozat, and Dan Montello, volume 4387 of *LNCS*, 39–58, Springer-Verlag Berlin Heidelberg, (2007).

[35] Matthias Westphal, Stefan Woelfl, and Zeno Gantner, 'GQR: A fast solver for binary qualitative constraint networks', in *AAAI Spring Symposium on Benchmarking of Qualitative Spatial and Temporal Reasoning Systems*, (2009).

[36] Michael F. Worboys, 'Event-oriented approaches to geographic phenomena.', *Int. Journal of Geographical Inf. Science*, **19**(1), 1–28, (2005).