Towards a Synergy of Qualitative Spatio-Temporal Reasoning and Smart Environments for Assisting the Elderly at Home*

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Abstract

Applications of smart environments are ever-increasing due to their possibilities of contributing towards an independent and active lifestyle for different user groups. An example of such an application can be found in health-care, where an elderly can be unobtrusively monitored and cared for in their own home. In this paper, we give a description of how qualitative spatio-temporal reasoning can be used to create services for the inhabitants of a sensorized home, with an emphasis on elderly patients, and hence make their lives more comfortable and safe. Further, we briefly review the related state of the art in qualitative spatio-temporal reasoning, and identify the limitations that we have to overcome in order to be able to provide better smart environment solutions.

1 Introduction

Over the past few decades, computers have made their way into our everyday lives, assisting us with performing common tasks in our homes or offices, such as video calling a relative from the other side of the world or creating a production schedule at work. This has been made possible through the ever-increasing availability of inexpensive computation and storage, along with a massive revolution in communications that allowed for high-bandwidth communications being available nearly everywhere. Further, the rapid technological advancement enabled us to equip our environments with various sensors and introduce new functionalities, making them "smart". Smart environments combine perceptual and reasoning capabilities with cheap computing power, among other things, in an attempt to create human-centered systems that are embedded in physical spaces (Cook and Das 2005). In particular, perceptual capabilities allow a system to behave in a human-friendly manner, whilst reasoning capabilities allow a system to be flexible and adapt as the context changes and as resources become more or less available. The concept of smart environments is closely related to the notion of *ubiquitous computing*, a term coined by Mark Weiser (Weiser, Gold, and Brown 1999), which promotes the ideas of *"a physical world that is richly and invisibly interwoven with sensors, actuators, displays, and computational elements, embedded seamlessly in the everyday objects of our lives, and connected through a continuous network"* (Weiser 1999; Weiser 1994; Weiser, Gold, and Brown 1999).

Qualitative Spatio-Temporal Reasoning (QSTR) is a major field of study in Artificial Intelligence, and in particular in Knowledge Representation & Reasoning, that deals with encoding the human perspective of the physical reality of space and time through simple qualitative descriptions such as *precedes*, *contains*, and *is left of* (Hazarika 2012). In particular, this encoding is achieved by restricting rich mathematical theories about temporal or spatial entities in such a way that specific aspects of these theories can be treated with simple qualitative (non-metric) languages. Such qualitative languages are defined over a finite vocabulary of spatial or temporal relations, called *base relations* (or *atoms*) (Ligozat and Renz 2004), a typical example being Interval Algebra (IA), introduced by Allen (Allen 1983), which considers time intervals as its temporal entities and whose each base relation represents an ordering of the four endpoints of two intervals in the timeline. The field of QSTR naturally extends to a plethora of areas and domains that include ambient intelligence, dynamic GIS, cognitive robotics, and spatio-temporal design (Bhatt et al. 2011), as it provides a concise framework that allows for rather inexpensive reasoning about entities located in space and time. In this context, and due to the type of qualitative abstraction offered, QSTR can surely be seen as an essential component of smart environments.

In this paper, we highlight the relationship between smart environments and QSTR in the context of a use case that involves monitoring and assisting elderly patients at home. In particular, we explain how QSTR can be used to obtain qualitative descriptions from data provided by various types of sensors, in order to create a spatially enhanced timeline of the patient's daily activities. A typical example could be that an elderly patient performs their daily routine of prescribed exercises *during* morning hours. Such qualitative signatures can be used to efficiently perform online recognition of spatio-temporal patterns that may help to detect alarming situations. For instance, with respect to our previous example, an alarming situation could be that the patient skipped their daily exercise routine several days in a row.

The rest of the paper is organized as follows. In Section 2 we give some preliminaries about sensorized environments

*We wish to acknowledge support from the MoveCare project (ID: 732158), which is funded by the European Commission under the H2020 framework programme for research and innovation.
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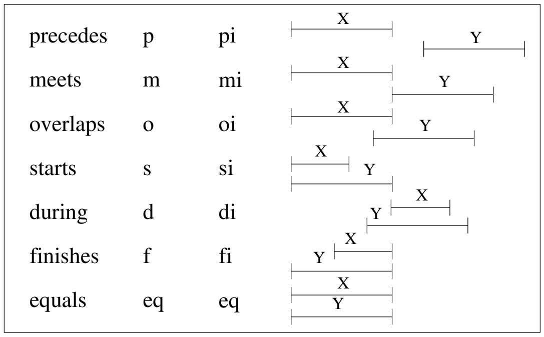

Figure 1: The base relations of Interval Algebra

and qualitative spatio-temporal reasoning. In Section 3 we present a use case that involves monitoring and assisting elderly patients at home, and showcase the involvement of QSTR techniques in that context. In Section 4 we review the related state of the art in QSTR and present some open problems that are relevant to the topic of this paper. Finally, in Section 5 we conclude the paper with a discussion.

2 Background

In this section we give some preliminaries about smart environments and qualitative spatio-temporal reasoning.

Smart Environments

A general definition of smart environments is provided in (Cook and Das 2005), where Cook and Das consider a smart environment to be anything that acts as a small world where different kinds of smart devices are continuously working to make inhabitants' lives more comfortable and their environment safer, by replacing the hazardous work and physical labor with automated agents and providing additional services. A more particular definition of smart environments considers them to be an application domain of *Sensor Networks* (Akyildiz and Kasimoglu 2004). Sensor networks are spatially distributed autonomous sensors that monitor physical or environmental conditions and cooperatively pass their data through the network to a main location. In this context, smart environments can be defined as any type of physical world that builds on a sensor network and involves physically embedded tiny devices capable of pervasive sensing, actuating, and computing (De 2014). These devices are interconnected through a continuous sensor network for data collection, in order to enable various pervasive applications and services. Typical sensor nodes comprise sensors that sense and/or measure temperature, humidity, luminosity, pressure, motion, sound, acceleration, CO_2 concentration, and orientation. RFID based sensor networks are also being used for daily activity identification and spatio-temporal pattern recognition (Buettner et al. 2009).

Qualitative Spatio-Temporal Reasoning

A binary qualitative spatial or temporal constraint language, is based on a finite set B of *jointly exhaustive and pairwise disjoint* relations defined over an infinite domain D, which is called the set of *base relations* (Ligozat and Renz 2004). The base relations of a particular qualitative constraint language can be used to represent the definite knowledge between any two of its entities with respect to the level of granularity provided by the domain D. The set B contains the identity relation Id, and is closed under the *converse* operation ($^{-1}$). Indefinite knowledge can be specified by a union of possible base relations, and is represented by the set containing them. Hence, 2^{B} represents the total set of relations. The set 2^{B} is equipped with the usual set-theoretic operations of union and intersection, the converse operation, and the *weak composition* operation denoted by the symbol $\diamond$ (Ligozat and Renz 2004). For all $r \in 2^{\mathsf{B}}$, we have that $r^{-1} = \bigcup\{b^{-1} \mid b \in r\}$. The weak composition ($\diamond$) of two base relations $b, b' \in \mathsf{B}$ is defined as the smallest (i.e., strongest) relation $r \in 2^{\mathsf{B}}$ that includes $b \circ b'$, or, formally, $b \diamond b' = \{b'' \in \mathsf{B} \mid b'' \cap (b \circ b') \neq \emptyset\}$, where $b \circ b' = \{(x,y) \in \mathsf{D} \times \mathsf{D} \mid \exists z \in \mathsf{D}$ such that $(x,z) \in b \wedge (z,y) \in b'\}$ is the (true) composition of b and b'. For all $r, r' \in 2^{\mathsf{B}}$, we have that $r \diamond r' = \bigcup\{b \diamond b' \mid b \in r, b' \in r'\}$.

As an illustration, consider the well known qualitative temporal constraint language of Interval Algebra (IA) introduced by Allen in (Allen 1983). IA considers time intervals (as its temporal entities) and the set of base relations $\mathsf{B} = \{$*equals* (eq), precedes (p), precedes inverse (pi), meets (m), meets inverse (mi), overlaps (o), overlaps inverse (oi), starts (s), starts inverse (si), during (d), during inverse (di), finishes (f), finishes inverse (fi)$\}$. Each base relation of IA represents a particular ordering of the four endpoints of two intervals in the timeline, as demonstrated in Figure 1. The base relation eq is the identity relation Id of IA. As another illustration, the Region Connection Calculus (RCC) is a first-order theory for representing and reasoning about mereotopological information (Randell, Cui, and Cohn 1992). The domain D of RCC comprises all possible non-empty regular subsets of some topological space. These subsets do not have to be internally connected and do not have a particular dimension, but are commonly required to be regular *closed* (Renz 2002). The base relations of RCC are the following ones: *disconnected* (DC), *externally connected* (EC), *equal* (EQ), *partially overlapping* (PO), *tangential proper part* (TPP), *tangential proper part inverse* ($TPPi$), *non-tangential proper part* ($NTPP$), and *non-tangential proper part inverse* ($NTPPi$). These 8 base relations form the RCC-8 constraint language.

3 Use Case

In this section we will present a use case based on an ongoing European project that involves incorporating QSTR techniques in a smart environment application. In particular, we will demonstrate how qualitative relations can be used to effectively model daily activities of an inhabitatnt of such an environment and we will motivate the use of such qualitative models for enhancing the services offered.

The MoveCare Project

As the European population is aging, the number of elderly needing care increases. However, caring solutions allowing patients to stay at home are too few and, hence, most of the elderly are moved to nursery homes too early. The developments in Information and Communication Technologies,

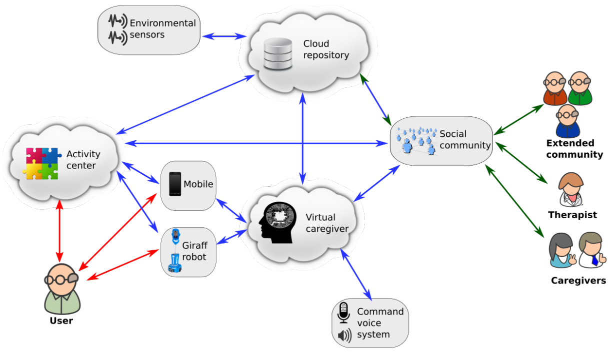

Figure 2: The MoveCare multi-actor platform

and specifically in Internet of Things, offer new possibilities to face this challenge. The MoveCare project is a European project that aims to create a complete solution to provide monitoring and assistance for elders at home.[1] It is a multi-actor platform integrating the following elements:

- an activity center;
- a virtual community;
- a virtual caregiver;
- an existing robotic system (viz., the Giraff[2] platform);
- environmental sensors.

An overview of this multi-actor platform is provided in Figure 2. In MoveCare, data are collected from different sources (such as environmental sensors, input from patients and caregivers, and social community statistics). A virtual caregiver reasons upon these data in order to identify trends in the elder's behavior and suggest proactive actions and activities to improve the user's life. The system also connects with therapists and caregivers in order to monitor the evolution of the state of the patient and alert in the case of an alarming change. At no time in the process is the user required to wear any specific device or change their habits.

The typical scenario for sensor-base monitoring systems is that of an elderly person who has some specific needs and potential medical conditions, but is still living at home. In order to increase the safety of the person and reduce the frequency of appointments needed at a care facility, the patient and caregivers have agreed to fit the patient's home with some sensors and a communication device, such as a tablet with a specific application installed. The challenge is to integrate and reason over all the information both from the sensors and the medical records at once, and derive the most likely conclusion, e.g., the current situation that the patient is in, the cause of some events, and the best action that the system has to take next.

During the course of the project, the smart apartment presented in Figure 3 will be used. This apartment is currently being equipped with several sensors such as pressure sensors, motion sensors, luminosity sensors, and door sensors. In Figure 3 the filled icons represent the sensors that have already

[1]http://www.movecare-project.eu/
[2]http://www.giraff.org/

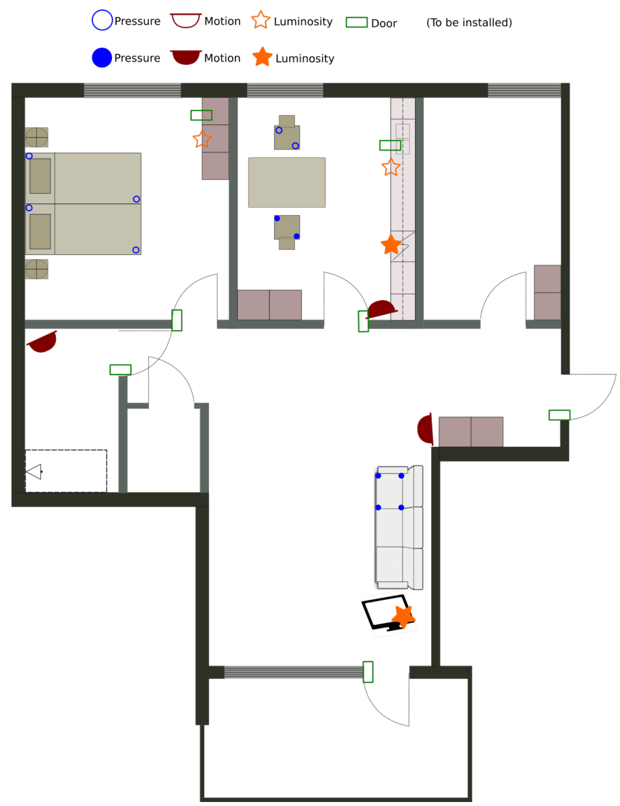

Figure 3: The smart apartment used in the MoveCare project with the location of the sensors

been installed in the apartment, whilst the non-filled icons represent the sensors that are planned to be used in the future and have not yet been installed. In detail, pressure sensors are used to monitor the state of the couch, chairs, and beds in order to detect the presence of the patient. Motion sensors are used to detect if the patient is present in the room and are able to detect if a person walks through the room without stopping. Luminosity sensors are currently used to detect the state of the oven and the TV (on/off), and door sensors are used to detect the state of the doors in the apartment (open/close). In the future, additional luminosity and door sensors will be installed in the kitchen and the bedroom to monitor some specific cupboards, for instance, the food cupboard, the medicine cabinet, and so on. The choice of door or luminosity sensors (or a combination of both) depends on the type of cupboard to be monitored.

QSTR Involvement and Challenges

The best way to showcase the involvement of QSTR techniques in a smart environment application is by first presenting a simple scenario in the context of our use case. Let us assume that we are monitoring a patient with a cardiovascular disease (CVD). Some of the symptoms of such a disease are shortness of breath, nausea, and extreme fatigue. These symptoms can perturb the everyday activities of a patient; for instance, their sleeping pattern may be affected and their daily exercise quota might be reduced or even completely

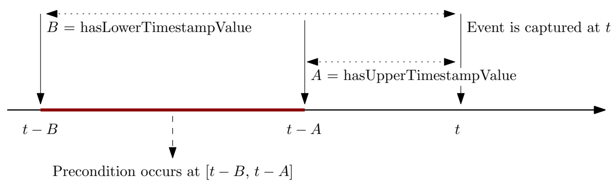

Figure 4: Temporal relation between an event occuring at time t and its precondition expected to be identified during the time interval [t-B, t-A]

dropped. Such observations may indicate a worsening of the patient's condition. Therefore, a crucial task is to create a high-level timeline of the patient's daily activities that can be provided to the caregiver as a reference, but also further processed by an automated reasoning system so that additional meaningful information can be extracted or even predicted. Such a timeline can be effectively modeled by relations of Interval Algebra.

Qualitative Model Construction The quality of daily activities accomplished by a patient has the potential to reflect their current health status. For an activity to be identified, it needs to be represented in the form of an event pertaining to certain required preconditions. As an example, let us assume that the activity "*watching TV*" is defined as a process of "*being in the living room*", where the TV is located (first precondition), while the "*TV is switched on*" (second precondition).

In MoveCare, the representation of an event and its dependencies is provided by an ontology called *SmartHome* (Alirezaie 2017), which is basically a network of ontology modules representing different aspects of a smart environment.[3] ***SmartHomeEvent*** is an ontology module that represents an event by encoding its preconditions along with certain temporal distances that involve the event itself and the preconditions. A temporal distance is defined as an independent ontology module that is made of two properties, namely, *hasLowerTimestampValue* and *hasUpperTimestampValue*, indicating the lower and the upper bound of a time interval respectively. Thus, the ***SmartHomeEvent*** ontology module represents an activity as an event whose each precondition (i.e., a specific situation) is expected to be identified at a time interval that has a certain temporal distance from the time point at which the activity occurs (see Figure 4). The Description Logic (DL) expressions of the classes in the aforementioned ontology modules are as follows.

$$\begin{aligned}\textbf{TemporalDistance} \sqsubseteq\ & \texttt{DUL:TimeInterval} \sqcap \\ & = 1\ hasLowerTimeStampValue.(\texttt{xsd:long}) \\ & = 1\ hasUpperTimeStampValue.(\texttt{xsd:long})\end{aligned}$$

$$\begin{aligned}\textbf{SmartHomeEvent} \sqsubseteq\ & \texttt{DUL:Event} \sqcap \\ & \exists\, \texttt{DUL:hasPrecondition}.EventCondition\end{aligned}$$

$$\begin{aligned}\textbf{EventCondition} \sqsubseteq\ & \texttt{DUL:Situation} \sqcap \\ & \exists\, \texttt{DUL:isPreconditionOf}.SmartHomeEvent \sqcap \\ & \exists\, \texttt{DUL:isObservableAt}.TemporalDistance\end{aligned}$$

[3]http://ecareathome-ontology.mpi.aass.oru.se/SmartHome.owl

These ontology modules provide a representation basis to express the temporal relations between smart home events (i.e., activities) and their preconditions. More precisely, the Interval Algebra relations between events and their preconditions can be inferred from the quantified temporal intervals associated with an instance of an activity in the ontology. The following DL expressions model the "watching TV" activity in the *SmartHome* ontology in the form of its beginning and ending preconditions:

- DL expressions to infer the beginning of a *WatchingTV* activity:

$$\begin{aligned}TD\_InLivingRoom \sqsubseteq\ & \textbf{TemporalDistance} \sqcap \\ & = 1\ hasLowerTimeStampValue.(-inf) \\ & = 1\ hasUpperTimeStampValue.(-3)\end{aligned}$$

$$\begin{aligned}TD\_TVSwictchedOn \sqsubseteq\ & \textbf{TemporalDistance} \sqcap \\ & = 1\ hasLowerTimeStampValue.(0) \\ & = 1\ hasUpperTimeStampValue.(0)\end{aligned}$$

$$\begin{aligned}WatchingTV \sqsubseteq\ & \textbf{SmartHomeEvent} \sqcap \\ & \exists\, \texttt{DUL:hasPrecondition}.InLivingRoom \sqcap \\ & \exists\, \texttt{DUL:hasPrecondition}.TVSwitchedOn\end{aligned}$$

$$\begin{aligned}InLivingRoom \sqsubseteq\ & \textbf{EventCondition} \sqcap \\ & \exists\, \texttt{DUL:isPreconditionOf}.WatchingTV \sqcap \\ & \exists\, \texttt{DUL:isObservableAt}.TD\_InLivingRoom\end{aligned}$$

$$\begin{aligned}TVSwitchedOn \sqsubseteq\ & \textbf{EventCondition} \sqcap \\ & \exists\, \texttt{DUL:isPreconditionOf}.WatchingTV \sqcap \\ & \exists\, \texttt{DUL:isObservableAt}.TD\_TVSwictchedOn\end{aligned}$$

- DL expressions to infer the ending of a *WatchingTV* activity:

$$\begin{aligned}TD\_TVSwictchedOff \sqsubseteq\ & \textbf{TemporalDistance} \sqcap \\ & = 1\ hasLowerTimeStampValue.(0) \\ & = 1\ hasUpperTimeStampValue.(0)\end{aligned}$$

$$\begin{aligned}TD\_NotInLivingRoom \sqsubseteq\ & \textbf{TemporalDistance} \sqcap \\ & = 1\ hasLowerTimeStampValue.(0) \\ & = 1\ hasUpperTimeStampValue.(0)\end{aligned}$$

$$\begin{aligned}WatchingTVEnd \sqsubseteq\ & \textbf{SmartHomeEvent} \sqcap \\ & \exists\, \texttt{DUL:hasPrecondition}.NotInLivingRoom \sqcap \\ & \exists\, \texttt{DUL:hasPrecondition}.TVSwitchedOff\end{aligned}$$

$$\begin{aligned}NotInLivingRoom \sqsubseteq\ & \textbf{EventCondition} \sqcap \\ & \exists\, \texttt{DUL:isPreconditionOf}.WatchingTVEnd \sqcap \\ & \exists\, \texttt{DUL:isObservableAt}.TD\_NotInLivingRoom\end{aligned}$$

$$\begin{aligned}TVSwitchedOff \sqsubseteq\ & \textbf{EventCondition} \sqcap \\ & \exists\, \texttt{DUL:isObservableAt}.WatchingTVEnd \sqcap \\ & \exists\, \texttt{DUL:isPreconditionOf}.TD\_TVSwictchedOff\end{aligned}$$

The two temporal distances *TD_TVSwitchedOn* and *TD_TVSwitchedOff* with the zero lower and upper bounds (which shows the synchronicity of an event with its precondition) indicate the ***equal*** Interval Algebra relation between *WatchingTV* and its precondition *TVSwitchedOn*. Likewise, the ***finishes*** Interval Algebra relation between *WatchingTV*

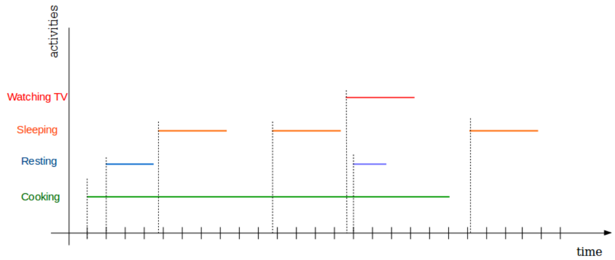

Figure 5: A timeline representation of activities

and *In_LivingRoom* is inferred via the two ontological concepts *TD_InLivingRoom* (that occurs at least 3 time-stamps before the activity takes place) and *TD_NotInLivingRoom*. Therefore, given the above scenario, the Interval Algebra relations between the activity "*WatchingTV*" and its preconditions are defined as follows:

WatchingTV **f** *InLivingroom*
WatchingTV **eq** *TVSwitchedOn*

The quantification of time intervals is of course scenario-dependent. Once the activities have been associated with time intervals, Interval Algebra relations between the activities themselves can be defined as well and give rise to a qualitative model that encodes a timeline of the patient's daily schedule. Note that this timeline is also spatially-enhanced, in the sense that the semantics of the activities provide information about the location of a patient during the day (e.g., the activity of cooking places the patient inside the kitchen). Such relations can be obtained from a combination of closure under the weak composition operation and automated generation using quantified intervals (Georgala, Sherif, and Ngomo 2016; Denis and Muller 2011). An example of a timeline is provided in Figure 5.

Qualitative models that are derived from the activities of a patient can help a caregiver to gain insight into the patient's daily routine and provide personalized services to ameliorate their living status. This becomes even more important when considering the fact that many elderly patients deal with memory issues and cannot provide a description of their daily routines by themselves. As mentioned in the beginning of this section, qualitative models can also be fed, online or offline, to an automated reasoning system so that additional information can be obtained, potentially in the form of recurring patterns that define alarming situations. Such an example could be, perhaps, a change in the cooking habits of the patient, which could be linked with a loss of appetite or some more serious related condition. These automated reasoning functionalities will form the basis of the virtual caregiver, a key component of our infrastructure as shown in Figure 2, and may be used to drive automated decision support for multiple actors in the system (such as smart devices). Finally, qualitative models can be further enhanced by considering *granular* timelines that allow one to state, for example, that the cooking activity of a patient occurs *just after* their exercise routine (Cohen-Solal, Bouzid, and Niveau 2015).

4 Open Problems

In Section 3 we presented a use case that involves monitoring and assisting elderly patients at home, and explained how QSTR techniques are involved in that context and how they can be used to build a better smart environment. In this section we will discuss some open problems in certain areas that require new contributions from the qualitative reasoning community in order to obtain a synergy between QSTR and smart environments. In doing so, we will also briefly review the related state of the art in QSTR and recall some particular results in the literature that may help address these open problems.

Dynamic Spatio-Temporal Reasoning

A lot has been done during the last few years in terms of designing efficient algorithms for dealing with qualitative spatial and temporal relations. In particular, we mention the main result of (Huang, Li, and Renz 2013), which suggests that reasoning with qualitative spatial or temporal constraint networks of bounded treewidth can be performed in polynomial time; reasoning problems are $\mathcal{NP}$-hard in general in the context of QSTR. This result lies on the use of particular graph decompositions (namely, tree decompositions), an overview of which can be found in (Sioutis, Salhi, and Condotta 2016). More recently, efficient algorithms were provided that are able to apply certain useful local consistencies in linear time in the number of triangles that exist within the constraint graph of a given qualitative spatial or temporal constraint network (Sioutis, Long, and Li 2016; Long, Sioutis, and Li 2016). Given the fact that these local consistencies are able to decide the most important reasoning problems associated with qualitative spatial or temporal constraint networks (such as the satisfiability checking problem) when particular subclasses of qualitative relations are involved (viz., *distributive* subclasses of relations (Long and Li 2015)), the algorithms of (Sioutis, Long, and Li 2016; Long, Sioutis, and Li 2016) become a good candidates for a smart environment application, as sensory events typically yield qualitative relations that belong to such subclasses (see again Section 3). Unfortunately, these algorithms are not online, that is, they can only be run for a fixed qualitative spatial or temporal constraint network, and not for a network that dynamically evolves over time as new spatial or temporal information is added to it, which is the case in smart environment applications. The naive approach would, of course, be to fix each time the state of the spatially or temporally augmented network and apply the algorithm of choice on the entirety of that network, but we should be able to make smarter use of existing spatial or temporal information. The lack of online algorithms for efficiently applying the local consistencies of (Sioutis, Long, and Li 2016; Long, Sioutis, and Li 2016) naturally extends to a lack of online algorithms for efficiently solving reasoning problems associated with qualitative spatial or temporal constraint networks in the general case where non-tractable networks are considered; however, this is an issue that we do not foresee being necessary to deal with for the use case at hand, since (and as hinted earlier) we expect the qualitative spatial and temporal constraint networks involved to be tractable.

Spatio-Temporal Pattern Recognition

As sensory events are triggered, new spatial and temporal relations occur that, as explained earlier, have to be taken into account and integrated into the existing qualitative spatio-temporal knowledge base. In addition, these spatial or temporal relations might be repetitive and, hence, constitute a pattern, or might be entirely new and, hence, potentially break a pattern. In either case, spatio-temporal patterns must be identified in order to be accounted for. As an example, let us consider a person who needs to take their medicine after their meal. A pattern could be that the person cooks the meal first and some minutes later opens the medicine cabinet. If one day the person opens the medicine cabinet before cooking the meal or does not open it at all, this would break a pattern and possibly create a new one. Some frameworks in the QSTR literature are able to model spatio-temporal information that evolves over time, mostly in the form of sequences of qualitative spatial or temporal constraint networks (Westphal et al. 2013; Sioutis et al. 2015; Cohen-Solal, Bouzid, and Niveau 2017) or formulas based on linear temporal logic (LTL) (Wolter and Zakharyaschev 2003), but, to the best of our knowledge, none of them actually deal with pattern mining. Some works involve checking if a set of spatial or temporal relations is a subset of a greater set of spatial or temporal relations (Kostakis and Gionis 2015). This problem has been shown to be $\mathcal{NP}$-hard in (Kostakis and Gionis 2015) for Interval Algebra, a result that was obtained through a reduction from the clique decision problem (Karp 1972). However, interesting tractable cases of this problem may exist, especially when taking into account the semantics of qualitative spatial or temporal relations and not viewing the problem strictly as a graph problem. For instance, there is ongoing work in simplifying the graph structures of networks of qualitative and even quantitative spatial and temporal constraints (Sioutis, Li, and Condotta 2015; Li et al. 2015; Lee et al. 2016). Such simplifications can result in unique minimal representations without loss of spatial or temporal information that in turn can facilitate spatio-temporal pattern recognition algorithms.

Spatio-Temporal Revision Operations

This section is closely related to the previous section concerning dynamic spatio-temporal reasoning. Indeed, all is well when the new spatial or temporal information that is taken into account agrees with the spatial and temporal information that we already have in our knowledge base, but what happens if the new piece of information is contradictory? This question has been partially answered in the literature for qualitative spatial or temporal constraint networks in the work of Condotta et al. in (Condotta, Kaci, and Schwind 2008; Condotta et al. 2009a; Condotta et al. 2009b; Condotta et al. 2010). In those studies, given an ensemble of sets of qualitative spatial or temporal relations, a new set of qualitative spatial or temporal relations is constructed by merging these different sets with the aid of certain aggregation functions. This new set of relations serves as a compromise between the sets of relations in the given ensembe, that is, it tries to fit in the best way possible all the contradictory pieces of information into a global and consistent view of the ensemble. The procedure itself is a direct adaptation of model-based methods for merging propositional knowledge bases (Konieczny and Pérez 1998; Konieczny and Pérez 2002; Konieczny, Lang, and Marquis 2004). A limitation of these frameworks is that all the agents that produce the spatial or temporal information are considered to be of equal importance. In a smart environment this is not a very realistic case, as the output of sensors (the agents in this context) might vary due to the age or the condition of the sensors themselves. We would need to extend the aforementioned framework to take the credibility of a sensor into account. Of course, the notion of credibility would also have to be defined. With respect to this problem, it would be interesting to study the notion of *controllability* for qualitative spatial or temporal constraint networks (Vidal and Fargier 1999), which is a property that guarantees satifiability of a given set of spatial or temporal relations for all possible valuations of these relations (in that sense, it can be viewed as a property that is stronger than *global consistency* (Dechter and van Beek 1997)).

5 Conclusion

Applications of smart environments are becoming ever-more common in everyday life, since they are very important for maintaining a pleasant and fruitful human-computer interaction. Examples of such applications can be found in healthcare, where patients are monitored through the use of unobtrusive sensors and assisted in their own home. In this paper, we gave an overview of how qualitative spatio-temporal reasoning is involved with such environments, and presented some scenarios where it can be used to offer services of better quality to the inhabitants of a sensorized home, with an emphasis on elderly patients. Further, we briefly reviewed the related state of the art in qualitative spatio-temporal reasoning, and identified some open problems in certain critical areas that need to be solved in order to be able to provide better smart environment solutions.

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