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Temporal Models: A Review

Zein Al Abidin Ibrahim[1], Ali Choumane[1], Majd Ghareeb[2]

[1] *LARIFA Team - Computer Science Department, Lebanese University, Beirut, Lebanon*
[2] *CCE Department, Lebanese International University, Beirut, Lebanon*
Email: zein.ibrahim@ul.edu.lb, ali.choumane@ul.edu.lb, majd.ghareeb@liu.edu.lb

ABSTRACT
In this paper, we present a review of the existing temporal models in the literature. More precisely, we review the models that handle temporal relations between intervals, between points or between intervals and points. The existing temporal models are categorized based on which type of information they handle. Three categories of temporal models are identified: qualitative temporal models, quantitative temporal models or hybrid temporal models. Once temporal information is represented, some reasoning methods about time will be presented in order to give a glance about how temporal information is processed.

KEYWORDS
Temporal Model — Temporal Representation — Temporal Reasoning — Temporal Relations — Interval — Point — Qualitative — Quantitative

1. Introduction

The temporal representation and the associated reasoning models are an essential feature in any activities that involve some changes with time. This is why many disciplines are related to this important theory such as natural language processing, specification and verification of programs and systems, temporal planning, audio-visual data analysis, social media mining, etc. Reader can refer to [1] for a list of possible applications.
The basic of the representation of time is given by Hayes who has introduced six notions of time to represent temporal relations in [2] that is to say: the basic physical dimension, the time-line, time intervals, time points, amount of time or duration, and time positions. This problem has been addressed by several researchers in order to represent and reason about these temporal entities.
We can find overviews of different approaches of temporal representation and reasoning in the survey of Chittaro and Montanari ([3] and [4]), in the survey of Vila ([5]), and in the review of Pani et al. ([6]). In this work, we aim to detail the most well-known temporal models of the literature. The temporal models involve the representation of time and how to reason about time. The article will be structured into two main sections. Section 2 will present the most well-known temporal representation methods. This section is decomposed into several subsections: The subsection 2.1 is dedicated for qualitative models, 2.2 introduces quantitative models while the subsection 2.3 presents hybrid temporal models. In section 3, we present some reasoning methods about time while section 3 concludes the article.

2. Temporal Representation

The existing models that express and reason about temporal relationships can be classified according to the type of the temporal entities they consider (point, interval, or both) or according to the type of temporal relations they deal with (qualitative, quantitative, or both). In the qualitative models, the interest is the nature of the observed relation (i.e. I before J). In the quantitative (known also as metric) case, the aim is to represent the numerical features of the relation between two entities such as the distance between I and J. In the rest of the paper, the temporal entities are noted as events regardless they are points or intervals.

2.1 Qualitative Models

The most well-known formalisms dealing with qualitative temporal relations are point-based (Vilain and Kautz's Point Algebra between points [7]), interval-based (Allen's Interval Algebra between intervals [8]), and hybrid formalisms (Vilain's Point-Interval Algebra [9], Ligozat's Generalized Interval Calculus [10]).

2.1.1 Vilain and Kautz's Point Algebra (PA)

Vilain and Kautz have proposed in [7] a point algebra (PA) with qualitative information. The points are elementary units along the time dimension. Each point (event) is associated with a time point.
Given two events (points) p1 and p2, three atomic (basic) temporal relations can be determined between them. An event can be before (<), after (>) or simultaneous (=) to a second event.

These relations are defined as follows:

$$before = \{(\mathbf{p}_1, \mathbf{p}_2) \in \mathbb{R}^2 : \mathbf{p}_1 < \mathbf{p}_2\}$$

$$after = \{(\mathbf{p}_1, \mathbf{p}_2) \in \mathbb{R}^2 : \mathbf{p}_1 > \mathbf{p}_2\}$$

$$simultaneous = \{(\mathbf{p}_1, \mathbf{p}_2) \in \mathbb{R}^2 : \mathbf{p}_1 = \mathbf{p}_2\}$$

The set of basic (atomic) temporal relations between events is noted as $B_{pt} = \{<, >, =\}$.
When two events $\mathbf{p}_1$ and $\mathbf{p}_2$ are related with the atomic relation **R**, we say that these two events satisfy **R** noted as $\mathbf{p}_1$ **R** $\mathbf{p}_2$.
In this algebra, each couple of events satisfy at least one atomic relation, which means that the point algebra (PA) is complete. Moreover, two events satisfying an atomic relation R cannot satisfy another atomic relation R'. We say here that the basic relations are mutually exclusive.
In some cases, relations between events may be indefinite. For example, we know that an event $\mathbf{p}_1$ cannot occur after an event $\mathbf{p}_2$. This means that $\mathbf{p}_1$ is either before or simultaneous to $\mathbf{p}_2$ and can be represented by a disjunction of the basic relations like $\mathbf{p}_1$ $\{<, =\}$ $\mathbf{p}_2$. Since there are 3 basic relations, $2^3 = 8$ disjunctions exist, each one representing an indefinite relation. The set of disjunctions is noted as $2^{B_{pt}}$ and defined as follows:
$2^{B_{pt}} = \{\emptyset, \{<\}, \{>\}, \{=\}, \{<,=\}, \{<,>\}, \{>,=\}, \{<,=,>\}\}$
An abbreviation for each disjunction may exist. For example, the $\{<, =\}$ may be noted as $\leq$, $\{>, =\}$ noted as $\geq$, and $\{<, >\}$ noted as $\neq$.
The set ø represents the impossibility to relate two events while the set {<,=,>} means that all the basic relations may be present between the two events. In addition to this set, the unary operation of converse and the binary operations of intersection and composition are defined.
In multimedia systems, an example of a point-based representation is the time-line, on which media objects are placed on several time axes. Though this representation is also used as an interval-based representation, we can find the time-line model applied in various applications such as HyTime [11].

2.1.2 Interval-based Algebra (IA)

The famous and well-known interval algebra is the one introduced by Allen in [8]. In this algebra, the elementary entities considered are time intervals, which can be ordered according to different relations. A time interval I is represented by a couple of ordered points on the time axis characterizing its start I_b and its end I_e time. An Allen's interval is noted a convex one to differentiate it from a later representation of intervals that deals with non-convex intervals.
Contrary to the point-based model, the interval can be seen as a point that has duration along the time dimension.
Allen proposed in his interval algebra (IA) a complete set of relations between two intervals. For two given intervals, there are 13 distinct possibilities to temporally relate them. These relations can be represented by 6*2 cases (corresponding to direct and inverse relations). In addition to them, there is a relation (the last one) that corresponds to the fact that two intervals have the same beginning and same ending points (Table 1). The set of the basic interval relations is the following:
$B_{int} = \{=, <, >, m, m_i, o, o_i, s, s_i, d, d_i, f, f_i\}$
The notation I R J means that I and J satisfy the relation R. One of the Allen's thirteen relations should relate each couple of intervals. Besides, the set of disjunctions of the basic relations in B_{int} is used to represent the indefinite relations. This set contains $2^{13} = 8192$ disjunctions and is noted as $2^{B_{int}}$. Since some temporal models are point-based and some others are interval-based, a switch between the models is made by representing the intervals relations as conjunctions of point basic relations between the interval boundaries (Table 1) [12].
The Allen's algebra consists of the 8192 possible relations between intervals together with the operations inverse $^{-1}$, intersection $\cap$, and composition $\wedge$, which are defined as follows:

- $\forall$ I, J: I R^{-1} J $\iff$ J R I
- $\forall$ I, J: I (R $\cap$ S) J $\iff$ I R J and I S J
- $\forall$ I, J: I (R $\wedge$ S) J $\iff$ $\exists$ K / I R K and K S J

Table 1. *Allen's interval-interval temporal relations*

Relation	**Symbol & Inverse**	**Point Notation**	**Example**
I *before* J	$<$ $>$	$I_b<I_e<J_b<J_e$	AAAA BBBBBBB
I *meets* J	m m_i	$I_b<I_e=J_b<J_e$	AAAA BBBBBBB
I *overlaps* J	o o_i	$I_b<J_b<I_e<J_e$	AAAA BBBBBBB
I *starts* J	s s_i	$I_b=J_b<I_e<J_e$	AAAA BBBBBBB
I *finishes* J	f f_i	$J_b<I_b<I_e=J_e$	AAAA BBBBBBB
I *equals* J	$=$ $=$	$I_b=J_b<I_e=J_e$	AAAAAAA BBBBBBBB
I *during* J	d d_i	$J_b<I_b<I_e<J_e$	AAAAAA BBBBBBBBBB

Motivated by the fact that the computational complexity of the Allen's formalism is intractable, several works have tried to identify subclasses of the Allen's algebra that are tractable [13, 14, 15].
Beek et al. in [14] have defined the pointisable algebra as being the set of relations in the Allen's interval algebra that can be expressed by one of the relations $<$, $\leq$, $=$, $\neq$, $\geq$, and $>$.
By the same way, Vilain et al. in [15] defined the Continuous Endpoint Algebra (CEA) that models only continuous relations between time points. This algebra represents the set of the Allen's interval algebra which can be expressed by the $<$, $\leq$, $=$, $\geq$, and $>$. Nebel et al. in [13] have defined the ORD-Horn algebra basing on the notion of ORD clause. This clause is defined as the disjunction of relations having the form x R y where the relation R is one of the relations $\leq$, $=$, and $\neq$. The ORD-Horn

Table 2. *Matrix representing the overlap relation*

$\cap$	**]-∞ 55[**	**{55}**	**]55 100[**	**{100}**	**]100 +∞[**
]-∞ 27[	1	0	0	0	0
{27}	1	0	0	0	0
]27 68[	1	1	1	0	0
{68}	0	0	1	0	0
]68 +∞[	0	0	1	1	1

is a subclass of the Allen's relations that can be written as ORD clauses containing only disjunctions with at most one relation of the form x=y or $x \leq y$. The other relations may be of the form $x \neq y$.

Beside the problem of tractability, some works in the literature have tried to provide another representation or extend the set of Allen's relations such as [16, 17, 18].

In [16], each interval I = [I_b I_e] is represented by five zones as the following:]-∞ I_b[, {I_b},]I_b I_e[,{I_e}, and]I_e +∞[. Consequently, each Allen's temporal relation is represented by a 5x5 matrix. Each element in the matrix indicates if there is intersection between the two associated zones or not. The matrix in Table 2 represents the overlap relation existing between the intervals I = [27 68] and J = [55 100]. Contrary to the previous representation, Pujari et al. have extended the set of Allen's relations by integration of the duration information. The following three qualitative relations to compare the duration of two intervals I and J have been introduced:

- {<}: Duration of I is less than the duration of J.
- {>}: Duration of I is bigger than the duration of J.
- {=}: Duration of I is equal to the duration of J.

Each Allen's relation is superscripted by one of the above relations to express the new information. For example, the meet relation noted as m becomes $m^{<}$, $m^{=}$, $m^{>}$. The new set of temporal relations is composed of 25 relations after excluding some impossible ones such as $=^{<}$, $=^{>}$, $f^{>}$, $f^{=}$, etc...

Ligozat et al. [17] have provided a graphical representation of the Allen's relations by regions. Each temporal relation is associated to a region in the Euclidean space. In this representation, each interval is considered as a point (x, y) in the two-dimensional space with the constraint $x < y$ which means that all intervals are in the half-plane H defined by the equation $X < Y$ in the (O, X, Y) plane. The set of intervals having the length L are situated on the line with the equation Y-X=L. In the Ligozat's representation, an interval (a, b) (using their representation) is in relation R with (x, y) if and only if (x, y) belongs to the region defined by the half-plane noted Reg(R, (a,b)). For example, the region associated to the overlap relation corresponds to the zone defined by: (1) $x < y$; (2) $a < b$; (3) $x < a$; (4) $a < y < b$. The (1) and (2) are deduced from the notion of intervals (beginning appears before the end) while (3) and (4) represent the fact that (x, y) overlaps (a, b). The figure 1 shows the graphical representation of the overlap relation while figure 2 presents the regions corresponding to the set of Allen's relations.

In the same context and starting from Allen's algebra, Cukierman et al. extend the temporal relations to work with unbounded intervals [19]. An unbounded interval may be a *since interval* with a finite beginning point and an infinite ending point, *until interval* with an infinite beginning point and a finite ending point, or *alltime* representing the time line with both infinite boundaries. Incomplete information about the start or the end of intervals has been also addressed by Freksa in [20].

In the interval algebra of Allen, intervals are considered as convex ones. A convex interval is defined as an interval with no gaps. Ladkin defines in [21] and [22] the notion of non-convex intervals defined as the union of convex ones. In his work, Ladkin has introduced an algebra based on a taxonomy of general relationships between non-convex intervals. As a generalization of Allen's algebra on convex intervals towards non-convex intervals, this will lead to an exponential increase of the number of binary relationships. Hence, he investigates the qualitative quantification of the binary relations that may hold between non-convex intervals. These relations are based on the qualifiers *mostly*, *always*, *partially* and *sometimes*, and a *disjunction* relation to represent relation alternatives. The algebra defined in [21] has the advantage of being independent of the number of subintervals of each non-convex interval (potentially indefinite). It generates non-convex relations from convex ones.

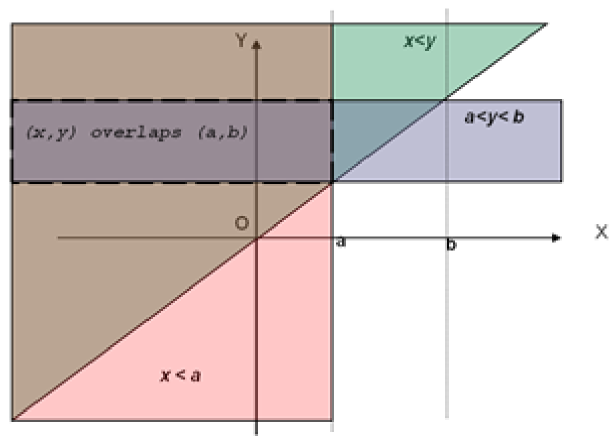

Figure 1. *Visualization of the region corresponding to the intervals which are in "overlap relation" with (a, b)*

2.1.3 Hybrid Formalism

2.1.3.1 Vilain's Point-Interval and Interval-Point Algebra

The Point-Interval and Interval-Point relations proposed by Vilain ([9]) are based on points, intervals, and the binary relations that may exist between them. It allows the temporal relations between objects of different types by combining intervals and points. Table 3 resumes the possible relations that may relate a point and an interval. Relations between an interval and a point may be computed similarly.

In [23], a set of models that base on the temporal relations be-

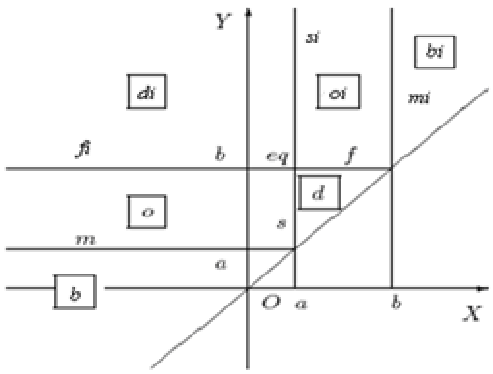

Figure 2. *Region Representation of the Allen's temporal relations (inspired from [17])*

Table 3. *Vilain's point-interval temporal relations*

Relation	Symbol &	Point Notation	Example
P *before* I	<	$P < I_b < I_e$	P IIIIIIIII
P *starts* I	s	$P = I_b < I_e$	P IIIIIIIII
P *finishes* I	f	$I_b < I_e = P$	P IIIIIIIII
P *during* I	*d*	$I_b < P < I_e$	P IIIIIIIII
P *after* I	>	$I_b < I_e < P$	IIIIIIIII P

tween intervals and points to compose multimedia data is cited (i.e. [24, 25]).

2.1.3.2 Meiri's Qualitative Algebra

In the qualitative algebra of Meiri [12], a qualitative constraint between two events e_i and e_j (each may be a point or an interval), is a disjunction of the form: $(e_i\ R_1\ e_j) \vee (e_i\ R_2\ e_j) \vee ... \vee (e_i\ R_k\ e_j)$

where each of the R's is a basic relation that may exist between two objects. Basing on this form, we can deduce the Interval-Interval relations, the Point-Point relations, the Point-Interval relations, and Interval-Point relations. We have already presented you in Table 1 and Table 3 the transformation of each relation in the QA form.

2.1.3.3 Ligozat's Generalized Hybrid Model

Based on the previously presented formalisms, Ligozat proposes a generic notion of points, intervals and relations between them. His proposition deals with convex and non-convex intervals and points. The proposed framework is based on the Vilain's point-interval relations [9] and Ladkin's non-convex interval ones [21]. In this approach, an interval is defined as a linearly ordered sequence of distinct points where a sequence of p points is called a p-interval. Consequently, a point is represented by a 1-interval while Allen's interval is a 2-interval. A 3-interval may represent three points, a point followed by an interval, or an interval followed by a point. Relations between a p-interval and a q-interval are called (p,q)-relations and noted by $\Pi(p,q)$. The relation between a p-interval $x=(x_1, x_2, ... x_p)$ and a q-interval $y=(y_1, y_2, ..., y_q)$ is defined as follows: The y q-interval is used to partition the domain into 2q+1 zones. The zones are: $zone_1$ = the set of points preceding y_1; $zone_2$ = the set of points between y_1 and y_2; $zone_{2q}$ = the set of points following y_q. By assigning each point of the p-interval to the zone it belongs to, we obtain a p zone numbers. In this approach, the Vilain's point formalism corresponds to the set $\Pi(1,1)$, the Vilain's point-interval one corresponds to $\Pi(1,2)$, while Allen's one is associated to $\Pi(2,2)$. Ligozat's Interval Calculus is based on the operations of transposition and composition which are defined on the set of (p,q)-relations. The transposition of the (p,q)-relation between x and y returns the (q,p)-relation between y and x. Similarly to the traditional composition operation between points or intervals, given the relation between a p-interval x and a q-interval y and the one between y and a r-interval z, composition returns the possible (p,r)-relation between x and z. Figure 3 shows a graphical representation of the special-case of Allen's temporal relations.

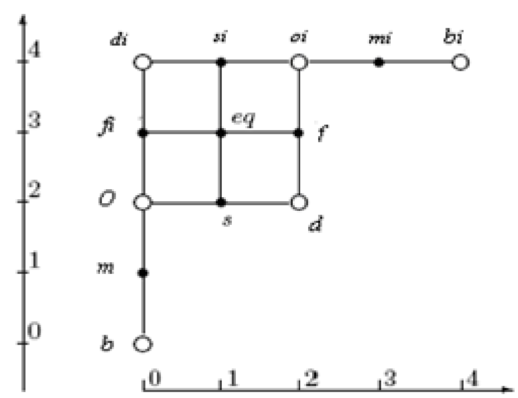

Figure 3. *Hass diagram of the Allen's temporal relations*

2.2 Quantitative Models

As some models have addressed qualitative temporal relationships, others have tackled the quantitative ones [26]. Dechter et al. have introduced the point-based Distance Algebra (DA) which allows the representation of quantitative temporal information between events. The DA models distances between time points, durations of intervals, and allows constraints about the value of dates. A point in this DA may represent the start time or the end time of an interval, an event, or an absolute temporal reference time (i.e 10h00 in the morning). A temporal relation between two points p_i and p_j is expressed by a set of intervals $I_{1ij}, I_{2ij}, ... I_{nij}$ corresponding to the following constraint: $p_j-p_i \in I_{1ij}$ or $p_j-p_i \in I_{2ij}$ ... or $p_j-p_i \in I_{nij}$. Here is an example:

Each day, the person X goes to the gym. He even takes his car or the bus. In the first case, the road lasts between 20 and 30 minutes while in the second one it lasts between 45 and 55 minutes. Let p_1 and p_2 be the temporal points corresponding to the departure to and the return from the gym. These points are expressed by the intervals [20 30], [45 55] representing the fact $20 \leq p_2 - p_1 \leq 30$ or $45 \leq p_2 - p_1 \leq 55$.

2.3 Qualitative and Quantitative Models

The temporal representation and reasoning have not been limited to qualitative or quantitative information but have tried to mix them in the same framework [12, 27].
Kautz et al. have augmented the Allen's algebra with quantitative constraints of the form -c R_1 (x-y) R_2 d where R_1 and $R_2 \in$ $<, \leq$ and x, y are the endpoints of the intervals.
In the Meiri's temporal model, four types of qualitative constraints are taken into account: constraints between two points, constraints between a point and an interval, constraints between an interval and a point, and constraints between two intervals as already presented. The quantitative information is similar to the one presented in the DA by Dechter et al. [26]. The quantitative constraints may have the following two forms:
Let e_1, e_2 ... e_n be time points or endpoints of intervals. The metric constraints may be expressed by:

1. $(c_1 \leq e_1 \leq d_1) \vee ... \vee (c_1 \leq e_n \leq d_1)$;
2. $(c_1 \leq e_n - e_1 \leq d_1) \vee ... \vee (c_1 \leq e_n - e_{n-1} \leq d_1)$;

2.4 Temporal Reasoning

One of the well-known reasoning mechanisms is to handle relations between temporal entities (points, intervals, etc...) which are then interpreted as temporal constraints. The constraints are represented by a temporal network where intervals (points) are associated to nodes and the arcs connecting nodes are labelled by temporal relations to represent qualitative information (i.e [8]). This network is a particular type of CSP (Constraint Satisfaction problems). Another particular CSP called Temporal CSP is used to represent quantitative information such as in (26) or qualitative and quantitative one such as in [12, 27]. A third type of network called the point-duration network (PDN) is used to reason about durations [28, 29, 30, 31].
However, given a network, the first principle problem is to search if this network represents consistent temporal information. This problem is solved by computing the minimal representation of the set of temporal constraints. The reasoning about temporal constraints is performed using different algorithms for constraint satisfaction. In the constraint satisfaction domain, the problem of satisfiability for a set of constraints between events variables (points or intervals) is the decision if there exists an assignment of values on the real line for the events variables, such that all of the specified constraints between events are satisfied. For example, the set of interval constraints {I m J, J m K, I m K} cannot be satisfied because the first two constraints imply that interval I must precede interval K which contradicts the third constraint. In contrary, the set {I {m, o} J, J {d, f^{-1}} K, I {m^{-1}, s} K} can be satisfied. The instances I = [0, 2], J = [1, 3], and K = [0, 4] constitute a model of this set.
The constraint satisfaction algorithms are characterized by their complexity to solve the problem. One of the main purposes of researchers was to distinguish between problems that are solvable in polynomial time and problems that are not. For example, deciding satisfiability in the Allen's interval algebra and the Vilain's point-interval algebra is NP-Complete (called also intractable). In the point algebra of Vilain and Kautz, the reasoning mechanism used is the path-consistent, which is proved polynomial-time. A polynomial time algorithm that solves all the instances of a set of the algebra is also known as tractable. Since the problem of satisfiability of the IA (Interval Algebra) is NP-complete, the question of identifying the tractable subsets of this algebra started to take place. The idea is to search particular subsets of a NP-complete algebra with a polynomial-time algorithm (tractable).
To do so, several works have focused on the identification of tractable subsets of IA that are closed under the operations of intersection, converse and composition. These subsets are called sub-algebras. Reader can refer to [13] for an overview of the tractable sub-algebras.
In spite of using network to solve the problem of satisfiability, Golumbic and Shamir reconsider the reasoning about temporal constraints from the point of view of graph theory [1]. They introduce the notion of macro-relation algebras as being suitable partitions of the Allen's thirteen relations. A first example is the A_3 macro-relation algebra containing three types of relations: (1) before ($<$); (2) after ($>$); (3) the remaining ones (n). The A_7 macro-relation algebra is obtained by refining the n macro-relation in the A_3 algebra into five macro-relations: C = {s, f, d}, C^{-1} = {s_i, f_i, d_i}, α = {m, o}, α^{-1} = {m_i, o_i} and the basic relation $=$. The third macro-relation algebra is the A_6 one. This algebra is obtained by assuming that all the endpoints of intervals are distinct. By this way, seven of the Allen's relations are eliminated and the remaining ones are: $<$, $>$, o, o_i, d, d_i.
The reader may refer to [32] for a survey of the constraint satisfaction problem (CSP) algorithms while Krokhin et al. provide a complete classification of the computational complexity of the algorithms of satisfiability of the IA [33].

2.5 Conclusion

In this article, we have made a review of the existing temporal models. More precisely, we have presented the temporal models that express temporal relations between intervals, between points or between intervals and points. We have also differentiated the models based on the type of information they handle. Three types are identified: qualitative temporal models, quantitative temporal models and hybrid temporal models. Some of the existing methods to reason about time is also introduced in order to highlight how temporal information is processed once represented.

References

[1] Golumbic, Martin and Shamir, Ron. Complexity and Algorithms for Reasoning about Time: A Graph-Theoretic Approach. In: *International journal of the ACM*, 1993, vol. 40, no 5, p. 1108-1133.

[2] Hayes, Patrick J. A Catalog of Temporal Theories. In: *University of Illinois*, 1996.

[3] Chittaro, Luca and Montanari, Angelo. Trends in Temporal Representation and Reasoning. In: *Knowledge Engineering Review*, 1996, vol. 11, no. 3, pp. 281-288.

[4] Chittaro, Luca and Montanari, Angelo. Temporal Representation and Reasoning in Artificial Intelligence: Issues and Approaches. In: *Annals of Mathematics and Artificial Intelligence*, 2002, vol. 28, no. 1-4, p. 47-106.

[5] Vila, Luis. A Survey on Temporal Reasoning in Artificial Intelligence. In: *Journal of Artificial Intelligence Communications*, 1994, vol. 7, no. 1, p. 4-28.

[6] Pani, Ashis, and Bhattacharjee G.. Temporal Representation and Reasoning in Artificial Intelligence: A Review. In: *Journal of Mathematical and Computer Modelling*, 2001, vol. 34, no. 1-2, p. 55-80.

[7] Vilain, Marc, and Kautz, Henry. Constraint Propagation Algorithms for Temporal Reasoning. In: *National Conference on Artificial Intelligence (AAAI86)*, 1986.

[8] Allen, James. Maintaining Knowledge about Temporal Intervals. In: *Journal of Communication of ACM*, 1983, vol. 26, no. 11, p. 832 – 843.

[9] Vilain, Marc. A System for Reasoning about Time. In: *National Conference on Artificial Intelligence (AAAI82)*, 1982.

[10] Ligozat, Gerard. On Generalized Interval Calculi. In: *National Conference on Artificial Intelligence (AAAI-91)*, 1991.

[11] ISO-10744. Information Technology - Hypermedia / Time-based Structuring Language (HyTime). *ANSI*, 1992, New York, USA.

[12] Meiri, Itay. Combining Qualitative and Quantitative Constraints in Temporal Reasoning. In: *Journal of Artificial Intelligence*, 1996, vol. 87, no. 1-2, p. 295-342.

[13] Nebel, Bernhard, and Burckert, Hans-Jurgen. Reasoning about Temporal Relations: A Maximal Tractable Subclass of Allen's Interval Algebra. In: *Journal of the ACM*, 1995, vol. 42, no. 1, p. 43-66.

[14] Van Beek, Peter, and Cohen, Robin. Exact and Approximate Reasoning about Temporal Relations. In: *Journal of Computational Intelligence*, 1990, vol. 6, no. 3, p. 132-144.

[15] Vilain, Marc, Kautz, Henry, and Van Beek, Peter. Constraint Propagation Algorithms for Temporal Reasoning: A Revised Report. In: *Readings in Qualitative Reasoning about Physical Systems, D. S. Weld and J. d. Kleer, Eds.*, 1990, p. 373-381.

[16] Zhang, Shichao and Zhang, Chengqi. Propagating Temporal Relations of Intervals by Matrix. In: *Journal of Applied Artificial Intelligence*, 2002, vol. 16, no. 1, p. 1-27.

[17] Ligozat, Gerard and Bestougeff, Helene. On Relations between Intervals. In: *Information Processing Letters*, 1989, vol. 34, no. 4, p. 177-182.

[18] Pujari, Arun, Kumari, Vijaya. and Sattar, Abdul. INDU: An Interval and Duration Network. In: *Australian Joint Conference on Artificial Intelligence*, 1999.

[19] Cukierman, Diana and Delgrande, James. A Theory for Convex Interval Relations including Unbounded Intervals. In: *International Florida Artificial Intelligence Research Society Conference*, 2004.

[20] Freksa, Christian. Temporal Reasoning based on Semi-intervals. In: *Journal of Artificial Intelligence*, 1992, vol. 54, no. 1-2, p. 199-227.

[21] Ladkin, Peter. Time Representation: A Taxonomy of Interval Relations. In: *National Conference on Artificial Intelligence*, 1986.

[22] Ladkin, Peter. The Logic of Time Representation. In: *University of California, Berkeley*, 1987.

[23] Duda, Anderzej and Keramane, Cherif. Structured Temporal Composition of Multimedia Data. In: *IEEE International Workshop on Multimedia Database Management Systems*, 1995.

[24] Buchanan, Cecelia and Zellweger, Polle. Automatic Temporal Layout Mechanisms. In: *ACM International Conference on Multimedia*, 1993.

[25] Dingeldein, Dennis. Modeling Multimedia Objects with MME. In: *Eurographics Workshop on Object Oriented Graphics*, 1994.

[26] Dechter, Rina, Meiri, Itay, and Pearl, Judea. Temporal Constraint Networks. In: *Journal of Artificial Intelligence*, 1991, vol. 49, no. 1-3, p. 61-95.

[27] Kautz, Henry and Ladkin, Peter. Integrating Metric and Qualitative Temporal Reasoning. In: *AAAI-91*, 1991.

[28] Condotta, Jean-Frank. Problèmes de Satisfaction de Contraintes Spatiales: Algorithmes et Complexité. In: *Institut de Recherche en Informatique de Toulouse*, 2000.

[29] Pujari, Arun and Sattar, Abdul. A New Framework for Reasoning about Points, Intervals and Durations. In: *International Joint Conference on Artificial Intelligence (IJCAI)*, 1999.

[30] Wetprasit, Rattana and Sattar, Abdul. Temporal Reasoning with Qualitative and Quantitative Information about Points and Durations. In: *National Conference on Artificial Intelligence (AAAI)*, 1998.

[31] Navarette, Isabel and Marin, Roque. Qualitative Temporal Reasoning with Points and Durations. In: *International Joint Conference on Artificial Intelligence (IJCAI)*, 1997.

[32] Schwalb, Eddie. and Vila, Lluís. Temporal Constraints: a Survey. In: *Journal of Constraints*, 1998, vol. 3, no. 2, p. 129-149.

[33] Krokhin, Andrei. Jeavons, Peter and Jonsson, Peter. The Tractable Subalgebras of Allen's Interval Algebra. In: *Journal of the ACM*, 2003, vol. 50, no. 5, p. 591-640.