Determining the preferred representation of temporal constraints in conceptual models

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Abstract. The need for expressing temporal constraints in conceptual models is well-known, but it is unclear which representation is preferred and what would be easier to understand by modellers. We assessed five different modes of representing temporal constraints, being the formal semantics, Description logics notation, a coding-style notation, temporal EER diagrams, and (pseudo-)natural language sentences. The same information was presented to 15 participants in an experimental evaluation. Principally, it showed that 1) there was a clear preference for diagrams and natural language versus a dislike for other representations; 2) diagrams were preferred for simple constraints, but the natural language rendering was preferred for more complex temporal constraints; and 3) a multi-modal modelling tool will be needed for the data analysis stage to be effective.

1 Introduction

Modelling of temporal constraints for information systems has received attention since the mid-1990s and continues to do so (e.g., [9, 15, 16]), for it adds expressiveness to the model so as to ensure data integrity. For instance, to ensure that each Alumnus must have been a Student at that university before (*evolving object*), that a couple registered as divorcing in a census database must have been marrying before (an *evolving relation*), or that flex-workers may not always have an Office assigned (*temporal attribute*). This need has not subsided, and, perhaps, even increased with Big Data and the Internet of Things, for that data is inherently temporal. Capturing such information may be achieved with a temporal conceptual data modelling language. This adds a challenge during the data analysis stage, however, for modelling temporal aspects of the universe of discourse is non-trivial. This is due in part to the limited language options available to capture all these constraints. For instance, TimERplus [10] does not consider transition constraints for evolving entities, ER_{VT} [2] omits transition constraints for relationships and attributes (other than freezing), and TimeER [7], while including more on temporal attributes, has no specification for temporal relationships either. Another reason may be the graphical modelling languages, which have only recently been evaluated on whether the temporal adornments make sense to modellers, and which ones they prefer [21]. That evaluation [21] also demonstrated that graphical notations are not unambiguous and that there was a steep learning curve. An alternative is to *verbalise* information in natural language, as is common for the ORM language [12]. One also could present modellers with the more precise logic-based semantics. This smorgasbord of representation options raises the following main questions:

1. Which representation is preferred for representing temporal information: formal semantics, Description Logics (DL), a coding-style notation, diagrams, or (pseudo-)natural language sentences?
2. What would be easier to understand by modellers: a succinct logic-based notation, a graphical notation, or a 'coding style' notation?

The aim of this paper is to answer these questions. We conducted a survey of modeller preference and understanding of these representation modes. For the formal semantics, slightly more succinct DL notation, coding-style representation, and graphical notation, we use an extended version of ER_{VT} [2]. Because new temporal constraints have been added since ER_{VT} was proposed, and to ensure the, with current knowledge, 'best' graphical representation, we devised an updated and extended notation in line with findings of [21]. This extended and updated notation resulted in the **T**emporal information **R**epresentation in **En**tity-Relationship **D**iagrams, TREND language. Finally, verbalisations—or: (pseudo-)natural language sentences—of the temporal constraints were elucidated in a separate research activity [13], which were added as a fifth option to choose from. The evaluation with 15 modellers showed 1) a clear preference for graphical or verbalised temporal constraints over the other three representations 2) 'simple' temporal constraints were preferred graphically and complex temporal constraints preferred in natural language and 3) their English specification of temporal constraints was inadequate. This suggests the need for *multi-modal* modelling languages in the process of temporal conceptual model development, especially among graphical and verbalised temporal constraints.

The remainder of the paper is structured as follows. We describe the five modes of representation in Sect. 2 and the experiment and its results in Sect. 3. We discuss the results and related works in Sect. 4 and conclude in Sect. 5.

2 Representing the same information in different ways

This section provides a succinct overview of the different notations for temporal elements and constraints. Because we use the logic-based reconstruction into $\mathcal{DLR}_{\mathcal{US}}$ [1] as the foundation for both the semantics and DL notation, this will be introduced first. This is followed by the creation of the diagrammatic notation in the extended ER_{VT}, TREND, and finally basic information is provided for the verbalisation into natural language.

2.1 The Description Logic $\mathcal{DLR}_{\mathcal{US}}$: syntax and semantics

The temporal Description Logic $\mathcal{DLR}_{\mathcal{US}}$ [1] is an expressive fragment of first order logic that combines the propositional temporal logic with *Since* and *Until* operators with the (atemporal) DL $\mathcal{DLR}$ [6] so that the temporal operators

$$
\begin{aligned}
C \to\ & \top \mid \bot \mid CN \mid \neg C \mid C_1 \sqcap C_2 \mid \exists^{\leqslant k}[U_j]R \mid \exists[F]A \mid \\
& \Diamond^+ C \mid \Diamond^- C \mid \Box^+ C \mid \Box^- C \mid \oplus C \mid \ominus C \mid C_1\ \mathcal{U}\, C_2 \mid C_1\ \mathcal{S}\, C_2 \\
R \to\ & \top_n \mid RN \mid \neg R \mid R_1 \sqcap R_2 \mid U_i/n : C \mid \\
& \Diamond^+ R \mid \Diamond^- R \mid \Box^+ R \mid \Box^- R \mid \oplus R \mid \ominus R \mid R_1\ \mathcal{U}\, R_2 \mid R_1\ \mathcal{S}\, R_2 \\
A \to\ & \top_A \mid AN \mid \neg A \mid F : C \mid \\
& \Diamond^+ A \mid \Diamond^- A \mid \Box^+ A \mid \Box^- A \mid \oplus A \mid \ominus A \mid A_1\, \mathcal{U}\, A_2 \mid A_1\, \mathcal{S}\, A_2
\end{aligned}
$$

$$
\begin{aligned}
\top^{\mathcal{I}(t)} &= \Delta^{\mathcal{I}}_O \\
\bot^{\mathcal{I}(t)} &= \emptyset \\
CN^{\mathcal{I}(t)} &\subseteq \top^{\mathcal{I}(t)} \\
(\neg C)^{\mathcal{I}(t)} &= \top^{\mathcal{I}(t)} \setminus C^{\mathcal{I}(t)} \\
(C_1 \sqcap C_2)^{\mathcal{I}(t)} &= C_1^{\mathcal{I}(t)} \cap C_2^{\mathcal{I}(t)} \\
(\exists^{\leqslant k}[U_j]R)^{\mathcal{I}(t)} &= \{\ o \in \top^{\mathcal{I}(t)} \mid \sharp\{\langle o_1, \ldots, o_n\rangle \in R^{\mathcal{I}(t)} \mid o_j = o\} \leqslant k\} \\
(\exists\,[F]A^{\mathcal{I}(t)} &= \{\ o \in \top^{\mathcal{I}(t)} \mid \sharp\{\langle o, d\rangle \in A^{\mathcal{I}(t)} \geq 1\}\} \\
(C_1\, \mathcal{U}\, C_2)^{\mathcal{I}(t)} &= \{\ o \in \top^{\mathcal{I}(t)} \mid \exists v > t.(o \in C_2^{\mathcal{I}(v)} \wedge \forall w \in (t, v).o \in C_1^{\mathcal{I}(w)})\} \\
(C_1\, \mathcal{S}\, C_2)^{\mathcal{I}(t)} &= \{\ o \in \top^{\mathcal{I}(t)} \mid \exists v < t.(o \in C_2^{\mathcal{I}(v)} \wedge \forall w \in (v, t).o \in C_1^{\mathcal{I}(w)})\}
\end{aligned}
$$

$$
\begin{aligned}
(\top_n)^{\mathcal{I}(t)} &= (\Delta^{\mathcal{I}}_O)^n \\
RN^{\mathcal{I}(t)} &\subseteq (\top_n)^{\mathcal{I}(t)} \\
(\neg R)^{\mathcal{I}(t)} &= (\top_n)^{\mathcal{I}(t)} \setminus R^{\mathcal{I}(t)} \\
(R_1 \sqcap R_2)^{\mathcal{I}(t)} &= R_1^{\mathcal{I}(t)} \cap R_2^{\mathcal{I}(t)} \\
(U_i/n : C)^{\mathcal{I}(t)} &= \{\ \langle o_1, \ldots, o_n\rangle \in (\top_n)^{\mathcal{I}(t)} \mid o_i \in C^{\mathcal{I}(t)}\} \\
(R_1\, \mathcal{U}\, R_2)^{\mathcal{I}(t)} &= \{\ \langle o_1, \ldots, o_n\rangle \in (\top_n)^{\mathcal{I}(t)} \mid \exists v > t.(\langle o_1, \ldots, o_n\rangle \in R_2^{\mathcal{I}(v)} \wedge \\
&\qquad \forall w \in (t, v).\ \langle o_1, \ldots, o_n\rangle \in R_1^{\mathcal{I}(w)})\} \\
(R_1\, \mathcal{S}\, R_2)^{\mathcal{I}(t)} &= \{\ \langle o_1, \ldots, o_n\rangle \in (\top_n)^{\mathcal{I}(t)} \mid \exists v < t.(\langle o_1, \ldots, o_n\rangle \in R_2^{\mathcal{I}(v)} \wedge \\
&\qquad \forall w \in (v, t).\ \langle o_1, \ldots, o_n\rangle \in R_1^{\mathcal{I}(w)})\} \\
(\Diamond^+ R)^{\mathcal{I}(t)} &= \{\langle o_1, \ldots, o_n\rangle \in (\top_n)^{\mathcal{I}(t)} \mid \exists v > t.\ \langle o_1, \ldots, o_n\rangle \in R^{\mathcal{I}(v)}\} \\
(\oplus R)^{\mathcal{I}(t)} &= \{\langle o_1, \ldots, o_n\rangle \in (\top_n)^{\mathcal{I}(t)} \mid \langle o_1, \ldots, o_n\rangle \in R^{\mathcal{I}(t+1)}\} \\
(\Diamond^- R)^{\mathcal{I}(t)} &= \{\langle o_1, \ldots, o_n\rangle \in (\top_n)^{\mathcal{I}(t)} \mid \exists v < t.\ \langle o_1, \ldots, o_n\rangle \in R^{\mathcal{I}(v)}\} \\
(\ominus R)^{\mathcal{I}(t)} &= \{\langle o_1, \ldots, o_n\rangle \in (\top_n)^{\mathcal{I}(t)} \mid \langle o_1, \ldots, o_n\rangle \in R^{\mathcal{I}(t-1)}
\end{aligned}
$$

$$
\begin{aligned}
(\top_A)^{\mathcal{I}(t)} &= \Delta^{\mathcal{I}}_O \times \Delta^{\mathcal{I}}_D \\
AN^{\mathcal{I}(t)} &\subseteq (\top_A)^{\mathcal{I}(t)} \\
(F : C)^{\mathcal{I}(t)} &= \{\ \langle o, d\rangle \in (\top_A)^{\mathcal{I}(t)} \mid o \in C^{\mathcal{I}(t)}\} \\
(A_1\, \mathcal{U}\, A_2)^{\mathcal{I}(t)} &= \{\ \langle o, d\rangle \in (\top_A)^{\mathcal{I}(t)} \mid \exists v > t.(\langle o, d\rangle \in A_2 \wedge^{\mathcal{I}(v)} \forall w \in (t, v).\langle o, d\rangle \in A_1^{\mathcal{I}(w)})\} \\
(A_1\, \mathcal{S}\, A_2)^{\mathcal{I}(t)} &= \{\ \langle o, d\rangle \in (\top_A)^{\mathcal{I}(t)} \mid \exists v < t.(\langle o, d\rangle \in A_2^{\mathcal{I}(v)} \wedge \forall w \in (v, t).\langle o, d\rangle \in A_1^{\mathcal{I}(w)})\} \\
(\Diamond^+ A)^{\mathcal{I}(t)} &= \{\langle o, d\rangle \in (\top_A)^{\mathcal{I}(t)} \mid \exists v > t.\langle o, d\rangle \in A^{\mathcal{I}(v)}\} \\
(\oplus A)^{\mathcal{I}(t)} &= \{\langle o, d\rangle \in (\top_A)^{\mathcal{I}(t)} \mid \langle o, d\rangle \in A^{\mathcal{I}(t+1)}\} \\
(\Diamond^- A)^{\mathcal{I}(t)} &= \{\langle o, d\rangle \in (\top_A)^{\mathcal{I}(t)} \mid \exists v < t.\langle o, d\rangle \in A^{\mathcal{I}(v)}\} \\
(\ominus A)^{\mathcal{I}(t)} &= \{\langle o, d\rangle \in (\top_A)^{\mathcal{I}(t)} \mid \langle o, d\rangle \in A^{\mathcal{I}(t-1)}\}
\end{aligned}
$$

Fig. 1. Syntax and semantics of $\mathcal{DLR}_{\mathcal{US}}$; o denote objects, d domain values, $v, w, t \in \mathcal{T}_p$.

can be used with relationships, entity types, and attributes. The syntax and semantics are included in Fig. 1. In short, as usual for DLs, there are concepts C (declared from atomic ones, CN), n-ary roles R (relationships, with $n \geq 2$, RN), binary attributes A between a class and a datatype, and DL role components (U, of which F denotes a role component in an attribute, $F \subseteq U$, and $F = \{\texttt{From}, \texttt{To}\}$). The selection expression $U_i/n : C$ denotes an n-ary relation whose i-th argument ($i \leq n$) is of type C and $[U_j]R$ denotes the j-th argument ($j \leq n$)—i.e., a DL role component, alike a projection over the role—in role R (we omit subscripts i and j if it is clear from the context). $\mathcal{U}$ntil and $\mathcal{S}$ince together with $\bot$ and $\top$ suffice to define the relevant temporal operators: $\Diamond^+$ (some time in the future) as $\Diamond^+ C \equiv \top\, \mathcal{U}\, C$, $\oplus$ (at the next moment) as $\oplus\, C \equiv \bot\, \mathcal{U}\, C$, and likewise for their past counterparts. Analogously, we have $\Box^+$ (always in the future) and $\Box^-$ (always in the past) are the duals of $\Diamond^+$ and $\Diamond^-$. The operators $\Diamond^*$(at some moment) and its dual $\Box^*$(at all moments) are defined as $\Diamond^* C \equiv C \sqcup \Diamond^+ C \sqcup \Diamond^- C$ and $\Box^* C \equiv C \sqcap \Box^+ C \sqcap \Box^- C$, respectively.

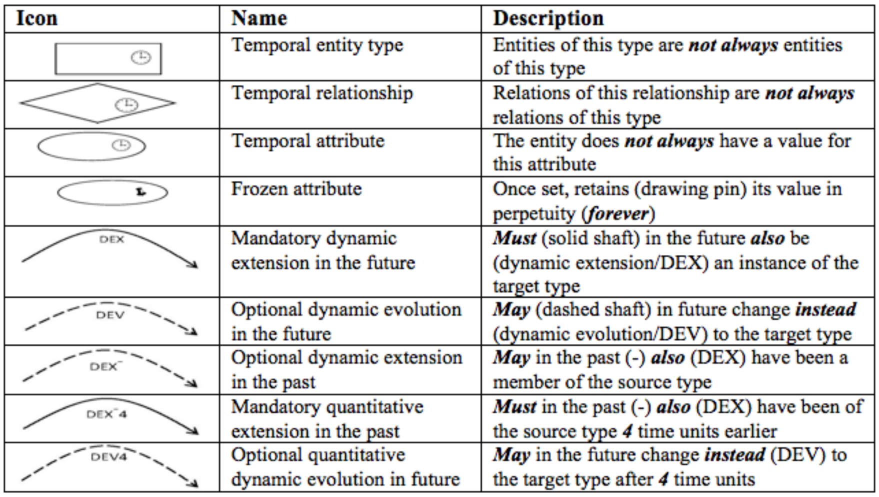
The model-theoretic semantics of $\mathcal{DLR_{US}}$ assumes a linear flow of time $\mathcal{T} = \langle \mathcal{T}_p, < \rangle$, where $\mathcal{T}_p$ is a set of countably infinite time points (chronons) and $<$ is isomorphic to the usual ordering on the integers. The language of $\mathcal{DLR_{US}}$ is interpreted in temporal models over $\mathcal{T}_p$, which are triples in the form $\mathcal{I} = \langle \mathcal{T}_p, \Delta^{\mathcal{I}}, \cdot^{\mathcal{I}(t)} \rangle$, where $\Delta^{\mathcal{I}}$ is the union of two non empty disjoint sets, the *domain of objects*, $\Delta^{\mathcal{I}}_O$, and *domain of values*, $\Delta^{\mathcal{I}}_D$, and $\cdot^{\mathcal{I}(t)}$ the interpretation function such that, for every $t \in \mathcal{T}_p$, every class C, and every n-ary relation R, we have $C^{\mathcal{I}(t)} \subseteq \Delta^{\mathcal{I}}_O$ and $R^{\mathcal{I}(t)} \subseteq (\Delta^{\mathcal{I}}_O)^n$; also, $(u, v) = \{w \in \mathcal{T}_p \mid u < w < v\}$. A *knowledge base* is a finite set Σ of $\mathcal{DLR_{US}}$ axioms of the form $C_1 \sqsubseteq C_2$ and $R_1 \sqsubseteq R_2$, and with R_1 and R_2 being relations of the same arity. An interpretation $\mathcal{I}$ satisfies $C_1 \sqsubseteq C_2$ ($R_1 \sqsubseteq R_2$) if and only if the interpretation of C_1 (R_1) is included in the interpretation of C_2 (R_2) at all time, i.e. $C_1^{\mathcal{I}(t)} \subseteq C_2^{\mathcal{I}(t)}$ ($R_1^{\mathcal{I}(t)} \subseteq R_2^{\mathcal{I}(t)}$), for all $t \in \mathcal{T}_p$.

This enables one to capture not only temporal entity types, relationships, and attributes, but also transition constraints for them. One can use either the $\mathcal{DLR_{US}}$ semantics notation directly, or its DL notation. For instance, the axiom $o \in Person^{\mathcal{I}(t)} \rightarrow \forall t'.o \in C^{\mathcal{I}(t')}$ (with $t, t' \in \mathcal{T}_p$) states that an object o is a member of the temporal interpretation (the "$\mathcal{I}(t)$") of the concept $Person$ at time t, and if that holds, then (the "$\rightarrow$") for all times t' in the set of time points $\mathcal{T}_p$, object o is still a member of $Person$; i..e, it holds at all time points in the past, present, and in the future. In $\mathcal{DLR_{US}}$ notation, this is represented as $\mathsf{Person} \sqsubseteq \Box^* \mathsf{Person}$. In contrast, $o \in Student^{\mathcal{I}(t)} \rightarrow \exists t' \neq t.o \notin Student^{\mathcal{I}(t')}$ states there is a time t' that is different from time t where an object is not a student (whereas at time t it was, is, or will be). This is captured in $\mathcal{DLR_{US}}$ as $\mathsf{Student} \sqsubseteq \Diamond^* \neg \mathsf{Student}$.

The core transition constraints are *dynamic extension* (Dex) and *dynamic evolution* (Dev). In an extension, the entity is *also* an instance of the other entity type whereas with evolution, the entity *ceases* to be an instance of the source entity type. An example of extension is $\mathsf{Employee} \sqcap \neg \mathsf{Manager} \sqcap \oplus \mathsf{Manager}$, and of evolution is $\mathsf{Caterpillar} \sqcap \neg \mathsf{Butterfly} \sqcap \oplus (\neg \mathsf{Caterpillar} \sqcap \mathsf{Butterfly})$. We use shorthand notation for these constraints, as in [2]: $\textsc{Dex}_{\mathsf{Employee},\mathsf{Manager}}$ and $\textsc{Dev}_{\mathsf{Caterpillar},\mathsf{Butterfly}}$, respectively.

2.2 ER_{VT}, EER^{++}_{VT}, and further extensions to TREND

The basic graphical and a textual version of ER_{VT} was introduced with $\mathcal{DLR_{US}}$ as its logic-based reconstruction [1] and fully described as a temporal conceptual modelling language in [2]. ER_{VT} focused on temporalising classes, but $\mathcal{DLR_{US}}$ is expressive enough to allow capturing temporal relationships and attributes, hence this was added by [14] and [15], respectively, and quantitative transition constraints, resulting EER^{++}_{VT}. The graphical notation, like with other temporal conceptual data modelling languages (e.g., [7, 11, 10, 16, 17, 19]), was ad hoc. This was investigated systematically by [21], with the relevant outcome that clocks



Icon	Name	Description
	Temporal entity type	Entities of this type are ***not always*** entities of this type
	Temporal relationship	Relations of this relationship are ***not always*** relations of this type
	Temporal attribute	The entity does ***not always*** have a value for this attribute
	Frozen attribute	Once set, retains (drawing pin) its value in perpetuity (***forever***)
DEX	Mandatory dynamic extension in the future	***Must*** (solid shaft) in the future ***also*** be (dynamic extension/DEX) an instance of the target type
DEV	Optional dynamic evolution in the future	***May*** (dashed shaft) in future change ***instead*** (dynamic evolution/DEV) to the target type
DEX⁻	Optional dynamic extension in the past	***May*** in the past (-) ***also*** (DEX) have been a member of the source type
DEX⁻4	Mandatory quantitative extension in the past	***Must*** in the past (-) ***also*** (DEX) have been of the source type ***4*** time units earlier
DEV4	Optional quantitative dynamic evolution in future	***May*** in the future change ***instead*** (DEV) to the target type after ***4*** time units

Fig. 2. Selection of the notation of the TREND diagram language.

on temporal elements were preferred over any other icon and over ER_{VT}'s S and T, and arrows labeled with text for the transition constraints (Dev and Dex) were preferred over the icons tested.

In preparing the questions for the evaluation, especially in finding examples and the natural language generation (NLG) part for the pseudo-natural language sentences, it came afore that *mandatory* transition constraints are likely to be more interesting for conceptual modelling than optional ones. All prior versions did not address this distinction, so we devised our own notation for it, in line with ERD notation practices: maintaining the arrow notation, where a dashed shaft denotes an optional transition and a solid shaft denotes a mandatory transition. It appeared than none of the previous works had a sample diagram with quantitative transition constraints, so a notation was devised for that. To 'unclutter' the textual adornments, only Dev and Dex are used cf. EER_{VT}^{++}'s RDex and ADex etc for the relationship and attribute transitions, for it can be easily deduced from the diagram (which elements are linked). A summary of the notation for temporal elements is listed in Fig. 2, with the other constraints following the same principles. Given that the primitives for the diagrammatic language are different from ER_{VT} and EER_{VT}^{++}, we refer to this language as TREND.

An example of such a TREND diagram is shown in Fig. 3. Office is a temporal attribute, for with flex-work, employees may not always have an office. The mandatory transition Dex^{-} indicates that a manager must have been working for the company as a regular employee before being promoted to manager, and thus that the transition from employee to manager happened in the past. Not all employees will be promoted to manager, hence, the optional Dex from employee to manager. Likewise, the transition from work to manage is optional.

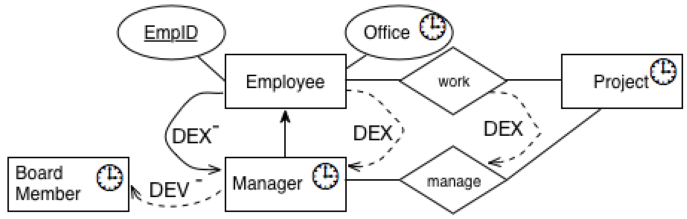


Fig. 3. Example of a temporally extended ER diagram in TREND notation.

2.3 Verbalising temporal conceptual models

Verbalising atemporal conceptual data models is well established for the Object-Role Modeling (ORM) language [8, 12], SBVR [18], and to some extent also for UML class diagrams [5]. These approaches are based on *templates*, where the natural language rendering of the constraint is the 'fixed' part of the sentence that then takes the vocabulary from the model with the constraints represented for it. A mandatory participation of an entity type in a relationship has a template like "*Each* <class1> <relationship1> *at least one* <class2>". Then if, say, <class1> = Professor, <relationship1> = teaches, and <class2> = Course in some conceptual model, it will generate the sentence *Each Professor teaches at least one Course*. The sentence planning stage of NLG [20] deals with which words to choose. For instance, the mandatory constraint also can be verbalised as "*Each* <class1> *must* <relationship1> *at least one* <class2>" to emphasise mandatory participation. Just like for atemporal constraints, it is possible to verbalise the temporal constraints and likewise decisions have to be taken on word choice. For instance, for a mandatory transition in the future, the 'nicer sounding' auxiliary verb "*will*" could be used, or a more strict auxiliary verb with a reference to the future, such as "*must be ... a later point in time*".

This has been investigated elsewhere [13], which we summarise here. For each of the relatively more interesting constraints (34 in total), 1-7 templates were designed and evaluated by three experts in temporal logic on whether each sentence captures the semantics adequately and which of the sentences were preferred. One of those questions is included in Fig. 4 for illustration. Observe here that with respect to the logic counterpart, often there is no literal 1:1 mapping between the axiom and the natural language sentences, but instead a 'free' rendering in natural language. For instance, consider the fairytale country where each non-tenured professor eventually will become a tenured professor, which can be formalised in $\mathcal{DLR}_{\mathcal{US}}$ as $\mathsf{NTProf} \sqsubseteq \Diamond^{+}\textsc{Dev}_{\mathsf{NTProf},\mathsf{TProf}}$, but one would not want to read *Each NTProf is a subclass of some time in the future evolves from NTProf to TProf*. Instead, a sentence like *Each NTProf must evolve to TProf, ceasing to be NTProf* sounds more natural. The outcome of this evaluation were the preferred sentences by majority voting, largely having chosen for the more natural-sounding templates. These selected sentences were used in the experiment that we will describe in Section 3.

(DEVM$^-$) Mandatory dynamic evolution, past: $o \in \text{DEVM}^{-\mathcal{I}(t)}_{C_1,C_2} \to (o \in \mathtt{C_1}^{\mathcal{I}(t)} \to \exists t' < t.o \in \text{DEV}^{\mathcal{I}(t')}_{C_1,C_2})$. For instance, Butterfly and the Caterpillar it used to be.
a. *Each ..$\mathtt{C_1}$.. must have been a(n) ..$\mathtt{C_2}$.. , but is not a(n) ..$\mathtt{C_2}$.. anymore.*
b. *Each ..$\mathtt{C_1}$.. was a(n) ..$\mathtt{C_2}$.. before, but is not a(n) ..$\mathtt{C_2}$.. now.*
c. *If ..$\mathtt{C_1}$.. , then ..$\mathtt{C_1}$.. was a(n) ..$\mathtt{C_2}$.. before, but is not a(n) ..$\mathtt{C_2}$.. anymore.*

Fig. 4. Verbalisation question for DEVM$^-$ (mandatory dynamic evolution in the past) with three templates to choose from. The experts preferred option b.

3 Evaluation of Temporal CDMLs

The aim of the experimental evaluation is to find out which mode of representation 'regular modellers' prefer regarding temporal entities and constraints in temporal conceptual modelling languages. Regular modellers refers to the typical computer scientist who is conversant in conceptual modelling and has a basic understanding of logic. Because theoretical computer science and logic is not popular and the results on graphical notations not encouraging, the hypothesis to test is: *The natural language rendering of the temporal aspects is the preferred mode of representation among modellers.* We will test this by means of a questionnaire with a selection of elements and constraints that are represented in five different modes among which the participants have to choose, an extra question on whether they understand some of the representations, and auxiliary questions (such as their mother tongue).

3.1 Materials and Methods

Methods The method followed a standard procedure for in-person questionnaires. In short, after purposive recruiting—honours or masters students who had attended either the Ontology Engineering or Logics for AI module—participants were informed about the aim of the experiment and given the consent form, and time to read the task and the provided background information on the notations. This was followed by about an hour in which to complete the questionnaire at their own pace. They did so in the same venue, with a researcher present at all times to answer any questions and to ensure that choices were given serious attention. All subjects volunteered for this experiment and were offered a small monetary incentive for participation.

After the experiment, submitted spreadsheets were combined with the typed-up paper-based data. Both researchers independently assessed the interpretations submitted for the $\mathcal{DLR}_{\mathcal{US}}$, coding-style, and TREND questions. Excel was used to analyse the data and chart results.

Materials The materials consisted of a Consent Form to sign, a softcopy and printed copy of the questionnaire, and a spreadsheet for entering answers.

The questionnaire had some written explanation on the logic and diagram notations, which was kept to a minimum as they had seen similar logic notation and ER diagrams before, and because models should be sufficiently intuitive not to require lengthy explanations. Then 33 elements and constraints were presented where they had to indicate notation preferences. The 33 were ordered thus: 6 basic examples distinguishing snapshot from temporal classes, relationships and attributes; all 8 possible dynamic constraints for classes (DEV/DEX x optional/mandatory x past/future); 1 persistent class example (PDEX); all 8 quantitative dynamic constraints for classes; all 8 dynamic constraints for relationships; and 2 dynamic constraints for attributes (frozen, and quantitative evolution). Instructions required entering a value from 5 (most preferred) down to 1 (least preferred), or 0 if they disliked a notation's representation of a constraint. One of the questions is shown in Fig 5.

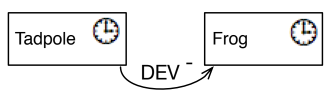
(DEVM$^-$) Mandatory dynamic evolution, past: For instance, Frog and the Tadpole it used to be.

a. $o \in Frog^{\mathcal{I}(t)} \rightarrow \exists t' < t.o \in \textsc{Dev}^{\mathcal{I}(t')}_{Tadpole,Frog}$

b. $\mathsf{Frog} \sqsubseteq \Diamond^- \textsc{Dev}_{\mathsf{Tadpole,Frog}}$

c. `DevM⁻(Tadpole,Frog)`

d. Diagram:



e. *Each* Frog *was a(n)* Tadpole *before, but is not a(n)* Tadpole *now*.

Fig. 5. Question for DEVM$^-$, mandatory dynamic evolution in the past.

To ascertain how well they understood the notations, a question asked them to interpret 3 examples: one comprising 9 $\mathcal{DLR}_{\mathcal{US}}$ axioms, one comprising 8 coding-style statements, and one TREND diagram with 5 temporal aspects. In the final section of the questionnaire they indicated if English was their first (home) language, if they were 4th year or Masters students, which courses they had studied (ontologies, logic, both) and which notation they would prefer for modelling rather than understanding/reading temporal constraints. The questionnaire ended with an invitation to give any other comments. The questionnaire and data are available at `http://www.meteck.org/files/ER17suppl.zip`.

3.2 Results and discussion

We first describe some pertinent details about the participants, which is followed by the quantitative results, the participants' comments, and finally the assessment on the participants' understanding of the models.

Participants Fifteen students participated in the experiment, of which 10 were 4th year students and 5 Masters students. Most participants took a full hour to complete the questionnaire, with three finishing early and two running out of time due to other commitments and failing to finish the last section or two. Everyone completed the first section on choosing between the alternative representations and all had clearly devoted considerable time to the 33 examples.

Quantitative results Responses were analysed based on 3 metrics: responses calibrated to a standard competition ranking on a scale of 1-5, a favourite (highest ranked), and a dislike (0). Aggregating over the participants, the diagrams were the favourite for 10 constraints and the natural language sentence for 25 (there being two 'ties'); no other notation was chosen as favourite for any constraint. The overall rating totals are summarised in Table 1. Favourites and dislikes aggregated by group of constraints are shown in Fig. 6.

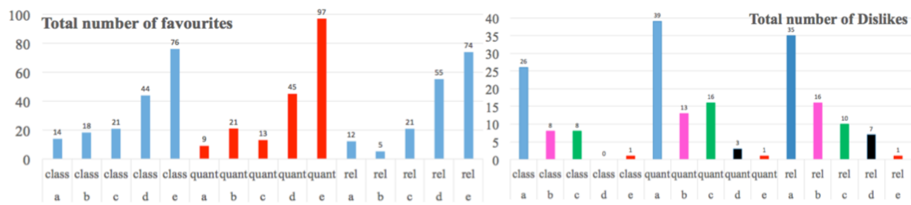


Fig. 6. The top-rated representation modes and 'dislike' ratings.

Zooming into details, a less straightforward picture of 'general winner' emerges; the two clearest of these results are shown Fig. 7: the 'simple' constraints of temporal elements (entity types, relationships, and attributes) were best represented in the diagram with the clock rather than as a sentence (option d; 57 favourites vs 28, and average rank 4.1 vs 3.5, respectively), whereas with transition (dynamic) constraints, the differences between diagrams and natural language were much smaller in favour of the sentence. For transition constraints for relationships on the future, the difference was smallest, with 26 vs 33 as favourite (average 3.9 vs 4.3), in favour of natural language sentences. The greatest difference was for class transitions on the past (19 vs 42 as favourite in favour

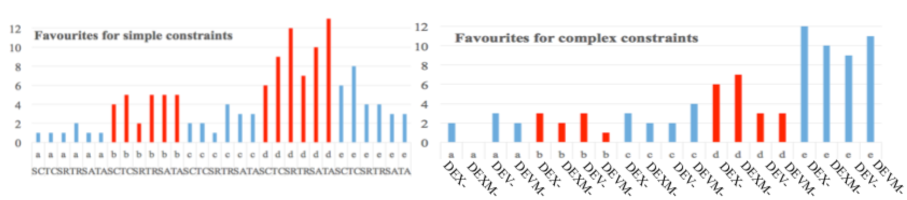


Fig. 7. Top choices by category of constraints, with a category A the 'simple' constraints—e.g., "C is a temporal class"—and category C one of the 'complex' set of constraints, being the transition constraints for classes in the past.

Table 1. Summary of the preference data. Percentages include 'tie' 1st/2nd choice, and 'tie' last choice.

	Rank Total	Average	Favourite Total	Dislikes	% Top 2	% Last
Formal semantics	785	1.6	49	136	15%	70%
$\mathcal{DLR}_{\mathcal{US}}$	1355	2.7	78	42	27%	16%
Coding-style	1406	2.8	77	45	31%	25%
TREND	1984	4.0	223	14	76%	7%
Natural language	2113	4.3	299	8	81%	3%

of English), which was also their first encounter with arrows for transitions that constrain the past. For the last examples of constraints on the past, the difference shrank to 29 vs 41 as favourite in favour of English, indicating that once familiar with those arrows, several participants favoured these as 'tie' best with English. Statistically, with a Kruskal-Wallis due to non-normal distribution of the data, the difference between graphical and natural language mode is significant for both the 'simple' (p=0.0003) and 'complex' (p=0.0002) constraints.

There is clear general *decrease* in preference from 'simple' temporal constraints in the DL representation in favour of natural language for the more complex (transition) constraints; that is, a natural language sentences such as "Person married-to Person *may be followed by* Person divorced-from Person, *ending* Person married-to Person." is deemed easier to understand than $\langle o, o' \rangle \in marriedTo^{\mathcal{I}(t)} \rightarrow \exists t' > t. \langle o, o' \rangle \in divorcedFrom^{\mathcal{I}(t')} \wedge \langle o, o' \rangle \notin marriedTo^{\mathcal{I}(t')}$ or $\Diamond^{+}\mathrm{R}\textsc{Dev}_{\mathsf{marriedTo},\mathsf{divorcedFrom}}$. However, $\mathsf{marriedTo} \sqsubseteq \Diamond^{*}\neg\mathsf{marriedTo}$ (a temporal relationship) was deemed easier to understand than the somewhat cumbersome sentence "*The objects participating in a fact in* Person married to Person *do* not *relate through* married-to *at some time*" (rank totals 54 and 49, respectively).

Preferences for class transitions were largely unaffected by the introduction of quantitative constraints (total rank changed by between 0.1% and 5% for the 5 notations). The distinction between dynamic extension (DEX) and dynamic evolution (DEV) similarly had negligible impact on preferences (total rank changes between 0.1% and 1.5%). This was also true for mandatory vs optional constraints (changes between 0.06% and 6%), and past vs future constraints(changes between 0.2% and 2%).

Respondent comments General comments made more than once were that the logic is "fine" for "simple" concepts but not "complex" examples. This is in agreement with the quantitative results (see Fig. 7). Also, it was noted that diagrams were best sometimes and natural language best at other times, as also indicated by the quantitative data. Some comments on the English verbalisation (option (e)) vs TREND (option (d)) are:

– "I would prefer D for an overview of information, but like E for clearing up any uncertainty/learning the notation of D";
– "D=5; E=5; although English sentences may be complicated";

– “it is quicker to interpret option (d) than most of the other options. Option (e) requires a lot of reading”;

Feedback on individual examples included:

– ”The +2, -1 are great ways to illustrate future and past”;
– “the use of the clock in the diagrams for dynamic constraints is favoured”;
– “ (English) “since” confusing, I am not sure of meaning” (by an English home language speaker);
– “Perhaps Dev+6 so syntax matches the ”-” ”;
– “option (c) and (d) are easier to write, however they require more interpretation they do not encode all the information”;
– “(c) and (b) are prefered when having to write the relationship. Option (e) and (a) are prefered when reading.”;
– “(c) would require memorization of the various “functions” such as “Sa” ”;
– “Since the source of the Dex is (clock) then the (clock) on the dest(ination) feels redundant”, which indeed are redundant, because it can be inferred thanks to the logical implications proven in [2, 14];
– “it is not clear why (DEV-) is not the same (as Dev) ... Can this not be achieved with Dev”, indicating a lack of understanding, which is also evident from the questions on testing their understanding.
– “(c) has a favourable score because its function name (Freez) is clear”;

Students twice noted that their preferences were changing as they progressed through the questionnaire due to repeated exposure improving their understanding of the new temporal concepts they were exposed to. One participant stated this for the diagrams only and another said this applied to (b), (c) and (d).

Interpretations and testing understanding outside the context of individual constraints This was shown to be the hardest task. One student did not interpret any of the examples, and several tackled only some parts of some of the three notations, possibly through lack of time. Since this data is thus incomplete, we can state only that at least 3 students understood at least one notation well and at least 2 all notations. It was clear that precise and complete natural language description does not come naturally even to Computer Science postgraduates, as no student gave all and only the expected interpretation; they were frequently imprecise and generally failed to convey all the semantics.

The authors were like-minded in their evaluation of students’ understanding. The values were calibrated on marks given for each constraint in the model and number of constraints in the model so as to compare the three fairly. The DL notation received a mark of 2.3, coding-style notation 2.7, and diagram notation 3.8. Thus, they understood the diagram best of the three notations.

The main source of fundamental errors were with the transition constraints—transition in the wrong direction and not distinguishing Dev from Dex—and with describing the distinction of mandatory versus optional constraints. In particular, $\mathsf{C} \sqsubseteq \Diamond^{+}\textsc{Dev}_{\mathsf{C,B}}$ and $\Diamond^{-}\textsc{Dev}_{\mathsf{C,B}}$ and similar were problematic[1]. Per-

[1] “C *must* evolve into a B some time in the future” and “C evolved into a B in the past”, with both ceasing to be a C, respectively.

haps surprisingly, this question was answered somewhat better for option c (the coding-style notation) than either the DL notation or the TREND diagram. Some examples of imprecise English encountered were:

- "can evolve to" and "evolved from" without stating ceasing to be the original;
- "used to be and continues to be" instead of "must previously have been";
- "were not" instead of "may not have been";
- "is", "gets", "will" or "can" instead of "may" or "must"
- "immutable", which has a specific meaning that at least the ontology engineering students had been exposed to, instead of "snapshot"
- "can have" (attribute), without adding "at some time and not at other times"

That said, also three temporal logic experts did mostly not agree unanimously on a preferred natural language rendering of the semantics [13], so perhaps the general discourse about temporal constraints is not well developed.

The participants expect they prefer creating models in TREND most ($n = 7$), then in natural language ($n = 5$), and then in DL or coding-style notation ($n = 1$ each). The preference for the former may be explained by the fact that they seem to understand it best. That it may not be the natural language sentences as most preferred for modelling is also substantiated by the comments to the first part of the questionnaire (see previous section).

4 Discussion

To the best of our knowledge, this is the first attempt to evaluate different modes of representing temporal information to figure out what may be the 'best' way. Extant proposals for temporal conceptual modelling languages focus on inclusion of features rather than fitness for purpose, such as by [2, 7, 9, 10, 14–16, 19] and on formal foundations [2, 7, 15, 16]. However, they will receive broader uptake only if they are understandable and usable for modelling. Gianni et al. [9] do propose a multi-modal interface for ORM diagrams adorned with temporal information and verbalisations, but the verbalisations are for individuals only, rather than the information represented in the model, and also this proposal was not evaluated with modellers. This paper sought to fill this gap, with the hypothesis that the verbalisations would be preferred. The results show that verbalisations are preferred mainly for 'complex' constraints, but it is not a 'clear winner' in all cases. This may suggest that there is a need for a *multimodal interface*, alike in NORMA [8], that allows one to switch back and forth between, at least, the diagrams and natural language sentences.

Also, the (pseudo-)natural language renderings may be better for communication, especially with domain experts, but data suggests the diagrammatic representation is likely to be favoured most during the authoring stage of the model. The models were still small, however, so caution has to be exercised extrapolating from these results and it deserves further attention. We did not test the participants' understanding of the natural language sentences because we could not devise a satisfactory way: writing the sentences in different English seemed superfluous and, e.g., drawing the semantics may not test their understanding of the English but instead their abilities in the other representation model (be this TREND or the semantics with timelines).

One could perhaps argue that a particular verbalisation pattern was not optimal, or some graphical notation was not, and that others would have to be tested with. However, both the graphical notation and sentences have been evaluated with modellers and experts and found preferable [13, 21], mitigating this argument. The (previously untested) graphical extension for quantitative transition constraints were deemed sufficiently clear by the participants. That said, these are currently limited when compared to natural language, in that they do not indicate if the given time units are a minimum, maximum or exact requirement, nor whether the previous state had to be retained continuously for that length of time or simply had to be true at some point that many time units ago. It would be useful to look into, especially since they are also easy to implement in temporal and atemporal databases with straight-forward triggers to provide easy integrity constraints.

Finally, the 33 constraints evaluated were a subset of the possible temporal constraints for conceptual models, and perhaps these are still too many. It may be of interest to constrain it further to those useful for temporal Ontology-Based Data Access only [3, 4], for those temporal logics are fragments of $\mathcal{DLR}_{\mathcal{US}}$ and thus would constitute fragments of TREND as well.

5 Conclusion

In evaluating the mode of representing temporal constraints, the experimental evaluation made clear that there was a preference for diagrams and natural language, and a dislike for the formal semantics and coding-style notations. Diagrams were preferred for simple constraints, but transition constraints were best verbalised in natural language. The results demonstrated that a multi-modal modelling tool will be needed for the data analysis stage to be effective, due to the differing preferences and abilities of understanding and modelling temporal constraints. It also showed that transition constraints in the past were hardest to understand, but there was at least an increase observed in grasping the new temporal notions as the participants went along in the questionnaire.

Both the graphical TREND language proposed in this paper, and the natural language sentence are, with the current state of the art, optimal. This may facilitate broader uptake of temporal conceptual modelling and, with that, larger experiments may be conducted.

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