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Natural language template selection for temporal constraints

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Abstract. Representing temporal knowledge and information in temporal logics for ontologies and conceptual data models has faced issues due to inaccessibility of the underlying logic and limited intuitiveness of diagrammatic extensions to the modelling languages. We aim to address this by designing controlled natural language templates for generating sentences that verbalise in English the temporal constraints defined in a temporal logic. We devised 101 templates, which were evaluated by experts in temporal logics and by novice temporal modellers on semantic adequacy and preference. There was only 12% unanimity among the experts, and 89% by majority voting. The novice temporal modellers were much more lenient in judgment on whether the templates captured the semantics adequately. Instead of a direct 1:1 mapping between an axiom's components and the natural language rendering, the more natural-sounding sentences were preferred, therewith linking an axiom type as a whole to a template.

Keywords. Temporal logics, Temporal ontologies, Controlled Natural Language, Temporal conceptual models

1. Introduction

Time is pervasive in communication and relevant for almost any subject domain of interest. For instance, a business rule that states that any manager of a company must already be an employee of that company, biological knowledge that each butterfly used to be a caterpillar, and census information stating that a divorce can only occur if there was a marriage before. Several options are at one's disposal to represent such temporal information, be this for ontology development or information system design. For ontology, the focus has been on fundamental representation choices such as 3-dimensional objects with time vs 4-dimensional entities. For representation languages, the emphasis is on features to represent more or less temporal constraints and automated reasoning over it, which can be grouped into ontology languages [2,3,9,22,24] and popular conceptual data modelling languages, such as the UML Class Diagram, Entity-Relationship, and Object-Role Modeling languages [2,4,10,12,14,17,18,21,23]. These works concern steps *before* involving modellers and domain experts. However, given that mod-

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ellers have great difficulty with using such temporal representation languages [15], then these advances are unlikely to be used. The two principal approaches to address this problem is to use a graphical notation or natural language sentences. To illustrate: a sample model in the TREND language [15] is shown in Figure 1-A. This is not immediately clear to anyone unless trained in the semantics of the temporal adornments (such as "DEX"; explained further below) [26]. Its logic-based reconstruction in the $\mathcal{DLR}_{\mathcal{US}}$ Description Logic (DL) [2], shown in Figure 1-B, is typically even less accessible to modellers. The remaining option is a natural language rendering, which is what we focus on in this paper.

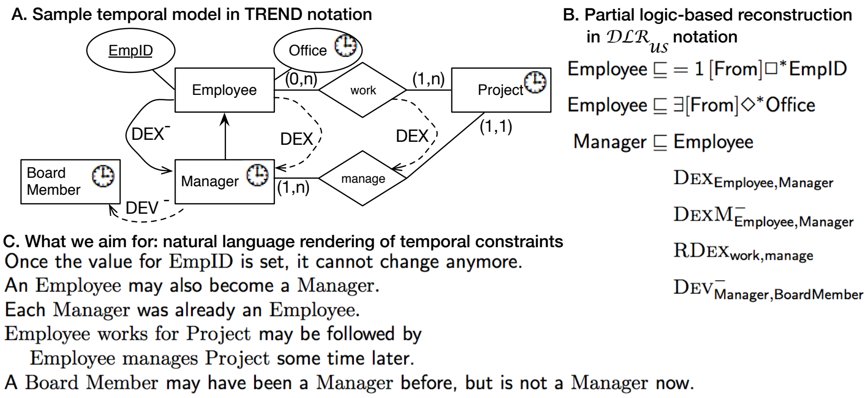

Figure 1. Example of a temporally extended ER diagram in TREND notation (A), with a subset of the corresponding $\mathcal{DLR}_{\mathcal{US}}$ axioms as logic-based reconstruction (B), and the verbalised temporal constraints of the model that resulted from this research (C).

The natural language option means to *verbalise* structured input or use Natural Language Generation (NLG). Atemporal verbalisation has been successful for both conceptual data models [6,13] and ontologies [1,5,7,25,27]; for instance, for the axiom $Manager \sqsubseteq Employee$ and a template Each `[subclass]` is a(n) `[superclass]` for simple subsumption, the verbalisation will generate Each Manager is an Employee. It is an obvious step to seek to use such a template-based approach also for the temporal constraints. Existing works only generate text from temporal data rather than information and knowledge; e.g., sample data for ORM diagrams [8], time series data [19], and querying temporal databases [20].

The aim is thus to find out what is the best way of verbalising the temporal constraints and answer *1) Does each proposed natural language sentence template capture the semantics of the temporal constraint adequately?* and *2) Which sentence among the options is preferred?* We used the semantics of the Description logic (DL) $\mathcal{DLR}_{\mathcal{US}}$ as structured information and knowledge representation, as it currently has the most comprehensive set of temporal constraints and it easily can be mapped to one's preferred logic or modelling language. We discuss the template development to verbalise the 34 temporal constraints. One or more templates were devised for each temporal constraint. The templates were evaluated by three temporal logic experts and five 'mixed experts' (experts in modelling, logic, or NLG, but not temporal). There was little unanimous agreement on template preferences among the experts. The 'mixed experts' judged many more sentences to be correct than the experts, yet there was even less agreement among the participants. Overall, 26 of the 34 constraints did result in preferred sentences, and the remaining 8 sentences were updated by taking into account the written feedback. These final templates map an axiom *type* as a whole to the template as a whole, rather than by consituent.

In the remainder of the paper, we first describe preliminaries in Section 2. Possible templates with word choices are discussed in Section 3. The evaluation is presented in Section 4. We discuss and conclude in Sections 5 and 6.

2. Preliminaries: language and time

Linguistically, there are two principal ways to refer to temporal points and intervals in a sentence: using verb tenses, such as 'have eaten' and 'will eat', or prepositions and adjuncts, such as 'before' and 'some time later', or both to stress the time dimension and relation between events at points or during intervals, like 'have eaten before [some other event]'. The major languages in the world have between zero (e.g., Chinese) and three (e.g., Romance languages) tenses, with variations using compound forms with auxiliary verbs.

Within commonly used information and knowledge representation that we restrict ourselves to here, not all verb tenses and adjuncts will be needed, because it is a restricted application domain concerning tracking the evolution of objects, relations, and, possibly, attributes over time, not, say, events that did not happen in the past ('could/would have done'). The core relevant temporal aspects are depicted in Figure 2. First, we have "snapshot (rigid)", which is essentially atemporal, or 'at all times' for the duration of the entity's existence. The "temporal options (antirigid)" denotes that an entity is an instance of a type at some time, but not at all times, which is indicated with a non-solid line. There are four core *transition constraints*: "extension" means that at some time an entity *also* instantiates another type and "evolution" means that the entity instantiates one type after another. These constraints may be quantitative (a fixed amount of time), and are either optional (universally quantified) or mandatory (existentially

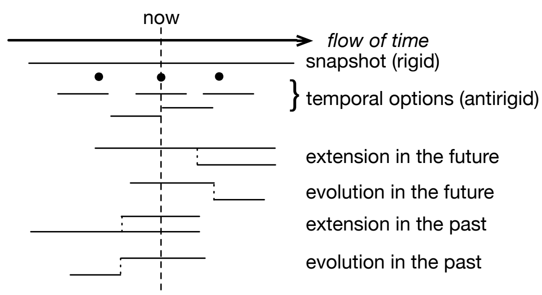

Figure 2. Flow of (linear) time with the main options included in temporal conceptual data models (based on [4]). The horizontal lines depict an object's life as a member of an entity type, a tuple (relation) as a member of a relationship, or an attribute.

quantified). As they can be declared for entity types, relationships, and attributes, this amounts to 48 possible temporal constraints. These changes can be covered by just a few verb tenses. Mainly, they constitute choices on the future single vs future continuous (respectively, the past).

Some of the temporal constraints are computationally more interesting than others. In particular, constraints on the future are trivially satisfied and thus cannot be checked, whereas constraints about the past—which must be present in a prior state of the data or knowledge base—and quantitative constraints can be checked. Also, it was difficult to devise good examples for some of the attribute constraints, and they are not used often in ontologies anyway. Taking this into account, we reduced it to 34 axiom types out of the 48. Further, it makes sense to include domain and range when verbalising a relationship of a conceptual model. This context is necessary because a conceptual model may reuse the name of an attribute or relationship, but never with the same entity types. This is in contrast with relations in ontologies that do not require a domain and range restriction, and as also reflected in $\mathcal{DLR}_{\mathcal{US}}$. We have made templates for both scenarios, but it appeared that the templates for the relations (OWL object properties, DL roles) in ontologies always resulted in a subset of those of conceptual models such that it required one conversion rule (illustrated below). Therefore, we opt here for the more comprehensive ones with domain and range.

3. Specific template options

We created 1-7 candidate templates for each constraint, which would verbalise the constraints more or less precisely or colloquially. For each list of options for a constraint, the first one is most literal with respect to the formal semantics, and the other ones are more or less precise rewordings that sound less 'clunky' and artificial. Regarding the formal counterpart, we rely on the formal foundations of TREND, being the semantics of $\mathcal{DLR}_{\mathcal{US}}$ [2], so as not to clutter the paper with too much repetition and syntax notation. The semantics here and in the following subsections is based on [4] that was extended with temporal relationships [14], and the additional mandatory constraints are adapted from [4]. Considering the usual model-theoretic semantics, we use a *temporal interpretation* of the signature of a conceptual data model $\mathcal{M}$. This is a structure of the form: $\mathcal{I} = \big((\mathbb{Z}, <), \Delta^{\mathcal{I}}, \{\cdot^{\mathcal{I}(t)} \mid t \in \mathbb{Z}\}\big)$, where $(\mathbb{Z}, <)$ is the set of integers denoting the intended *flow of time*, $\Delta^{\mathcal{I}} \neq \emptyset$ is the *interpretation domain* divided into $\Delta^{\mathcal{I}}_C$ over classes and $\Delta^{\mathcal{I}}_D$ over data types, and $\cdot^{\mathcal{I}(t)}$, for $t \in \mathbb{Z}$, is the *interpretation function* which assigns a set $C^{\mathcal{I}(t)} \subseteq \Delta^{\mathcal{I}}$ to each entity type $C \in \mathcal{C}$, a set $R^{\mathcal{I}(t)}$ of tuples over $\Delta^{\mathcal{I}}_C \times \Delta^{\mathcal{I}}_C$ to each relation $R \in \mathcal{R}$ and a set $A^{\mathcal{I}(t)}$ of tuples over $\Delta^{\mathcal{I}}_C \times \Delta^{\mathcal{I}}_D$ to each attribute $A \in \mathcal{A}$. While $\mathcal{DLR}_{\mathcal{US}}$ permits n-ary relations, we present just the case for binaries. The formalisation of all constraints is available in the supplementary material at `http://www.meteck.org/files/CREOL17suppl.zip`.

3.1. Model elements

The entity types, relationships, and attributes can be divided into *atemporal* ('snapshot') and *temporal* entities, where the former has no explicit specification of time—or: holds globally at all times—and the latter do. A temporal entity type is formalised as $o \in C^{\mathcal{I}(t)} \rightarrow \exists t' \neq t.o \notin C^{\mathcal{I}(t')}$. A template option with a closer 1:1 match between the axiom type with its structure and the natural sentence and, say, the entity type Student would generate If an object is an instance of entity type `Student`, then there is some time where it is not a `Student` or one could paraphrase it as Each `Student` is not a `Student` for some time, among the possible options.

For temporal relationships, with the semantics $r \in R^{\mathcal{I}(t)} \rightarrow \exists t' \neq t.r \notin R^{\mathcal{I}(t')}$, we devised two options that amounted to largely just shuffling around the constituents of the template, with $\mathtt{C_i}$ an entity type and $\mathtt{R_i}$ a relationship:

(a) The objects in the facts in ..$\mathtt{C_1}$.. ..$\mathtt{R_1}$.. ..$\mathtt{C_2}$.. do, at some time, not relate through ..$\mathtt{R_1}$..
(b) The objects participating in a fact in ..$\mathtt{C_1}$.. ..$\mathtt{R_1}$.. ..$\mathtt{C_2}$.. do not relate through ..$\mathtt{R_1}$.. at some time.

Note that for an ontology setting, one can simply drop the $\mathtt{C_1}$ and $\mathtt{C_2}$ variables for the entity types: The objects in ..$\mathtt{R_1}$.. do, at some time, not relate through ..$\mathtt{R_1}$.. .

The semantics of a basic temporal attribute is $o \in C^{\mathcal{I}(t)} \wedge \langle o, d\rangle \in A^{\mathcal{I}(t)} \rightarrow \exists t' \neq t.\langle o, d\rangle \notin A^{\mathcal{I}(t')}$, where the templates assume that any 'has' from the attribute's name is dropped if it is already in the name (e.g., hasColour), or it is substituted with the verb in the attribute's name. For instance, its option (e) with an example about bonus payments would generate a sentence alike An `Employee receives` a `Bonus`, but not always.

3.2. Dynamic constraints

The two basic types of dynamic constraints are extension and evolution (recall Figure 2), where *extension* has the element remain a member of the source class and in an *evolution* it stops being member of the source class once it evolves to the target class. This may be at 'some' time or at a metric (quantitative) time, and it may persist or not. They can be optional or mandatory, i.e., whether some object, relation, or attribute *may* evolve or all objects/relations that instantiate the class/relationship *must* evolve. This can be verbalised more or less harshly, just like with atemporal constraints[2]. That is, for future tense one can use the auxiliary verb 'will' versus the stronger-sounding 'has to' or 'must'. Likewise, for the past there is a similar type of difference between 'was already/before/earlier, but not now' vs. 'must have been'. For instance, mandatory dynamic evolution in the past ($\textsc{DevM}^-$), i.e., $o \in \textsc{DevM}^{-\mathcal{I}(t)}_{C_1,C_2} \rightarrow (o \in \mathtt{C_1}^{\mathcal{I}(t)} \rightarrow \exists t' < t.o \in \textsc{Dev}^{\mathcal{I}(t')}_{C_1,C_2})$ where the semantics of $\textsc{Dev}$ is $o \in \textsc{Dev}^{\mathcal{I}(t)}_{C_1,C_2} \rightarrow (o \in \mathtt{C_1}^{\mathcal{I}(t)} \wedge o \notin \mathtt{C_2}^{\mathcal{I}(t)} \wedge o \in \mathtt{C_2}^{\mathcal{I}(t+1)} \wedge o \notin \mathtt{C_1}^{\mathcal{I}(t+1)})$, with, e.g., Butterfly (to be filled in for $\mathtt{C_2}$ in the template) and the Caterpillar ($\mathtt{C_1}$) it used to be, with the following possible templates:

(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.

Persistence (PDex/PDev) has the change holding at all times in the future, which is built from whatever will be chosen from the possible templates and appended by a phrase like , and this remains so. or , and this remains so indefinitely..

For quantitative extension and evolution, we need a specific number for counting and, implicitly, some time unit to be able to construct, e.g., 'after

[2]e.g., 'each Prof teaches at least one course' vs. 'each Prof must teach at least one course'.

at least 3 years'. The number is denoted with the variable $\mathtt{D}_1$ in the template. For instance, mandatory quantitative extension in future (QEXM), i.e., $o \in \text{QEX}^{\mathcal{I}(t)}_{C_1,C_2} \rightarrow (o \in \mathtt{C_1}^{\mathcal{I}(t)} \rightarrow \exists (t+n) > t.o \in \text{QEX}^{\mathcal{I}(t+n)}_{C_1,C_2})$, e.g., all `Students` (to be slotted in at $\mathtt{C}_1$) have to `Volunteer` ($\mathtt{C}_2$) in the second year ($\mathtt{D}_1$) of their study, with template options:

(a) Each ..C₁.. will also become a(n) ..C₂.. after [at least/at most/exactly] ..D₁.. .
(b) If ..C₁.. for [at least/at most/exactly] ..D₁.. , then ..C₁.. becomes a(n) ..C₂.. as well.

Regarding word choice in template design for relationships, the transition concerns overlapping or successive processes; thus verbs such as 'precede' and 'follows' are applicable. On their own, they do not distinguish between the two cases of whether the relations may co-exist or if one occurs after the other. This can be addressed by disambiguating both cases, or one of the two with the other left implicit. We chose the latter option, and add it to the evolution cases rather than the extension cases, as they are stricter constraints. Likewise, 'sequentially' and 'successively' are roughly synonyms and imply that earlier state has ended, so the only core difference to test is whether that should be made explicit, e.g., with inclusion of terms such as 'ending' or 'terminating', or not. For instance, for mandatory dynamic extension for relationships in the past (RDEXM$^-$), i.e., $\langle o,o'\rangle \in \text{RDEXM}^{-\ \mathcal{I}(t)}_{R_1,R_2} \rightarrow (\langle o,o'\rangle \in \mathtt{R_2}^{\mathcal{I}(t)} \rightarrow \exists t' < t.\langle o,o'\rangle \in \text{RDEX}_{R_1,R_2}{}^{\mathcal{I}(t')})$, where the semantics of 'just' RDEX is $\langle o,o'\rangle \in \text{RDEX}_{R_1,R_2}{}^{\mathcal{I}(t)} \rightarrow (\langle o,o'\rangle \in \mathtt{R_1}^{\mathcal{I}(t)} \rightarrow \exists t' > t.\langle o,o'\rangle \in \mathtt{R_2}^{\mathcal{I}(t')})$, option (a) was Each ..C₁.. ..R₁.. ..C₂.. is preceded by ..C₁.. ..R₂.. ..C₂... For instance, every passenger who boards a flight must have had a check-in process before with its template option (a) then results in a somewhat clunky Each `Passenger boards Flight` is preceded by `Passenger checksIn Flight`. Note that also here it is easy to see how this template can be adapted for ontologies by dropping the $\mathtt{C}_1$ and $\mathtt{C}_2$ variables.

These time markers are more challenging with the more complex constraints. For instance, mandatory dynamic evolution for relationships in the past (RDEVM$^-$), with the typical example that any pair of humans who are `divorced` were `married` before that. The full set of template options to choose from was:

(a) Each ..C₁.. ..R₁.. ..C₂.. is strictly preceded by ..C₁.. ..R₂.. ..C₂.. .
(b) Each ..C₁.. ..R₁.. ..C₂.. is preceded by ..C₁.. ..R₂.. ..C₂.. and they are not in that ..C₁.. ..R₂.. ..C₂.. relation anymore.
(c) If ..C₁.. ..R₁.. ..C₂.. , then it was preceded by ..C₁.. ..R₂.. ..C₂.. and they are not in that ..C₁.. ..R₂.. ..C₂.. relation now.
(d) Each ..C₁.. ..R₁.. ..C₂.. must have been preceded by ..C₁.. ..R₂.. ..C₂.. and they are then not in that ..R₂.. relation anymore.
(e) If ..C₁.. ..R₁.. ..C₂.. , then it must have been preceded by ...C₁.. ..R₂.. ..C₂.. , but ..C₁.. not ..R₂.. ..C₂.. anymore.

Two dynamic attribute constraints were included in the evaluation, which were uncontentious, and therefore they are omitted here due to space limitations.

4. Evaluation

The templates designed for the temporal elements and constraints are evaluated aiming to answer:

1. Does each proposed template for a natural language sentence capture the semantics of the temporal constraint adequately?

2. Which sentence among the options is preferred?

The principal approach is to use a two-pronged survey: a small group of experts in temporal logic, and a 'mixed' group of experts in related relevant fields that is not temporal logic, which includes modellers, NLG experts, and logicians.

4.1. Materials and methods

A survey was designed with the temporal constraints and elements, and 1-7 templates for each. The participants were given a brief written explanation of the logic and how to read a template, an example for each constraint, and the scope of the evaluation. They were instructed to evaluate each template on whether it would capture the meaning adequately, which could be answered with either "yes", "sort of" denoting borderline, or "no", and which of the templates they preferred, if any, among the set of templates for that constraint. They also were allowed to comment on each template option.

The three temporal logic experts are remote colleagues and were recruited by email through purposive sampling. The mixed group also was recruited through purposive sampling, with as prerequisite that they have a good to excellent understanding of modelling, logic, or NLG. No personal information was recorded other than whether they have English as their mother tongue language. The answers were collected in a pre-formatted spreadsheet. A follow-up interview with one expert was also conducted to obtain further qualitative feedback on the choices.

All materials and results are available at `http://www.meteck.org/files/CREOL17suppl.zip`.

4.2. Results and discussion

We present first the results of the experts and then those of the mixed group.

4.2.1. Experts' judgements

An overview of the quantitative results is included in Table 1. 41% of the templates were deemed to properly represent the semantics of the temporal constraint, though only 12 templates received the same score (either all "yes", "sort of", or "no") with most (78) receiving two the same verdicts, reaching 89% then. Four templates of constraints were unanimously preferred: those for Mandatory Quantitative Extension and for Evolution (QexM and QevM) and the two attribute constraints (Freez 'frozen attribute' and AQev 'Quantitative evolution, attribute'). With majority voting, this increased to 13 constraints. This is remarkable, because the experts know each other well and have collaborated. Even the simple constraint of 'temporary class' (Tc) had three different verdicts for its option (b) ..C_1.. is an entity type whose objects are, for some time in their existence, not instances of ..C_1.., as did option (b) of dynamic evolution in the past (Dev$^-$).

Quantitative extension and evolution used the grammatically correct 'for' in the sentence, but this was deemed wrong. Instead, the experts preferred 'since'. This may be due to either the $\mathcal{S}$ince operator in the logic, or it has a stronger sense of time and fewer senses than the multiple-use 'for', or that neither of the experts has English as mother tongue. A follow-up interview on this matter with one of the experts (e3 in the data) revealed that at least for e3 it was not so much

Table 1. Aggregates for experts and the mixed group (rounded) on whether a template captures the semantics adequately; n: number; avg.: average; sd: standard deviation; pct: percent.

	Temporal logics group				**Mixed experts group**				Both			
	n	avg.	sd.	pct.	n	avg	sd.	pct.	n	avg.	sd.	pct.
Yes	125	42	15	41%	324	65	19	64%	449	56	21	56%
Sort of	98	33	16	32%	130	26	19	26%	228	29	18	28%
No	80	27	9	26%	44	9	8	9%	124	16	12	15%
Total	303				498							

about 'for' vs 'since' but the fine-grained distinction between "for an x amount of time since x" (or: holding between x ago and now) vs. "x chronons ago" but it may not hold some time between x and now. On closer inspection, the logic stated the latter, while the former was intended, which is what caused the confusion.

Regarding 'preceded by' and 'followed by' in the templates (recall Section 3.2), there were a few comments such as "*I don't like "followed" that can be understood as "at the next time point"*". Thus, only using strictly/immediately to indicate the next/previous time point and therewith leaving implicit when this may not be the case when it is not stated explicitly was found to be ambiguous. Put differently: an explicit time marker was perceived to be needed also for the 'some time'. We updated the templates accordingly (see online supplementary material).

An important result to note for the preferred templates, is that they do *not* follow the structure of the axiom, regardless whether it would be rendered in the formal semantics or $\mathcal{DLR_{US}}$ syntax. That is, the preferred templates amount to a mapping between an *axiom type* rather than the axiom's *structure*. To illustrate:

- Formal Semantics: $o \in \textsc{DevM}^{-\mathcal{I}(t)}_{C_1,C_2} \rightarrow (o \in \mathsf{C_1}^{\mathcal{I}(t)} \rightarrow \exists t' < t.o \in \textsc{Dev}^{\mathcal{I}(t')}_{C_1,C_2})$: "For objects involved in a mandatory dynamic evolution in the past, if o is an instance of C_1, then there exists a time t' earlier than time t such that at that earlier time t' it evolved from C_1 to C_2."
- $\mathcal{DLR_{US}}$ shorthand notation: $\mathsf{C_1} \sqsubseteq \Diamond^{-}\textsc{Dev}_{\mathsf{C_1},\mathsf{C_2}}$: "Each C_1 is a subclass of some time in the past dynamically evolved from C_1 to C_2"
- $\mathcal{DLR_{US}}$ full notation: $\mathsf{C_1} \sqsubseteq \mathsf{C_1} \sqcap \neg\mathsf{C_2} \sqcap \oplus(\neg\mathsf{C_1} \sqcap \mathsf{C_2})$: "Each C_1 is a subclass of C_1 and not C_2 and at the next moment (not C_1 and C_2)"

versus the preferred rendering Each C_1 was a C_2 before, but is not a C_2 now. Not linking each axiom component to a fragment of the natural language sentence deviates from common practices of verbalising ontologies and conceptual models (e.g., [13,25,27]) even when they may be using additional grammar rules to make the output sentence grammatically better [7,11,16]. It might suggest that templates with fewer words were preferred. This is not substantiated by the data, however: 12 preferences were sole or shared shortest template in the sense of number of words, 9 were sole or shared longest template, and 3 were neither.

The follow-up interview with expert e3 included a clarification on the aforementioned for/since issue. Expert e3 also noted that if neither expert has English as first language, this may have contributed to the low amount of unanimity. It may seem disconcerting that experts each use their own terminology, but e3 did not see that as a real issue, "*for there is the logic that does have the precise meaning anyway*" and thus "*resolves any confusion that may arise from using* *slightly different terminology*" (paraphrased). In this light, it is not likely that asking many more temporal logic experts will make the results converge. Lastly, e3 suggested that the relative large difference in "yes" between e3 and e1 (29 vs 62 'yes') may be due to attitude toward judging, in that e3 aimed for one and at most two "yes" per constraint. However, this does not explain why e2 had only 34 "yes", but where no such criterion could have been used.

4.2.2. Mixed experts' assessment results

The aggregate result for the mixed experts are included in Table 1. The main interesting outcome is the large differences with the temporal logic experts on whether the templates capture the semantics adequately. The mixed experts deemed many more sentences to be fully or borderline acceptable. This is in large part explainable in that the experts have a better grasp of the subtleties of the temporal constraints. A clear illustration of this is RDevM$^-$ 'Dynamic evolution for relationships, past, mandatory' option (a), where e1 had commented "*Absolutely false!*" with 2 "no" and 1 "sort of" from the experts, yet it had 3 "yes" and 2 "sort of" from the mixed group, and Sr 'Snapshot relationship' option (a) received 3 "no" from the experts, yet 2 "yes" and 3 "sort of" from the mixed group.

Further, the aggregate evens out the more strict grading by the single mixed expert who has English as first language (p1 in the data), which may also contribute to assessing precision of verbalising the constraints, and one of the two logicians who is well-versed in modal logics and thus may grasp the finesses of temporal logics better. The aforementioned for/since issue of Qex$^-$ 'Quantitative extension, past, optional' and QexM$^-$ 'Quantitative extension, past, mandatory' was absent from the mixed group, who deemed it mostly acceptable.

Regarding preferences for a particular template, there was no unanimous preference on any template, 4 where 4 out of 5 agreed on a preference, and 17 by majority voting (3 out of 5). As to unanimity of verdicts, the mixed group answered the same on 6 templates. There is a slight preference for shorter sentences: 13 preferences were sole or shared shortest template, 5 were sole or shared longest template, and 4 were neither.

Few comments were made by the mixed participants. Recurring ones include NLG expert (p2)'s option that several templates were either vague (e.g., option (a) of Tc 'Temporal class'), repetitive (PDex/PDev 'Persistent extension/evolution'), or that it "*does not sound natural enough*" (e.g., Dev$^-$ 'Dynamic evolution, past, optional'). Participant p1 provided most feedback on word choices and preferences; e.g., instead of ..., but is not now in Qev$^-$ 'Quantitative evolution, past, optional' and QevM$^-$ 'Quantitative evolution, past, mandatory', rather ..., but is not a C_2 now, a dislike for the use of sequentially in dynamic evolution templates (which the experts marked down as well), and on ceasing in the template suggesting instantaneous change "*rather than stating so explicitly*".

5. Discussion

The outcome with the preferred templates is, to the best of our knowledge, the first proposal for linking temporal knowledge or information to natural language. The number of participants is relatively small, but a larger group will neither resolve the low inter-annotator agreement of the temporal logic experts, nor the comparatively high 'yay-saying' among the mixed expert group whose difference would likely be exacerbated with, say, a group of 4th year student participants that are less conversant in temporal constraints. It is nigh on impossible to examine whether a non-expert group would really have understood the logic, because it would require participants to communicate the meaning in a different mode than the natural language, and those alternative modes were precisely a problem that the natural language approach aimed to address. rendering it difficult to discern whether a lack of understanding may be due to the other representation, Simplicity or potential difficulty of the templates, as measured by number of words, did not show unequivocal preference for shorter templates (hence, sentences), especially among the experts. The data collected cannot explain this, and it thus merits further investigation whether some temporal constraints indeed cannot be simplified further without losing their meaning.

Looking back at Figure 1, the temporal entities and constraints are now verbalised as shown in Figure 1-C. One might pose that once implemented, it may end up in too many sentences for a modeller to check. However, one could 1) further prioritise constraints and 2) rely on an automated reasoner. Regarding prioritisation, the mandatory, past, and quantitative constraints are more interesting from an information systems point of view, for they can be easily implemented in a database as integrity constraints. Optional past and future constraints may be interesting for querying and database updates only. Regarding the latter: with the logic foundation, one could specify just a few important temporal constraints and let the rest be inferred by the reasoner thanks to the logical implications [4,14,17]; e.g., if the relationship is temporal, then so are the participating classes, and if a superclass is temporal then so are its subclasses.

6. Conclusions

Template selection of temporal constrains in temporal logics and logic-based temporal conceptual modelling languages showed low expert inter-annotator unanimous agreement, although 89% with majority voting. The experts were more strict (41%) on whether a template captured the semantic than the mixed group (64%), noting that there were few unanimous preferences. Taking into account judgement of semantics, indicated preferences, and comments, all 34 axiom types now have a template for verbalisation. The templates map as a whole to an axiom type rather than their constituents.

We have recently completed a modelling experiment showing that, on the whole, the template-based natural language was preferred over other notations (semantics, DL, diagram, coding-style) especially for the more complex constraints [15]. Therefore, we plan to create bi-directional mappings between the logic and the (pseudo-)natural language and design a multi-modal modelling interface. We also expect that it then will be easier to collect data to investigate the effect natural language renderings on modelling further.

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