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Appendix of the paper entitled: "Natural language template selection for temporal constraints"

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C. Maria KEET[1]
Department of Computer Science, University of Cape Town, South Africa

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. 101 templates were designed and 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. Final templates

Considering the usual model-theoretic semantics, we use here a *temporal interpretation* of the signature of a conceptual data model $\mathcal{M}$ for this. 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 $A \in \mathcal{A}$.

The remainder of the appendix lists the abbreviation of the constraint, description, formalisation, and 'winning' template. Starred constraints are updated templates cf. those presented during the evaluation.

[1]Corresponding Author: C. Maria Keet, Department of Computer Science, University of Cape Town, Cape Town, South Africa; E-mail: mkeet@cs.uct.ac.za.

- (SC) Snapshot class,
  $o \in C^{\mathcal{I}(t)} \rightarrow \forall t' \in \mathcal{T}. o \in C^{\mathcal{I}(t')}$;
  ..$\mathtt{C}_1$.. is an entity type whose objects will always be a(n) ..$\mathtt{C}_1$.. .
- (TC) Temporary class,
  $o \in C^{\mathcal{I}(t)} \rightarrow \exists t' \neq t. o \notin C^{\mathcal{I}(t')}$;
  Each ..$\mathtt{C}_1$.. is not a(n) ..$\mathtt{C}_1$.. for some time.
- (SR) Snapshot relationship,
  $r \in R^{\mathcal{I}(t)} \rightarrow \forall t' \in \mathcal{T}. r \in R^{\mathcal{I}(t')}$;
  Each ..$\mathtt{C}_1$.. ..$\mathtt{R}_1$.. ..$\mathtt{C}_2$.. endures indefinitely.
- (TR) Temporal relationship,
  $r \in R^{\mathcal{I}(t)} \rightarrow \exists t' \neq t. r \notin R^{\mathcal{I}(t')}$;
  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.
- (SA) Snapshot attribute,
  $o \in C^{\mathcal{I}(t)} \wedge \langle o, d \rangle \in A^{\mathcal{I}(t)} \rightarrow \forall t' \in \mathcal{T}. \langle o, d \rangle \in A^{\mathcal{I}(t')}$;
  Each object in entity type ..$\mathtt{C}_1$.. having attribute ..$\mathtt{A}_1$.. has ..$\mathtt{A}_1$.. at all times.
- (TA) Temporal attribute,
  $o \in C^{\mathcal{I}(t)} \wedge \langle o, d \rangle \in A^{\mathcal{I}(t)} \rightarrow \exists t' \neq t. \langle o, d \rangle \notin A^{\mathcal{I}(t')}$;
  Each object in entity type ..$\mathtt{C}_1$.. having attribute ..$\mathtt{A}_1$.. does not have a(n) ..$\mathtt{A}_1$.. at some time.
- (DEX) Dynamic extension in the future,
  $o \in \mathrm{DEX}^{\mathcal{I}(t)}_{C_1,C_2} \rightarrow (o \in \mathtt{C_1}^{\mathcal{I}(t)} \wedge o \notin \mathtt{C_2}^{\mathcal{I}(t)} \wedge o \in \mathtt{C_2}^{\mathcal{I}(t+1)})$;
  A(n) ..$\mathtt{C}_1$.. may also become a(n) ..$\mathtt{C}_2$.. .
- (DEXM) Mandatory DEX,
  $o \in \mathrm{DEXM}^{\mathcal{I}(t)}_{C_1,C_2} \rightarrow (o \in \mathtt{C_1}^{\mathcal{I}(t)} \rightarrow \exists t' > t. o \in \mathrm{DEX}^{\mathcal{I}(t')}_{C_1,C_2})$;
  Each ..$\mathtt{C}_1$.. also has to become a(n) ..$\mathtt{C}_2$.. .
- (DEX$^-$) Dynamic extension in the past
  $o \in \mathrm{DEX}^{-\mathcal{I}(t)}_{C_1,C_2} \rightarrow (o \in \mathtt{C_1}^{\mathcal{I}(t)} \wedge o \notin \mathtt{C_2}^{\mathcal{I}(t)} \wedge o \in \mathtt{C_2}^{\mathcal{I}(t-1)})$;
  A(n) ..$\mathtt{C}_1$.. may have been a(n) ..$\mathtt{C}_2$.. before.
- (DEXM$^-$) Mandatory DEX, past
  $o \in \mathrm{DEXM}^{-\mathcal{I}(t)}_{C_1,C_2} \rightarrow (o \in \mathtt{C_1}^{\mathcal{I}(t)} \rightarrow \exists t' < t. o \in \mathrm{DEX}^{\mathcal{I}(t')}_{C_1,C_2})$;
  Each ..$\mathtt{C}_1$.. was already a(n) ..$\mathtt{C}_2$.. .
- (DEV) Dynamic evolution, future, optional
  $o \in \mathrm{DEV}^{\mathcal{I}(t)}_{C_1,C_2} \rightarrow (o \in \mathtt{C_1}^{\mathcal{I}(t)} \wedge o \notin \mathtt{C_2}^{\mathcal{I}(t)} \wedge o \in \mathtt{C_2}^{\mathcal{I}(t+1)} \wedge o \notin \mathtt{C_1}^{\mathcal{I}(t+1)})$;
  A(n) ..$\mathtt{C}_1$.. may evolve to become a(n) ..$\mathtt{C}_2$.. ceasing to be a(n) ..$\mathtt{C}_1$.. .
- (DEVM) Mandatory dynamic evolution, future
  $o \in \mathrm{DEVM}^{\mathcal{I}(t)}_{C_1,C_2} \rightarrow (o \in \mathtt{C_1}^{\mathcal{I}(t)} \rightarrow \exists t' > t. o \in \mathrm{DEV}^{\mathcal{I}(t')}_{C_1,C_2})$;
  Each ..$\mathtt{C}_1$.. must evolve to ..$\mathtt{C}_2$.. ceasing to be a(n) ..$\mathtt{C}_1$.. .
- (DEV$^-$) Dynamic evolution, past, optional
  $o \in \mathrm{DEV}^{-\mathcal{I}(t)}_{C_1,C_2} \rightarrow (o \in \mathtt{C_1}^{\mathcal{I}(t)} \wedge o \notin \mathtt{C_2}^{\mathcal{I}(t)} \wedge o \in \mathtt{C_2}^{\mathcal{I}(t-1)} \wedge o \notin \mathtt{C_1}^{\mathcal{I}(t-1)})$;
  A(n) ..$\mathtt{C}_1$.. may have been a(n) ..$\mathtt{C}_2$.. before, but is not a(n) ..$\mathtt{C}_2$.. now.
- (DEVM$^-$) Mandatory dynamic evolution, past:
  $o \in \mathrm{DEVM}^{-\mathcal{I}(t)}_{C_1,C_2} \rightarrow (o \in \mathtt{C_1}^{\mathcal{I}(t)} \rightarrow \exists t' < t. o \in \mathrm{DEV}^{\mathcal{I}(t')}_{C_1,C_2})$;
  Each ..$\mathtt{C}_1$.. was a(n) ..$\mathtt{C}_2$.. before, but is not a(n) ..$\mathtt{C}_2$.. now.
- (PDEX/PDEV) Persistent extension or evolution; persistence-part of the

constraint, for classes (similar for relations and attributes):
$o \in C_1^{\mathcal{I}(t)} \rightarrow \forall t' > t. o \in C_1^{\mathcal{I}(t')}$;
<selected DEX/DEV option>, and this remains so indefinitely.

- (QEX) Quantitative extension, future, optional, where here and in the following variants, $n \in \mathbb{Z}$ and $t + n \in \mathcal{T}_p$, and for QEX then:
  $o \in \text{QEX}_{C_1,C_2}^{\mathcal{I}(t)} \rightarrow \exists(t+n) > t.(o \in \texttt{C}_1{}^{\mathcal{I}(t)} \land o \notin \texttt{C}_2{}^{\mathcal{I}(t)} \land \texttt{C}_2{}^{\mathcal{I}(t+n)})$;
  A(n) ..$\texttt{C}_1$.. may also become a(n) ..$\texttt{C}_2$.. after [at least/at most/exactly] ..$\texttt{D}_1$.. .
- (QEXM) Quantitative extension, future, mandatory
  $o \in \text{QEX}_{C_1,C_2}^{\mathcal{I}(t)} \rightarrow (o \in \texttt{C}_1{}^{\mathcal{I}(t)} \rightarrow \exists(t+n) > t. o \in \text{QEX}_{C_1,C_2}^{\mathcal{I}(t+n)})$;
  Each ..$\texttt{C}_1$.. will also become a(n) ..$\texttt{C}_2$.. after [at least/at most/exactly] ..$\texttt{D}_1$.. .
- (QEX^-) Quantitative extension, past, optional
  $o \in \text{QEX}_{C_1,C_2}^{\mathcal{I}(t)} \rightarrow \exists(t-n) < t.(o \in C_1^{\mathcal{I}(t-n)} \land o \in C_2^{\mathcal{I}(t)} \land o \notin C_2^{\mathcal{I}(t-n)})$;
  A ..$\texttt{C}_1$.. may already be a(n) ..$\texttt{C}_2$.. for [at least/at most/exactly] ..$\texttt{D}_1$.. since ..$\texttt{D}_1$.. . **
- (QEXM^-) Quantitative extension, past, mandatory
  $o \in \text{QEXM}^{-\mathcal{I}(t)}_{C_1,C_2} \rightarrow (o \in C_1^{\mathcal{I}(t)} \rightarrow \exists(t-n) < t. o \in \text{QEX}_{C_1,C_2}^{\mathcal{I}(t-n)})$;
  Each ..$\texttt{C}_1$.. was already a(n) ..$\texttt{C}_2$.. for [at least/at most/exactly] ..$\texttt{D}_1$.. since ..$\texttt{D}_1$.. . **
- (QEV) Quantitative evolution, future
  $o \in \text{QEV}_{C_1,C_2}^{\mathcal{I}(t)} \rightarrow \exists(t+n) > t.(o \in \texttt{C}_1{}^{\mathcal{I}(t)} \land o \notin \texttt{C}_2{}^{\mathcal{I}(t)} \land o \in \texttt{C}_2{}^{\mathcal{I}(t+n)} \land o \notin \texttt{C}_1{}^{\mathcal{I}(t+n)})$;
  A ..$\texttt{C}_1$.. may progress to a(n) ..$\texttt{C}_2$.. after [at least/at most/exactly] ..$\texttt{D}_1$.. , ceasing to be a(n) ..$\texttt{C}_1$.. .
- (QEVM) Quantitative evolution, future, mandatory
  $o \in \text{QEVM}_{C_1,C_2}^{\mathcal{I}(t)} \rightarrow (o \in C_1^{\mathcal{I}(t)} \rightarrow \exists(t+n) > t. o \in \text{QEV}_{C_1,C_2}^{\mathcal{I}(t+n)})$;
  Each ..$\texttt{C}_1$.. must progress to a(n) ..$\texttt{C}_2$.. after [at least/at most/exactly] ..$\texttt{D}_1$.. , ceasing to be a(n) ..$\texttt{C}_1$.. .
- (QEV^-) Quantitative evolution, past
  $o \in \text{QEV}^{-\mathcal{I}(t)}_{C_1,C_2} \rightarrow \exists(t-n) < t.(o \in C_1^{\mathcal{I}(t)} \land o \notin C_2^{\mathcal{I}(t)} \land o \in C_2^{\mathcal{I}(t-n)} \land o \notin C_1^{\mathcal{I}(t-n)})$;
  A(n) ..$\texttt{C}_1$.. may have been a(n) ..$\texttt{C}_2$.. before for a period of [at least/at most/exactly] ..$\texttt{D}_1$.. , but is not a $\texttt{C}_2$ now. **
- (QEVM^-) Quantitative evolution, past, mandatory
  $o \in \text{QEVM}^{-\mathcal{I}(t)}_{C_1,C_2} \rightarrow (o \in C_1^{\mathcal{I}(t)} \rightarrow \exists(t-n) < t. o \in \text{QEV}_{C_2,C_1}^{\mathcal{I}(t-n)})$;
  Each ..$\texttt{C}_1$.. was a(n) ..$\texttt{C}_2$.. before for a period of [at least/at most/exactly] ..$\texttt{D}_1$.. , but is not a $\texttt{C}_2$ now. **
- (RDEX) Dynamic extension for relationships, future, optional
  $\langle o, o' \rangle \in \text{RDEX}_{R_1,R_2}{}^{\mathcal{I}(t)} \rightarrow (\langle o, o' \rangle \in \texttt{R}_1{}^{\mathcal{I}(t)} \rightarrow \exists t' > t. \langle o, o' \rangle \in \texttt{R}_2{}^{\mathcal{I}(t')})$;
  ..$\texttt{C}_1$.. ..$\texttt{R}_1$.. ..$\texttt{C}_2$.. may be followed by ..$\texttt{C}_1$.. ..$\texttt{R}_2$.. ..$\texttt{C}_2$.. some time later. **
- (RDEXM) Dynamic extension for relationships, mandatory,
  $\langle o, o' \rangle \in \text{RDEXM}_{R_1,R_2}^{\mathcal{I}(t)} \rightarrow (\langle o, o' \rangle \in \texttt{R}_1{}^{\mathcal{I}(t)} \rightarrow \exists t' > t. \langle o, o' \rangle \in \text{RDEX}_{R_1,R_2}^{\mathcal{I}(t')})$;
  Each ..$\texttt{C}_1$.. ..$\texttt{R}_1$.. ..$\texttt{C}_2$.. will be followed by ..$\texttt{C}_1$.. ..$\texttt{R}_2$.. ..$\texttt{C}_2$.. .
- (RDEX^-) Dynamic extension for relationships, past, optional
  $\langle o, o' \rangle \in \text{RDEX}^-_{R_1,R_2}{}^{\mathcal{I}(t)} \rightarrow (\langle o, o' \rangle \in \texttt{R}_1{}^{\mathcal{I}(t)} \rightarrow \exists t' < t. \langle o, o' \rangle \in \texttt{R}_2{}^{\mathcal{I}(t')})$.
  ..$\texttt{C}_1$.. ..$\texttt{R}_1$.. ..$\texttt{C}_2$.. may be preceded by ..$\texttt{C}_1$.. ..$\texttt{R}_2$.. ..$\texttt{C}_2$.. some time earlier. **

- (RDEXM$^-$) Dynamic extension for relationships, past, mandatory
$\langle o,o'\rangle \in \mathrm{RDEXM}^{-}_{R_1,R_2}{}^{\mathcal{I}(t)} \rightarrow (\langle o,o'\rangle \in \mathtt{R_1}^{\mathcal{I}(t)} \rightarrow \exists t' < t.\langle o,o'\rangle \in \mathrm{RDEX}^{-}_{R_1,R_2}{}^{\mathcal{I}(t')})$;
Each ..$\mathtt{C_1}$.. ..$\mathtt{R_1}$.. ..$\mathtt{C_2}$.. was preceded by ..$\mathtt{C_1}$.. ..$\mathtt{R_2}$.. ..$\mathtt{C_2}$.. some time earlier. **
- (RDEV) Dynamic evolution for relationships, future, optional,
$\langle o,o'\rangle \in \mathrm{RDEV}^{\mathcal{I}(t)}_{R_1,R_2} \rightarrow (\langle o,o'\rangle \in \mathtt{R_1}^{\mathcal{I}(t)} \rightarrow \exists t' > t.\langle o,o'\rangle \in \mathtt{R_2}^{\mathcal{I}(t')} \wedge \langle o,o'\rangle \notin \mathtt{R_1}^{\mathcal{I}(t')})$;
..$\mathtt{C_1}$.. ..$\mathtt{R_1}$.. ..$\mathtt{C_2}$.. may be followed by ..$\mathtt{C_1}$.. ..$\mathtt{R_2}$.. ..$\mathtt{C_2}$.. , ending ..$\mathtt{C_1}$.. ..$\mathtt{R_1}$.. ..$\mathtt{C_2}$.. .
- (RDEVM) Dynamic evolution for relationships, future, mandatory,
$\langle o,o'\rangle \in \mathrm{RDEVM}^{\mathcal{I}(t)}_{R_1,R_2} \rightarrow (\langle o,o'\rangle \in \mathtt{R_1}^{\mathcal{I}(t)} \rightarrow \exists t' > t.\langle o,o'\rangle \in \mathrm{RDEV}^{\mathcal{I}(t')}_{R_1,R_2})$;
Each ..$\mathtt{C_1}$.. ..$\mathtt{R_1}$.. ..$\mathtt{C_2}$.. will be followed by ..$\mathtt{C_1}$.. ..$\mathtt{R_2}$.. ..$\mathtt{C_2}$.. , terminating the ..$\mathtt{C_1}$.. ..$\mathtt{R_1}$.. ..$\mathtt{C_2}$.. relation.
- (RDEV$^-$) Dynamic evolution for relationships, past, optional:
$\langle o,o'\rangle \in \mathrm{RDEV}^{-}_{R_1,R_2}{}^{\mathcal{I}(t)} \rightarrow (\langle o,o'\rangle \in \mathtt{R_1}^{\mathcal{I}(t)} \rightarrow \exists t' < t.\langle o,o'\rangle \in \mathtt{R_2}^{\mathcal{I}(t')} \wedge \langle o,o'\rangle \notin \mathtt{R_1}^{\mathcal{I}(t')})$;
..$\mathtt{C_1}$.. ..$\mathtt{R_1}$.. ..$\mathtt{C_2}$.. may have been preceded by ..$\mathtt{C_1}$.. ..$\mathtt{R_2}$.. ..$\mathtt{C_2}$.. and they are not in that ..$\mathtt{C_1}$.. ..$\mathtt{R_2}$.. ..$\mathtt{C_2}$.. relation now.
- (RDEVM$^-$) Dynamic evolution for relationships, past, mandatory
$\langle o,o'\rangle \in \mathrm{RDEVM}^{-}_{R_1,R_2}{}^{\mathcal{I}(t)} \rightarrow (\langle o,o'\rangle \in \mathtt{R_1}^{\mathcal{I}(t)} \rightarrow \exists t' < t.\langle o,o'\rangle \in \mathrm{RDEV}_{R_1,R_2}{}^{\mathcal{I}(t')})$;
Each ..$\mathtt{C_1}$.. ..$\mathtt{R_1}$.. ..$\mathtt{C_2}$.. must have been preceded by ..$\mathtt{C_1}$.. ..$\mathtt{R_2}$.. ..$\mathtt{C_2}$.., and terminating that ..$\mathtt{C_1}$.. ..$\mathtt{R_2}$.. ..$\mathtt{C_2}$.. relation. **
- (SRDEX/SRDev) Persistence (see PDEX/PDEV),
<selected DEX/DEV option>, and this remains so indefinitely.
- (FREEZ) "frozen" attribute
$a \in \mathrm{FREEZ}^{\mathcal{I}(t)} \rightarrow \forall t' > t.a \in \mathtt{A}^{\mathcal{I}(t')}$;
Once the value for ..$\mathtt{A_1}$.. is set, it cannot change anymore.
- (AQEV) Quantitative evolution, where a is a binary relation between a class and a data type,
$a \in \mathrm{AQEV}^{\mathcal{I}(t)}_{A_1,A_2} \rightarrow \exists (t+n) > t.(a \in \mathtt{A_1}^{\mathcal{I}(t)} \wedge a \notin \mathtt{A_2}^{\mathcal{I}(t)} \wedge a \in \mathtt{A_2}^{\mathcal{I}(t+n)} \wedge a \notin \mathtt{A_1}^{\mathcal{I}(t+n)})$ where $n \in \mathbb{Z}$;
Each ..$\mathtt{C_1}$..'s ..$\mathtt{A_1}$.. changes after [at least/at most/every] ... to ..$\mathtt{A_2}$.. .