A Formalization of Subjective and Objective Time Ontologies

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Topics

- Objectives
- Ontology & Temporal Notions
- Temporal Logics from J.E. McTaggart & A.N. Prior
- Objective & Subjective Temporal Notions
- Time Ontology Formalization & Properties
Our Aims

- Define an Upper Time Ontology

- Help with the Semantic Web:
  - Describe temporal content of web pages
  - Automated natural language translation engines
Ontology Definition

- **Ontology:** the metaphysical study of the nature of **being and existence**  
  (WordNet)

- **Ontology:** (computer science) a rigorous and exhaustive organization of some knowledge domain that is usually hierarchical and contains all the relevant entities and their relations  
  (WordNet)
Time & Ontology

- “Study of Being & Existence” implies a time notion: the present
- Therefore time is intrinsically part of any ontology
Time & Event in Ontologies

- Event is result of change perception
- Change perception enables notion of time
- Time is then used to record Event
  (Event = Something happens at a given place & time - Wordnet)
- Therefore, time and event are tightly linked
  (And so must be their ontologies)
McTaggart’s Temporal Notions

- **Temporal Notions:**
  - **A-Series:** past, present and future
  - **B-Series:** before and after

A-Series: defines changes & enables time notions
B-Series: not time notions (no time direction & no perception of change), unless A-series included
Therefore, B-Series $\Rightarrow$ A-Series

But an A-series (in particular the present) cannot be logically defined (it is ‘unreal’) therefore time is subjective
Prior’s Temporal Notions

First-Grade Temporal Notions:
- Earlier
- Later
- Always earlier
- Always later

based on 2 ‘modalities’: 
  - Possibility (◊)
  - Necessity (□)

Second-Grade Temporal Notions =
First-Grade Temporal Notions + Notion of the Present
Recent Temporal Logics

**OWL-Time (initially from DARPA):**
- Instant, Interval are only 2 main temporal concepts
- Other temporal notions are relations over instant & interval

**J. F. Allen:**
- Interval is the only main temporal notion
- Instant is a “small interval”

**Related concepts:**
- Causation, concurrency, belief, plan
Subjective & Objective Times

Summary on time notions:

- the present cannot be defined (logically or mathematically)

- the present is the basis for time notions (in particular notion of instant of time)

- but the present can be perceived by all although the perceptions may be different.

Therefore, time could be subjective or objective
Time Ontology Formalization

Presupposed Notions:

- Instant (of time)

- Order or direction of time (e.g. earlier & later)

- Propositional Logic: Truth-value of a proposition

- First-Order Logic: Universal & existential quantifiers ("∀" and "∃")
Canon / Ontology

Real World

Abstract World

Individuals

Concepts

Relations

$K = (T, I, \leq, \text{conf}, B)$

Ontology Formalization

\[ K = (T, I, \leq, \text{conf}, B) \]

- **\( T \):** set of concepts (\( TC \)) & relations (\( TR \))
  - e.g. isChild (Person, Person)
- **\( I \):** set of instances of \( TC \)
  - e.g. 'John' is a 'Person'
- **\( \leq \):** subsumption relation in \( T \)
  - e.g. MalePerson \( \leq \) Person \( \leq \) LivingEntity
- **Conf** (conformance relation) maps an individual to a concept type
  - e.g. \( \text{conf}('John') = 'Person' \)
- **\( B \) (canonical basis relation),** maps a relation to the concepts that are used with that relation (canonical = pattern of usage)
  - e.g. \( B('isChild') = ('Person', 'Person') \)
**Time Ontology - Individuals**

\[ K = (T, I, \leq, \text{conf}, B) \]

\( I \): set of ‘atomic temporal propositions’

- A proposition with a temporal property
- Cannot be further divided into temporal sub-propositions connected by logical connectives, such as ‘not’, ‘and’, ‘or’.

Example:

\[ Q = \text{“it was hot yesterday but it will be cooler tomorrow”} \]
\[ Q = \text{“it was hot yesterday”} \land \text{“it will be cooler tomorrow”} \]
Time Ontology - Conformance

\[ K = (T, I, \leq, \text{conf}, B) \]

- \( \text{Conf} \) (conformance relation) maps an atomic temporal proposition to a temporal concept type

Example

Q = “it was hot yesterday but it will be cooler tomorrow”
Q = “it was hot yesterday” \( \cap \) “it will be cooler tomorrow”

\( \text{conf}('it was hot yesterday') = 'Past' \)
Time Ontology - Concepts

\[ K = (T, I, \leq, \text{conf}, B) \]

- Temporal Concepts \( T_C \)

\[ SF = \text{"Subjective Future" is a function:} \]
\[ SF: P \times T \times O \rightarrow P \]
\[ SF(p, t, o) = \exists o \exists t \geq \text{Now} \ T(p, t, o) \]

- \( P \) = Proposition Space
- \( T \) = Time Space
- \( O \) = Observer Space
First-Grade Objective Temporal Notions

- **Anteriority (A):**
  \[ A(p,t) = q \text{ with } q = \exists t' \leq t \ T(p,t') \]

- **Posteriority (Po):**
  \[ \exists t' \geq t \ T(p,t') \]

- **Permanent Anteriority (PeA):**
  \[ \forall t' \leq t \ T(p,t') \]

- **Permanent Posteriority (PePo):**
  \[ \forall t' \geq t \ T(p,t') \]

- **Temporariness (T) = Anteriority or Posteriority**
  \[ T(p) = \exists t \ A(p,t) \cup \ Po(p,t) = \exists t \ T(p,t) \]

- **Permanency (Pe) = Permanent Anteriority and Permanent Posteriority**
  \[ Pe(p) = \forall t \ PeA(p,t) \cap PePo(p,t) = \forall t \ T(p,t) \]

- **Discrete Permanency = Anteriority and Posteriority**
  \[ DPe(p) = \forall t_0 \ A(t_0,p) \cap Po(t_0,p) \]
  \[ = \forall t_0 \ \exists t \ \exists t': t \leq t_0 \leq t', \ T(p,t) \cap T(p,t') \]
Time Ontology - Relations

\[ K = (T, I, \leq, \text{conf}, B) \]

- **Temporal Relations** \( TR \)
  - Not (\( \neg \) )
  - Conjunction (\( \cap \) )
  - Disjunction (\( \cup \) )

- **Order in Temporal Relations:**
  \[ \cap \geq \cup \]

(similar to propositional implication \( \Rightarrow \))
Temporal Relations - Example

- P = “Objective Past”
  Past: P → P
  Past(p) = “∃t \leq \text{Now } T(p,t)”

- SF = “Subjective Future”
  SF: P \times T \times O → P
  SF(p,t,o) = “∃o ∃t \geq \text{Now } T(p,t,o)”

- P ∩ SF: P \times T \times O → P
  (P ∩ SF) (p,t,o) = P(p) ∩ SF(p,t,o)
  = “∃t \leq \text{Now } T(p,t)” ∩ “∃o ∃t \geq \text{Now } T(p,t,o)”

  e.g. The phenomenon p has occurred in the past and I believe that it will occur again.
## Temporal Concepts & Relations

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<th></th>
<th>Concepts</th>
<th>Relations</th>
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<td><strong>Objective Ontology</strong></td>
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<td>10</td>
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<tr>
<td><strong>Subjective Ontology</strong></td>
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Objective Time Ontology

1. Anteriority $\geq$ Temporariness
2. Discrete Permanency $\geq$ Anteriority, Future, Past, Posteriority
3. Future $\geq$ Temporariness
4. Past $\geq$ Temporariness
5. Permanency $\geq$ Discrete Permanency, Permanent Anteriority, Permanent Future, Permanent Past, Permanent Posteriority
6. Permanent Anteriority $\geq$ Anteriority
7. Permanent Future $\geq$ Future
8. Permanent Past $\geq$ Past
9. Permanent Posteriority $\geq$ Posteriority
10. Posteriority $\geq$ Temporariness

Proof of 1.
$A(p,t) = \exists t' \leq t \, T(p,t')$
$T(p) = \exists t \, T(p,t)$
If $\exists t$ such that $A(p,t)$ is true, then $T(p)$ is true
Objective Time Ontology

Graphical Representation

Time Ontology – Example 1

- $Q = "\text{The truth } p \text{ will be revealed to all in the future}"
- $Q = \exists t \geq \text{Now} \ \forall O \ T(p,t,O)$
- $Q = \exists t \geq \text{Now} \ T(p,t)$
- $Q$ is an instance of the “Future” concept type

$\text{conf}(Q) = F$
Time Ontology – Example 2

- \( Q = \text{“Someone will know the truth } p\text{”} \)
- \( Q = \exists O \exists t \geq \text{Now } T(p,t,O) \)
- \( Q \) is an instance of the “Subjective Future” temporal concept type

\[ \text{conf}(Q) = \text{SF} \]
Time Ontology – Example 3

- $Q = \text{"The phenomenon } p \text{ has been observed throughout the ages"}$
- $Q = \forall t \leq \text{Now } \exists O \ T(p,t,O)$
- $Q$ is an instance of the "Indeterminate Subjective Permanent Past" temporal concept type

$\text{conf}(Q) = \text{ISPePa}$
Time Ontology – Example 4

- \( Q = \) “Someone has always observed the phenomenon \( p \)”
- \( Q = \) “\( \exists O \ \forall t \leq \text{Now}: T(p,t,O) \)”
- \( Q \) is an instance of the “Subjective Permanent Past” concept type

\[ \text{conf}(Q) = \text{SPePa} \]
Time Ontology Axioms

\[ \forall p \ p \Rightarrow (\forall c \ c(p)) \]
If a proposition is true, then it is true under any temporal concept type.

\[ T(p \Rightarrow q, t) = (T(p, t) \Rightarrow T(q, t)) \]
If at time t, “p implies q” is true, then “p is true at t” implies “q is true at time t”, and vice-versa.

\[ T(p \cap q, t) = (T(p, t) \cap T(q, t)) \]

Etc.
Time Ontology Properties

1. \( c(p \Rightarrow q) \models (c(p) \Rightarrow c(q)) \)

If “p implies q” is true under a temporal concept type c, then “p is true under c” implies “q is true under c”.

E.g.
If “p implies q” has always been true
(i.e., “p implies q” = a Permanent Past truth),
then
“p has always been true” \( \Rightarrow \) “q has always been true”
Time Ontology Properties
(cont’d)

2. \((p \Rightarrow q) \models (\forall c (c(p) \Rightarrow c(q))\)
3. \(c(\neg p) \models \neg c(p)\)
4. \(c(p \cap q) \models (c(p) \cap c(q))\)
5. \((c(p) \cup c(q)) \models c(p \cup q)\)
6. \((\neg(c(p) \cap c(q))) = (\neg c(p) \cup \neg c(q))\)
   (similar to De Morgan’s Theorem)
7. \((c(\neg p) \cup c(\neg q)) \models \neg (c(p) \cap c(q))\)
8. \((\neg(c(p) \cup c(q))) = (\neg c(p) \cap \neg c(q))\)
   (similar to De Morgan’s Theorem)
9. \((c(\neg p) \cap c(\neg q)) \models \neg (c(p) \cup c(q))\)
10. \(c((p \Rightarrow q) \cap p) \models c(q)\) (Temporal Modus Ponens)
11. \(c((p \Rightarrow q) \cap \neg q) \models c(\neg p)\) (Temporal Modus Tollens)
12. \(c(p \Rightarrow q) \models (\neg c(q) \Rightarrow \neg c(p))\) (Temporal Transposition)
13. \((c(p) \cup c(q \cap r)) \models (c(p \cup q) \cap (c(p \cup r)))\) (Temporal Distribution)
Final Note 1

Soundness & Completeness of a Theory:

- Soundness: \( \vdash \Rightarrow \models \)
- Completeness: \( \models \Rightarrow \vdash \)
Final Note 2

Natural language translation:

- 2 types of document:
  - 1 for the mind (legal, scientific documents, ...)
  - 1 for the heart (poems, verses, lyrics, ...)

- Each requires a different type of ontology with different criteria for categorization
Conclusion

Contribution to knowledge representation & temporal reasoning with:

- Time ontology formalization based on McTaggart’s and Prior’s temporal notions & linking event with time
- Subjective temporal concepts formalized for the first time
- All temporal concept types and their relations identified & graphically represented
- Axioms & Properties defined, linking our theory to propositional logic and proving soundness of our theory.
- Assistance to Future Semantic Web, e.g.,
  - describe the temporal content of web pages
  - build automated natural language translation engines
Thank You !