Temporal Ontology for Representation and Reasoning about Uncertain Historical Time Periods

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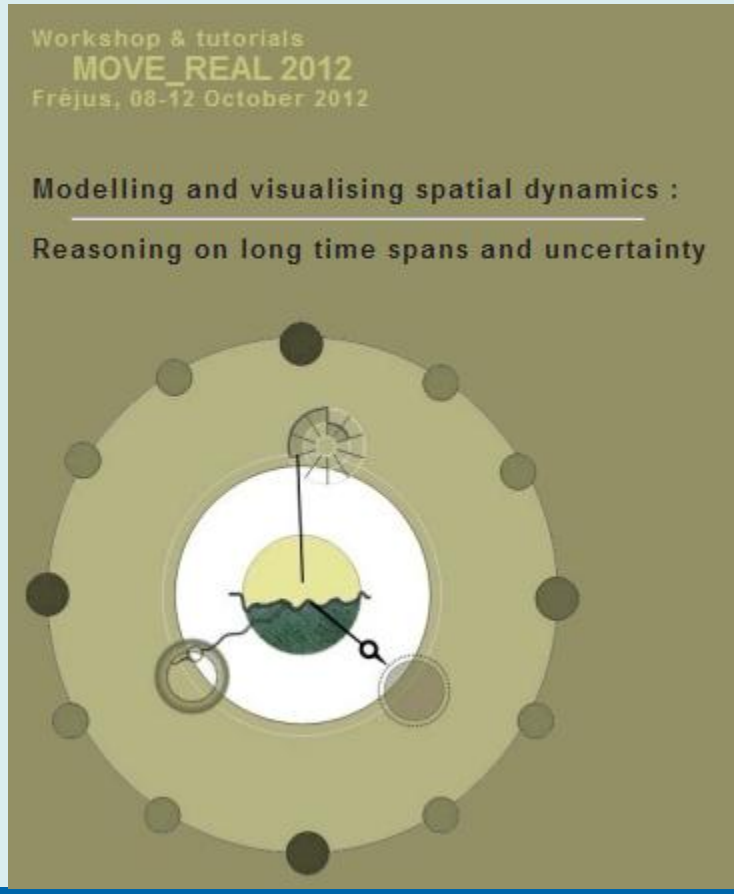

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Motivation

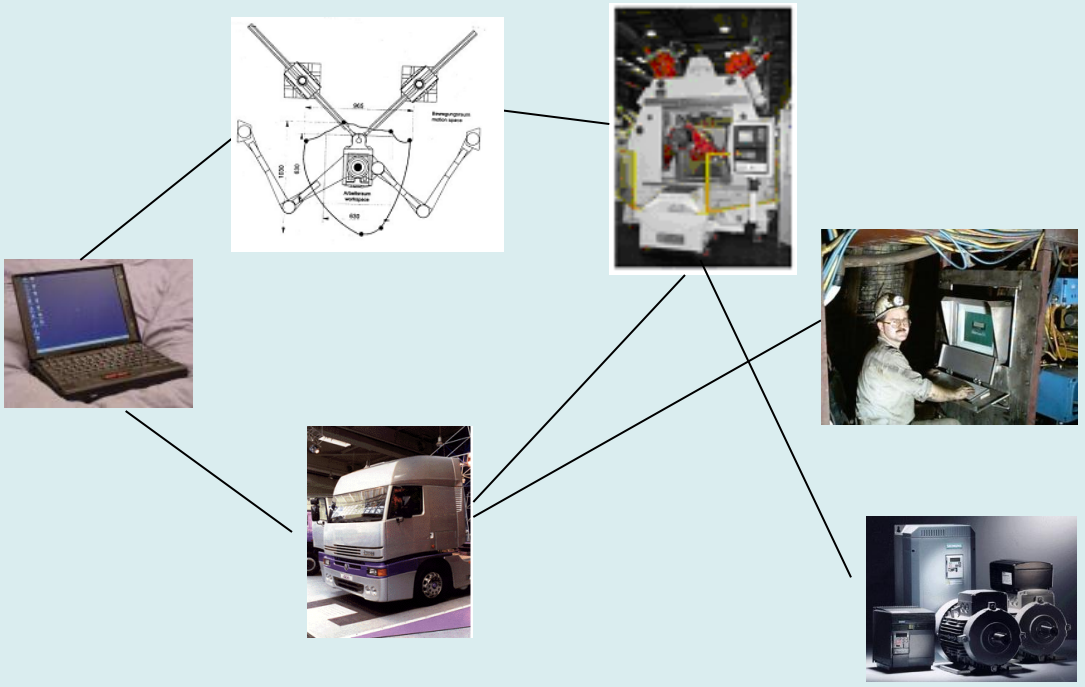
Preservation of cultural heritage: historical object records

- Objects located in space and time, embedded in social, history, and art context
- Temporal properties of objects
  - Existence, origin, restoration, destruction, burning, etc.
  - "*by the middle of the thirteenth century*", "*during the reign of the King Charles IV*"

- Some general inaccuracy reasons in object dating:
  - Data not available (i.e. no written resources)
  - Events lasting for a time referred to as a single instant (e.g. building of a church)
  - Experts use different expressions of the same historical events
  - Even with scientific methods for artefact dating historians can differ in conclusions

→ Inference mechanism suitable and effective for sufficiently accurate localisation in time with uncertainty in temporal assertions

World of Objects and Relations



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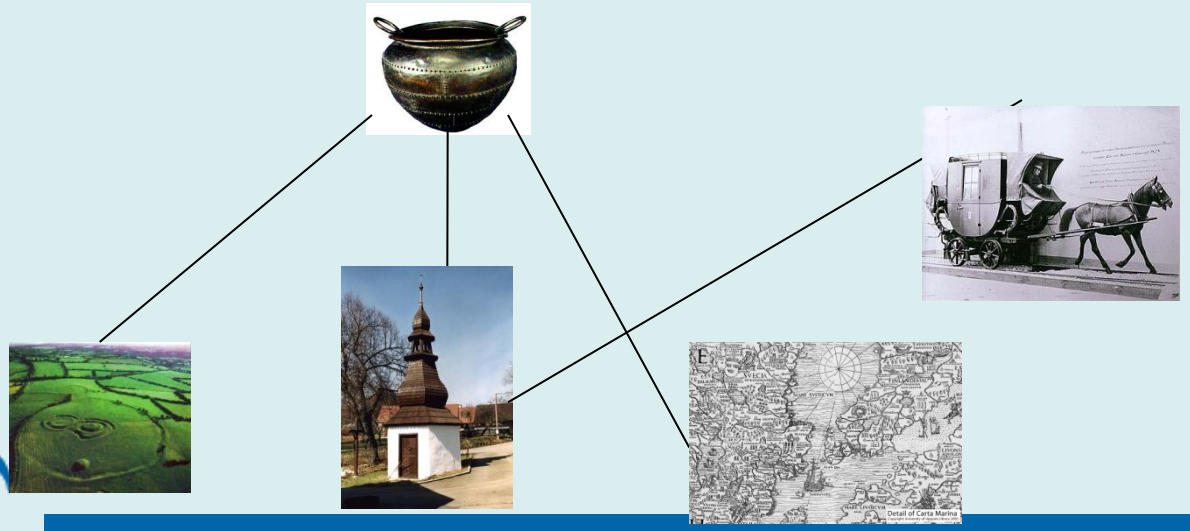

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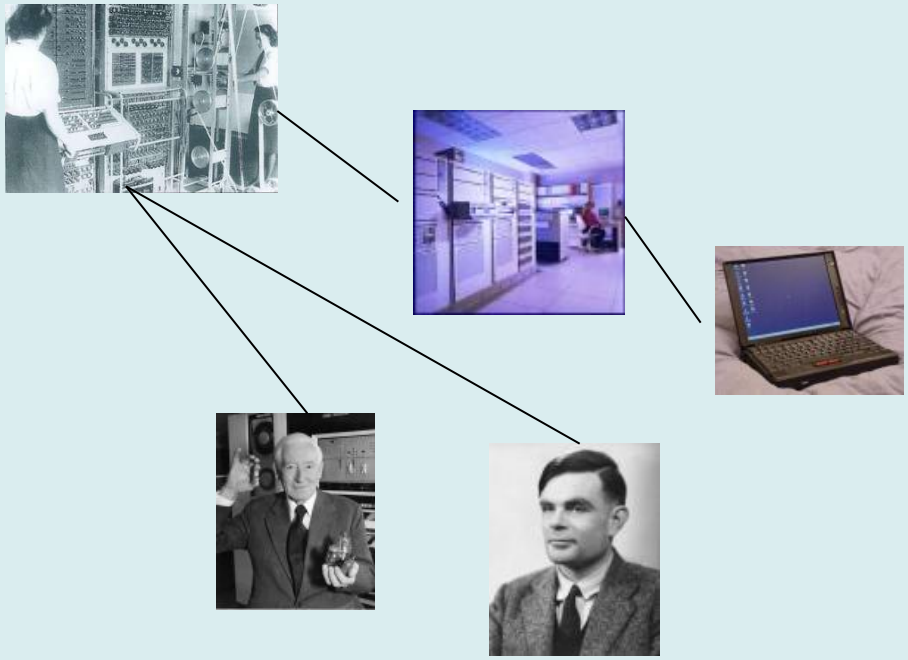

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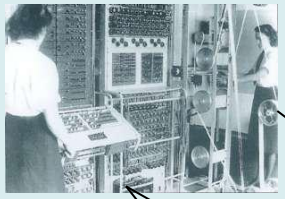
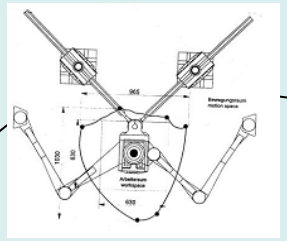


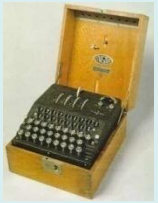
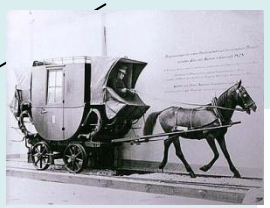
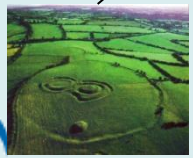
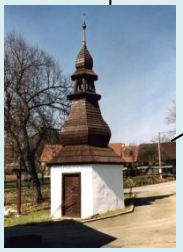










Uncertain Historical Time Statements

- Bronze bull, Bull Rock at Adamov, Horák Culture, recent Halstat epoch, 6th century BC
- Modrá (by Velehrad), St. John Church, before mid 9th century
- Holubice, Virgin Mary Rotunda, before year 1224
- Louka (Znojmo), Closter Church crypt, around year 1200
- Prague, Virgin Mary before Tyn, third fourth of 14th century
- St. Venceslaus, St. Venceslaus Chapel, St Vitus Catedral in Prague, 1373
- Master of Třeboň altar, Madonna of Roudnice, after year 1380
- Pernštejn Castle, end of 15th century
- Benedikt Ried, Wladislaw Hall, Prague Castle, 1493-1502
- Dobříš Castle, park, founded around year 1750

Chadraba, R., Dvorsky, J., eds. The History of Czech Figurative Art. (in Czech) Volumes I.-IV. Academia, Prague, 1984, and 1989.

Analysis of Time in Data

- Temporal properties of existing objects
  - Existence, origin, restoration, destruction, burning, etc.
  - In general events that are of high importance for objects' history
- Duration of a time period
  - E.g. war length, reign of a king, life period
  - Could be expressed in terms of starting and ending time points
  - May be relative as well (e.g. for three month) and thus having no exact starting or ending time
- Individual expressions of time
  - Wide range of precise, imprecise, or uncertain artefact dating
  - Difficulties and further inaccuracy in any subsequent use of the data
  - They may be inherent in the data (not explicit)
  - Expressions with different semantics (e.g. tomorrow, at the beginning of the year, Monday, June 5th)
- Assigning object's time property value
  - Not simple sticking to a defined position on a timescale
  - Inexact positions on the timescale
  - Inexact durations
  - Time continuity and causality – implicit bindings of the time events and periods, need to be respected during inferrence

Statement Categories

Most frequent expressions in the domain of interest with respect to accuracy:

1. **Precise statements**
   - The whole data is available, maximum precision is reached, e.g. “January 12, 2012, 12:30:00”
2. **Statements with higher granularity**
   - Data is available, but not so precise
   - It is necessary to distinguish instants and intervals, e.g. “February 6, 1973” can be seen either as an instant of higher granularity or as a 24 hour time interval
3. **Incomplete statements**
   - Some information is missing for precise time identification
   - One may intentionally use this kind of statement for recurring temporal positions – regularly repeated instants, e.g. “January 12, 12:30:00”
4. **Uncertain statements with absolute specification of uncertainty**
   - “Between February 12 and February 13, 2012”
5. **Uncertain statements with relative specification of uncertainty**
   - “Around February 12, 2010”, “Before 13th century AD”
6. **Statements referencing other statements with temporal properties**
   - “The period before the WWII”, “during the reign of the King Charles IV”, “yesterday”, “next year”
7. **Statements with unknown or missing information**
   - “Time when something happened…”

Comments on the Categories

- Relative multiplicity of recurrence (e.g. often, rarely, and sometimes) is left aside.
- Expressions related to the current time e.g. *yesterday*, *tomorrow* implicitly belong to the category 6 (referencing other statements)
- Semantics of the same temporal statement may vary depending on the context, particularly between very distant time periods in past
  - *around the year 1500* can have more uncertainty included than the statement *around the year 2000* because historical evidence from late 15th and early 16th century is less precise in comparison to late 20th century

What Is An Ontology

- An ontology is an explicit description of a domain
  - concepts
  - properties and attributes of concepts
  - restrictions on properties and attributes
  - Individuals *(often, but not always)*
- An ontology defines
  - a common vocabulary
  - a shared understanding

Why Develop an Ontology?

- To share common understanding of the structure of information
  - among people
  - among software agents
- To make domain assumptions explicit
- To enable reuse of domain knowledge
  - to avoid “re-inventing the wheel”
  - to introduce standards to allow interoperability

Ontology components

- Concepts
  - Person, Pet, Country
- Properties and attributes of concepts
  - hasPet, livesInCountry
- Restrictions on properties and attributes
  - Persons *always* lives in Countries
- Individuals *(often, but not always)*
  - Matthew, Fido, France

Theoretical Framework for Reasoning in the Time Domain

- Core concepts
- Temporal relations
- Time granularity
- Allen relationships for time points with granularity
- Time uncertainty
- Uncertain point relationships
- Constraints and consistency checking
- Parameterization of uncertainty

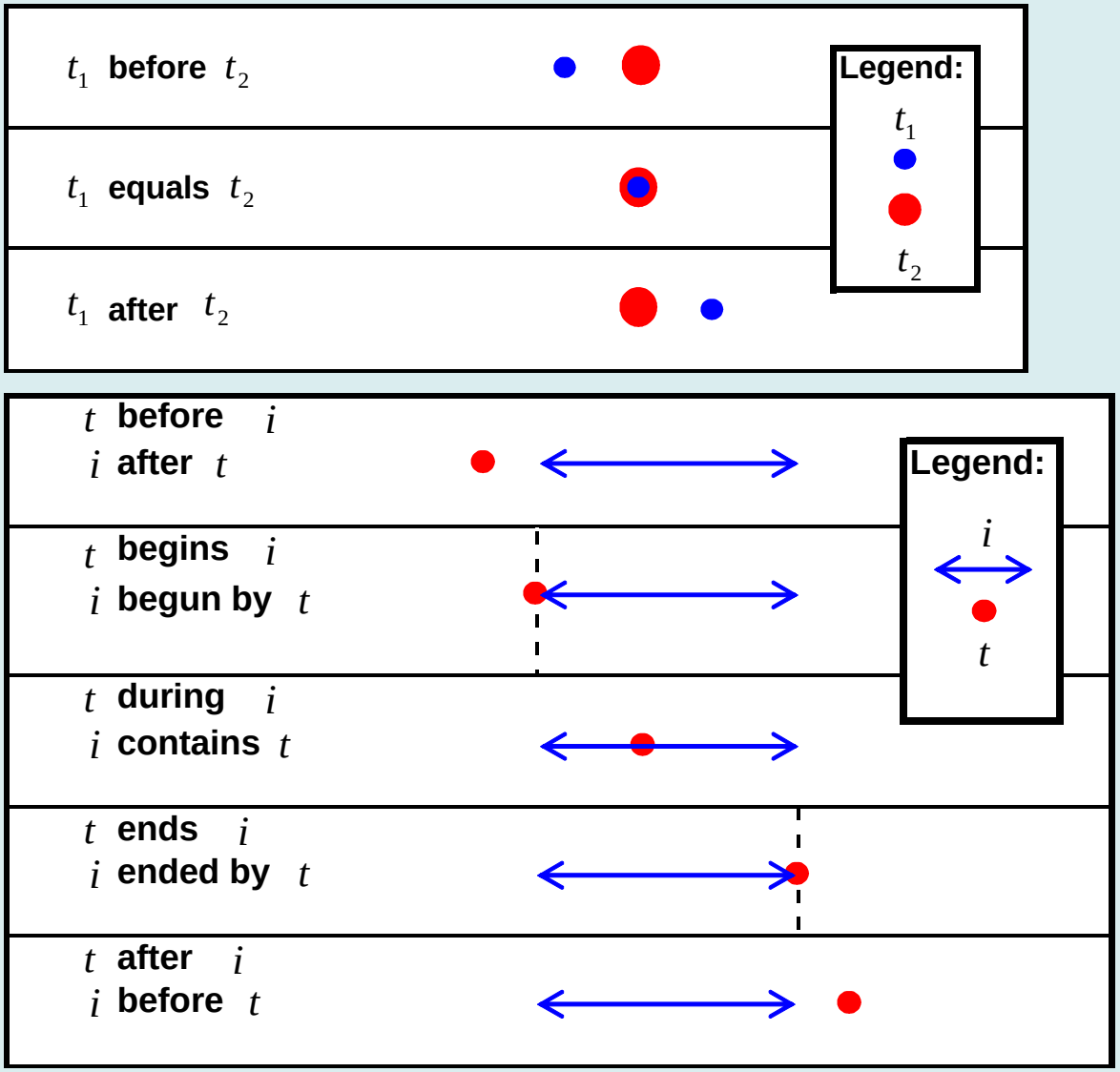
Core Concepts

- Temporal Entity
- Temporal Scale
- Temporal Position
- Time Point *t*
  - Attribute **location** *Loc(t)* of type temporal position
- Temporal Relations
- Time Quantity *Q*

  $Q = | Loc(t_2) - Loc(t_1) |$
- Time Interval $I(t_1, t_2)$
  - Starting point t_1, ending point t_2

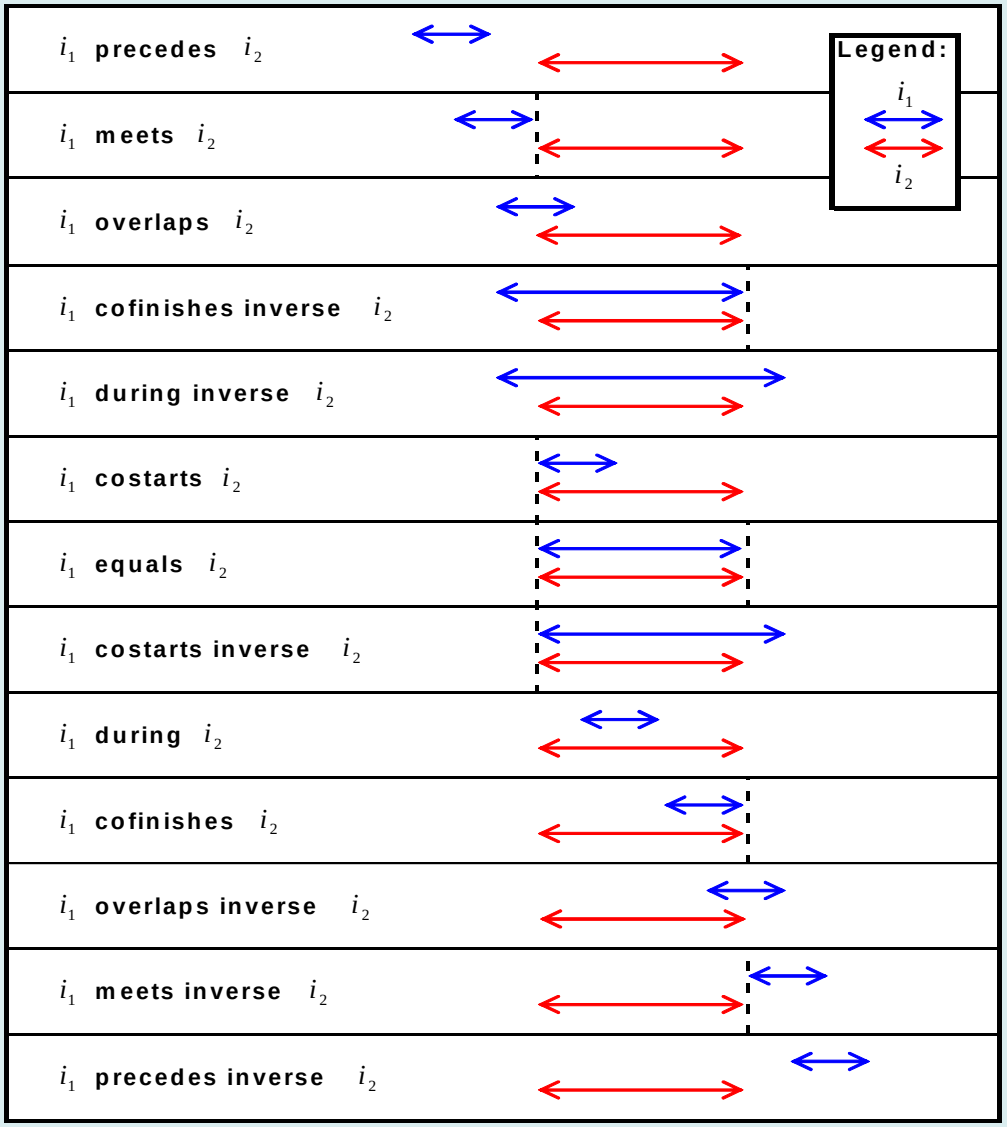
    $Loc(t_1) <= Loc(t_2)$
  - Duration $Dur(I(t_1, t_2)) = Loc(t_2) - Loc(t_1)$

Relations of Time Points and Intervals



Allen's Algebra

- James F. Allen '83
- 13 possible time interval relations



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Time Granularity

- *“May, 12, 2012”* – day granularity
- *“In 2011”* – year granularity
- Finest granularity – finest temporal scale
- Granularity temporal scale

<table>
<tr><td>Finest</td><td colspan="65"></td></tr>
<tr><td>Day</td><td>-1</td><td>0</td><td>1</td><td>2</td><td>3</td><td>4</td><td>5</td><td>6</td><td>7</td><td>8</td><td>9</td><td>10</td><td>11</td><td>12</td><td>13</td><td>14</td><td>15</td><td>16</td><td>17</td><td>18</td><td>19</td><td>20</td><td>21</td><td>22</td><td>23</td><td>24</td><td>25</td><td>26</td><td>27</td><td>28</td><td>29</td><td>30</td><td>31</td><td>32</td><td>33</td><td>34</td><td>35</td><td>36</td><td>37</td><td>38</td><td>39</td><td>40</td><td>41</td><td>42</td><td>43</td><td>44</td><td>45</td><td>46</td><td>47</td><td>48</td><td>49</td><td>50</td><td>51</td><td>52</td><td>53</td><td>54</td><td>55</td><td>56</td><td>57</td><td>58</td><td>59</td><td>60</td><td>61</td><td>62</td><td>63</td></tr>
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<tr><td>Month</td><td colspan="2">0</td><td colspan="31">1</td><td colspan="28">2</td><td colspan="4">3</td></tr>
<tr><td>Year</td><td colspan="2">2002</td><td colspan="63">2003</td></tr>
<tr><td>Century</td><td colspan="65">21</td></tr>
</table>

- Time Point with Granularity
  - Granularity value
  - Representing time interval vs. position on the granularity temporal scale

Uncertain Points

- Time Uncertainty *u*
- Uncertain Time Point ^{u}t
  - *Location* not given, but *constrained* by:
- Range of uncertainty of ^{u}t
  - "Absolute": *FromTimePoint* and *ToTimePoint*
  - "Relative": *BeforeRelTime, AfterRelTime, BeforeGranularity* and *AfterGranularity*
- Representing time interval

Constraint and Consistency Checking

36 stories from South-Bohemian castles annotated and evaluated

- In two stories, lord Oldřich of Rožmberk was mentioned
- Temporal inconsistency was found in these two stories

  Story 1: “Oldřich of Rožmberk died in 1390”
  Story 2: “Oldřich, a confirmed enemy of Hussites”

- Hussite movement was a consequence of burning Jan Hus in 1415 after he had been accused of being a heretic

- Contradiction in the visitor’s mind: Oldřich mentioned in both stories could not be the same person

- Temporal reasoning on the set of semantic story annotations including representation of time discovers the inconsistence

Uncertainty Parameters

- Semantics of the same temporal statement may vary depending on the context, particularly between very distant time periods in past
  - *Around the year 1500* can have more uncertainty included than the statement *around the year 2000* because historical evidence from late 15th and early 16th century is less precise in comparison to late 20th century

- Parameters can be replaced by functions

Knowledge Modelling with OCML

- Operational Conceptual Modeling Language

  E. Motta, KMI Open University

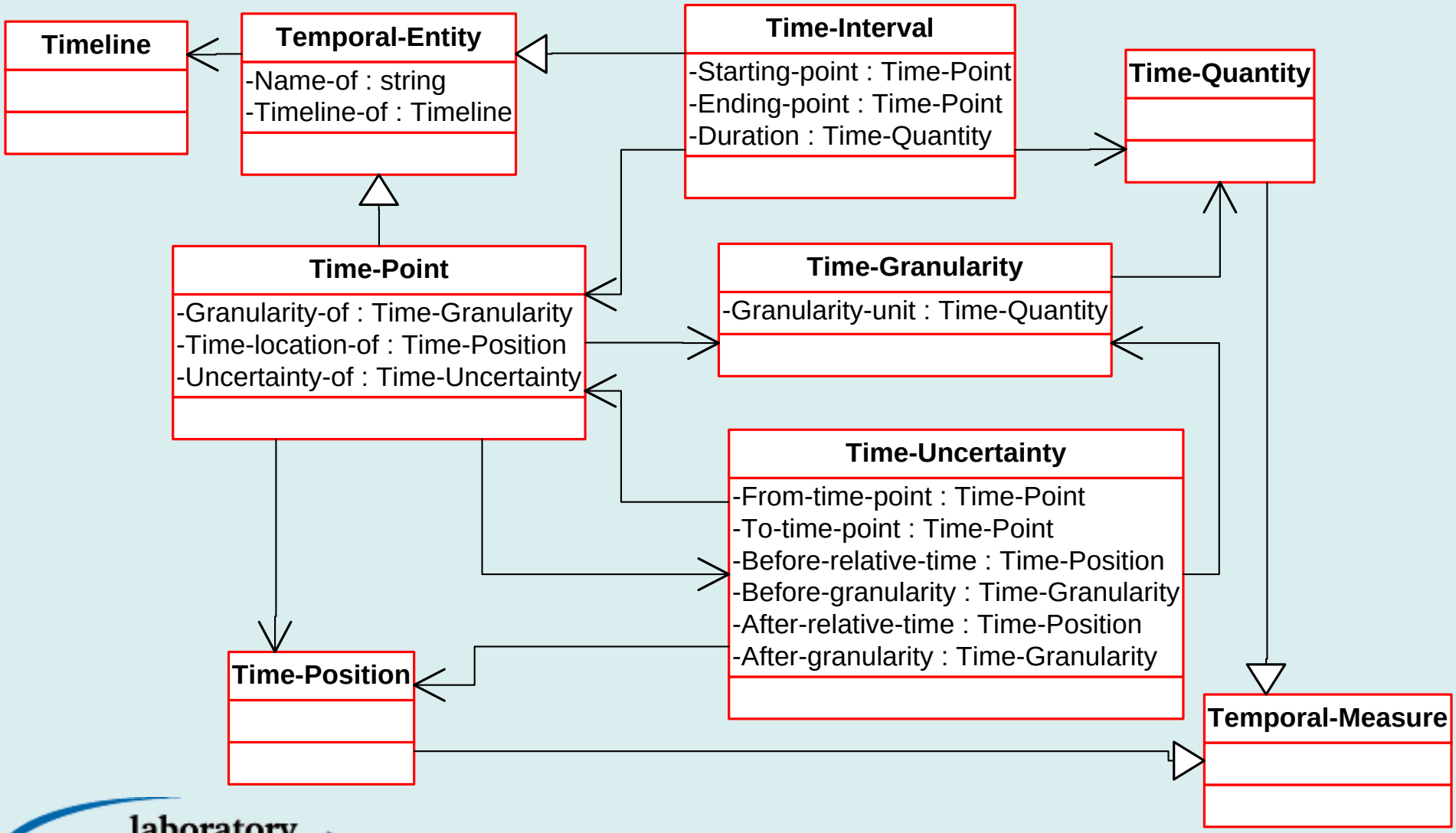
- Implementated in LISP language with CLOS
- Based on Frames (Minsky)
- Proof system
  - Inheritance
  - Backtracking
  - Functional evaluation
  - Procedures

- Modelling approaches: *object-oriented* and *relation based*

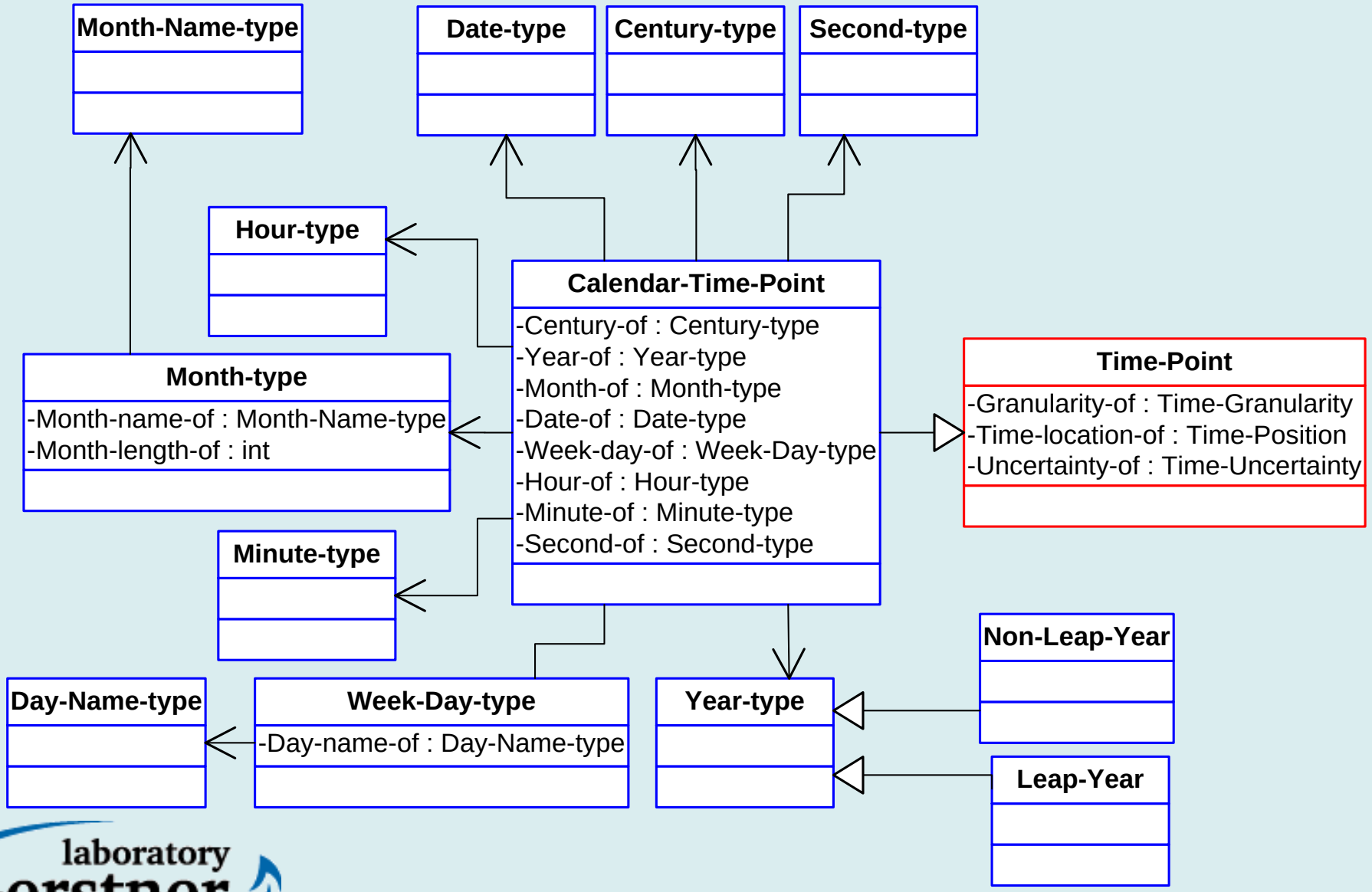
Temporal Reasoning Engine

- Inference capabilities of OCML language
- Temporal coordinate system of *Common LISP*
  - Temporal scale zero ~ 1.1.1900 0:00:00 UTC
  - Shortest interval: second
- Decoding and encoding functions, extension to history
- Property *timeline-of* (*temporal-entity)*
  - Different kinds of temporal entities
  - Multiple timelines for temporal entities are allowed
  - Constraining queries by a timeline of interest
  - Kind of namespaces or stereotypes
- Time point and time interval relations, rules, and functions respecting both time granularity and uncertainty

Temporal Ontology Classes



Calendar Time Point



Constraint Satisfaction

- General constraints that should always be satisfied, when working with temporal entities:

- Example: *transitivity* of functions *before* and *equals*:
  - *t1 before t2 and t2 before t3* $\Rightarrow$ *t1 before t3*
  - *t1 equals t2 and t2 equals t3* $\Rightarrow$ *t1 equals t3*

- To prevent model inconsistency, corresponding transitive closures have to be taken into account e.g. via additional axioms

- When adding new facts, corresponding constraints are checked

Simple Examples (1) – *Emperor's life*

Time Points:

```
(def-instance Charles-IV-birth Calendar-Time-point
  ( (date-of 14) (month-of 5) (year-of 1316)
    (granularity-of day-granularity)))
(def-instance Charles-IV-start-reign Calendar-Time-point
  ( (date-of 26) (month-of 8) (year-of 1346)
    (granularity-of day-granularity)))
(def-instance Charles-IV-death Calendar-Time-point
  ( (date-of 29) (month-of 11) (year-of 1378)
    (granularity-of day-granularity)))
```

Intervals:

```
(def-instance Reign-Charles-IV Time-interval
  ( (starting-point Charles-IV-start-reign)
    (ending-point Charles-IV-death)))
(def-instance Life-Charles-IV Time-interval
  ( (starting-point Charles-IV-birth)
    (ending-point Charles-IV-death)))
```

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Simple Examples (2) - *Around the year 470*

Uncertainty Parameter:

```
(def-instance param-around-unc time-parameter((value-of 10)))
```

Time Uncertainty:

```
(def-instance Around-a-Year Time-Uncertainty
  ( (Before-relative-time param-around-unc)
    (Before-granularity year-granularity)
    (After-relative-time param-around-unc)
    (After-granularity year-granularity)))
```

Uncertain Time Point:

```
(def-instance Sokrates-Birth Calendar-Time-point
  ( (year-of 470) (granularity-of year-granularity)
    (uncertainty-of around-a-year)))
```

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Time Inference

Knowledge base: All the periods of reign of Czech kings

Intention: Find the Czech King ruling immediately after Ferdinand III the time interval of

Query:

```
(ocml-eval
  (findall ?a
   (and    (timeline-of ?a Kings)
           (meets Ferdinand-III ?a))))
```

Result: King Leopold I

```
(LEOPOLD-I)
```

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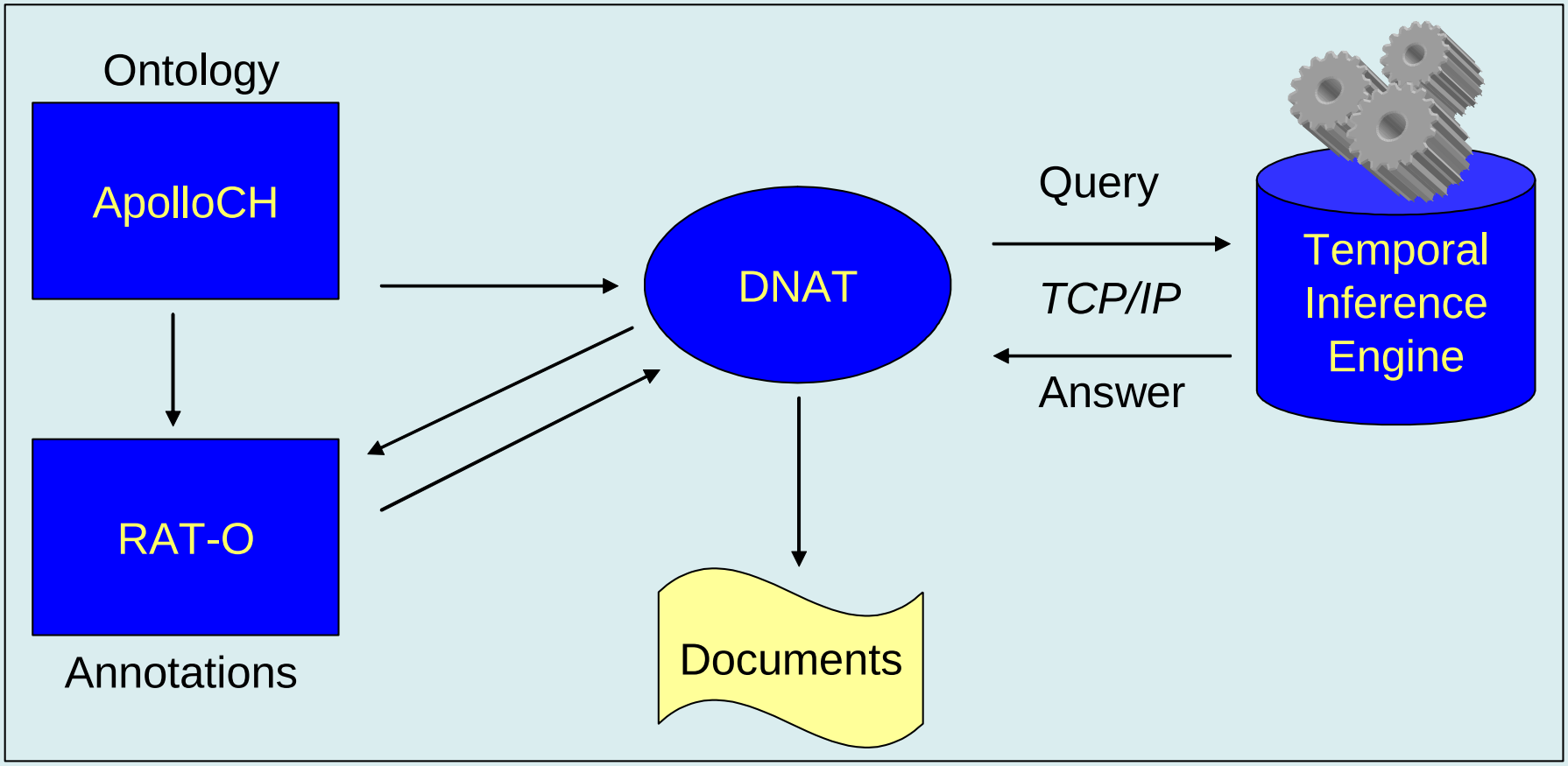
Coverage of Statement Categories

ID	*Statement Category* / Example	Regular DBMS	Possibilistic DB	Temporal Theory in OCML	Notes
1	***Exact and precise*** January 12, 2004, 12:30:00	**Regular data**	**Regular data**	**slot time-location-of**	
2	***With higher granularity*** January 12 2004	N/A	N/A	**slot granularity-of**	
3	***Incomplete*** January 12, 12:30:00	N/A	N/A	**relevant slots used**	*time-location-of* not filled in
4	***Uncertain with absolute specification*** Between February 12 and February 13, 2004	N/A	**Date within interval**	**slot uncertainty-of**	using *from-time-point, to-time-point*
5	***Uncertain with relative specification*** around February 12, 2000; before 13th century	N/A	**Operator applied on date**	**slot uncertainty-of**	using *before-relative-time, after-relative-time*
6	***Referencing other temporal statements*** the period before the WWII, during the reign of the King Charles IV	N/A	N/A	**slot uncertainty-of**	using *from-time-point,* and *to-time-point*
7	***Missing or unknown temporal information***	**using NULL**	**using NULL**	**instance with empty slots**	

Annotation (CIPHER Knowledge Framework)



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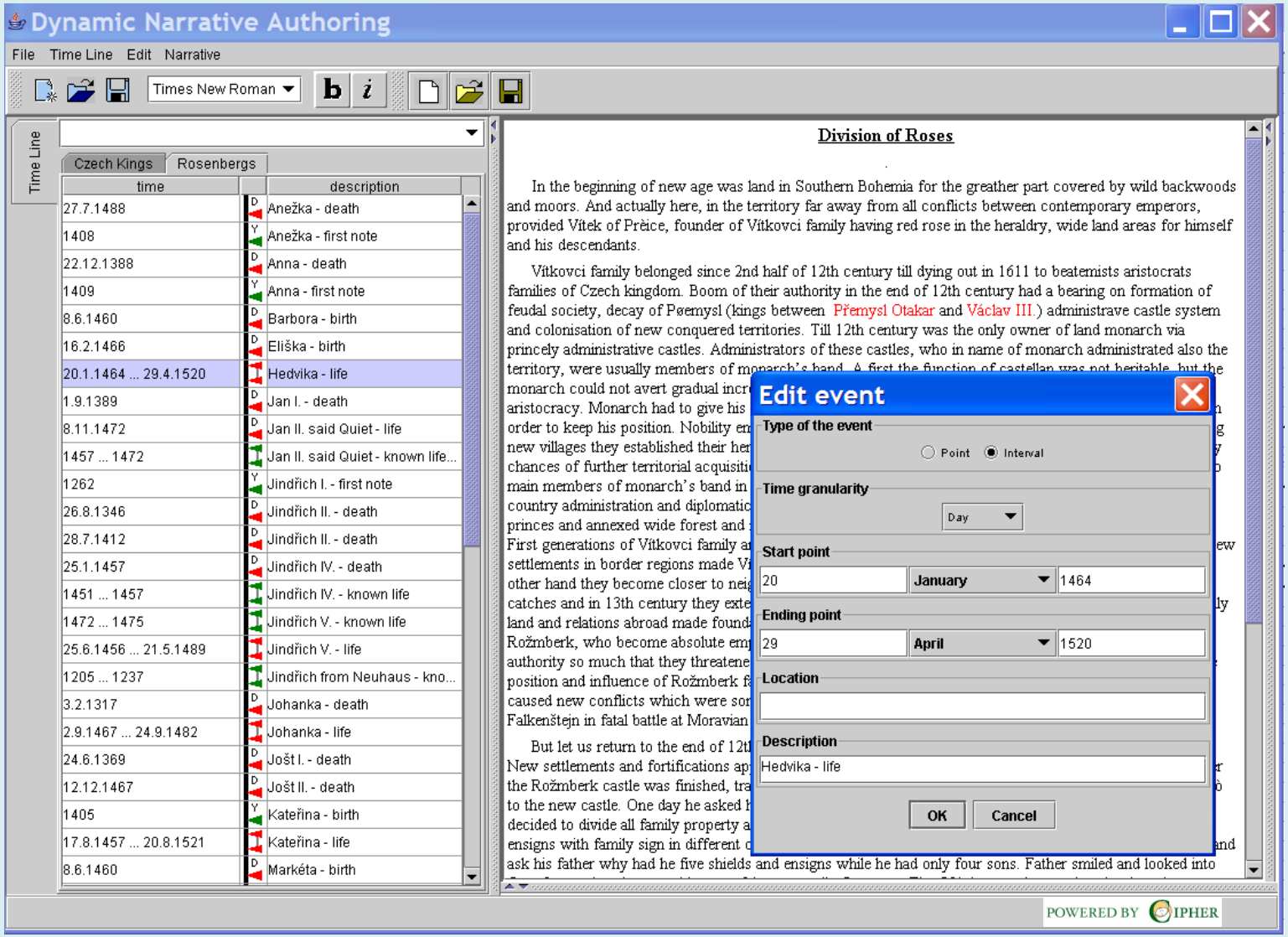
CIPHER
ommunities of Interest Promoting Heritage of European Regions

Authoring with DNAT



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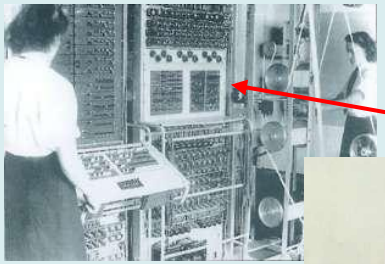
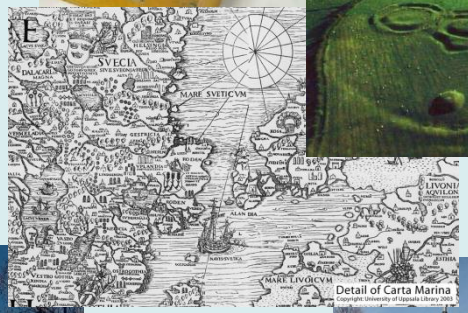
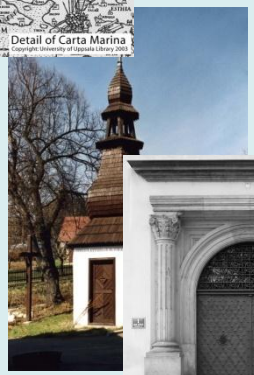
Annotation: Stories and Narratives

- *Story*
  - Set of facts, events, and knowledge about a given theme collected
- *Telling a story*
  - Choose facts, events (knowledge) on a given theme that best support his subjective statements or conclusions and passes over those of “lower importance”
  - *Interprets* the story – creates a realization of a story, a narrative
- *Narrative*
  - One of many possibly realizations of a story in terms of text or speech
- *Story views* of the same story
  - may differ not just in writing or literary form but also in the number of details incorporated in a particular story view (i.e. narrative)
  - A past event including historical context within the borders of either world or regional history
- Different parallel series of historical events are supported using the organization of events into *timelines*
  - *Temporal inference engine:* processing facts and queries including timeline info
- *Ontology of actions* for intrinsic relations
  - Based on 13 abstract classes to classify every possible action by Roger Shank

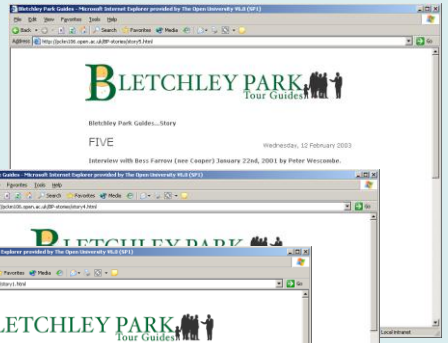
Heritage Objects

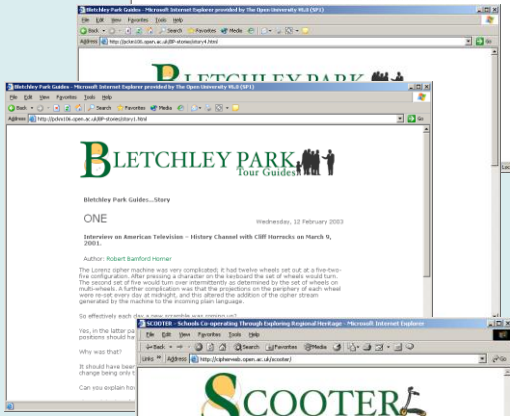






Text





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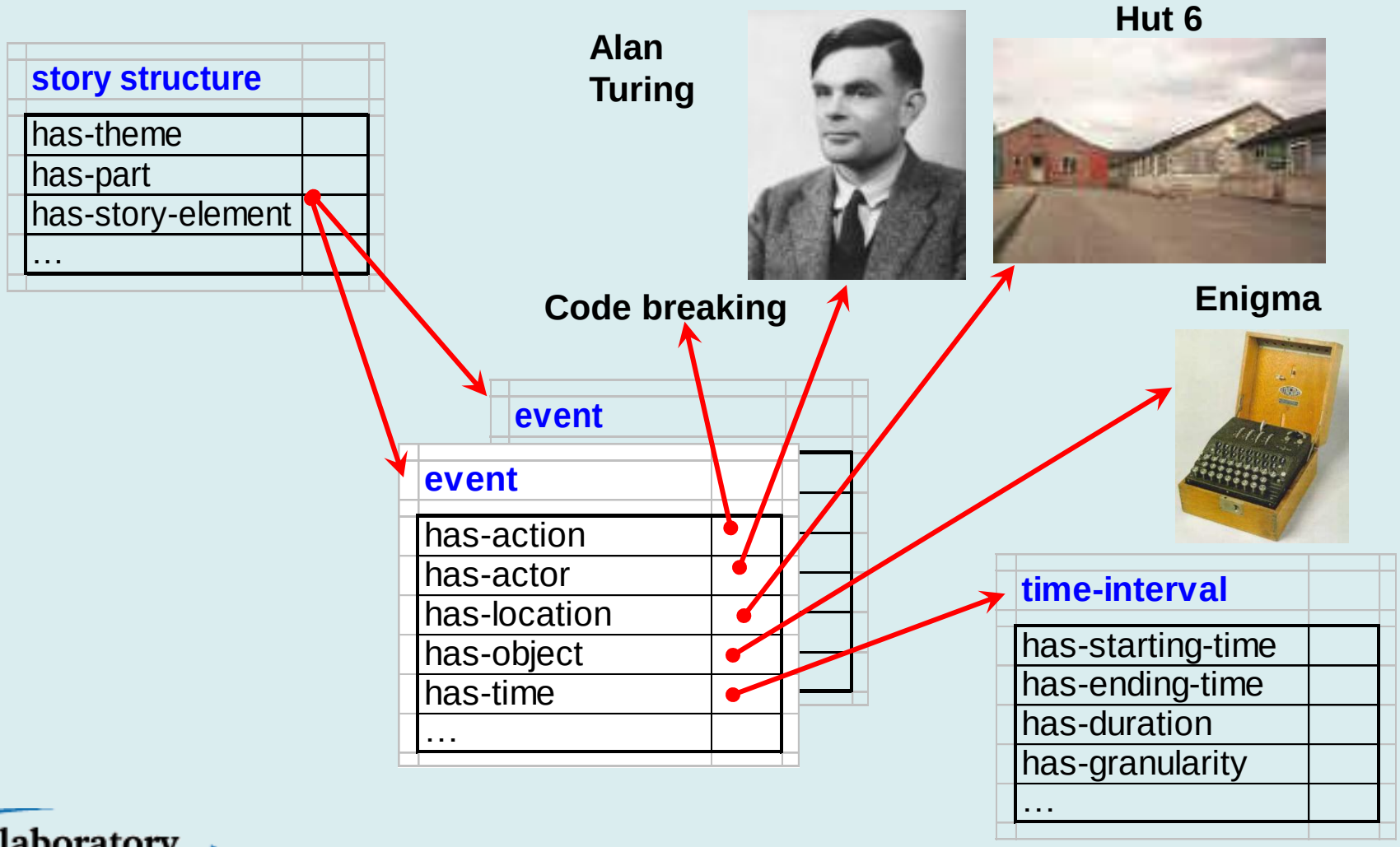
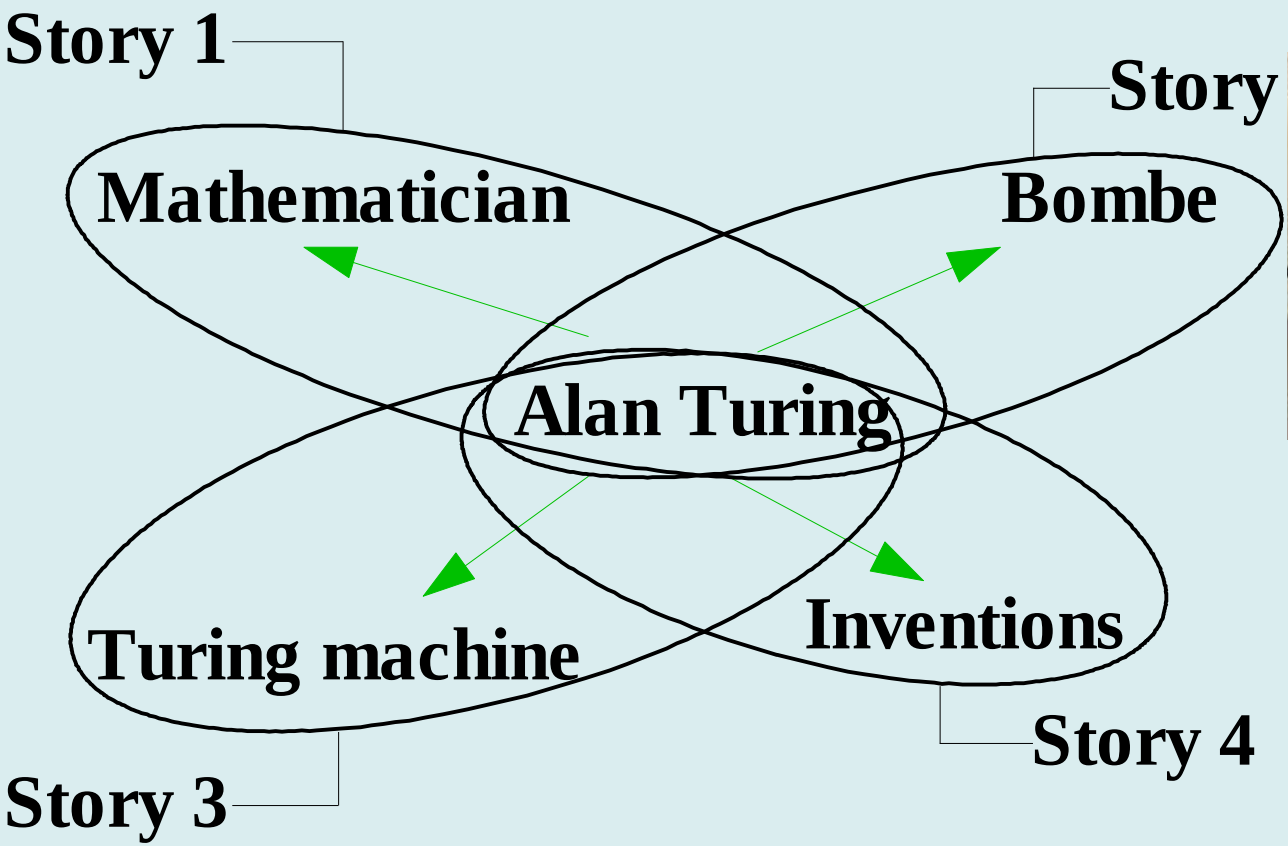
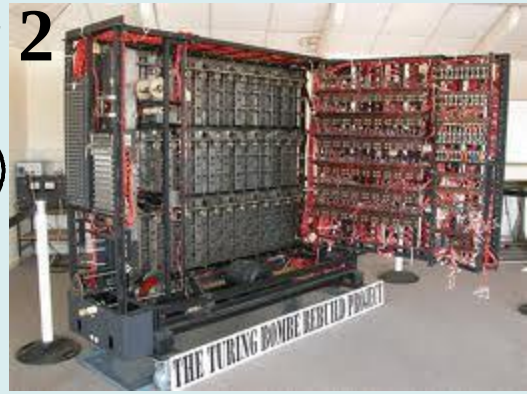
Document Structure

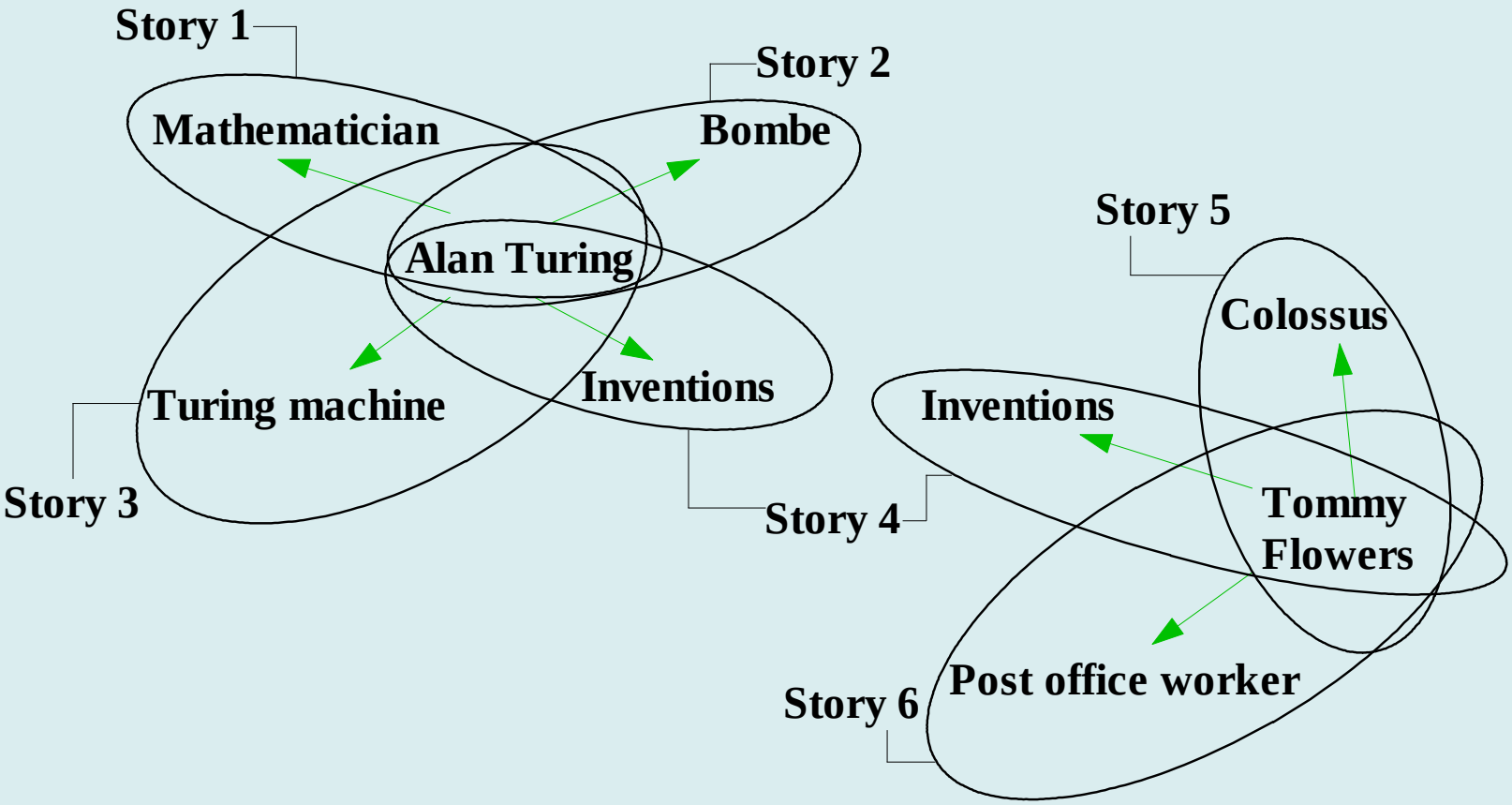


Concept Understanding

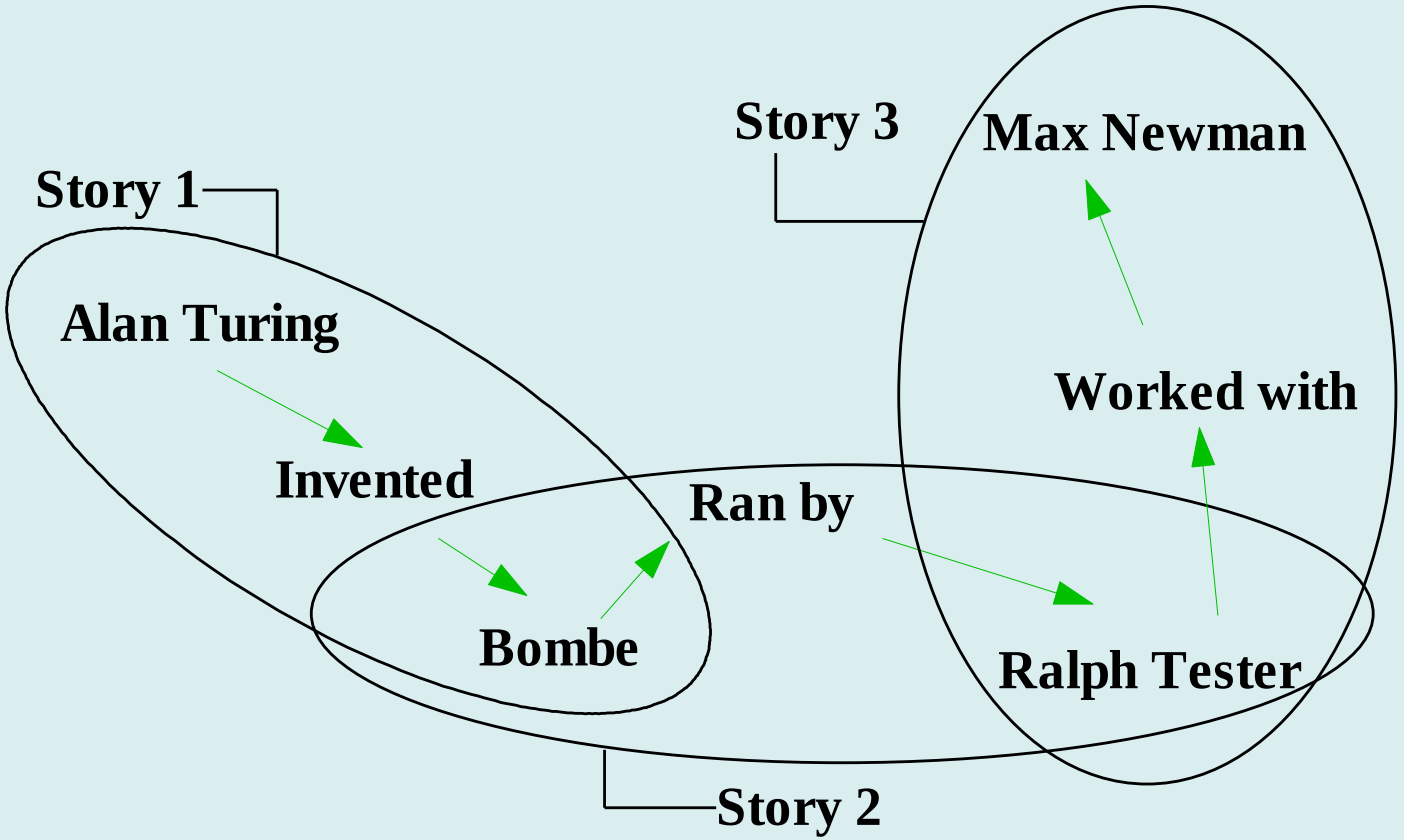




Concept Comparison



Concept Relationships



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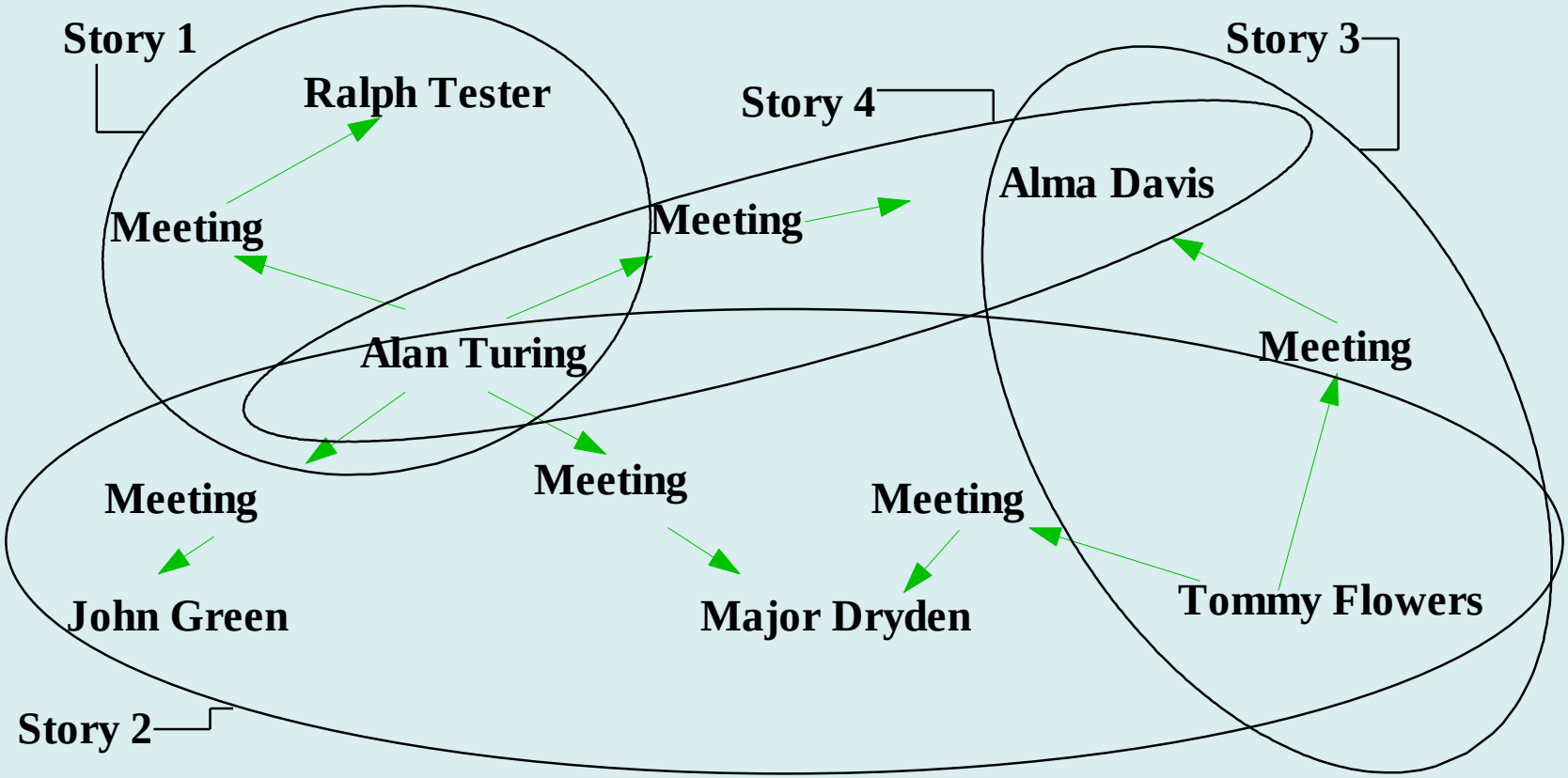
Event Mapping



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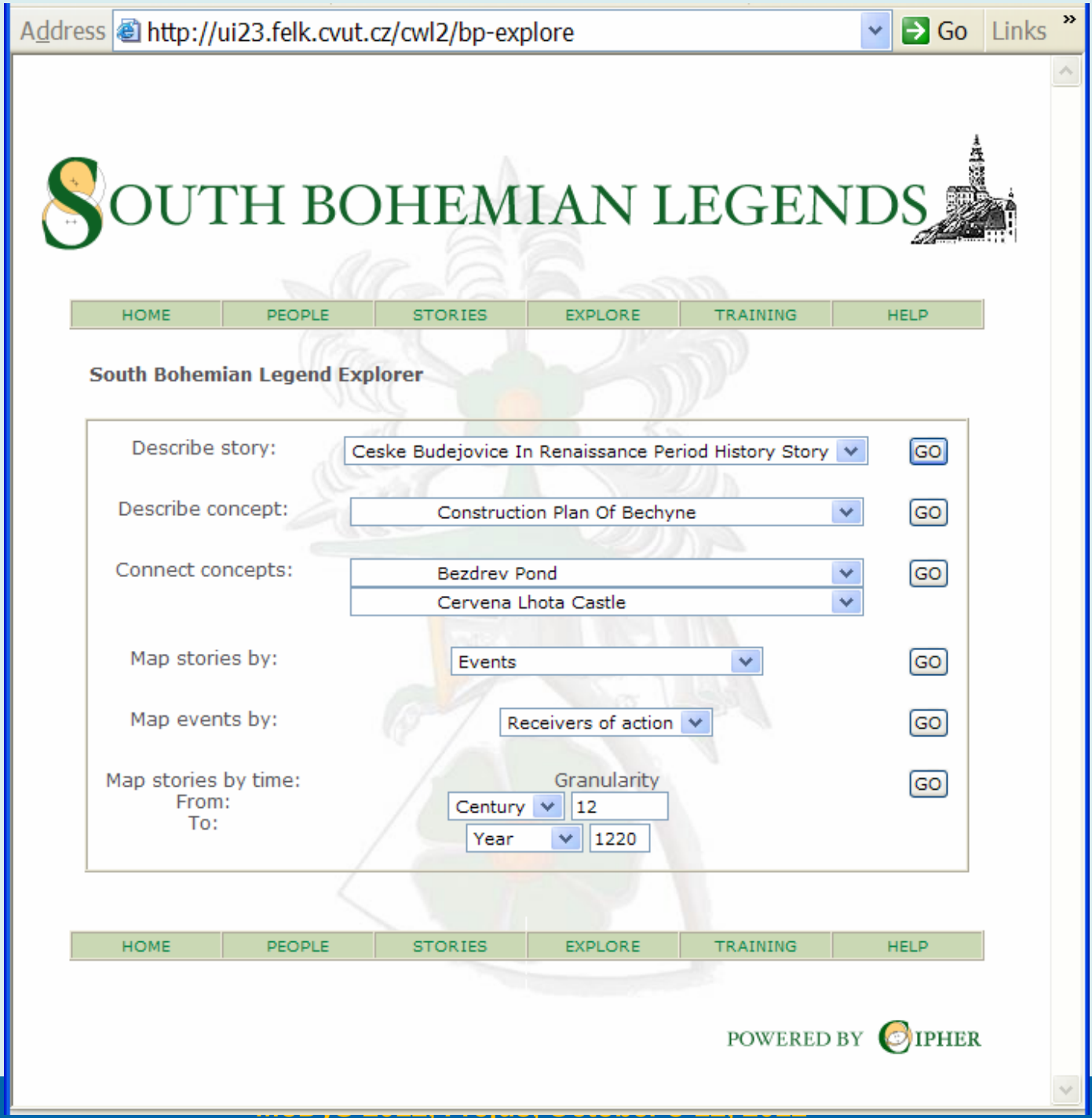
Story Fountain

Around 350 Temporal Entities



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Story Fountain Results

Year 1205 — DEATH-OF-JINDRICH
Classified as Death
Event locations Jindrichuv Hradec Town
Receivers of action Jindrich Of Hradec
Time specifications Year 1205

Jindrichuv Hradec and the Ghost of Hradec
Story Description: JINDRICHUV-HRADEC-GHOST-STORY

By: Pavel Hajek
Date: Tuesday , 17 February 2004. 15:7

Year 1205 — BIRTH-OF-JINDRICH
Classified as Birth
People or groups Vitek Of Prcice
Receivers of action Jindrich Of Hradec
Time specifications Year 1205

First Third Of 13th Century — FOUNDATION-OF-HRADEC-CASTLE
Classified as Production
People or groups Jindrich Of Hradec
Event locations Jindrichuv Hradec Town
Receivers of action Jindrichuv Hradec Castle
Time specifications First Third Of 13th Century

Second Half Of 12th Century — ACQUIRING-TERRITORY-BY-VITEKS
Classified as Acquisition
Event locations Southern Bohemia, Southern Moravia
People or groups Vitek Of Prcice, Vitek Iii, Vitek Of Krumlov, Vitek Of Landstejn
Time specifications Second Half Of 12th Century

Year 1195 — FOUNDATION-OF-VIMPERK-CASTLE
Classified as Production
People or groups Albrecht Iii Of Luk
Receivers of action Vimperk Castle
Time specifications Year 1195

The History of Vimperk
Story Description: VIMPERK-CASTLE-AND-TOWN-STORY

By: Pavel Hajek
Date: Wednesday , 9 June 2004. 18:37

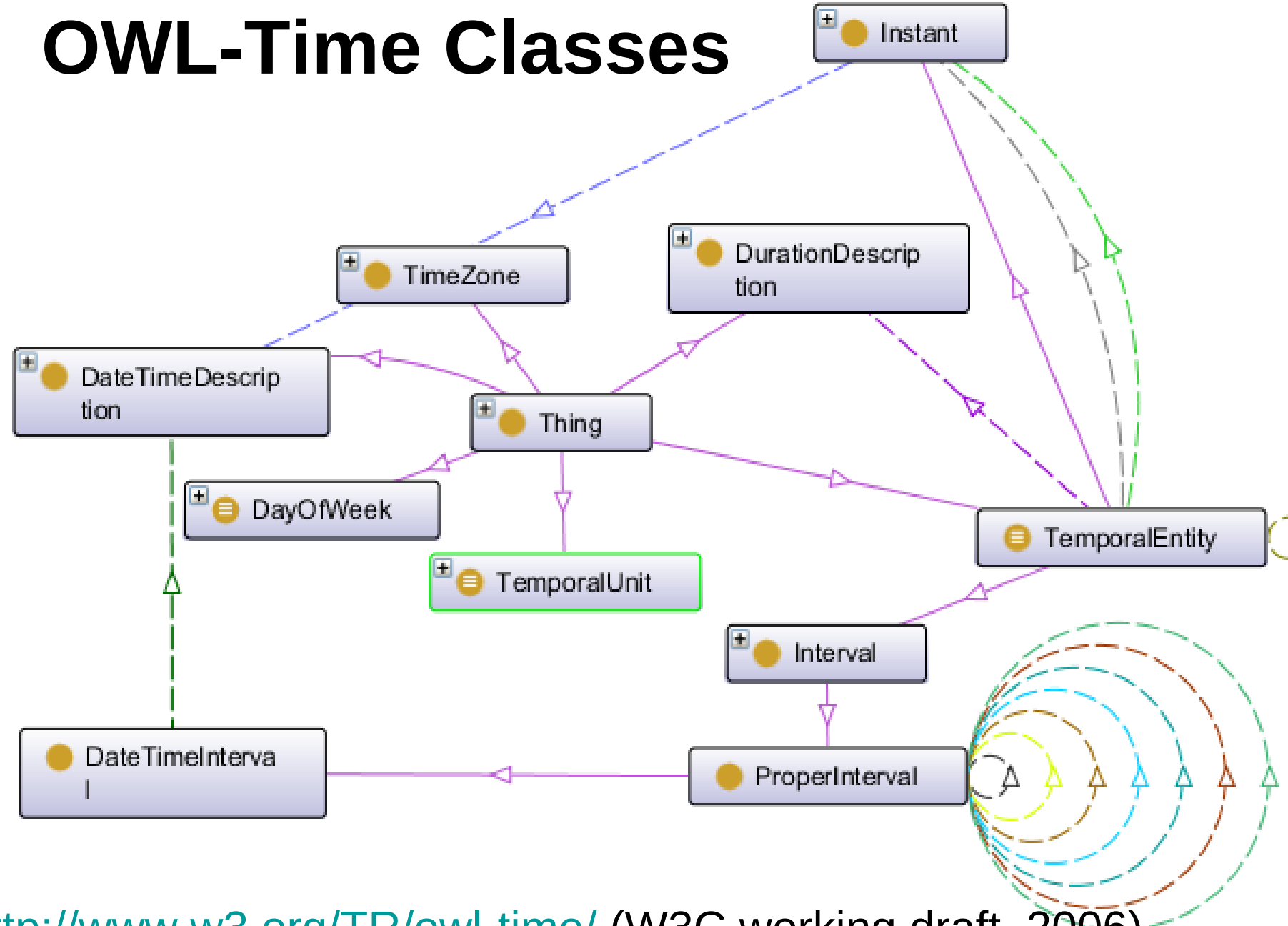
Year 1174 — FOUNDATION-OF-KLASTEREC-VILLAGE
Classified as Production
People or groups Benedictian Worker Monks
Receivers of action Klasterec Village
Time specifications Year 1174

Somewhere Between 1174 1195 — FOUNDATION-OF-VIMPERK-TOWN
Classified as Production
People or groups Benedictian Worker Monks
Event locations Vimperk Town
Receivers of action Vimperk Town
Time specifications Somewhere Between 1174 1195

Web Ontology Language (OWL)
OWL 2, Description Logic

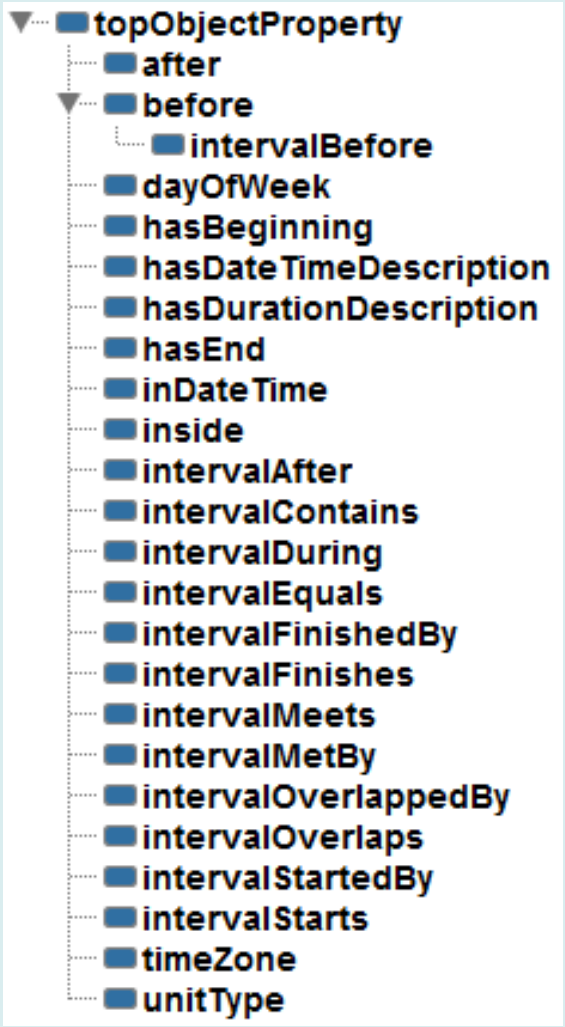
- W3C Recommendation (2004, 2009)
  for Semantic Web
- OWL DL supports those users who want the maximum expressiveness while retaining computational completeness
  - Based on Description Logic
  - Well defined semantics
  - Allows inference
  - Known reasoning algorithms
  - Available reasoners (e.g. FACT++, Pellet, HermiT, Racer Pro)

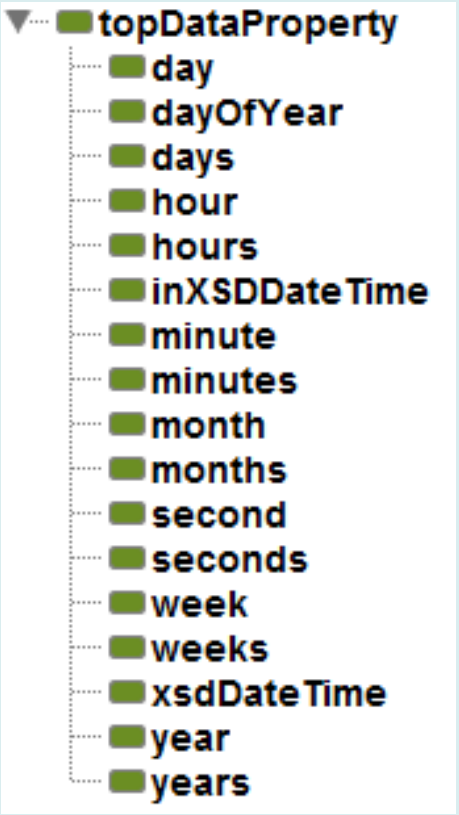
OWL-Time Classes



http://www.w3.org/TR/owl-time/ (W3C working draft, 2006)

OWL-Time Properties



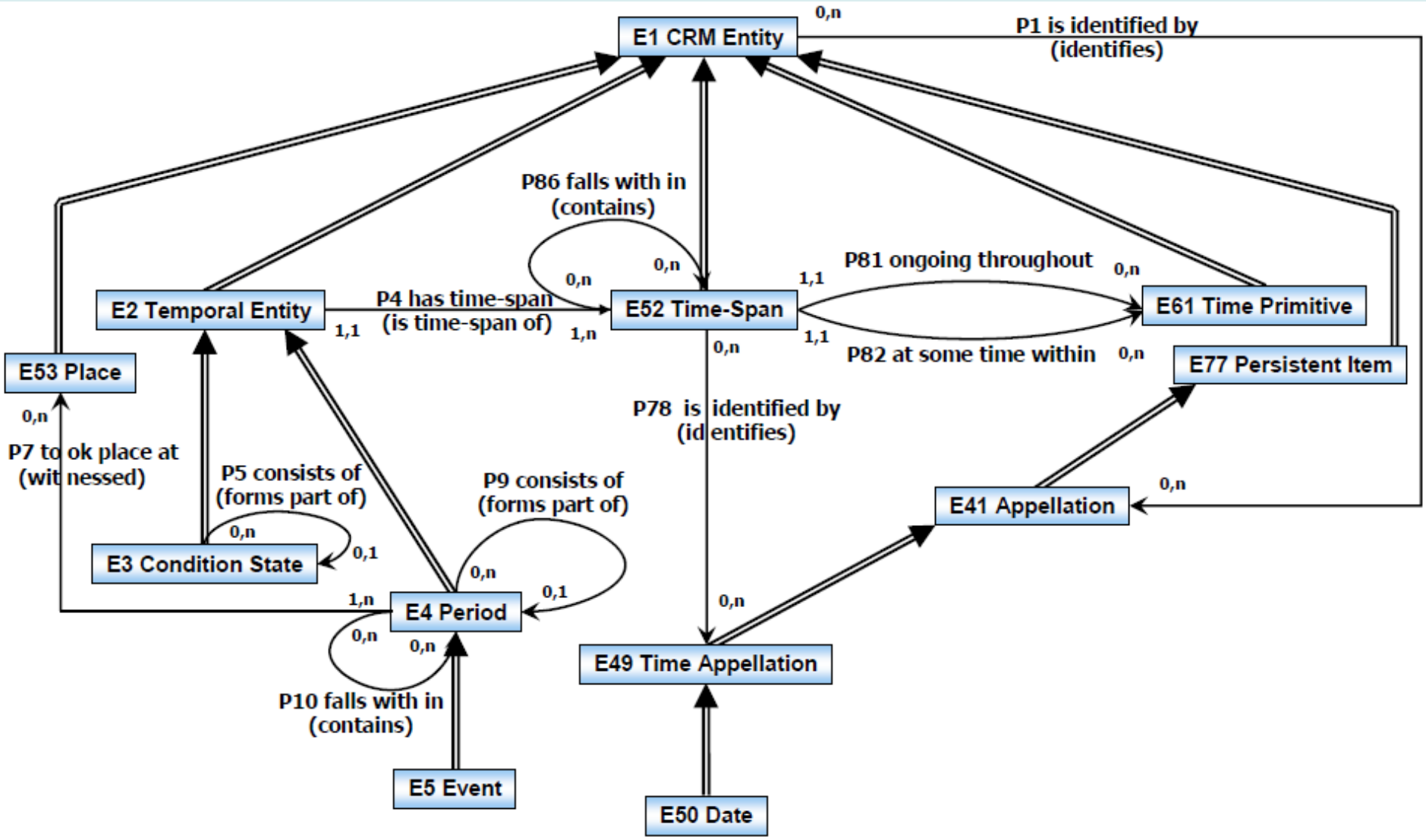


Ontology Inference vs. Relational Database Search

- Dynamically changing knowledge structure
  - Add new knowledge
  - Revise existing knowledge
- Parameterized queries utilizing ontology taxonomy structure (flexible tree selection)
- Parameterized relationships (in DB, schema querying would be necessary)

- Possibility to represent ontology in a relational database
  - OWL2 QL Profile (limited OWL 2 sub-language)
  - Sound and complete conjunctive query answering in LOGSPACE with respect to the size of the data

CIDOC – ICOM Int. Council of Museums Conceptual Reference Model



Other Related Approaches

- Theoretical temporal formalisms
  - Temporal Logics
  - Temporal Ontology
    - Zhou and Fikes; TimeML
    - DAML-Time
  - Temporal Granularity (Hobbs, Bettini)
- Temporal reasoning and inference
  - SRI's New Automated Reasoning Kit (SNARK), Tools for temporal logic of actions (TLA)
  - Assumption Based Evidential Language (ABEL)
  - WebCal (Ohlbach)

Temporal Ontology Challenges

- Large range of calendars can be included in the inference system by including the corresponding date transformation rules.
- Functionally variable relative uncertainty types for the statements like *About*, which can be different in the recent history and bigger for much earlier times.
- Recurring temporal entities might be represented by *non-convex time intervals* possibly containing “holes”, e.g. with respect to their duration.
- Web ontology language (OWL2)
- Combining relational database extension and the ontology-based inference
- OWL2QL and OWL2RL profiles
- Linked Data

Questions & Contact

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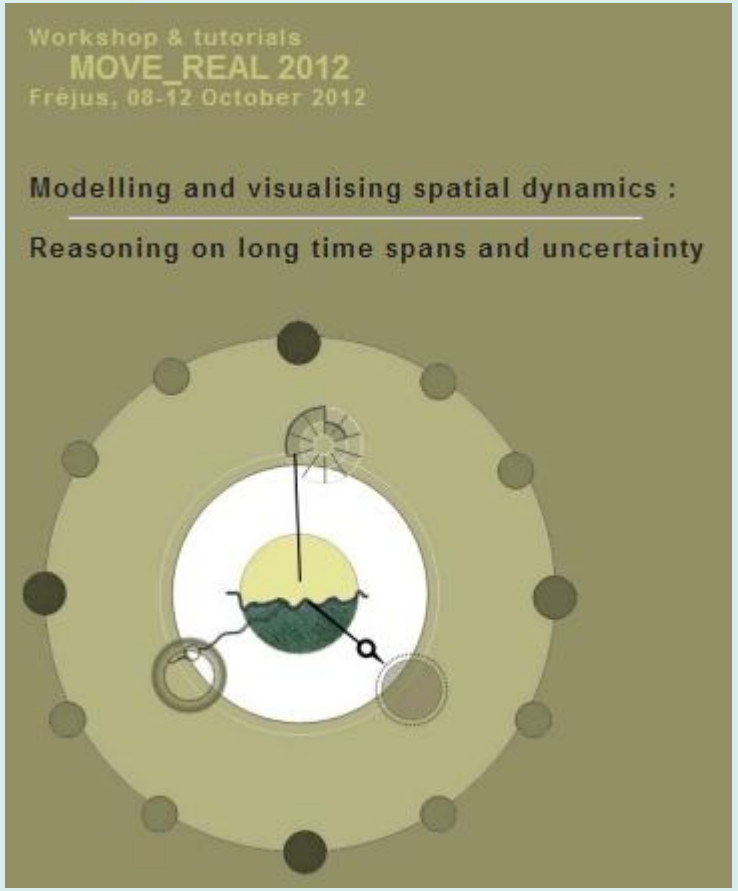

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