It’s About Time

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Time in Natural Language?

- Information Retrieval: “give me the articles from the press one week after the Columbia disaster”

- Question Answering: “was there any shuttle mission in 1987?” (“shuttle accident in ‘86, missions suspended in the following 2 years”)

- Summarization: “give me a short biography on Edward Teller, in chronological order”

- Intelligence: “could US have WMD?” (if the country did things in certain pattern)
Could Mozart & Beethoven meet in Vienna?

“At 14 Beethoven was able to deputize for his teacher. Three years later, recognizing his talent, Prince Maximilian Franz sent him to Vienna to further his education. He would soon return less then four months later on the news that his mother was dying. She passed away on July 17th 1787.”

“Mozart went to Munich to compose the opera late in 1780. Soon after, he was summoned from Munich to Vienna, where the Salzburg court was in residence on the accession of a new emperor. Mozart lived in Vienna for the rest of his life, until he died in 1791.”
Answer?

Beethoven’s trip to Vienna

Mozart’s trip to Vienna

(computer:) ... Yes they could, in 1791, when Beethoven was 17.
(truth is, nobody really knows)
What are Involved?

• NL annotations: DAML Time ontology [Hobbs et al, 02], Timex2, TimeML [Pustejovsky et al 02]...
  • Reasoning efficiency and power?

• Modeling calendars: algebraic representations [Ning et al 02], string-based representation [Wijsen, 00], calendar logics [Ohlbach & Gabbay 98]
  • Nice but how do we account for under-specification and temporal quirks in NL?

• Reasoning: temporal logics [Gabbay et al 94], temporal constraint solving [Dechter, et al 91]...
  • Naive-clock syndrome: time is all but a uniformly distributed clicks
  • Superhuman precision: every time is specified to the limit
## Task 1: Mess of Human Languages

<table>
<thead>
<tr>
<th>Sept. 9, 1987</th>
<th>simple, anchorable</th>
</tr>
</thead>
<tbody>
<tr>
<td>on Wednesday/Wednesdays</td>
<td>interval or point? which Wednesday?</td>
</tr>
<tr>
<td>Wednesday or/and Friday</td>
<td>disjunction/enumeration</td>
</tr>
<tr>
<td>last semester</td>
<td>bizarre temporal units</td>
</tr>
<tr>
<td>today/yesterday/tomorrow</td>
<td>deictic expressions</td>
</tr>
<tr>
<td>last week/Wednesday</td>
<td>shifting with unit/non-unit</td>
</tr>
<tr>
<td>an hour and 30 minutes</td>
<td>versatile quantities</td>
</tr>
<tr>
<td>from now until 1995</td>
<td>intervals</td>
</tr>
<tr>
<td>every week/Wednesday in May</td>
<td>recurrence</td>
</tr>
<tr>
<td>the second Sunday in May</td>
<td>ordinals</td>
</tr>
<tr>
<td>once a day</td>
<td>rate</td>
</tr>
</tbody>
</table>
Task 2: Mess of Human Calendars

• Weird weeks

• Leap years/seasons

• Different timezones/daylight saving times

• Lunar/solar-based calendars

• Holidays!

• New units

“In the West, Easter is celebrated on the Sunday following the full moon next after the vernal equinox (thus, it falls between Mar. 22 and Apr. 25)”
Task 3: Beauty of Constraint Solving (so let’s start here)

Temporal Constraint Satisfaction Problems (TCSP)  
(Dechter, Meiri & Pearl, 1991)

A set of temporal variables $X_i$
Domains of the variables - integers
A set of time-difference constraints $a < X_j - X_i < b$
Satisfy all constraints!

It takes John 30-40 minutes to commute to work, and it takes Fred 20-30 minutes to do so. Today John left home between 7:10 and 7:20, and Fred arrived at work between 8:00 and 8:10. We also know that John arrived about 10-20 minutes after Fred left home.

(adapted from Dechter, Meiri & Pearl, 1991)
TCSP & Shortest Paths

distance graph

minimal network

all-pairs-shortest algorithm

runs in polynomial time!
Minimal Networks
Answer...

• Consistent? Yes iff there’s no negative cycle.
  • “Could Beethoven & Mozart meet?”
    (yes because it’s consistent)

• Minimal set of feasible values for a variable?
  • “What are the possible times of event x?”

• Minimal intervals between two variables?
  • “What are the possible temporal relations between event x and y?”
TCSP in NL?

Problem I: Not all times are created equal

\[ d_{ij} \leftarrow \min(d_{ij}, d_{ik} + d_{kj})? \]

\[ X_i = \text{feb} \Rightarrow \text{“2 months”} \]

\[ X_i = \text{mar} \Rightarrow \text{“60 days”} \]

Problem II: Where is this from?

Problem III: How do you compare/add distances?

Problem IV: How about under-specified times?

“Friday”

Basic services from calendars
Task 2: Calendars

Beethoven’s trip to Vienna

Mozart’s trip to Vienna

calendar (CSP)

E1
T1

E2
T2

E3
T3

E4
T4= {17_day, jul, 1789}

E5
T5=late({1780})

E6
T6

E7
T7= {1791}

[14 years]

[3 years]

[0, 4 months]
Task 2: Calendars

early/mid/late morning
previous/next/every morning

Cover mappings: \( C_{\text{qoy, month}}(1_{\text{qoy}}) = \{\text{jan, feb, mar}\} \)
Time Detective

“Over the long holiday weekend honoring Martin Luther King Jr.'s birthday, the mission managers suspended their meetings, and some participants took time off. They met on the next day, Jan. 21, five days into the flight.”

“The first shuttle mission flew in 1981.”

A time coordinate is a peeking window into the calendar constraint system!
Comparing/adding times

Quickly, which of the following is the earliest?

\[ c_1 = \{1995_{\text{year}}, 1_{\text{qoy}}\} \quad c_2 = \{1995_{\text{year}}, \text{apr}\} \quad c_3 = \{1995_{\text{year}}, \text{feb}\} \]

\[ c_3 < c_2 \quad c_1 < c_2 \quad c_1 \ ? \ c_3 \]

**Rule #1:** only coordinates based on the same grounded chain are comparable.

**Rule #2:** \( x < y \) to be true if and only if every possible \( x \) is earlier than every possible \( y \)

Quickly, add 2 seconds to 23:59:59 on Feb. 28, 2004?

(periodicity provides shortcut.)
Task 1: Messy Languages

(someone got to do it)

• Every temporal expression gives one of the following temporal objects:
  • **Coordinate** (C): Points at certain granularity;
    \{1987_{year}, sep, 9_{day}\}
  • **Quantity** (Q): Polarity neutral duration;
    \{1_{hour}, 30_{min}\}
  • **Enumeration** (E): Set of points (including intervals);
    \[[\{tue\}, \{thu\}]\]
Really Messy Stuff

- Using operators to construct complex objects
  - fuzzy shifting: $\{\{2003_{\text{year}}, \text{sep}\} + |2_{\text{morning}}|\}$
  - intervals: $[\{\text{may}\}: + |2_{\text{month}}|]$
  - ordinals: $\{|2_{\text{sun}}| @ \{\text{may}\}\}$
  - arithmetic recurrence: $[\{\text{bi 1896}_{\text{year}}\}/|4_{\text{year}}|]$
- Using relations to construct complex objects
  $\{(>= 4, <= 5)_{\text{hour}}\}$
Granularity Conversion

- Why does it matter?
  - $\{2003_{\text{year,sep}}\} + |2_{\text{morning}}|$

- What is it?
  - Set of minimal units

- Conversion installs a new set of minimal units into an object.

\[
g(\{2003_{\text{year,sep}}\}) = \{\text{month}\} \quad g(|2_{\text{morning}}|) = \{\text{tod}\}
\]

\[
\rightarrow \{\text{day}\} (\{2003_{\text{year,sep}}\}) = \{2003_{\text{year,sep},(\leq 30, \geq 1)_{\text{day}}}\}
\]
Re-interpretation

Re-interpreting a $C$ into an $E$

$$C \Rightarrow E_{\{\text{day}\}}(\{2003_{\text{year}}, \text{sep}\}) = [i[\min(\rightarrow_{\{\text{day}\}}(\{2003_{\text{year}}, \text{sep}\})) : \max(\rightarrow_{\{\text{day}\}}(\{2003_{\text{year}}, \text{sep}\}))]]$$
$$= [i[\{2003_{\text{year}}, \text{sep}, 1_{\text{day}}\} : \{2003_{\text{year}}, \text{sep}, 30_{\text{day}}\}]]$$

$$C \Rightarrow E_{\{\text{year}\}}(\{2003_{\text{year}}, \text{sep}\}) = [\{2003_{\text{year}}\}]$$
Type System

• Type of an object is $C$, $Q$, $E$ decorated by its granularity

  • type of $\{2003_{\text{year}}, \text{sep}\}$ is $C_{\{\text{month}\}}$

• Operators are typed

  • $+$ (forward fuzzy shifting):

    $$E_{\rightarrow g(u(op_2))} \times Q_{g(op_2)} \rightarrow C_{\rightarrow g(op_2)}$$

• Type coercion kicks in!
Fuzzy Shifting

Type of ‘+’: \( E \rightarrow_{g(u(op_2))} Q_{g(op_2)} \rightarrow C \rightarrow_{g(op_2)} \)

\[ e + q := \{ \max(e[−1]) \oplus u_1 n^1 \ldots \oplus u_m n^m, c_q \} \]

Quantity \( q \) can be broken into pure-unit quantity, and a set of implied constraints

\[ |2_{\text{morning}}| \iff u(|2_{\text{morning}}|) = |2_{\text{day}}| \]
\[ \{\text{morning}\} \]

\[ \{\{2003_{\text{year}}, \text{sep}\} + |2_{\text{morning}}|\} \]
\[ = \{ \max([i[\{\text{sep}, 1_{\text{day}}\}] : \{\text{sep}, 30_{\text{day}}\}][−1]) \oplus_{\text{day}} 2, \{\text{morning}\}\} \]
\[ = \{\{\text{sep}, 30_{\text{day}}\} \oplus_{\text{day}} 2, \{\text{morning}\}\} \]
\[ = \{\text{oct}, 2_{\text{day}}, \text{morning}\} \]
Temporality Focus

• Represent the current temporal focus as anonymous variables ‘_’:
  
  • “tomorrow”: \{- + |1_{day}|\}
  • “today”: \{- + |0_{day}|\}
  • “next week”: \{- + |1_{week}|\}
  • “next Wednesday”: \{- + |1_{wed}|\}
  • “Wednesday” (future): \{+|1_{wed}@{bi _}\}

• Two assumptions:
  
  • Initial temporal focus is always available
  • Temporal focus shifts throughout discourse
Summary

Beethoven’s trip to Vienna

Mozart’s trip to Vienna

E1
T1
[14 years]
event
temporal object (variable)

E2
T2
[3 years]

E3
T3
[0,4 months]

E4
T4= {17_day, jul, 1789}

temporal object (variable)

E5
T5=late({1780})

E6
T6
[0, ]

E7
T7=\{1791\}

E8
T8
[0, ]

E9
T9
[0, ]

E10
T10=late({1780})

calendar (CSP)
Are We There Yet?

• Analyze complexity impact brought by the operators and relations
• Evaluation!
• Improve efficiency of calendar operations by restricting the constraint languages (i.e., intensional constraints)
• Learning tasks
  • Temporal focus shifting
  • Deciding whether a timex is a generic
    “Our youth today need our prayers more than ever.”
Thank you!
Constraint Satisfaction Problem (CSP)

V: a set of variables
D: domains of the variables
C: a set of constraints
Satisfy all constraints!

Solving methods:
arc-consistency
path-consistency
tree-search with backtracking etc...

Map-coloring problem
System Overview

Texts → Parser → NET → WordNet

Node Parser

Syntax/Semantics Interface

Focus Manager → Evaluator

Facts → TDB

Queries → Reasoner → Answers

offline

online