From *Language to Time*: A Temporal Expression Anchorer

Benjamin Han, Donna Gates and Lori Levin

Language Technologies Institute
Carnegie Mellon University

This work is supported by the Defense Advanced Research Projects Agency (DARPA) under the project RADAR.
Introduction

- Many Natural Language applications need to understand the semantics of *temporal expressions*.

- We developed a constraint-based meaning representation TCNL (Time Calculus for Natural Language).

- We developed system TEA (Temporal Expression Anchorer) for normalizing temporal expressions.

- Experiments on emails showed promising results.
Date: Thu, 11 Sep 1997 00:14:36 -0500

I have put an outline out in the n10f1 OpReview directory... (omitted)

We have very little time for this. Please call me Thursday night to get clarification. I will need graphs and prose in files by Saturday Noon.

– Mary

ps. Mark and John, I waited until AFTER midnight to send this.
**Application II: QA**

**Mozart’s Activity 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 within two weeks on the news that his mother was dying. She passed away 3 months later on July 17, 1787.

“Mozart went to Munich to compose the opera late in 1780. The next year, 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.”

**Beethoven’s trip to Vienna**

**Mozart**

- $T_5 = \{1780 \text{ year}\}$
- $T_6 : \{1780 \text{ year}\} + 1 \text{ year}$
- $T_7 = \{1791 \text{ year}\}$

**Beethoven**

- $T_4 = \{17 \text{ day, } \text{ Jul}, 1787 \text{ year}\}$
- $T_1' \{1784 \text{ year}\}$
- $T_2 \{1770 \text{ year}\}$
- $T_3 \{1784 \text{ year}\}$
- $T_4 \{17 \text{ day, } \text{ Jul}, 1787 \text{ year}\}$
- $T_5 = \{1780 \text{ year}\}$
- $T_6 : \{1780 \text{ year}\} + 1 \text{ year}$
- $T_7 = \{1791 \text{ year}\}$

Yes they might have met in Vienna!
Temporal Expressions

• 4 types of expressions
  • **Explicit**: Immediately anchorable ("June 2005").
  • **Deictic**: Anchorable w.r.t. the *speech time* ("tomorrow", "last year")
  • **Relative**: Anchorable w.r.t. the *temporal focus* - time central to the discourse ("on Friday")
  • **Durational**: Certain length in time ("two days", "less than two hours")
Temporal Expressions are Complex...

- Many different temporal terms
  summer, quarter, ...

- Granularity matters
  \( \text{tomorrow} \neq \text{now.day} + 1 \) (now = June 15, 2006 14:00)

- Often under-specified (next slide)
... Especially for Relative Expressions

- Dependency on speech time (tense)
  - “The company announced on Wednesday...”
  - “The company will announce on Wednesday...”

- Dependency on focus
  - “Are you free on Wednesday?”
  - “Let’s meet next week. How about Wednesday?”

- Hour ambiguity (appears frequently in emails)
  - “I’ll be in school at 9-12.”
... I will need graphs and prose in files by Saturday Noon.

Identify verb chunks and tense/aspect

Build TCNL representation

Evaluate TCNL formulae

Date: Thu, 11 Sep 1997 00:14:36

[min/19970913T12????]
Temporal Expression Anchorer

Calendar Model
  - Constraint Solver

Finite-state Parser
  - TCNL formulae

Discourse Module
  - instantiated and disambiguated TCNL formulae

Evaluator Module
  - sentences with anchored temporal expressions (using ISO8601-like format)

TEA

sentences with temporal expressions
Time Calculus for Natural Language

- TCNL has two components
  - A (typed) representational language.
  - A constraint-based calendar model that supports the representational language.

- Features
  - Calendar-agnostic: new temporal units can be added.
  - Captures the *intensional* meaning of temporal expressions.
  - Exposes contextual dependency by using variables.
  - Type system and operators make granularity conversion and re-interpretation a transparent process.
TCNL: Types

• Three types in TCNL:

• **Coordinates**: Loosely a time point
  “September 2005”: \{sep, 2005\_year\}

• **Quantities**: Loosely a duration
  “2 days”: \|2\_day\|

• **Enumerations**: Sets of coordinates
  “Wednesday and Friday”: \[\{\text{wed}\}, \{\text{fri}\}\]
  “from Wednesday to Friday”: \[\{\text{wed}\}::\{\text{fri}\}\]
More Complex Stuff

• Variables

• Speech time (now): “tomorrow”: \{now+|1\_day|\}

• Temporal focus (_): can move in a discourse
  “Friday the next week”: \{fri, _+|1\_week|\}

• Operators: +/-, @, etc.
  “the 2nd Sunday in May”: \{|2\_\{sun\}|@\{may\}\}

• Relations: <, >, f, d, de, etc [Allen 1984]
  “a Friday before yesterday”: \{fri, < \{|-_|1\_day|\}\}
Coordinate Prefixes

• **Focus** prefixes: +/-/\^  
  - Specifies the relation with focus for *non-generics*.  
    “on Friday” = +\{fri\} is evaluated as  
    \{1{fri} | @\{>= _\}\}  
  - \^ is the *saliency* prefix: try + and − and returns the interpretation closest to the focus.

• **Tense** prefixes: f/p  
  - Specifies the relation with the speech time.  
    “Friday” (future) = f\{fri\} is evaluated as \{fri,>=now\}  
  - “on Friday” (future) = +f\{fri\} =  
    \{1{fri} | @\{>= __, >= now\}\}
Re-interpretation and Granularity Conversion

• “the first week of May, 2006”
  = \{ | l\_week | @\{may, 2006\_year\} \}

• Type requirement of @ (ordinal operator) is
  \( Q \times E \rightarrow C \); granularity requirement is \( g(\text{RHS}) \leftarrow g(\text{LHS}) \)

• Re-interpret coordinate \{\text{may, 2006\_year}\} of granularity month as an enumeration in week:
  \[
  [\{104633\_week\} : \{104637\_week\} ]
  \]

• Choose the first element: \{104633\_week\}
Calendar Model

Year component
- Year
- Month
- Day
- Time-of-day
- Hour
- Minute
- Second

Week component
- Week
- Day-of-week
- Time-of-week

X component

unit constraints
alignment constraints
is-measured-by relation
is-periodic-in relation

(* marks a representative)

Benjamin Han, Donna Gates and Lori Levin, TIME 2006, Budapest, Hungary
“Friday the 13th”

Constraint Propagation (AC-3) and Distribution

unit constraints
alignment constraints
is-measured-by relation
(* marks a representative)
is-periodic-in relation
Comparing Times

Anchor path of \text{hour} = \langle \text{year, month, day, hour} \rangle

Anchor path of \text{time-of-day} = \langle \text{year, month, day, time-of-day} \rangle

“7am, February 29, 2004” is earlier than “afternoon on February 29, 2004”
Add = Iterate-and-test

Add \( x \) days to “Feb 29, 2004”
Finite-State Parsing

- Identify the nearest verb chunk and its tense/aspect.
- Partial semantics (granularity) is available to the parser.

"Tuesday before Christmas"
= \{\text{tue}, < \{25_{\text{day}}|@\{\text{dec}\}\}\} \quad \ldots 1

"Tuesday before 6pm"
= \{< \{\text{tue},18_{\text{hour}}\}, \text{de} \{\text{tue}\}\} \quad \ldots 2

Pattern "X before Y":
- If granularity of X is coarser than Y, choose 2.
- Otherwise choose 1.
Discourse Processing

- Instantiate \texttt{now} and \_ (focus).
\[
\{-+\mid 2_{\text{day}}\} = \{\{2006_{\text{year}}, \text{jun}, 5_{\text{day}}\}+\mid 2_{\text{day}}\}
\]

- Disambiguation

  \begin{itemize}
  \item Coordinate: pick the closest to the focus
  \[
  \{3_{\text{hour}}\} \mid \{15_{\text{hour}}\} \rightarrow \{15_{\text{hour}}\} \quad (\text{focus: 1pm})
  \]

  \item Enumeration: pick the shortest one that begins closest to the focus
  \[
  [((\{3_{\text{hour}}\} \mid \{15_{\text{hour}}\}) : (\{5_{\text{hour}}\} \mid \{17_{\text{hour}}\}))] \rightarrow
  [\{15_{\text{hour}}\} : \{17_{\text{hour}}\}] \quad (\text{focus: 1pm})
  \]
  \end{itemize}
Focus Tracking

• Heuristic 1: Use the most recently mentioned time as the focus.

• Heuristic 2: Do not use noun-modifying time as the focus.

Date: Sep 19, 1997 10:33:15

IT basically analyses the breakdown on labor costs and compares our 1998 labor costs with their demands for 1999-2000.

... I will check mail on Sunday and see any feedback.
Demo: TimeShell
(interactive front-end of TEA)
Experiments: Emails

• Data collected from MBA students @ CMU during a 14-week course running simulated companies [Kraut et al., 2004].

• Hand-picked 1,196/15,000+ emails, and divided them into 5 sets: email1-email5.

• All datasets were tagged using MinorThird* rules and manually corrected.

• Evaluated by two of the authors.

* http://minorthird.sourceforge.net
### Basic Statistics

<table>
<thead>
<tr>
<th></th>
<th># of emails</th>
<th># of tempex</th>
<th>explicit</th>
<th>deictic</th>
<th>relative</th>
<th>durational</th>
</tr>
</thead>
<tbody>
<tr>
<td>email1</td>
<td>253</td>
<td>300</td>
<td>3 (1%)</td>
<td>139 (46.33%)</td>
<td>158 (52.67%)</td>
<td>N/A</td>
</tr>
<tr>
<td>email2</td>
<td>253</td>
<td>344</td>
<td>19 (5.5%)</td>
<td>112 (32.6%)</td>
<td>187 (54.4%)</td>
<td>27 (7.8%)</td>
</tr>
<tr>
<td>email4 (part.)</td>
<td>149</td>
<td>279</td>
<td>71 (25.4%)</td>
<td>77 (27.6%)</td>
<td>108 (38.7%)</td>
<td>22 (7.9%)</td>
</tr>
<tr>
<td>email5</td>
<td>126</td>
<td>213</td>
<td>14 (6.6%)</td>
<td>105 (49.3%)</td>
<td>92 (43.2%)</td>
<td>3 (1.4%)</td>
</tr>
</tbody>
</table>

- Explicit expressions account for 9%.
- Estimated baseline = Explicit % + Deictic %.
- Real baseline using **email1** (didn’t use tense/aspect, no focus tracking): 50%.
- Developed on **email2** and **email5**, and tested on **email4**.
Emails are Hard (vs. Newswire)

• Newswire has more explicit expressions
  • [Mani et al., 2003] reported 25% in the North American News Corpus. We have 9%.

• Other quirks of emails
  • Reply/forwarding.
  • Addressing to multiple recipients.
  • Creative formatting/spelling.
  • Human errors.
Examples

Creative formatting

So here is the summary of the today’s meeting... (snipped)

<table>
<thead>
<tr>
<th>Presenter</th>
<th>Time (min)</th>
<th>Items</th>
</tr>
</thead>
<tbody>
<tr>
<td>Takeshi</td>
<td>12</td>
<td>Company’s Past Performance, and Our Goal</td>
</tr>
<tr>
<td>George</td>
<td>8</td>
<td>The Overall Strategy, and the ...</td>
</tr>
</tbody>
</table>

Addressing to multiple people

Mike,

I will show you the table on Wednesday ... (snipped)

Emily,

If you are able to finish your sections Monday night... (snipped)

Human errors

Date: Mon, 15 Sep 1997 00:20:11

As for the labor proposal, we should have it first thing tomorrow (Monday) morning... (snipped)
Results

<table>
<thead>
<tr>
<th></th>
<th>Accuracy</th>
<th>Parsing errors</th>
<th>Human errors</th>
<th>Anchoring errors</th>
</tr>
</thead>
<tbody>
<tr>
<td>email2 (dev)</td>
<td>78.2%</td>
<td>10.47%</td>
<td>1.7%</td>
<td>9.63%</td>
</tr>
<tr>
<td>email5 (dev)</td>
<td>85.45%</td>
<td>5.16%</td>
<td>1%</td>
<td>8.39%</td>
</tr>
<tr>
<td>email4 (testing)</td>
<td>76.34%</td>
<td>17.92%</td>
<td>&lt; 1%</td>
<td>5.74%</td>
</tr>
</tbody>
</table>

• Accuracy = \[
\frac{\text{# of correctly anchored expressions in dataset } X}{\text{total # of expressions in dataset } X}
\]

• Parsing errors: Finite-state Parser failed transducing a temporal expression into its TCNL representation.

• Anchoring errors: incorrect focus, anchoring generics, etc.
Related Work


- Normalizing temporal expressions on newswire: [Mani and Wilson 2000], [Schilder and Habel 2001], [Filatova and Hovy 2001], [Mani et al. 2003].

- Normalizing temporal expressions on transcribed phone conversations: [Wiebe et al., 1998]
  
  - Reported average accuracy 80.9% on CMU corpus and 68.9% on NMSU corpus.
Conclusion

• Developed TCNL and its underlying constraint-based reasoning mechanism for temporal expressions.

• Connected natural language with the representation through the development of TEA.

• Experiments on a novel and challenging genre: emails.

• TEA showed promising performance, but much room for improvement.
Future Work

• Expand representation/parsing coverage: recurrence expressions ("3-5 every Tuesday and Thursday", "every 4 years").

• A better focus tracking method using various syntactic/semantic cues.

• Detect generics/non-generics.

• Testing on other genres (newswire ongoing).
Questions?
# TCNL: Operators

<table>
<thead>
<tr>
<th>operator</th>
<th>Type requirement</th>
<th>Granularity requirement</th>
<th>Semantics</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>+ and −</td>
<td>$C \times Q \rightarrow C$</td>
<td>$g(LHS) \leftarrow g(RHS)$</td>
<td>fuzzy forward/backward shifting</td>
<td>{now+</td>
</tr>
<tr>
<td>++ and −−</td>
<td>$C \times Q \rightarrow C$</td>
<td>$g(LHS) \leftarrow \min(g(LHS) \cup g(RHS))$</td>
<td>exact forward/backward shifting</td>
<td>{now++</td>
</tr>
<tr>
<td>@</td>
<td>$Q \times E \rightarrow C$</td>
<td>$g(RHS) \leftarrow g(LHS)$</td>
<td>ordinal</td>
<td>{</td>
</tr>
<tr>
<td>&amp;</td>
<td>$C \times C \rightarrow C$</td>
<td>$g(LHS) \leftarrow \min(g(LHS) \cup g(RHS))$</td>
<td>distribution</td>
<td>{now &amp;{now+</td>
</tr>
<tr>
<td></td>
<td>$C \times E \rightarrow E$</td>
<td></td>
<td></td>
<td>{</td>
</tr>
<tr>
<td></td>
<td>$E \times C \rightarrow E$</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>$E \times E \rightarrow E$</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
## TCNL: Relations

<table>
<thead>
<tr>
<th>Relations</th>
<th>Type requirement</th>
<th>Semantics</th>
</tr>
</thead>
<tbody>
<tr>
<td>$&lt;, \leq, \geq, &gt;$</td>
<td>$Q \times Q$</td>
<td>shorter-than, shorter-than or equal-to, longer-than or equal-to, and longer-than</td>
</tr>
<tr>
<td>$&lt;, \leq, \geq, &gt;$</td>
<td>$C \times C$</td>
<td>before, before or equal-to, after or equal-to, and after</td>
</tr>
<tr>
<td>$b, s, d, \text{de}, f, \text{di}$</td>
<td>$C \times E$</td>
<td>LHS is before/starting/during/during-equal/finishing/after RHS; \text{de} is defined as (s or d or f).</td>
</tr>
<tr>
<td>$b, s, f, bi$</td>
<td>$E \times C$</td>
<td>LHS is a maximal interval that is before/starting at/finishing at/after RHS.</td>
</tr>
<tr>
<td>$b, m, o, s, d, f, =, \text{fi}, \text{di}, \text{si}, \text{oi}, \text{mi}, \text{bi}$</td>
<td>$E \times E$</td>
<td>See [1].</td>
</tr>
</tbody>
</table>
TCNL vs. Timex3/TimeML

• Different goals
  • Timex3/TimeML is designed mainly for annotation, and it includes event annotations too.
  • TCNL is designed to be a *computable* representation.

• TCNL is calendar-agnostic: new temporal units/values can be added
  • fiscal quarters, semesters, etc.

• TCNL delegates focus tracking to an external mechanism
TCNL vs. Timex3/TimeML

- Example: “two weeks from next Tuesday”

Timex3/TimeML (Saurí et al., 2006):

```xml
<TIMEX3 tid="t1" type="TIME" value="2002-08-06"
  temporalFunction="true" anchorTimeID="t0">
two weeks from next Tuesday</TIMEX3>
```

TCNL:

\[ \{\{-+|1\{tue}\}|}++|2\text{week}\} \] (what _ denotes is decided separately)
Results

• Accuracy on each expression type

<table>
<thead>
<tr>
<th></th>
<th>explicit</th>
<th>deictic</th>
<th>relative</th>
<th>durational</th>
</tr>
</thead>
<tbody>
<tr>
<td>email2 (dev)</td>
<td>89.47%</td>
<td>94.64%</td>
<td>67.38%</td>
<td>77.78%</td>
</tr>
<tr>
<td>email5 (dev)</td>
<td>100.00%</td>
<td>94.29%</td>
<td>73.91%</td>
<td>66.67%</td>
</tr>
<tr>
<td>email4 (testing)</td>
<td>95.77%</td>
<td>83.12%</td>
<td>74.07%</td>
<td>0.00%</td>
</tr>
<tr>
<td>weighted avg</td>
<td>94.26%</td>
<td>90.71%</td>
<td>71.28%</td>
<td>48.99%</td>
</tr>
</tbody>
</table>

% = 100% - \( \frac{\text{# or errors on expression type } X \text{ in dataset } Y}{\text{total # of expression type } X \text{ in dataset } Y} \)

Easiest (emails vs. news = 9% vs. 25%)

Creative formatting (numbers in table)
Results

- Percentages of errors made on each expression type

<table>
<thead>
<tr>
<th></th>
<th>explicit</th>
<th>deictic</th>
<th>relative</th>
<th>durational</th>
</tr>
</thead>
<tbody>
<tr>
<td>email2 (dev)</td>
<td>2.67%</td>
<td>8.00%</td>
<td>81.33%</td>
<td>8.00%</td>
</tr>
<tr>
<td>email5 (dev)</td>
<td>0.00%</td>
<td>19.35%</td>
<td>77.42%</td>
<td>3.23%</td>
</tr>
<tr>
<td>email4 (testing)</td>
<td>4.55%</td>
<td>19.70%</td>
<td>42.42%</td>
<td>33.33%</td>
</tr>
<tr>
<td>weighted avg</td>
<td>2.91%</td>
<td>14.53%</td>
<td>65.70%</td>
<td>16.86%</td>
</tr>
</tbody>
</table>

\[
\% = \frac{\# \text{ of errors on expression type } X \text{ in dataset } Y}{\text{total } \# \text{ of errors in dataset } Y}
\]
Error Cases

Speech time can change too

Date: Wed, 10 Sep 1997 12:02:27
Subject: Fwd: Yes we have class

Please start the meeting at 6:00PM without me first. (snipped)

--- Forwarded message begins here ---
Date: Tue, 9 Sep 1997 20:11:41

... I just wanted to remind you that we will have class tomorrow night in Mellon auditorium. (snipped)

Focus tracking is hard

Date: Fri, 19 Sep 1997 02:34:19

... The next move is Tuesday next week. Let's get together Monday 3:30PM. (snipped)

Forward referencing focus

Date: Sun, 07 Sep 1997 09:32:15

... We have got a 9am scheduled for Tues and I'd like to leave it at that. (snipped)

Richer calendar model is needed

Date: Mon, 25 Aug 1997 09:24:37

So the first day of our school year has begun. (snipped)

Generics

The deadline for the announcement is the morning of the game move prior to the game move in which your firm wants to buy or sell your own stock.

(snipped)

Tense can hurt (or lexical semantics matters too)

Date: Mon, 25 Aug 1997 09:24:37

... Well, I reserved 318 room from 4pm to 7pm. (snipped)

If you wish to buy or sell stock on wednesday, the s-1 should be posted on Sunday morning.