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Natural Language Processing
IN2361

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Chapter 22
Time and
Temporal Reasoning

- content is based on [1]
- certain elements (e.g. equations or tables) were taken over or taken over in a modified form from [1]
- citations of [1] or from [1] are omitted for legibility
- errors are fully in the responsibility of Georg Groh
- BIG thanks to Dan and James for a great book!

Representations of Time

- Temporal logic: events ←→ points or intervals

I arrived in New York.
I am arriving in New York.
I will arrive in New York.

$$\exists e \, Arriving(e) \wedge Arriver(e, Speaker) \wedge Destination(e, NewYork)$$

↳ without temporal logic

$$\exists e, i, n \; Arriving(e) \wedge Arriver(e, Speaker) \wedge Destination(e, NewYork) \wedge IntervalOf(e, i) \wedge EndPoint(i, n) \wedge Precedes(n, Now)$$

$$\exists e, i, n \; Arriving(e) \wedge Arriver(e, Speaker) \wedge Destination(e, NewYork) \wedge IntervalOf(e, i) \wedge MemberOf(i, Now)$$

$$\exists e, i, n \; Arriving(e) \wedge Arriver(e, Speaker) \wedge Destination(e, NewYork) \wedge IntervalOf(e, i) \wedge EndPoint(i, n) \wedge Precedes(Now, n)$$

Representations of Time

- Allen interval algebra

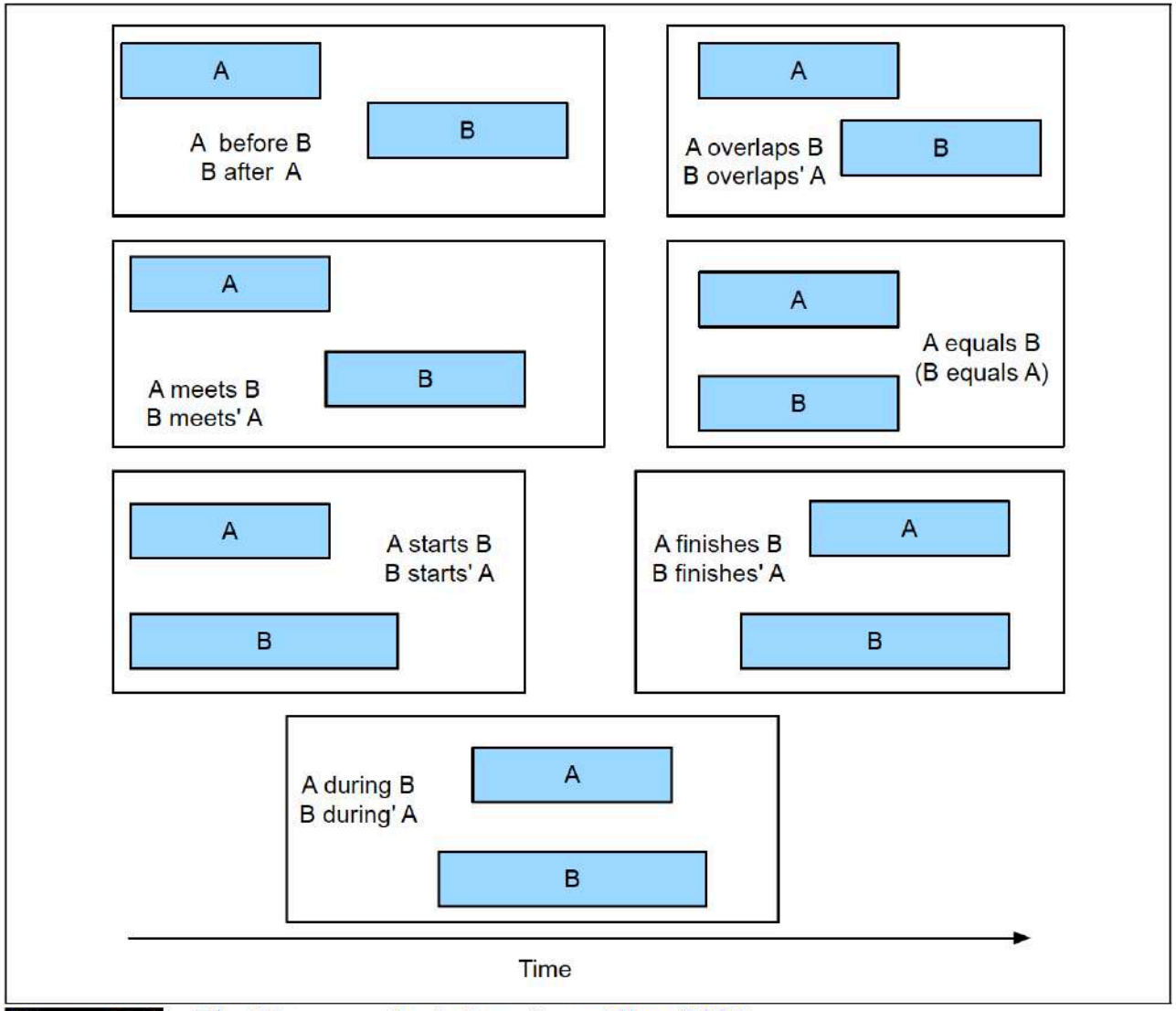


Figure 22.1 The 13 temporal relations from Allen (1984).

Representations of Time

- Allen interval algebra

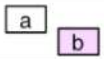
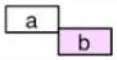
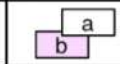
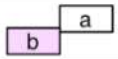
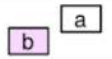
precedes	meets	overlaps	finished by	contains	starts	equals	started by	during	finishes	overlap-ped by	met by	preceded by
												
p	m	o	F	D	s	e	S	d	f	O	M	P

Table 1. Allen's thirteen basic relations

Relation		Converse	
precedes	(p)	(P)	preceded by
meets	(m)	(M)	met by
overlaps	(o)	(O)	overlapped by
finished by	(F)	(f)	finishes
contains	(D)	(d)	during
starts	(s)	(S)	started by
equals (e)			

Table 2. Converses of Allen's basic temporal relations

.	p	m	o	F	D	s	e	S	d	f	O	M	P
p	(p)	(p)	(p)	(p)	(p)	(p)	(p)	(p)	(pmosd)	(pmosd)	(pmosd)	(pmosd)	*full*
m	(p)	(p)	(p)	(p)	(p)	(m)	(m)	(m)	(osd)	(osd)	(osd)	(Fef)	(DSOMP)
o	(p)	(p)	(pmo)	(pmo)	(pmoFD)	(o)	(o)	(oFD)	(osd)	(osd)	*concur*	(DSO)	(DSOMP)
F	(p)	(m)	(o)	(F)	(D)	(o)	(F)	(D)	(osd)	(Fef)	(DSO)	(DSO)	(DSOMP)
D	(pmoFD)	(oFD)	(oFD)	(D)	(D)	(oFD)	(D)	(D)	*concur*	(DSO)	(DSO)	(DSO)	(DSOMP)
s	(p)	(p)	(pmo)	(pmo)	(pmoFD)	(s)	(s)	(seS)	(d)	(d)	(dfO)	(M)	(P)
e	(p)	(m)	(o)	(F)	(D)	(s)	(e)	(S)	(d)	(f)	(O)	(M)	(P)
S	(pmoFD)	(oFD)	(oFD)	(D)	(D)	(seS)	(S)	(S)	(dfO)	(O)	(O)	(M)	(P)
d	(p)	(p)	(pmosd)	(pmosd)	*full*	(d)	(d)	(dfOMP)	(d)	(d)	(dfOMP)	(P)	(P)
f	(p)	(m)	(osd)	(Fef)	(DSOMP)	(d)	(f)	(OMP)	(d)	(f)	(OMP)	(P)	(P)
O	(pmoFD)	(oFD)	*concur*	(DSO)	(DSOMP)	(dfO)	(O)	(OMP)	(dfO)	(O)	(OMP)	(P)	(P)
M	(pmoFD)	(seS)	(dfO)	(M)	(P)	(dfO)	(M)	(P)	(dfO)	(M)	(P)	(P)	(P)
P	*full*	(dfOMP)	(dfOMP)	(P)	(P)	(dfOMP)	(P)	(P)	(dfOMP)	(P)	(P)	(P)	(P)

Table 4a. Composition of basic interval relations

a	(pmMP)		*b*
"John was in the room"	p		"I touched the light switch"
	m		
	M		
	P		
b	(mo)		*c*
"I touched the light switch"	m		"The light was on"
	o		

Table 3. Example "Turn on the light"

Language ←?→ Representations of Time

Ok, we fly from San Francisco to Boston at 10. → refers to future event

Flight 1390 will be at the gate an hour now. → refers to past event

Flight 1902 arrived late.
Flight 1902 had arrived late.
} both in past but second has important event(s) between then and now

solution: Reichenbach's reference point approach:

When Mary's flight departed, I ate lunch.
When Mary's flight departed, I had eaten lunch.

Reichenbach's Reference Point Approach

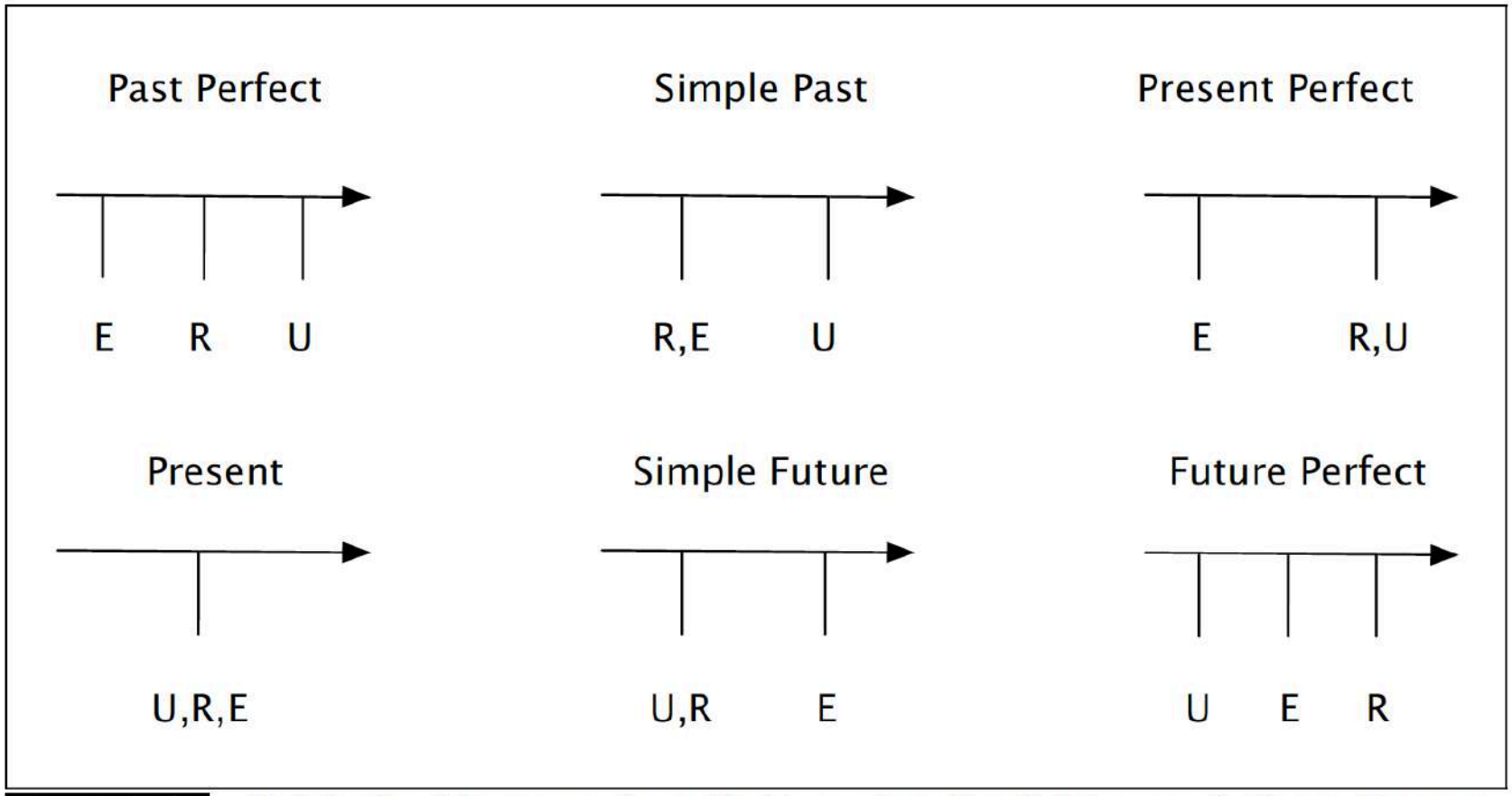


Figure 15.5 Reichenbach's approach applied to various English tenses. In these diagrams, time flows from left to right, **E** denotes the time of the event, **R** denotes the reference time, and **U** denotes the time of the utterance.

Aspect

- Events (involve change) vs states (do not involve change)
- Stative expressions: event participant is in a state at point in time

  I like Flight 840.
  I need the cheapest fare.
  I want to go first class.

- Activity expressions: event participant does activity (event) over interval in time

  She drove a Mazda.
  I live in Brooklyn.

- Accomplishment expressions: interval has definitive end-point, results in state change

  He booked me a reservation.
  United flew me to New York.

- Achievement expressions: point in time, results in state change

  She found her gate.
  I reached New York.

Time Bank Corpus

- Time ML:
  - EVENT (events and states),
  - TIME (time points),
  - TLINKS (Allen relations between time points),
  - ALINKS (aspectual relationships btw. Events and subevents),
  - SLINKS (facts)

```
<TIMEX3 tid="t57" type="DATE" value="1989-10-26"  functionInDocument="CREATION_TIME">
10/26/89  </TIMEX3>

Delta Air Lines earnings <EVENT eid="e1" class="OCCURRENCE"> soared </EVENT> 33% to a
record in  <TIMEX3 tid="t58" type="DATE" value="1989-Q1" anchorTimeID="t57"> the
fiscal first quarter </TIMEX3>, <EVENT eid="e3"  class="OCCURRENCE">bucking</EVENT>
the industry trend toward <EVENT eid="e4" class="OCCURRENCE">declining</EVENT>
profits.
```

Time Bank Corpus

- Time ML:
  - EVENT (events and states),
  - TIME (time points),
  - TLINKS (Allen relations between time points),
  - ALINKS (aspectual relationships btw. Events and subevents),
  - SLINKS (facts)

(22.25) **[DCT:11/02/891]**$_1$: Pacific First Financial Corp. **said**$_2$ shareholders **approved**$_3$ its **acquisition**$_4$ by Royal Trustco Ltd. of Toronto for $27 a share, or $212 million. The thrift holding company **said**$_5$ it **expects**$_6$ to **obtain**$_7$ regulatory **approval**$_8$ and **complete**$_9$ the **transaction**$_{10}$ by **year-end**$_{11}$.

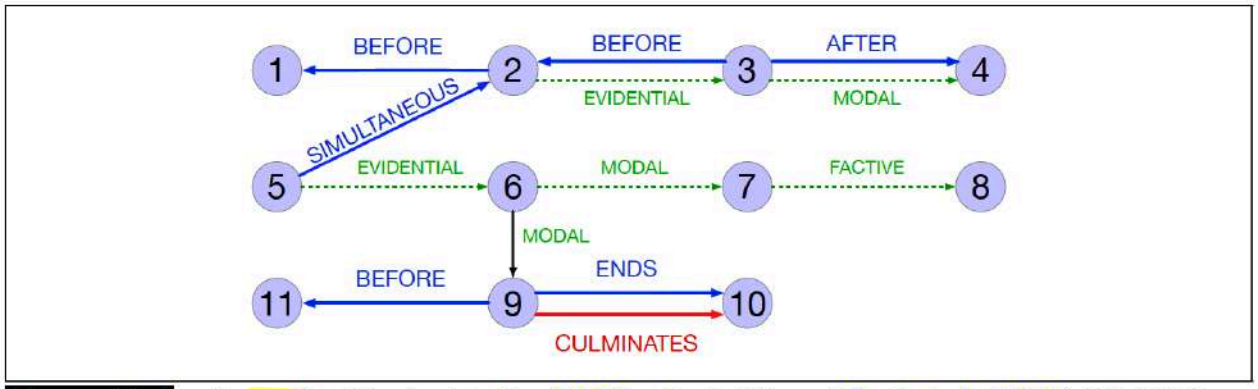


Figure 22.4 A graph of the text in Eq. 22.25, adapted from (Ocal et al., 2022). TLINKS are shown in blue, ALINKS in red, and SLINKS in green.

Extracting Temporal Expressions

- Steps:

BIO sequence tag

usually not simple

1. Extracting **temporal expressions**
2. **Normalizing** these expressions, by converting them to a standard format.
3. **Linking** events to times and extracting time graphs and timelines

Extracting Temporal Expressions

- Absolute points in time, durations, and relations between them

Absolute	Relative	Durations
April 24, 1916	yesterday	four hours
The summer of '77	next semester	three weeks
10:15 AM	two weeks from yesterday	six days
The 3rd quarter of 2006	last quarter	the last three quarters

- Temporal expressions: grammatical constructions with temporal triggers as heads.

  Lexical triggers: nouns, proper nouns, adjectives, or adverbs; temporal expressions: noun phrases, adjective phrases, and adverbial phrases

Category	Examples
Noun	*morning, noon, night, winter, dusk, dawn*
Proper Noun	*January, Monday, Ides, Easter, Rosh Hashana, Ramadan, Tet*
Adjective	*recent, past, annual, former*
Adverb	*hourly, daily, monthly, yearly*

Extracting Temporal Expressions

- supervised sequence labelling with any ML seq. classifier using IOB:

A fare increase initiated last week by UAL Corp's...
O O O O B I O O O

- features that may be used:

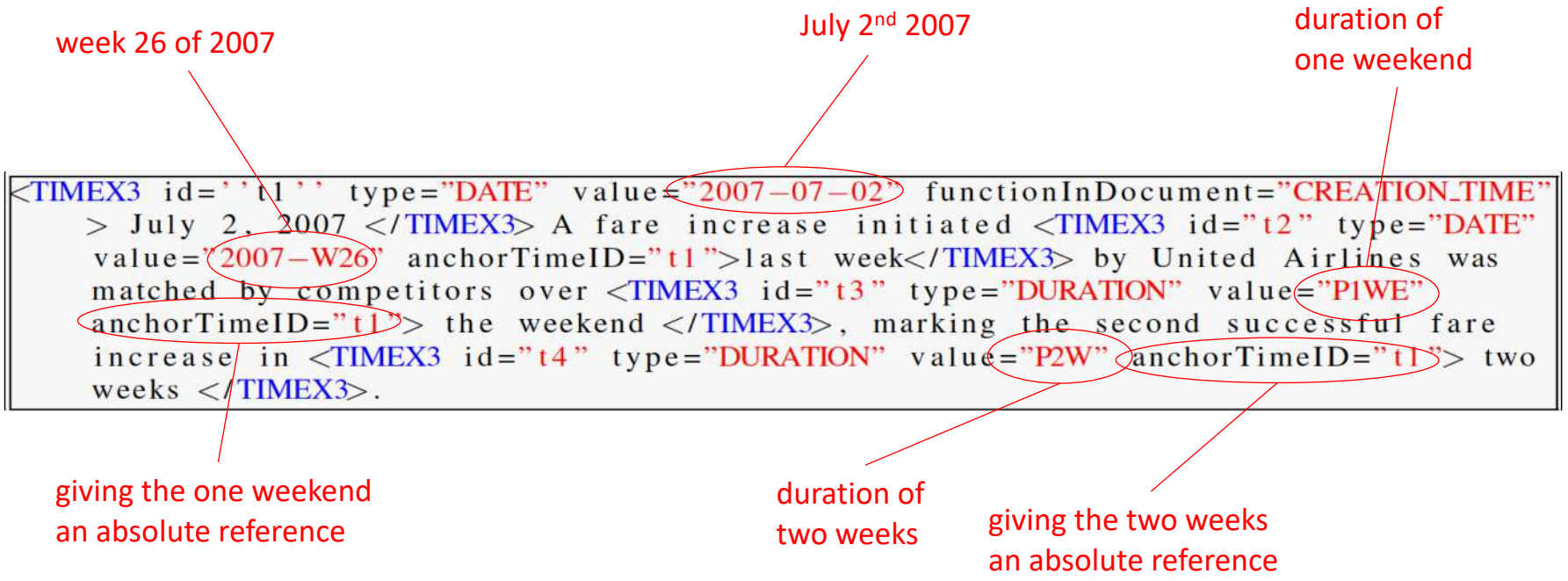
Feature	Explanation
Token	The target token to be labeled
Tokens in window	Bag of tokens in the window around a target
Shape	Character shape features
POS	Parts of speech of target and window words
Chunk tags	Base-phrase chunk tag for target and words in a window
Lexical triggers	Presence in a list of temporal terms

- challenge: false positives:

1984 tells the story of Winston Smith...
...U2's classic *Sunday* Bloody *Sunday*

Temporal Normalization

- → map to ISO8601 standard



- further examples:

Unit	Pattern	Sample Value
Fully specified dates	YYYY-MM-DD	1991-09-28
Weeks	YYYY-Wnn	2007-W27
Weekends	PnWE	P1WE
24-hour clock times	HH:MM:SS	11:13:45
Dates and times	YYYY-MM-DDTHH:MM:SS	1991-09-28T11:00:00
Financial quarters	Qn	1999-Q3

Temporal Normalization

- Most approaches for temporal normalizations: rule systems

„… 3 years old …“ matched by

```
pattern: /(\d+)[-\s]($TEUnits)(s)?([-\s]old)?/
result: Duration($1, $2)
```

\d : digit
\s: any whitespace
() mark match group;
$1, $2,… refer to value of first, second,… match group

- document or communication act has a logical temporal anchor (e.g. time of creation, time of publication, today, now, etc.)

Temporal Normalization

- → logical temporal arithmetic:
  - *tomorrow* = anchor of today + 1d , *yesterday* = anchor of today - 1d
  - anchor: 2007W26 → *50 weeks later* = week (((26 + 50) mod 53) + 1) of 2008

- but: complexity of absolute referencing may be high:
  - *…was matched by competitors over the weekend…* → "last weekend" (relative to anchor)
  - *Security checks will continue at least through the weekend* → "coming weekend" (relative to anchor)

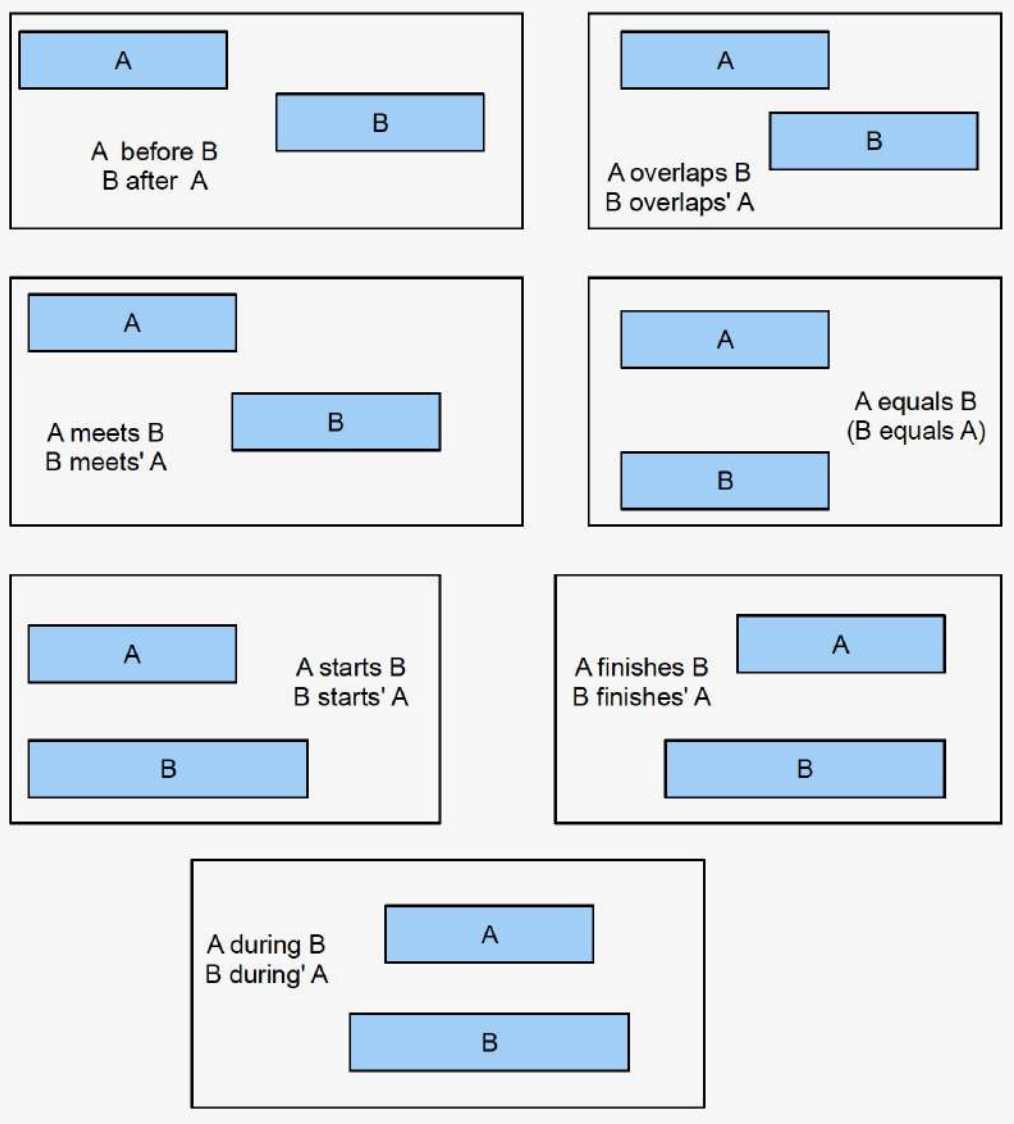
    for both cases: indicator: tense of verb
  - *…next Friday…* : "immediate next Friday" or "Friday next week"? → heuristic: the closer today's anchor is to "immediate next Friday" the more probable is "Friday next week"

Temporal Ordering of Events

- absolute positioning of events in anchored timeline or partial ordering of events (after, before etc.) (useful in e.g. question answering)

- example for partial ordering: determining that fare increase by American Airlines came after fare increase by United

- partial ordering: binary relation detection and classification task; target relations: Allen temporal logic relations



Bibliography

(1) Dan Jurafsky and James Martin: Speech and Language Processing (3rd ed. draft, version Jan, 2023); Online: https://web.stanford.edu/~jurafsky/slp3/ (URL, Oct 2023) (this slideset is especially based on chapter 22)

(2) Russel, Norvig: Artifical Intelligence, 3rd edition

(3) University of California, Irvine, lecture slides https://ics.uci.edu/~alspaugh/cls/shr/allen.html (URL, Jan 2024)

Recommendations for Studying

- minimal approach:

  work with the slides and understand their contents! Think beyond instead of merely memorizing the contents

- standard approach:

  minimal approach + read the corresponding pages in Jurafsky [1]

- interested students

  standard approach + do a selection of the exercises in Jurafsky [1]