Course: Common Sense Reasoning

5. Temporal and Spatial Reasoning

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Qualitative temporal reasoning

- Time is a one-dimensional physical quantity with different qualitative aspects
  - Instants (today, now, tomorrow, …)
  - Durations (long, brief, …)
  - Temporal organization (before, during, …)
  - Granularity hierarchies (day, month, year, …)

There are multiple approaches for temporal reasoning

- Temporal logics
  - Modal temporal logic
    - [Tool: STeP (Stanford Temporal Prover)]
  - Moszkowski's ITL (interval logic)

- Constraint satisfaction methods
  - Allen's interval algebra

Allen's Interval Algebra uses a set of relations

[Allen 1983]

James F. Allen
(1950)

University of Rochester

Relation	Symbol	Symbol for Inverse	Pictoral Example
X *before* Y	<	>	XXX YYY
X *equal* Y	=	=	XXX YYY
X *meets* Y	m	mi	XXXYYY
X *overlaps* Y	o	oi	XXX YYY
X *during* Y	d	di	XXX YYYYYY
X starts Y	s	si	XXX YYYYY
X finishes Y	f	fi	XXX YYYYY

A table expresses how to compose relations

$$(A\ r\ C) = (A\ r1\ B) \otimes (B\ r2\ C)$$

B r2 C / A r1 B	<	>	d	di	o	oi	m	mi	s	si	f	fi
"before" <	<	no info	< o m d s	<	<	< o m d s	<	< o m d s	<	<	< o m d s	<
"after" >	no info	>	> oi mi d f	>	> oi mi d f	>	> oi mi d f	>	> oi mi d f	>	>	>
"during" d	<	>	d	no info	< o m d s	> oi mi d f	<	>	d	> oi mi d f	d	< o m d s
"contains" di	< o m di fi	> oi di mi si	o oi dur con =	di	o di fi	oi di si	o di fi	oi di si	di fi o	di	di si oi	di

...

Example

- Premises:
  - “During the trip, John makes a phone call”

    `call {during, starts, finishes} trip`
  - “After the trip, he goes to a restaurant”

    `trip {before, meets} restaurant`
- Reasoning:
  - Application of the composition table:

    `call {before, meets} restaurant`

Allen's algebra has multiple applications

- Planning
  - E.g. therapy planning, robot planning
- Natural language
  - E.g. story understanding
- Scenario description
  - E.g. historical sequence of events
- Others:
  - E.g. causal reasoning (diagnosis), traffic analysis, …

Qualitative spatial reasoning

[Cohn, Renz, 2008]

- Space is a multi-dimensional physical quantity
- Spatial reasoning has multiple aspects to represent
  - Topology (“touch”, “inside”)
  - Orientation (“to the left”, “north east”)
  - Distance (“far”, “near”)
  - Relative positions (“above”, “in front of”)
  - Size (“large”,”tiny”)
  - Shape (“oval”, “convex”)

Qualitative spatial reasoning differs from a quantitative approach

Qualitative approach

- Reasoning about space with qualitative relations and values such as “near”, “large”, “inside”

Quantitative approach

- Classical view based on metric measurements
- Raster and vector representations for GIS

Spatial reasoning is more complex than temporal reasoning

- Time is well defined for a qualitative approach
  - Time: duration, order
- Space is more complex due to its multi-dimensionality
  - Space: size, direction, distance, shape, topology, …

There are multiple spatial characteristics that may be considered

- Part-of relation:
  - Dividing complex objects into parts
  - Spatial granularity
- Spatial change:
  - Change of location (motion)
  - Change of shape
- Others:
  - Point (or lines) versus regions
  - Continuous versus discrete
  - Fuzzy representations

There is a controversy about the limitations of qualitative spatial representation

"The poverty conjecture"

[Forbus et al., 1987]

- Space cannot be adequately represented by using only qualitative methods (because multi-dimensionality)

There has been an increasing amount of research which tends to refute this conjecture [Cohn, 1995]

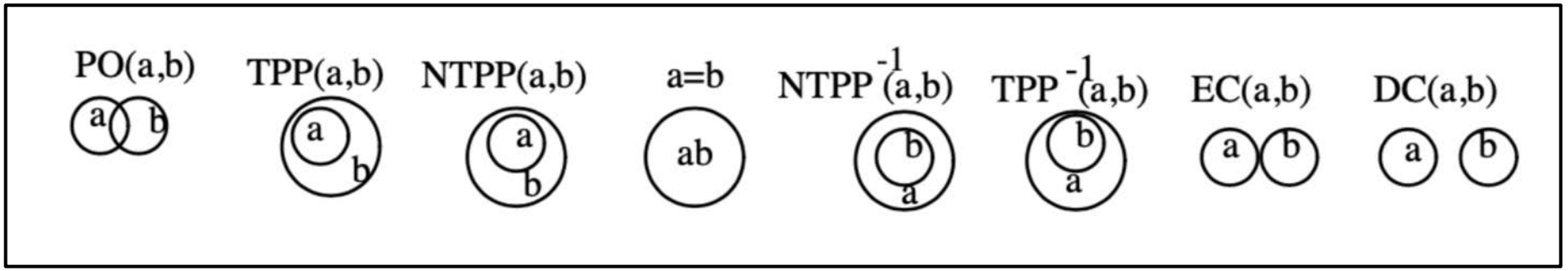
- There are proposals about combination of different spatial aspects [Renz, Nebel, 2007]

Spatial reasoning has multiple applications

- Geographic information systems
- Robot planning and navigation
- Interpret visual inputs
- Natural language understanding
- Engineering design
- Reasoning about physical systems
- Others:
  - Document structure recognition / design
  - Visual programming languages,
  - Image acquisition using figure captions
  - Etc.

Region Connected Calculus (RCC8) is a method for spatial reasoning

[Randell, Cui, Cohn, 1992]



DC	disconnected
EC	externally connected
EQ	equal
PO	partially overlapping
TPP	tangential proper part
TPPi	tangential proper part inverse
NTPP	non-tangential proper part
NTPPi	non-tangential proper part inverse

A table expresses how to compose relations

$$(A\ r\ C) = (A\ r1\ B) \otimes (B\ r2\ C)$$

⊗	DC	EC	PO	…
DC	all	DC,EC,PO,TPP,NTPP	DC,EC,PO,TPP,NTPP	
EC	DC,EC,PO,TPPi,NTPPi	DC,EC,PO,TPP,TPPi,EQ	DC,EC,PO,TPP,NTPP	
PO	DC,EC,PO,TPPi,NTPPi	DC,EC,PO,TPPi,NTPPi	all	
TPP	DC	DC,EC	DC,EC,PO,TPP,NTPP	
…				

Reasoning using RCC8 has computational issues

[Renz, Nebel, 2007]

- RCC-8 is NP-complete
- RCC8 applies constraint satisfaction techniques
- RCC8 can be computationally tractable using:
  - limited sizes,
  - subsets of relations,
  - heuristics and search strategies

Example: Spatial relations between two properties

- Two houses are connected via a road.
- Each house is located on an own property.
- The first house possibly touches the boundary of the property.
- The second one surely does not.

What can we infer about the relation of the second property to the road?

Example: Representation and inference

```
house1 DC house2
house1 {TPP, NTPP} property1
house1 {DC, EC} property2
house1 EC road
house2 {DC, EC} property1
house2 NTPP property2
house2 EC road
property1 {DC, EC} property2
road {DC, EC, TPP, TPPi, PO, EQ, NTPP, NTPPi} property1
road {DC, EC, TPP, TPPi, PO, EQ, NTPP, NTPPi} property2
```

Using constraint satisfaction algorithms with the RCC8 compositional table:

```
road {PO, EC} property1
road {PO, TPP} property2
```

That is, the road either overlaps with the second property, or is even (tangential) part of it.

There are other approaches similar to RCC8

- RCC-5
  - Ignores relations about regions touching each other
- RCC-23
  - Represents convexity
- Star Calculus
  - Represents orientation
- …

Future lines of research

- Integration:
  - Spatial aspects (e.g., orientation & topology)
  - Qualitative-quantitative
  - Space and time (spatio-temporal reasoning)
- Others:
  - Uncertainty
  - Expressiveness/efficiency tradeoff

Course “Common sense reasoning”.

Work citation in APA style:

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