Knowledge Representation

A very brief intro

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Knowledge Representation

Plan for today

- Knowledge-based systems
  - Explicit knowledge
  - Inferred knowledge
  - Domain-specific stuff
  - Changing premises
  - Uncertainty
  - Semantic anchoring

- Architectures
- Self-awareness

Explicit knowledge

Facts about:

- objects
Explicit knowledge

Facts about:
- objects
- places
- times
- events
- processes
- behaviours

vehicle dynamics
rigid body interactions
traffic laws
...
Background knowledge for all this includes:

- ontologies
- theories

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...
### Explicit knowledge

Background knowledge for all this includes:
- ontologies
- theories
- physics
- mereology
- ...

Not everything needs to be explicit, nor expressed in one monolithic formalism

### Inferred knowledge

(or: turning implicit into explicit)
- logics (language)
- theorem proving (mechanics)
- modes of reasoning

### Logics: modal

- take a logical language, let $\alpha$ be a wff
- $\Box\alpha$ is a wff
- $\Diamond\alpha$ is a wff
- normally $\Box\alpha \leftrightarrow \neg\Diamond\neg\alpha$

Intended meaning?

- $\Box\alpha$ means **Necessity** $\alpha$
take a logical language, let $\alpha$ be a wff

- $\Box \alpha$ is a wff
- $\Diamond \alpha$ is a wff
- normally $\Box \alpha \iff \neg \Diamond \neg \alpha$

Intended meaning?
- $\Box \alpha$ means **Necessarily** $\alpha$
- $\Diamond \alpha$ means **Agent knows** $\alpha$
- $\Diamond \alpha$ means **Agent believes** $\alpha$
- $\Box \alpha$ means **Always in the future** $\alpha$
- $G \alpha$ means **Always in the future (or: Globally)** $\alpha$
Logics: Kripke semantics

Actually, meaning of modal formulae is defined on graph structures

Nodes: possible worlds
Edges: reachability relation

Logics: temporal

- Globally (always):
  \( \square \phi \)
- Finally (eventually):
  \( \diamond \phi \)
- Next:
  \( \circ \phi \)
- Until:
  \( \psi \cup \phi \)

Cf. Richard Murray’s verification of autonomous car controller:

\( (\phi^e_{\text{init}} \land \square \phi^e_{\text{safe}} \land \diamond \phi^e_{\text{prog}}) \rightarrow (\phi^s_{\text{init}} \land \square \phi^s_{\text{safe}} \land \diamond \phi^s_{\text{prog}}) \)

Logics: description

Earlier known as semantic networks. Formal version of semantic web languages (OIL, DAML, OWL).

Effective reasoning:
- inheritance via SubsetOf (SubClass) and MemberOf (isA) links
- intersection paths
- special meaning of some links (e.g. cardinality constraints)
- classification, consistency, subsumption
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Representation: ontologies

Lots of robot-related ontologies:
knowrob, IEEE CORA (Standard 1872-2015), intelligent systems ontology (2005, NIST), ...

Modes of reasoning: Deduction

RedLightAt(intersection1)
∀(x)RedLightAt(x) → ○StopBefore(x)
thus
○StopBefore(intersection1)

General Pattern:
- prior facts
- domain knowledge
- observations
- conclusions
Sound.

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**Modes of reasoning: Induction**

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\[
\begin{align*}
\text{OnDesk}(\text{monitor}1) & \land \text{Monitor}(\text{monitor}1), \\
\text{OnDesk}(\text{monitor}2) & \land \text{Monitor}(\text{monitor}2), \\
\text{OnDesk}(\text{monitor}3) & \land \text{Monitor}(\text{monitor}3), \\
\text{OnDesk}(\text{monitor}4) & \land \text{Monitor}(\text{monitor}4), \\
\text{OnDesk}(\text{monitor}5) & \land \text{Monitor}(\text{monitor}5)
\end{align*}
\]

thus

\[
\forall(x) \text{Monitor}(x) \to \text{OnDesk}(x)
\]

General pattern:

- Observe
- Generalize

Fallible. Constructs hypotheses, not true facts. However, most of our practical reasoning, in particular learning, is of this kind.

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**Modes of reasoning: Abduction**

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General pattern:

- prior facts
- domain knowledge
- observations

Given a theory T and observations O

\[
E \text{ is an explanation of } O \text{ given } T \text{ if } E \cup T \models O \text{ and } E \cup T \text{ is consistent.}
\]

Probablilistic abduction: maybe Elin will mention it.

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Modes of reasoning: Abduction

General pattern:
- prior facts
- domain knowledge
- observations
- explain the observation

Given a theory $T$ and observations $O$,
$E$ is an explanation of $O$ given $T$ if $E \cup T \models O$ and $E \cup T$ is consistent.

Usually we are interested in most plausible $E$, sometimes minimal $E$, most elegant $E$, ...

Probabilistic abduction: maybe Elin will mention it.

What do we want to represent?
- objects
- places
- times
- events
- processes
- behaviours
- vehicle dynamics
- rigid body interactions
- traffic laws
- ...

Qualitative spatial reasoning

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RCC8: region connection calculus
Given e.g., $\text{contains}(A, B) \land \text{covers}(B, C)$ we can conclude $\text{contains}(A, C)$

\[ \square (\text{meet}(A, B) \rightarrow \square (\text{meet}(A, B) \lor \text{disjoint}(A, B) \lor \text{overlap}(A, B))) \]

Interval calculus (Allen 1983)

- A is before B or B is after A
- A meets B or B is met by A
- A overlaps with B or B is overlapped by A
- A starts B or B is started-by A
- A during B or B contains A
- A finishes B or B is finished-by A
- A and B are cotemporal

Invalidating conclusions

- Tweety is a bird.
- So it flies.
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Invalidating conclusions

- Tweety is a bird.
- So it flies.
- But Tweety is a penguin.
- So it doesn’t fly.

Non-monotonic reasoning.

Truth-maintenance systems.


Uncertainty

Every perception is associated with uncertainty. Account for that.

Approaches:

- probabilistic representations
- fuzzy approaches
- multi-valued logics

Transformations between representations as needed.

Back to KnowRob
KnowRob lessons

Beetz and Tenorth, AIJ, 2016:
1. No fixed levels of abstraction, no layers, no “black boxes”;
2. A knowledge base should reuse data structures of the robot’s control program;
3. Symbolic knowledge bases are useful, but not sufficient;
4. Robots need multiple inference methods;
5. Evaluating a robot knowledge base is difficult.

Architectures of knowledge-based systems

AIMA agents (cf. introductory lecture)
- Logical agents - declarative, compositional
- Rule-based systems - compositionality on the rule level
- Layered systems (distribution of concerns)
- Blackboards - compositionality of reasoners (knowledge sources) (KnowRob, our SIARAS system)
- Stream-oriented reasoning - Heintz@LiU

KnowRob as a blackboard

Self-awareness: Autoepistemic logic

- Distribution axiom $K$:
  \[(K\alpha \land K(\alpha \rightarrow \beta)) \rightarrow K\beta\]
- Knowledge axiom $T$:
  \[K\alpha \rightarrow \alpha\]
- Positive introspection $4$:
  \[K\alpha \rightarrow K\alpha\]
- Negative introspection $5$:
  \[\neg K\alpha \rightarrow K\neg K\alpha\]
Self-awareness: motivation

- true autonomy requires self-awareness
- autoepistemic logic captures just one aspect: awareness of own knowledge
- resource limitations: anytime algorithms, active logic
- interaction: distributed knowledge
- interaction: shared knowledge
- explanation of own behaviour (trust)

References 1

https://www.youtube.com/watch?v=ymUFadN_MO4 (How Watson learns)
Representations for robot knowledge in the KnowRob framework, Moritz Tenorth, Michael Beetz, Artificial Intelligence Journal, in press, available on the journal site
Logics for Artificial Intelligence, Raymond Turner, Ellis Horwood, 1984

References 2