CS616
Knowledge Representation and Reasoning

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Overview

- Teaching week: 8–12 March 2004
- Do check the website regularly for announcements
- Lectures presented in 4 parts:
  - Part I (Sattler, 3) Early KR formalisms, first-order logic
  - Part II (Schmidt, 8) Modal logic
  - Part III (Schmidt, 4) Description logic
  - Part IV (Sattler, 10) Extended DLs and applications

Aims of the course

- To provide an introduction to various extensions of classical propositional logic: first-order logic, modal logics, description logics, extended description logics
- To formalise knowledge and questions about this knowledge in these logics
- To use automated reasoning systems for answering these questions, and study underlying theories:
  SPASS for modal logic, ICOM for description logic
- To study applications and extensions, e.g.,
  - agents, semantic web, ontologies, and conceptual modeling
  - non-standard reasoning, temporal, non-monotonic, and defaults

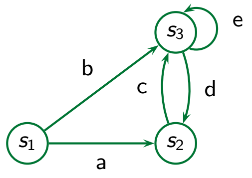
Part I: Early KR formalisms and first-order logic

- Early AI/KR research was very enthusiastic with very high goals
  - early KR formalisms were quite attractive
  - but also came with several problems which are well understood today
- Why first order logic? What is missing in propositional logic?
  - FOL allows to describe different objects and their relationship
  - FOL is "the unifying formalism" of many KR formalisms

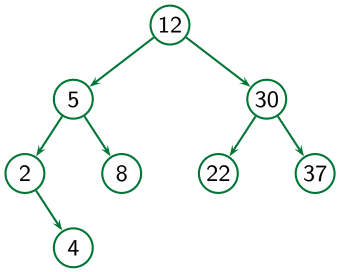
Why modal logic? Why description logic? (1)

First-order logic is a very expressive language, can capture wide range of knowledge $\rightsquigarrow$ Why ML? Why DL?

- ML and DL are expressively weaker than FOL.
- ML and DL are simpler, more natural languages, yet powerful enough to describe useful structures:



transition systems used to model program executions



trees

Why modal logic? Why description logic? (2)

- ML and DL are very popular in CS and AI, have been "reinvented" many times.
- There are many applications.
- Modal and description logics have nice computational properties.
  - Reasoning in first-order logic is undecidable
many MLs and DLs are decidable
some MLs and DLs are undecidable

    We will mostly study decidable logics.
  - The MLs and DLs we study have nice computational complexity.

Part II: Modal logic

- The language of modal logic
- Structures which interpret ML
- Symbolic model checking
- Properties of ML structures
- Hilbert-style deduction systems
- Reduction to first-order logic, using SPASS
- Modal logic and agents

Modal logics

- Modal logics are a *formal way* of handling notions of necessity, possibility, knowledge, belief, time, actions, etc ('modalities')
- Modal logics allows us to model different modes of truths:
  - Tony Blair is the prime minister of Britain
is true now, but will not be true forever.
  - The square root of 625 is 25
is true (by definition), but it is not known by everyone.
  - This is the best of all possible worlds
may or may not be true, but there are people who believe it and others who don't.

Modal operators and examples

Op.	Name	Meaning
$\mathbf{K}_i$	knowledge operator	agent i knows
$\mathbf{B}_i$	belief operator	agent i believes
$\bigcirc$	next operator	after next election

$$\mathbf{K}_{\text{Adam}}(\text{prime\_minister}(\text{Tony, GB}) \wedge \bigcirc(\text{prime\_minister}(\text{Tony, GB}) \vee \neg\text{prime\_minister}(\text{Tony, GB})))$$

Adam knows, Tony is currently the p.m. and after the next election Tony will either be p.m. or not.

$$\mathbf{K}_{\text{Eve}}\text{prime\_minister}(\text{Tony, GB}) \wedge \mathbf{B}_{\text{Eve}} \bigcirc \neg\text{prime\_minister}(\text{Tony, GB})$$

Eve knows Tony is currently the p.m. and believes after the next election Tony will not be p.m.

Modal logic: Applications

Modal logics have applications in

- program specifications
- program semantics
- concurrent programs
- communication protocols
- specification of rational (logic-based) agents
- reasoning about actions
- natural language processing
- accident analysis

Part III: Description logics

- Language, knowledge bases
- Meaning/semantics of description logic statements, meaning of knowledge bases
- Inferential services:
  consistency, subsumption, instance checking, classification, querying mechanisms
- Algorithms to solve these types of problems
- DLs as ontology languages and the semantic web

Purpose of description logics

- Whereas modal logics are used to model and reason about the thinking of agents, ...
- Description logics are about
  - modelling world knowledge, i.e. 'objective knowledge' of a particular domain of application
  - and reasoning about it
- DL systems have similar applications as databases but are more flexible and more expressive
- DLs systems are used for modelling ontologies which play an important role in the intelligent use of the web
  - semantic web

Motivation

A classical database stores information in a series of tables which represent relations.

Query: Is there a grandfather?

has_son		male
Phillip	Charles	Phillip
Charles	William	Charles
...	...	William
...	...	...

Answer: No

Why not?

What is missing is a definition of the concept grandfather (a view).

Suitable concept definitions in description logic would be:

$$\text{grandfather} \doteq \text{male} \sqcap \exists \text{has\_son}.\exists \text{has\_son}.\text{human}$$

$$\text{male} \mathrel{\dot{\sqsubseteq}} \text{human}$$

Services of description logic systems

- DLs allow the description of both concrete (database) and abstract information (concept definitions).
- A DL system provides inferential services which can fully automatically deduce new information from given information
  E.g. that Phillip is a grandfather
- In short: DLs are formalisms for representing and reasoning about information
- In contrast, to databases, DLs systems can handle incomplete knowledge bases.

Application areas

- Formal specification of ontologies for application domains
  E.g. medical expert systems, telecom systems configurations, component knowledge bases in the chemical industry, ...
  New concepts are defined using already defined concepts; relationships are defined from concept definitions
- Consistency checks of formal specifications; coherence checks of ontologies
- Automatic classification of concepts $\rightsquigarrow$ concept taxonomies
  E.g. botanical classification taxonomy
- Definition of concepts that occur in databases
- More expressive querying of databases
- Semantic web
- ...

Semantic web

- Internet search engines are based on keyword search.
  Disadvantage: the number of answers is huge; many answers are completely irrelevant, while some more intersting answers are not found
- **Idea:** The **semantic web** aims to facilitate *intelligent* use of the web.
  Annotate web documents with a machine understandable description of their content, so that intelligent search/reasoning engines can do better than keyword search.
- **Realisation:** for "machine understandable description", use DLs (or variations),
  base "intelligent search engines" on DL reasoners

Part IV: Extensions and applications

- **ICOM:** a tool for intelligent conceptual modeling built to design and reason about ER/UML schemas, based on DLs
- **Non-standard reasoning services:**
  - applying DLs requires more than classical logical reasoning (validity, satisfiability, etc)
  - to support domain experts which are not DL experts,
  - e.g. to add new concepts into a knowledge base
  - Example NSRS: approximating concepts
    computing the least common subsumer of some concepts
    computing the most specific concept for an individual, etc.

Part IV: Extensions and applications

- **Temporal DLs:**
  - so far, DLs were static
  - to express knowledge about changes, actions, processes, etc., requires a notion of time, e.g.,
  - `CS_Student` **implies** **eventually** (`Rich` **or** `Famous`)
- **Defaults:**
  - so far, we only have strict axioms `Bird` **implies** `CanFly`
  - some applications want default axioms
    `Bird` **implies_by_default** `CanFly` (because of Penguins, broken wings, oil desasters, etc.)
  - how to extend FOL or DLs with such "defaults"

Pre-course work

- **Elementary set theory**
  What is a set, a relation, a function, set operations (intersection, union, etc), properties of binary relations (reflexivity, symmetry, transitivity, etc).
- **Propositional logic** (Boolean logic)
  Very simple representation language; expressively weak; modal logics and description logics are natural extensions.
- **First-order logic**
  First order logic formulae, their meaning, validity and satisfiability, translating between natural language and first-order logic.

Exercise sheet will be made available.

Reading material

- Course unit does not follow a specific book: copies of the slides are made available.
- Recommended reading material: listed on the course description webpage. List is not final and may change until the start of the module.
- The books on the webpage are available in the Resources Centre. No need to buy a book for this course unit.
- Copies of any additional papers will be made available on the web.

Coursework

- Exercises and assignments are of varying difficulty – those in the teaching week are aimed to consolidate the material of the lectures and are thus easier.
- Some exercises and assignments are to be done with pencil and paper, some will require the use of tools (SPASS for the ML & DL part, ICOM for the DL application part).
- For the **post-course work** you will be given a selection of topics from which you choose one.
  This work may involve writing a program, formalising problems, using reasoning tools for solving such problems, a case study on some research in one of the areas, or a mixture of these.

Assessment

- 5% assignments in the pre-course week,
- 25% assignments in the teaching week,
- 30% post-course work,
- 40% exam