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Description Logics and OWL

Based on slides from
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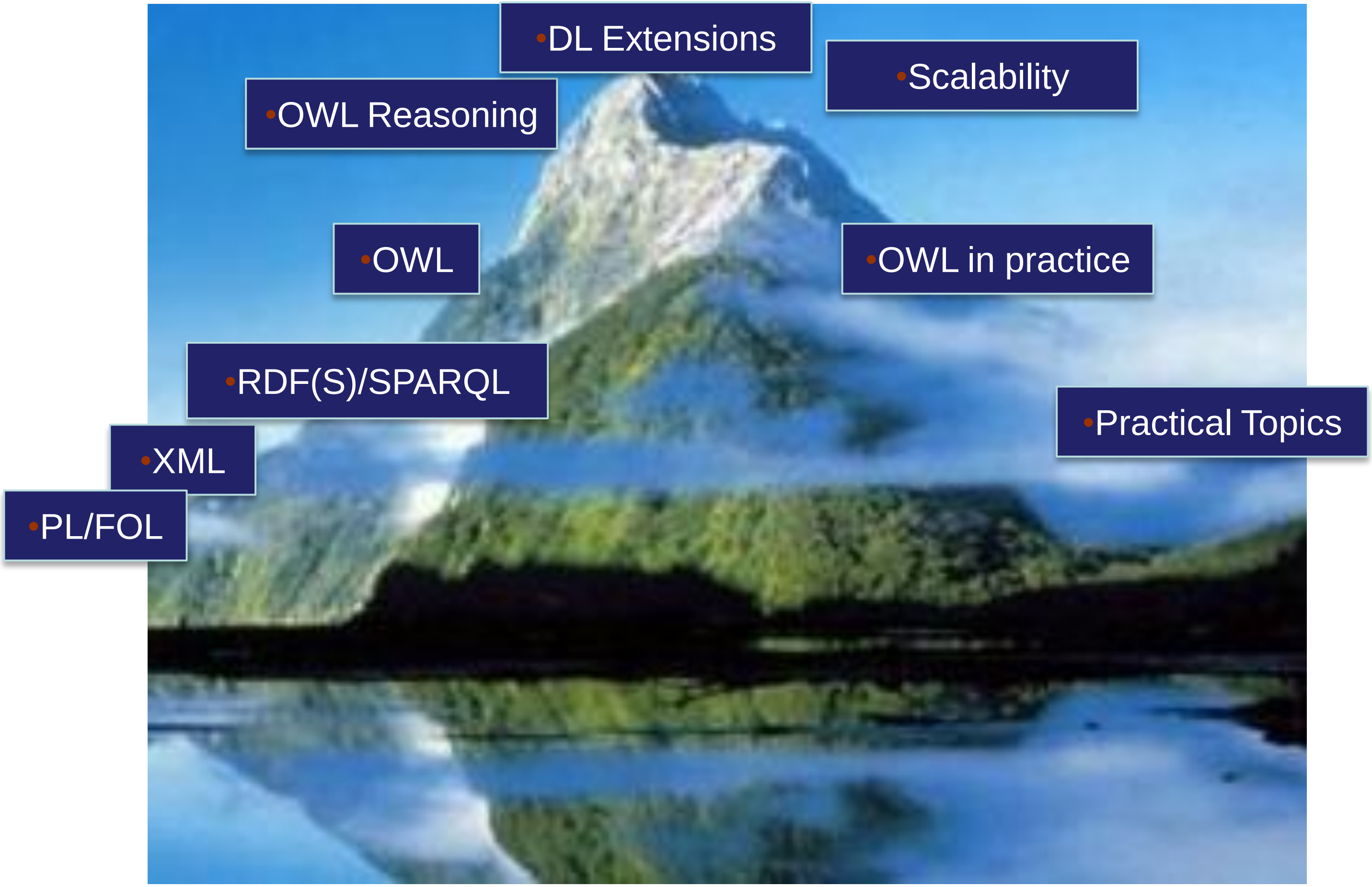
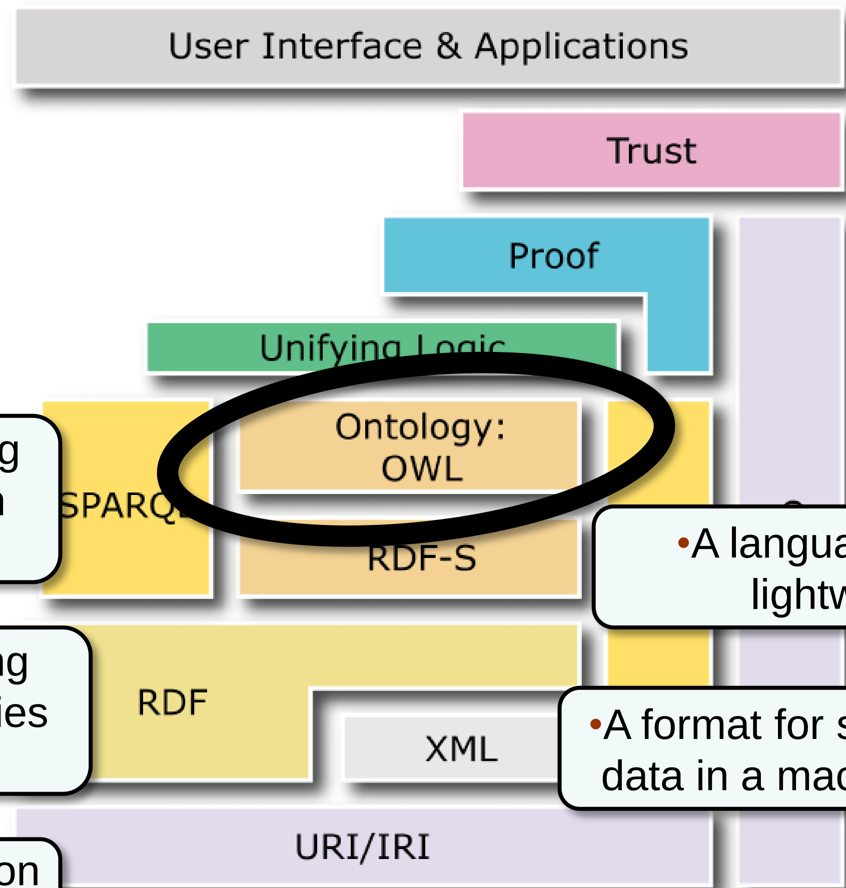
University of Manchester (now in Oxford)

Where are we?


DL Extensions
Scalability
OWL Reasoning
OWL
OWL in practice
RDF(S)/SPARQL
Practical Topics
XML
PL/FOL

Back to the cake …



- A language for querying information specified in RDF.
- A model for describing resources with properties and property values.
- Unique identification
- of resources
- A language for describing a lightweight ontology.
- A format for specifying structured data in a machine-readable form

- Semantic Web Layer Cake, Image source: http://www.w3.org/2007/03/layerCake.svg

Model the following in RDF(S):

- Every pizza in the class PizzaMargarita has tomatoes as a topping.
- No pizza in the class PizzaMargarita has a topping from the class Meat.

Why RDFS is not enough?

- RDFS cannot express negations
- Defined property restrictions are global
- Missing cardinalities for properties
- Relations between (sub-)classes (e.g. disjunction)

OWL – Web Ontology Language

- *"The OWL Web Ontology Language is designed for use by applications that need to process the content of information instead of just presenting information to humans."*
- OWL has been developed as a vocabulary extension of RDF
- Explicitly represents the meaning of terms in vocabularies and the relationships between those terms. (Ontology)

OWL – The Story

- 2004 - **OWL** W3C Recommendation
- 2009 - **OWL 2** W3C Recommendation

•http://piqs.de

OWL = ***W****eb* ***O****ntology* ***L****anguage*

- Why not WOL?
  - Obvious pronunciation which is easy on the ear
  - Opens up great opportunities for logos
  - Owls are associated with wisdom
  - It has an interesting back story

Ontology: Origins and History

a philosophical discipline—a branch of philosophy that deals with the nature and the organisation of reality

- Science of Being (Aristotle, Metaphysics, IV, 1)
- Tries to answer the questions:
  - *What characterizes being?*
  - *Eventually, what is being?*
- How should things be classified?

Ontology in Computer Science

- An ontology is an engineering artefact consisting of:
  - A vocabulary used to describe (a particular view of) some domain
  - An explicit specification of the intended meaning of the vocabulary.
    - almost always includes how concepts should be classified
  - Constraints capturing additional knowledge about the domain

- Ideally, an ontology should:
  - Capture a shared understanding of a domain of interest
  - Provide a formal and machine manipulable model of the domain

Example Ontology

- Vocabulary and meaning ("definitions")
  - **Elephant** is a concept whose members are a kind of animal
  - **Herbivore** is a concept whose members are exactly those animals who eat only plants or parts of plants
  - **Adult_Elephant** is a concept whose members are exactly those elephants whose age is greater than 20 years
- Background knowledge/constraints on the domain ("general axioms")
  - **Adult_Elephant**s weigh at least 2,000 kg
  - All **Elephant**s are either **African_Elephant**s or **Indian_Elephant**s
  - No individual can be both a **Herbivore** and a **Carnivore**

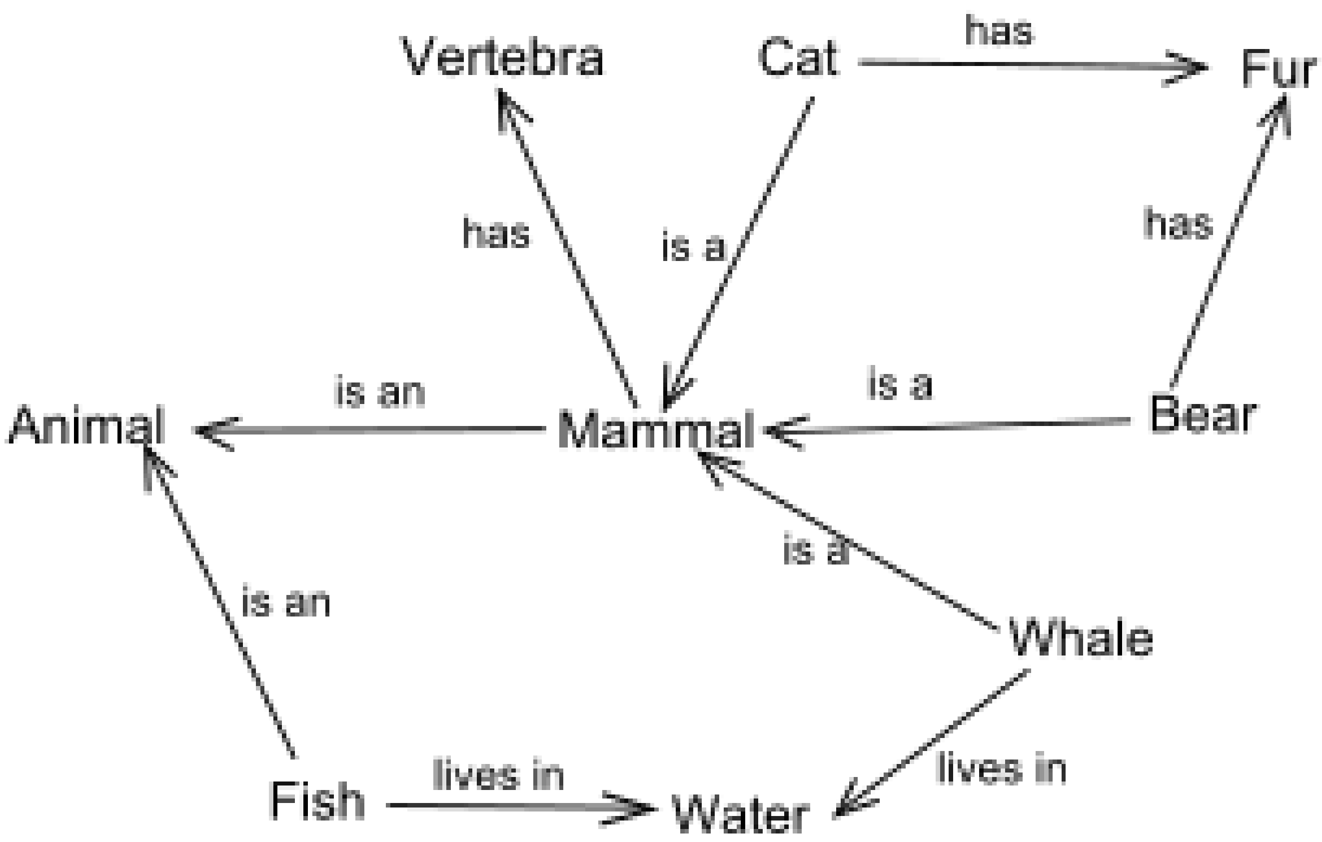
Combining OWL with RDF Schema

- Ideally, OWL would extend RDF Schema
  - Consistent with the layered architecture of the Semantic Web
- **But** simply extending RDF Schema would work against obtaining expressive power and efficient reasoning
  - Combining RDF Schema with logic leads to uncontrollable computational properties
- We need another logic as a base:
  - Description logics!

What Are Description Logics?

- A family of logic based Knowledge Representation formalisms
  - Descendants of semantic networks and KL-ONE
  - Describe domain in terms of concepts (classes), roles (properties, relationships) and individuals
- Distinguished by:
  - Formal semantics (typically model theoretic)
    - Decidable fragments of FOL (often contained in C_2)
    - Closely related to Propositional Modal & Dynamic Logics
    - Closely related to Guarded Fragment
  - Provision of inference services
    - Decision procedures for key problems (satisfiability, subsumption, etc)
    - Implemented systems (highly optimised)

A simple semantic network



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DL Basics

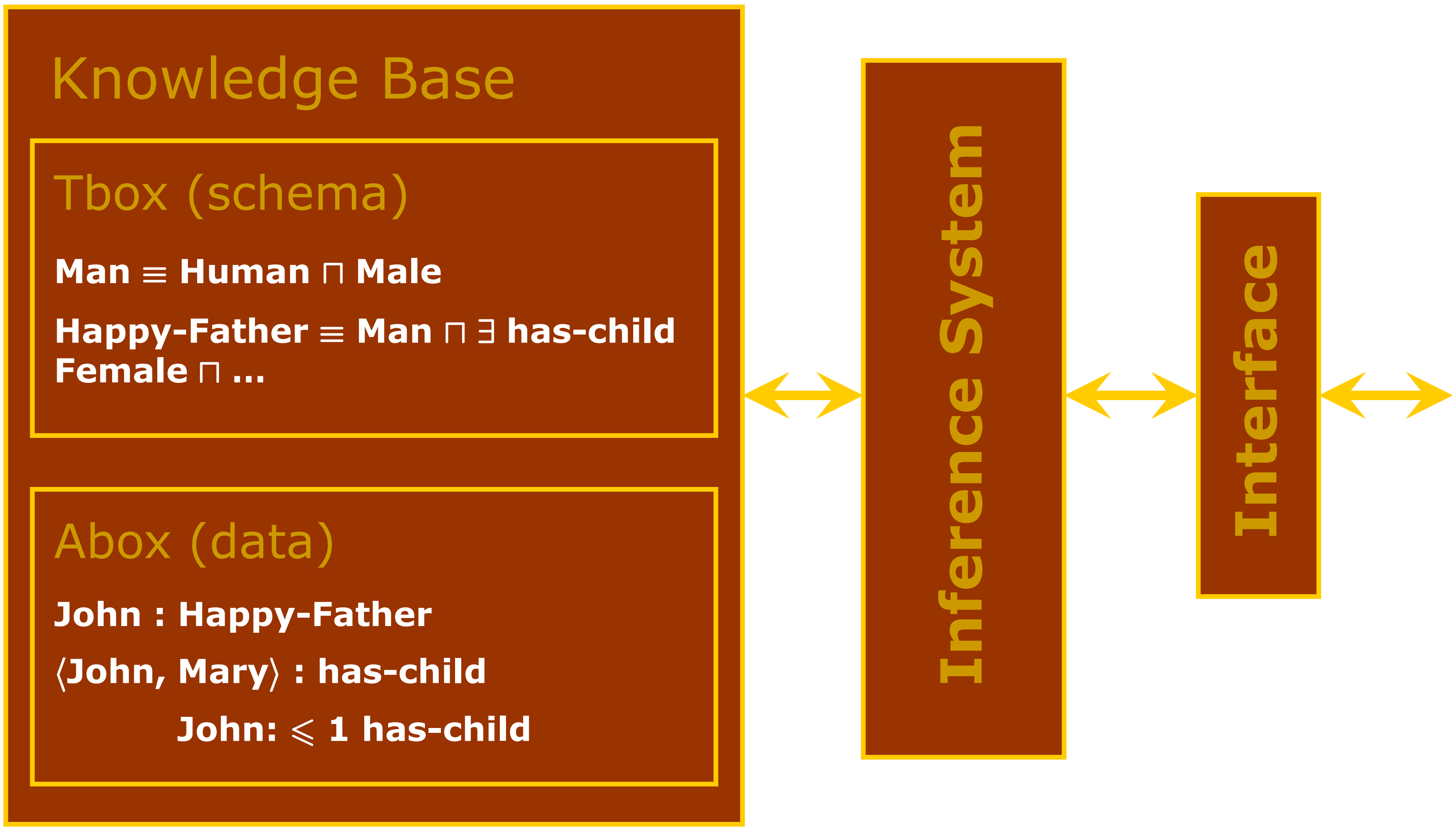
- Concept names are equivalent to unary predicates
  - In general, concepts equiv to formulae with one free variable
- Role names are equivalent to binary predicates
  - In general, roles equiv to formulae with two free variables
- Individual names are equivalent to constants
- Operators restricted so that:
  - Language is decidable and, if possible, of low complexity
  - No need for explicit use of variables
    - Restricted form of ∃ and ∀ (direct correspondence with ◊ and [])

Modal Logic: intuition

You can read '□' as "necessarily" and '◊' as "possibly." But modal logics, like other formal systems, can have many applications. Depending on the application, they might have many different meanings, for example:

□	◊
it is logically necessary that	it is logically possible that
it could not have failed to happen that	it might have happened that
it must be the case that	it might be the case that
it is now settled that	it is still possible that
it is obligatory that	it is permitted that
it is provable that	it is not refutable that
A believes that	

DL System Architecture



The DL Family

- Given description logic is defined by a set of concept and role forming operators
- Smallest propositionally closed DL is $\mathcal{ALC}$
  - Concepts constructed using ⊓, ⊔, ¬, ∃ and ∀
- Additional letters indicate other extensions
  - More later …

Task

- Define Concept expressions for talking about the university domain!

DL Semantics

- Semantics defined by interpretations
- An interpretation $\mathcal{I} = (\Delta^{\mathcal{I}}, \cdot^{\mathcal{I}})$, where
  - $\Delta^{\mathcal{I}}$ is the domain (a non-empty set)
  - $\cdot^{\mathcal{I}}$ is an interpretation function that maps:
    - Concept (class) name $\mathrm{A} \rightarrow$ subset $\mathrm{A}^{\mathcal{I}}$ of $\Delta^{\mathcal{I}}$
    - Role (property) name $\mathrm{R} \rightarrow$ binary relation $\mathrm{R}^{\mathcal{I}}$ over $\Delta^{\mathcal{I}}$
    - Individual name $\mathrm{i} \rightarrow \mathrm{i}^{\mathcal{I}}$ element of $\Delta^{\mathcal{I}}$

DL Semantics (cont.)

- Interpretation function $\cdot^{\mathcal{I}}$ extends to concept (and role) expressions in the obvious way, e.g.:

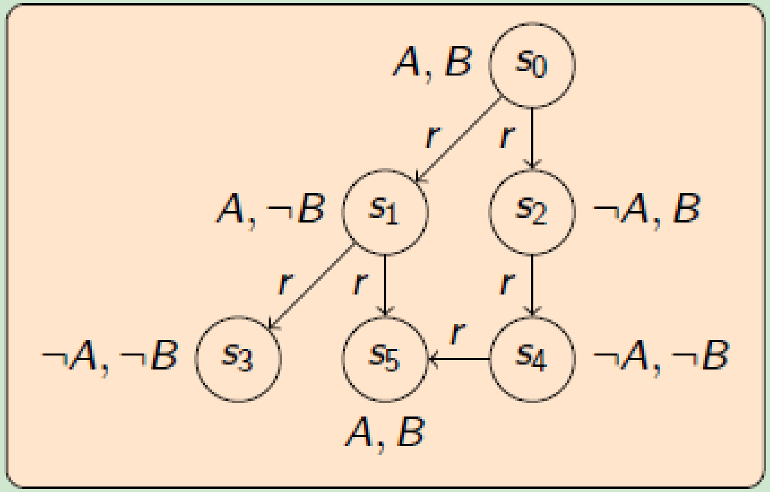
$$
\begin{array}{lcl}
(C \sqcap D)^{\mathcal{I}} & = & C^{\mathcal{I}} \cap D^{\mathcal{I}} \\
(C \sqcup D)^{\mathcal{I}} & = & C^{\mathcal{I}} \cup D^{\mathcal{I}} \\
(\neg C)^{\mathcal{I}} & = & \Delta^{\mathcal{I}} \setminus C^{\mathcal{I}} \\
\{x\}^{\mathcal{I}} & = & \{x^{\mathcal{I}}\} \\
(\exists R.C)^{\mathcal{I}} & = & \{x \mid \exists y. \langle x, y \rangle \in R^{\mathcal{I}} \wedge y \in C^{\mathcal{I}}\} \\
(\forall R.C)^{\mathcal{I}} & = & \{x \mid \forall y. (x, y) \in R^{\mathcal{I}} \Rightarrow y \in C^{\mathcal{I}}\} \\
(\leqslant n R)^{\mathcal{I}} & = & \{x \mid \#\{y \mid \langle x, y \rangle \in R^{\mathcal{I}}\} \leqslant n\} \\
(\geqslant n R)^{\mathcal{I}} & = & \{x \mid \#\{y \mid \langle x, y \rangle \in R^{\mathcal{I}}\} \geqslant n\} \\
(R^{-})^{\mathcal{I}} & = & \{(x, y) \mid (y, x) \in R^{\mathcal{I}}\}
\end{array}
$$

Task

- Translate the following into Englisch and than into FOL:
  1. $Father \sqcap \forall.child.(Doctor \sqcup Manage)$
  2. $\exists manages.(Company \sqcap \exists employs.Doctor)$
  3. $Father \sqcap \forall child.(Doctor \sqcup \exists manages.(Company \sqcap \exists employs.Doctor))$

Task

Let $\mathcal{I}$ be the following $\mathcal{ALC}$ interpretation on the domain $\Delta^{\mathcal{I}} = \{s_0, s_1, \ldots, s_5\}$. Calculate the interpretation of the following concepts:



$$\top^{\mathcal{I}} =$$

$$\bot^{\mathcal{I}} =$$

$$A^{\mathcal{I}} =$$

$$B^{\mathcal{I}} =$$

$$(A \sqcap B)^{\mathcal{I}} =$$

$$(A \sqcup B)^{\mathcal{I}} =$$

$$(\neg A)^{\mathcal{I}} =$$

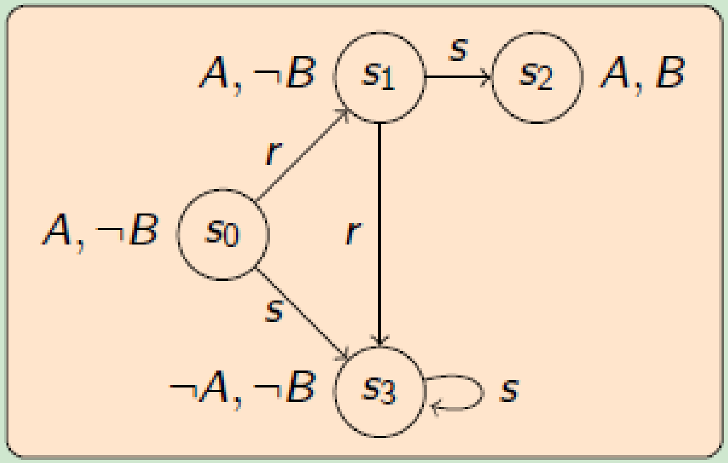
$$(\exists r.A)^{\mathcal{I}} =$$

$$(\forall r.\neg B)^{\mathcal{I}} =$$

$$(\forall r.(A \sqcup B))^{\mathcal{I}} =$$

Task

Let $\mathcal{I}$ be the following $\mathcal{ALC}$ interpretation on the domain $\Delta^{\mathcal{I}} = \{s_0, s_1, \ldots, s_5\}$. Calculate the interpretation of the following concepts:



$$(A \sqcup B)^{\mathcal{I}} =$$
$$(\exists s.\neg A)^{\mathcal{I}} =$$
$$(\forall s.A)^{\mathcal{I}} =$$
$$(\exists s.\exists s.\exists s.\exists s.A)^{\mathcal{I}} =$$
$$(\neg\exists r.(\neg A \sqcup \neg B))^{\mathcal{I}} =$$
$$(\exists s.(A \sqcup \forall s.\neg B) \sqcup \neg\forall r.\exists r.(A \sqcup \neg A))^{\mathcal{I}} =$$

DL Knowledge Base

- A DL Knowledge base $\mathcal{K}$ is a pair $\langle \mathcal{T}, \mathcal{A} \rangle$ where
  - $\mathcal{T}$ is a set of "terminological" axioms (the Tbox)
  - $\mathcal{A}$ is a set of "assertional" axioms (the Abox)
- Tbox axioms are of the form:

  $\mathrm{C} \sqsubseteq \mathrm{D}$, $\mathrm{C} \equiv \mathrm{D}$, $\mathrm{R} \sqsubseteq \mathrm{S}$, $\mathrm{R} \equiv \mathrm{S}$ and $\mathrm{R}^+ \sqsubseteq \mathrm{R}$

  where C, D concepts, R, S roles, and R^+ set of transitive roles
- Abox axioms are of the form:

  $\mathrm{x}{:}\mathrm{D}$, $\langle \mathrm{x},\mathrm{y} \rangle{:}\mathrm{R}$

  where x,y are individual names, D a concept and R a role

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Knowledge Base Semantics

- An interpretation $\mathcal{I}$ satisfies (models) a Tbox axiom A ($\mathcal{I} \models \mathrm{A}$):

  $\mathcal{I} \models \mathrm{C} \sqsubseteq \mathrm{D}$ iff $\mathrm{C}^{\mathcal{I}} \subseteq \mathrm{D}^{\mathcal{I}}$ $\quad$ $\mathcal{I} \models \mathrm{C} \equiv \mathrm{D}$ iff $\mathrm{C}^{\mathcal{I}} = \mathrm{D}^{\mathcal{I}}$

  $\mathcal{I} \models \mathrm{R} \sqsubseteq \mathrm{S}$ iff $\mathrm{R}^{\mathcal{I}} \subseteq \mathrm{S}^{\mathcal{I}}$ $\quad$ $\mathcal{I} \models \mathrm{R} \equiv \mathrm{S}$ iff $\mathrm{R}^{\mathcal{I}} = \mathrm{S}^{\mathcal{I}}$

  $\mathcal{I} \models \mathrm{R}^+ \sqsubseteq \mathrm{R}$ iff $(\mathrm{R}^{\mathcal{I}})^+ \subseteq \mathrm{R}^{\mathcal{I}}$
- $\mathcal{I}$ satisfies a Tbox $\mathcal{T}$ ($\mathcal{I} \models \mathcal{T}$) iff $\mathcal{I}$ satisfies every axiom A in $\mathcal{T}$
- An interpretation $\mathcal{I}$ satisfies (models) an Abox axiom A ($\mathcal{I} \models \mathrm{A}$):

  $\mathcal{I} \models \mathrm{x{:}D}$ iff $\mathrm{x}^{\mathcal{I}} \in \mathrm{D}^{\mathcal{I}}$ $\quad$ $\mathcal{I} \models \langle \mathrm{x,y} \rangle{:}\mathrm{R}$ iff $(\mathrm{x}^{\mathcal{I}},\mathrm{y}^{\mathcal{I}}) \in \mathrm{R}^{\mathcal{I}}$
- $\mathcal{I}$ satisfies an Abox $\mathcal{A}$ ($\mathcal{I} \models \mathcal{A}$) iff $\mathcal{I}$ satisfies every axiom A in $\mathcal{A}$
- $\mathcal{I}$ satisfies an KB $\mathcal{K}$ ($\mathcal{I} \models \mathcal{K}$) iff $\mathcal{I}$ satisfies both $\mathcal{T}$ and $\mathcal{A}$

Task

- Let Man, Woman, Male, Female, and Human be concept names, and let has-child, is-brother-of, is-sister-of, and is-married-to be role names. Try to construct a TBox that contains definitions for:
  - Mother, Father, Grandmother, Grandfather, Aunt, Uncle, Niece, Nephew, Mother-of-at-least-one-male