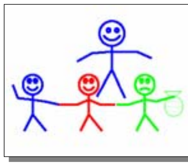
Description Logic(s)

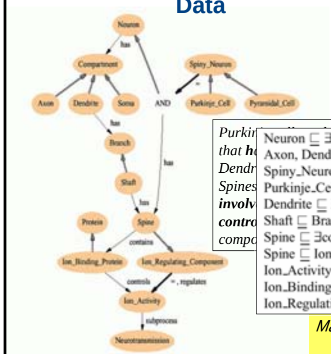
- Formerly known as "terminological logic(s)"
- Idea: logic language for
  - defining concepts in terms of other concepts
  - interrelating concepts
  - ➔ constraining the meaning of concepts
- DL definition of "Happy Father"

(Example from Ian Horrocks, Ulrike Sattler)



$$\texttt{Man} \sqcap (\exists \texttt{has-child.Blue}) \sqcap (\exists \texttt{has-child.Green}) \sqcap (\forall \texttt{has-child.Happy} \sqcup \texttt{Rich})$$

Example: Domain Knowledge to "glue" SYNAPSE & NCMIR Data



Purkir… that h… Dendr… Spines… involv… contro… compo…

$\text{Neuron} \sqsubseteq \exists \text{has.Compartment}$
$\text{Axon, Dendrite, Soma} \sqsubseteq \text{Compartment}$
$\text{Spiny\_Neuron} \equiv \text{Neuron} \sqcap \exists \text{has.Spine}$
$\text{Purkinje\_Cell, Pyramidal\_Cell} \sqsubseteq \text{Spiny\_Neuron}$
$\text{Dendrite} \sqsubseteq \exists \text{has.Branch}$
$\text{Shaft} \sqsubseteq \text{Branch} \sqcap \exists \text{has.Spine}$
$\text{Spine} \sqsubseteq \exists \text{contains.Ion\_Binding\_Protein}$
$\text{Spine} \sqsubseteq \text{Ion\_Regulating\_Component}$
$\text{Ion\_Activity} \sqsubseteq \exists \text{subprocess\_of.Neurotransmission}$
$\text{Ion\_Binding\_Protein} \sqsubseteq \text{Protein} \sqcap \exists \text{controls.Ion\_Activity}$
$\text{Ion\_Regulating\_Component} \equiv \exists \text{regulates.Ion\_Activity}$

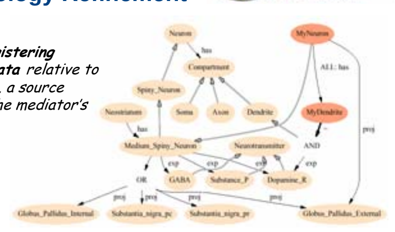
*Made usable for the **system** using Description Logic*

formalized as an "ontology graph"

Source Contextualization through Ontology Refinement

Biomedical Informatics Research Network

*In addition to **registering** ("hanging off") **data** relative to existing concepts, a source may also **refine** the mediator's domain map...*

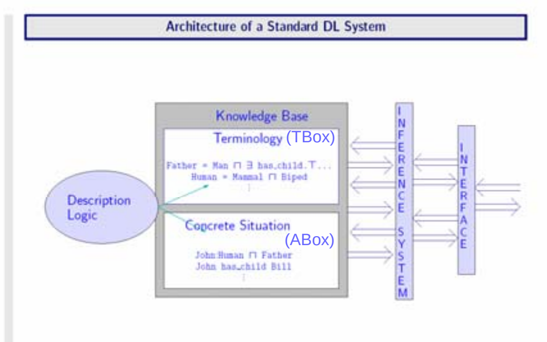


$\texttt{MyDendrite} \equiv \texttt{Dendrite} \sqcap \exists \texttt{exp.Dopamine\_R}$
$\texttt{MyNeuron} \sqsubseteq \texttt{Medium\_Spiny\_Neuron} \sqcap \exists \texttt{proj.Globus\_pallidus\_external} \sqcap \forall \texttt{has.MyDendrite}$

*⇒ sources can register **new concepts** at the mediator ...*
*⇒ increase your **data usability***

Roots

- "Structured Inheritance Networks" [Brachman 1977]
- KL-ONE [Brachman, Schmolze 1985]
- Core ideas:
  – Building blocks: atomic **concepts** (unary predicates), atomic **roles** (binary predicates), **individuals** (constants)
  – **Constructors** for building complex concepts and roles from simpler ones
  – Automated **inference** for **concept subsumption** and **instance classification** (is-a/is-instance-of are *not* explicitly given by the user, but inferred from concept definitions/instance properties)



Source: Description Logics Tutorial, Ian Horrocks and Ulrike Sattler, ECAI-2002, Lyon, France, July 23rd, 2002

Knowledge Base (DL-Style)

- ***Terminological* Knowledge (TBox)**
  – Concept **Definition** (naming of concepts):

$$\text{Spiny\_Neuron} \equiv \text{Neuron} \sqcap \exists \text{has.Spine}$$

  – **Axiom** (constraining of concepts):

$$\text{Neuron} \sqsubseteq \exists \text{has.Compartment}$$

  => a mediators "glue knowledge source"
- ***Assertional* Knowledge (ABox)** about Individuals
  – *n27_img118 : Neuron*
  => the concrete instances/individuals of the concepts/classes that your sources export

Example TBox

1. P
2. F
3. $W \equiv P \sqcap F$
4. $M1 \equiv P \sqcap \neg W$
5. $M2 \equiv W \sqcap \exists h1.P$
6. $F2 \equiv M1 \sqcap \exists h1.P$
7. $P2 \equiv (F2 \sqcup M2)$
8. $G \equiv M2 \sqcap \exists h1.P2$
9. $W2 \equiv W \sqcap \exists h2.M1$
10. $M3 \equiv M2 \sqcap \forall h1.\neg W$

Atomic concepts = {P,F,W, M1,…}
Base concepts = {P,F}
Defined concepts = {W, M1, M2, …}
Roles = {*h1*,*h2*}

Concept Definition $\boxed{A \equiv C}$
Axiom $\boxed{C \sqsubseteq D}$
where A atomic concept,
C, D complex concept expressions

Example TBox

1. $P \equiv$ Person
2. $F \equiv$ Female
3. $W \equiv P \sqcap F$
4. $M1 \equiv P \sqcap \neg W$
5. $M2 \equiv W \sqcap \exists hasC.P$
6. $F2 \equiv M1 \sqcap \exists hasC.P$
7. $P2 \equiv (F2 \sqcup M2)$
8. $G \equiv M2 \sqcap \exists hasC.P2$
9. $W2 \equiv W \sqcap \exists hasH.M1$
10. $M3 \equiv M2 \sqcap \forall hasC.\neg W$

- **Base concepts** = {Person, Female}

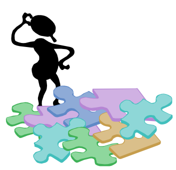
… occur on the RHS only

Defined concepts = {P, F, W, …}

… occur on the LHS (& maybe RHS)

- **Base interpretation** *J*: interpret base concepts only
- **Extension** *I* of *J*: on same domain as *J* and agrees (on base) with *J*
- TBox *T* is **definitorial** if every base interpretation has exactly one extension that is a *model* of *T*

Problem / Exercise



1. $P \equiv$ Person
2. $F \equiv$ Female
3. $W \equiv P \sqcap F$
4. $M1 \equiv P \sqcap \neg W$
5. $M2 \equiv W \sqcap \exists hasC.P$
6. $F2 \equiv M1 \sqcap \exists hasC.P$
7. $P2 \equiv (F2 \sqcup M2)$
8. $G \equiv M2 \sqcap \exists hasC.P2$
9. $W2 \equiv W \sqcap \exists hasH.M1$
10. $M3 \equiv M2 \sqcap \forall hasC.\neg W$

- Let the **interpretation** *I*(Person(x)) be "x is a person".
- Similarly, *I*(Female(x)) = "x is female".

- Question: What do W, M1, etc. mean?

Back to Reasoning with the Family ...

$$
\begin{aligned}
\mathsf{Woman} &\equiv \mathsf{Person} \sqcap \mathsf{Female}\\
\mathsf{Man} &\equiv \mathsf{Person} \sqcap \neg\mathsf{Woman}\\
\mathsf{Mother} &\equiv \mathsf{Woman} \sqcap \exists\mathsf{hasChild.Person}\\
\mathsf{Father} &\equiv \mathsf{Man} \sqcap \exists\mathsf{hasChild.Person}\\
\mathsf{Parent} &\equiv \mathsf{Father} \sqcup \mathsf{Mother}\\
\mathsf{Grandmother} &\equiv \mathsf{Mother} \sqcap \exists\mathsf{hasChild.Parent}\\
\mathsf{MotherWithManyChildren} &\equiv \mathsf{Mother} \sqcap \geqslant 3\,\mathsf{hasChild}\\
\mathsf{MotherWithoutDaughter} &\equiv \mathsf{Mother} \sqcap \forall\mathsf{hasChild}.\neg\mathsf{Woman}\\
\mathsf{Wife} &\equiv \mathsf{Woman} \sqcap \exists\mathsf{hasHusband.Man}
\end{aligned}
$$

- concept *definition:* MyConcept $\equiv$ *DL-formula*
- concept *inclusion:* MyConcept $\subseteq$ *DL-formula*
- finite set of definitions is a *terminology* or *TBox* if for every atomic concept *A* there is at most one axiom whose lhs is *A*

Definitorial Terminologies

- In a Tbox *T* we distinguish: *primitive concepts* (occurring only on rhs) and *defined concepts* (occurring on lhs)
- *T* is *definitorial* if every interpretation of primitive concepts yields exactly one model of *T* (and thus for the defined concepts)

➔ meaning of defined concepts is fixed once the primitive concepts are interpreted !

- *A directly uses B* in *T* if *B* appears in the rhs of the definition of *A*
- *A uses B* is the transitive closure of '*directly uses'*
- *T* is *cyclic* if *A uses A* for some *A; else acyclic*

One can show: If *T* is acyclic then *T* is definitorial

What about this one?

$$\mathsf{Human}' \equiv \mathsf{Animal} \sqcap \forall\mathsf{hasParent.Human}'$$

Expansion of Terminologies

- For acyclic *T* we can "unfold" concept definitions until every defined concepts is specified in terms of primitive concepts only

➔ the *expansion* of a TBox *T*

- Example:

$$
\begin{aligned}
\mathsf{Woman} &\equiv \mathsf{Person} \sqcap \mathsf{Female}\\
\mathsf{Man} &\equiv \mathsf{Person} \sqcap \neg(\mathsf{Person} \sqcap \mathsf{Female})\\
\mathsf{Mother} &\equiv (\mathsf{Person} \sqcap \mathsf{Female}) \sqcap \exists\mathsf{hasChild.Person}\\
\mathsf{Father} &\equiv (\mathsf{Person} \sqcap \neg(\mathsf{Person} \sqcap \mathsf{Female})) \sqcap \exists\mathsf{hasChild.Person}\\
\mathsf{Parent} &\equiv ((\mathsf{Person} \sqcap \neg(\mathsf{Person} \sqcap \mathsf{Female})) \sqcap \exists\mathsf{hasChild.Person})\\
&\quad \sqcup ((\mathsf{Person} \sqcap \mathsf{Female}) \sqcap \exists\mathsf{hasChild.Person})\\
\mathsf{Grandmother} &\equiv ((\mathsf{Person} \sqcap \mathsf{Female}) \sqcap \exists\mathsf{hasChild.Person})\\
&\quad \sqcap \exists\mathsf{hasChild}.(((\mathsf{Person} \sqcap \neg(\mathsf{Person} \sqcap \mathsf{Female}))\\
&\qquad\qquad \sqcap \exists\mathsf{hasChild.Person})\\
&\qquad\qquad \sqcup ((\mathsf{Person} \sqcap \mathsf{Female})\\
&\qquad\qquad\quad \sqcap \exists\mathsf{hasChild.Person}))\\
\mathsf{MotherWithManyChildren} &\equiv ((\mathsf{Person} \sqcap \mathsf{Female}) \sqcap \exists\mathsf{hasChild.Person}) \sqcap \geqslant 3\,\mathsf{hasChild}\\
\mathsf{MotherWithoutDaughter} &\equiv ((\mathsf{Person} \sqcap \mathsf{Female}) \sqcap \exists\mathsf{hasChild.Person})\\
&\quad \sqcap \forall\mathsf{hasChild}.(\neg(\mathsf{Person} \sqcap \mathsf{Female}))\\
\mathsf{Wife} &\equiv (\mathsf{Person} \sqcap \mathsf{Female})\\
&\quad \sqcap \exists\mathsf{hasHusband}.(\mathsf{Person} \sqcap \neg(\mathsf{Person} \sqcap \mathsf{Female}))
\end{aligned}
$$