INFO216:
Advanced Modelling

Theme, spring 2017:
Modelling and Programming the Web of Data

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Session S13: OWL DL

- Themes:
  - description logic
  - decision problems
  - OWL DL
  - Manchester OWL-syntax
- Practical stuff:
  - perhaps Jena's OntModel class
  - we skip Protege-OWL 3 programming

Readings

- Forum links (cursory):
  - http://www.w3.org/TR/owl2-primer/
    - show: Turtle and Manchester syntax
    - hide: other syntaxes
  - Description Logic Handbook:
    - Chapter 1: Nardi & Brachman:
      Introduction to Description Logics
    - Chapter 2: Baader & Nutt:
      Formal Description Logics *(gets hard)*

Description Logic (DL)

Description logics *(perhaps from INFO100?)*

- Description Logic (DL)
  - a simple *fragment* of predicate logic
    - ...or, rather, a *family of such fragments*
  - not very *expressive* ("uttrykkskraftig")
  - but (can have) *good decision problems*, i.e.,
    - it answers *decision problems* (rather) quickly
- Suitable for describing *concepts* ("begreper")
  - formal basis for *OWL DL*
  - can be used to:
    - describe *concepts* and their *roles* ("Tbox")
    - describe *individuals* and their *roles* ("ABox")

Relationship to other logics

- *Proposition logics* are about *statements* (*propositions*):
  “Martha is a Woman” ⇐
  “Martha is Human” ∧ “Martha is Female”
- (First order) *predicate logics* are about *predicates* and *objects*:
  - $\forall x.(\mathrm{Woman}(x) \Leftrightarrow \mathrm{Human}(x) \wedge \mathrm{Female}(x))$
- *Description logics* are about *concepts*:
  - $\mathrm{Woman} \doteq \mathrm{Human} \sqcap \mathrm{Female}$
  - ...and also *roles* and *individuals*
- There are many other logic systems:
  - *modal logics*: necessarily □, possibly ◊
  - *temporal logics*: always □, sometimes ◊, next time ○

Definition of concepts ("begreper")

- **Woman $\doteq$ Human $\sqcap$ Female**
- **Man $\doteq$ Human $\sqcap$ $\neg$Woman**
- **Parent $\doteq$ Mother $\sqcup$ Father**
  - concepts: **Male, Human, Father, Mother...**
  - definition: $\doteq$
  - conjuction (and): $\sqcap$
  - disjunction (or): $\sqcup$
  - negation (not): $\neg$
  - nested expressions: **(   )**
- **Childless** $\doteq$??

Definition of concepts ("begreper")

- **Woman ≐ Human ⊓ Female**
- **Man ≐ Human ⊓ ¬Woman**
- **Parent ≐ Mother ⊔ Father**
  - concepts: **Male, Human, Father, Mother...**
  - definition: ≐
  - conjuction (and): ⊓
  - disjunction (or): ⊔
  - negation (not): ¬
  - nested expressions: **(   )**
- **Childless ≐ Human ⊓ ¬Parent**

Atomic and defined concepts and roles

- *Atomic concepts* are given
  - *corresponds to OWL-NamedClasses that are not composed from other classes*
- *Defined concepts*
  - *corresponds to OWL-NamedClasses that are composed from other classes*
  - defined by *concept expressions*
  - appear on the left side of $\doteq$ axioms
- Similar distinction between *atomic and defined roles*

Roles

- **Mother** $\doteq$ **Female** $\sqcap$ $\exists$**hasChild**.$\top$
- **Bachelor** $\doteq$ **Male** $\sqcap$ $\neg\exists$**hasSpouse**.$\top$
- **Uncle** $\doteq$ **Male** $\sqcap$ $\exists$**hasSibling.Parent**
  - roles: **hasChild, hasSibling...**
  - universal concept ("top"): $\top$
  - existential restriction: $\exists$
- **Grandparent** $\doteq$??
- **Grandparent** $\doteq$ ..((w/o Mother & Father))..
- **Uncle** $\doteq$ ..((without Parent))..

Roles

- **Mother ≐ Female ⊓ ∃hasChild.**⊤
- **Bachelor ≐ Male ⊓ ¬∃hasSpouse.**⊤
- **Uncle ≐ Male ⊓ ∃hasSibling.Parent**
  - roles: **hasChild, hasSibling...**
  - universal concept ("top"): ⊤
  - existential restriction: **∃**
- **Grandparent ≐ Human ⊓ ∃hasChild.Parent**
- **Grandparent** ≐ ..((w/o Mother & Father))..
- **Uncle** ≐ ..((without Parent))..

Roles

- **Mother ≐ Female ⊓ ∃hasChild.⊤**
- **Bachelor ≐ Male ⊓ ¬∃hasSpouse.⊤**
- **Uncle ≐ Male ⊓ ∃hasSibling.Parent**
  - roles: **hasChild, hasSibling...**
  - universal concept ("top"): ⊤
  - existential restriction: **∃**
- **Grandparent ≐ Human ⊓ ∃hasChild.Parent**
- **Grandparent ≐ Human ⊓ ∃hasChild.∃hasChild.⊤**
- **Uncle** ≐ ..((without Parent))..

Roles

- $\mathbf{Mother} \doteq \mathbf{Female} \sqcap \exists \mathbf{hasChild}.\top$
- $\mathbf{Bachelor} \doteq \mathbf{Male} \sqcap \neg\exists \mathbf{hasSpouse}.\top$
- $\mathbf{Uncle} \doteq \mathbf{Male} \sqcap \exists \mathbf{hasSibling}.\mathbf{Parent}$
  - roles: **hasChild, hasSibling...**
  - universal concept ("top"): $\top$
  - existential restriction: $\exists$
- $\mathbf{Grandparent} \doteq \mathbf{Human} \sqcap \exists \mathbf{hasChild}.\mathbf{Parent}$
- $\mathbf{Grandparent} \doteq \mathbf{Human} \sqcap \exists \mathbf{hasChild}.\exists \mathbf{hasChild}.\top$
- $\mathbf{Uncle} \doteq \mathbf{Male} \sqcap \exists \mathbf{hasSibling}.\exists \mathbf{hasChild}.\top$

Null concept

- **Male ⊓ Female ⊑ ⊥**
  - null concept ("bottom"): ⊥
  - subsumption (sub concept): ⊑
  - equivalence: **≡**
- ≐ is used for *definitions* (or just ≡)
- ≡ are used for *equivalence axioms*
- ⊑ are used for *specialisation axioms*
- *This was our first axiom!*
  - so far we have just defined *concepts*
  - we have not used them in *axioms*
- Note the use of `... ⊑ ⊥` ("subsumption of bottom")
  - to say that something is not the case

More about roles

- $\textbf{HappyFather} \doteq \textbf{Father} \sqcap \forall\textbf{hasChild.HappyPerson}$
  - universal value restriction: $\forall$
- $\textbf{MotherOfOne} \doteq \textbf{Mother} \sqcap (=1\ \textbf{hasChild}.\top)$
- $\textbf{Polygamist} \doteq (\geq 3\ \textbf{hasSpouse}.\top)$
  - number restrictions: $=, \geq, \leq$
- $\textbf{Narsissist} \doteq \exists\textbf{hasLoveFor}.\underline{\textbf{Self}}$
  - **self references**: $\underline{\textbf{Self}}$
- **MassMurderer** ≐ ??
- **SelfHater** ≐ ??

More about roles

- **HappyFather $\doteq$ Father $\sqcap$ $\forall$hasChild.HappyPerson**
  - universal value restriction: **$\forall$**
- **MotherOfOne $\doteq$ Mother $\sqcap$ (=1 hasChild.$\top$)**
- **Polygamist $\doteq$ ($\geq$3 hasSpouse.$\top$)**
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- **Narsissist $\doteq$ $\exists$hasLoveFor.Self**
  - **self references**: **Self**
- **MassMurderer $\doteq$ ($\geq$4 hasKilled).Human**
- **SelfHater** $\doteq$??

More about roles

- **HappyFather ≐ Father ⊓ ∀hasChild.HappyPerson**
  - universal value restriction: **∀**
- **MotherOfOne ≐ Mother ⊓ (=1 hasChild.⊤)**
- **Polygamist ≐ (≥3 hasSpouse.⊤)**
  - number restrictions: **=, ≥, ≤**
- **Narsissist ≐ ∃hasLoveFor.Self**
  - **self references**: **Self**
- **MassMurderer ≐ (≥4 hasKilled).Human**
- **SelfHater ≐ ∃haterOf.Self**

Inverse and transitive roles

- $\mathbf{Child} \doteq \mathbf{Human} \sqcap \exists \mathbf{hasChild}^{-}.\top$
- $\mathbf{hasParent} \doteq \mathbf{hasChild}^{-}$
- $\mathbf{hasSibling} \doteq \mathbf{hasSibling}^{-}$
- $\mathbf{BlueBlood} \doteq \forall \mathbf{hasParent}^{*}.\mathbf{BlueBlood}$
  - inverse role: $\mathbf{hasChild}^{-}$
  - symmetric role: $\mathbf{hasSibling}^{-}$
  - transitive role: $\mathbf{hasParent}^{*}$
- **Niece** $\doteq$??

Inverse and transitive roles

- $\texttt{Child} \doteq \texttt{Human} \sqcap \exists \texttt{hasChild}^{-}.\top$
- $\texttt{hasParent} \doteq \texttt{hasChild}^{-}$
- $\texttt{hasSibling} \doteq \texttt{hasSibling}^{-}$
- $\texttt{BlueBlood} \doteq \forall \texttt{hasParent}^{*}.\texttt{BlueBlood}$
    - inverse role: $\texttt{hasChild}^{-}$
    - symmetric role: $\texttt{hasSibling}^{-}$
    - transitive role: $\texttt{hasParent}^{*}$
- $\texttt{Niece} \doteq \texttt{Human} \sqcap \exists \texttt{hasChild}^{-}.\texttt{hasSibling}.\top$
- *We are starting to define roles*
    - so far, we have only defined *concepts*

Composite roles

- Similar to composite concepts, e.g.:
  - **hasUncle ≐ hasParent o hasBrother**
  - **hasLovedChild ≐ hasChild ⊓ hasLoveFor**
  - **hasBrother ≐ (hasSibling | Male)**
- Mostly *not* supported by reasoning engines
  - they have "bad decision problems"
    - meaning that they compute slowly or intractably
  - ...with some exceptions
- **hasDaughter** ≐ ??
- **halfSibling** ≐ ??

Composite roles

- Similar to composite concepts, e.g.:
  - **`hasUncle ≐ hasParent o hasBrother`**
  - **`hasLovedChild ≐ hasChild ⊓ hasLoveFor`**
  - **`hasBrother ≐ (hasSibling | Male)`**
- Mostly *not* supported by reasoning engines
  - they have “bad decision problems”
    - meaning that they compute slowly or intractably
  - ...with some exceptions
- **`hasDaughter ≐ (hasChild | Female)`**
- **`halfSibling ≐ ??`**

TBox

- *Terminology box* (TBox):
  - a collection of axioms about concepts and properties
  - axioms are definitions, equivalences or subsumptions
  - *definitions* ($\doteq$): atomic concept on the left hand side *(l.h.s.)*
  - *equivalence* ($\equiv$): concept expressions on both sides
  - *subsumption* ($\sqsubseteq$): concept expressions on both sides
- *Acyclic TBoxes:*
  - contains only definitions
  - every defined concept (or role) can be *expanded* into an expression of only atomic concepts (or roles)
- *Expanded concepts* (or *roles*)
  - defined only in terms of *atomic concepts* (and *roles*)

Statements about individuals

- So far we have defined concepts and roles (*TBox*)
- We have two types of axioms about individuals (*ABox*):
  - *class assertion* (using a *concept*):

    Märtha : Female ⊓ Royal
  - *role assertion* (using a *role*):

    <Märtha, EmmaTallulah> : hasChild

    <Märtha, HaakonMagnus> : hasBrother
- *Axioms* about concepts/roles and *assertions* about individuals/roles are used to create knowledge bases:
  - concepts, roles in the *TBox* (“the tags”)
  - individuals, roles in the *ABox* (“the tagged data”)

Syntaxes differ a bit...

- So far we have defined concepts and roles (*TBox*)
- We have two types of axioms about individuals (*ABox*):
  - *class assertion* (using a *concept*):
    `Female(Märtha),(Female ⊓ Royal)(Märtha)`
  - *role assertion* (using a *role*):
    `hasChild(Märtha, EmmaTallulah)`
    `hasBrother(Märtha, HaakonMagnus)`
- *Axioms* about concepts/roles and *assertions* about individuals/roles are used to create knowledge bases:
  - concepts, roles in the *TBox* ("the tags")
  - individuals, roles in the *ABox* ("the tagged data")

Types of axioms

- Terminology axioms (in the TBox):
  - subsumptions: $\mathbf{C} \sqsubseteq \mathbf{D}$
  - equivalences: $\mathbf{C} \equiv \mathbf{D}$

    corresponds to: $\mathbf{C} \sqsubseteq \mathbf{D}$, $\mathbf{D} \sqsubseteq \mathbf{C}$
  - definitions: $A \doteq \mathbf{C}$
- Individual assertions (in the ABox):
  - class assertions: **a:C**
  - role assertions: **<a,b>:R**
- A knowledge base $\mathcal{K} = (\mathcal{T}, \mathcal{A})$ consists of
  - TBox: $\mathcal{T}$ and ABox: $\mathcal{A}$

C and D are *classes*,
A is an *atomic class*!

a and b are *individuals*.
R is a *role*!

Decision Problems

Reasoning over knowledge bases

- *What more can we do with ontologies?*
- For example:
  - a *security ontology* that describes an organisation and its computer systems as concepts, roles and individuals
  - can answer *competency questions*, e.g.:
    - are all the *security levels* subclasses of one another?
    - what is the highest security level of a *temporary*?
    - what is the necessary security level of a *component*?
    - which employees have access to *critical data*?
    - for which *security roles* is an employee qualified?
    - which individuals are *suspicious persons*?
  - *DL offers a clear and compact way or representing and reasoning about questions such as these!*

Decision problems

- A computational problem with a yes/no answer, e.g.
  - is C *subsumed* by D ($\mathcal{K} \models \mathbf{C} \sqsubseteq \mathbf{D}$)?
  - are C and D *consistent* ($\mathcal{K} \models \mathbf{C} \sqcap \mathbf{D}$)?
  - does *a* *belong* to C ($\mathcal{K} \models \mathtt{a:C}$)?
  - is *a* *R-related* to *b* ($\mathcal{K} \models \mathtt{<a,b>:R}$)?

C and D are classes,
a and b are individuals.
R is a role!

- *Decidability ("bestembarhet")*:
  - we can always calculate the yes/no answer in finite time
- *Semi-decidability ("semibestembarhet")*:
  - we can always calculate a yes-answer in finite time,
    ...but not always a no-answer
- *Undecidability ("ubestembarhet"):*
  - we cannot always calculate the answer in finite time

Decision problems for concepts

- There are four basic decision problems for concepts:
  - consistency: whether there is an individual **a** so that

    $\mathcal{T} \models a{:}C$,

    $\mathcal{T} \not\models C \sqsubseteq \bot$
  - subsumption: $\mathcal{T} \models C \sqsubseteq D$,

    $\mathcal{T} \models C \sqcap \neg D \sqsubseteq \bot$
  - equivalence: $\mathcal{T} \models C \equiv D$ *or* $C \equiv_{\mathcal{T}} D$,

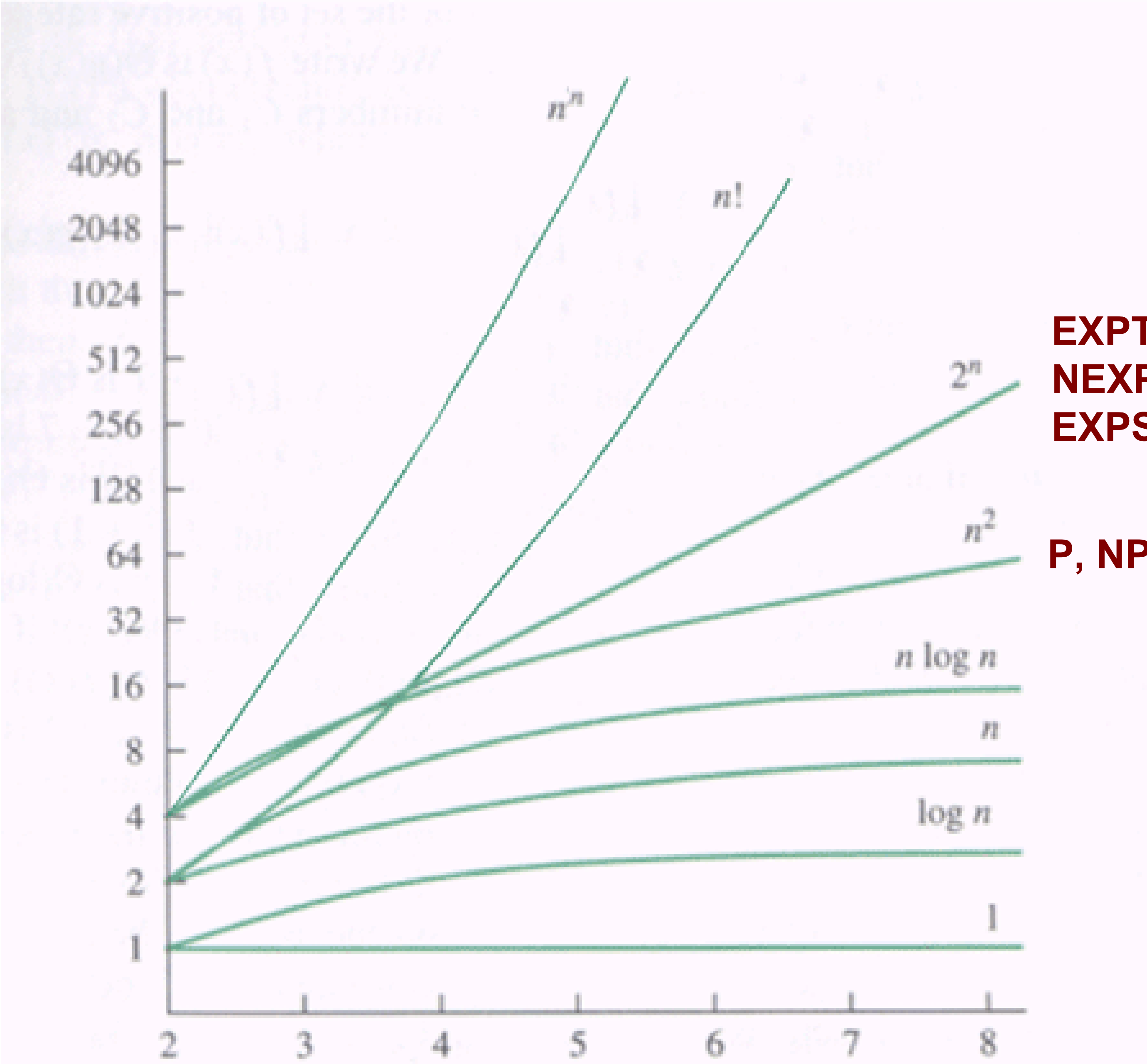
    $\mathcal{T} \models C \sqsubseteq D,\ D \sqsubseteq C$
  - disjunction: $\mathcal{T} \models C \sqcap D \sqsubseteq \bot$
- *All four can be reduced to subsumption or consistency!*
- $\mathcal{T}$ can be *emptied*, by expanding all its concepts

Decision problems for individuals

- Decision problems for individuals and roles:
  - instance checking: $\mathcal{A} \models$ **a:C**,
    $\not\models \mathcal{A} \sqcap \neg$**(a:C)**
    *is individual **a** member of class **C**?*
  - role checking: $\mathcal{A} \models$ **<a,b>:R**,
    $\not\models \mathcal{A} \sqcap \neg$**(<a,b>:R)**
    *is individual **a** **R**-related to individual **b**?*
  - classifications (not yes/no):
    to which classes does **a** belong?
    all individuals of class **C**?
- *All boil down to consistency checking for ABoxes*
  - ...under certain (rather weak) conditions

Complexity

- Decidability is often necessary
  - but not enough
  - we also want a decision "in reasonable time"
  - different DL-variants have different *complexity*
  - many different *complexity classes*
    - polynomial (**P**), exponential (**EXP**)...
    - ...in time and space
- *Tractable* (or *feasible*) complexity
  - acceptable complexity for large knowledge bases
  - typically *polynomial* complexity (**P**)
  - complexity grows $O(n^c)$ of problem size n



EXPTIME,
NEXPTIME,
EXPSPACE

P, NP, PSPACE

DL-complexity

- We have presented many DL-notations
  - *do not* use all at the same time!
  - that gives high complexity
  - which is why we have different OWL Profiles
- Complexity calculator on the net:
  - *Complexity of reasoning in Description Logics*
    http://www.cs.man.ac.uk/~ezolin/dl/

OWL DL

Relation to OWL

- OWL DL and description logic are closely matched
  - everything in OWL DL has a DL-counterpart
  - most everything in DL can be expressed in OWL DL
- DL is a family of logic systems:
  - some of them correspond to particular OWL profiles
  - OWL1 DL: $\mathcal{SHOIN}^{(\mathcal{D})}$
  - OWL2 DL: $\mathcal{SROIQ}^{(\mathcal{D})}$

OWL profiles revisited

- OWL "1" (2002):
  - *OWL Full – "anything goes"*
  - OWL DL – fragment of OWL Full,
    - formal semantics through *description logic*
  - OWL Lite – simple fragment of OWL DL, not much used
- OWL 2 (2008):
  - *OWL2 Full – "anything goes"*
  - OWL2 DL – fragment of OWL2 full, extension of OWL DL
  - OWL2 DL – has three further fragments:
    - OWL2 EL – quick reasoning, fragment of OWL2 DL
    - OWL2 RL – rule language, fragment of OWL2 DL
    - OWL2 QL – query language, fragment of OWL2 DL

And there is more...

- A few other constructions
- Formal definitions of
  - syntax (rules for valid expressions, reasoning)
  - semantics (rules for interpreting expressions)
- Tools and techniques
- Lots of applications

Protege-OWL

Protege-OWL

- Extension of Protegé
  - ordinary Protegé supports *frames*
  - Protegé-OWL
    - reuses much of the Protege-Frames GUI

Protege-OWL 3.x

- Supports OWL 1.1:
  - uses *Jena* internally
  - wraps Jena's API with a *Protege-OWL API*
    - stays with Jena's graph metaphor
    - you “create the ontology as a graph”
  - many plug-ins:
    - SWRL, Jess, reasoning...
  - still actively developed

Protege-OWL 4.x, 5 beta

- Supports OWL 2:
  - complete reimplementation of internals
  - *not* based on Jena
  - offers a dedicated *OWL API* (in Java)
    - description-logic metaphor
    - your “build the ontology from axioms”
  - more and more plug-ins
  - still actively developed

Manchester OWL syntax

Manchester OWL-syntax

- A simple DL notation without special symbols
  - used by Protege-OWL to construct classes
  - similar to DL syntax
- **Class: Woman**
  EquivalentTo: Human and Female
- **Class: Man**
  EquivalentTo: Human and not Female
- **Class: Parent**
  EquivalentTo: Mother or Father
- Can be used to *serialise* complete ontologies
  - ...we will look mostly at Tbox expressions
- http://www.w3.org/TR/owl2-manchester-syntax/

Comparison

- DL:

  Male $\doteq$ Human $\sqcap$ ¬Female

- Machester OWL:

```
Class: Man
    EquivalentTo: Human and not Female
```

- TURTLE:

```
family:Man owl:equivalentClass
        owl:intersectionOf (
                family:Human
                [    a owl:Class ;
                     owl:complementOf family:Woman
                ]
        ) .
```

Roles in Manchester OWL syntax

```
• Class: Mother
        EquivalentTo:
        Female and hasChild some owl:Thing
• Class: Bachelor
        EquivalentTo:
        Male and not hasSpouse some owl:Thing
• Class: Uncle
        EquivalentTo:
        Male and hasSibling some Parent
```

- universal concept (top): `owl:Thing`
- existential restriction: `some`

Null concept in Manchester OWL syntax

- **Class:** <class-name>
  EquivalentTo: Male and Female
  SubClassOf: owl:Nothing
  - null concept (bottom): **owl:Nothing**
  - subsumption (subconcept): **SubClassOf:**
  - equivalence: **EquivalentTo:**
    - ...used both for *definitions* and for *axioms*

More roles in Manchester OWL syntax

- Class: HappyFather
  EquivalentTo:
  Father and hasChild only Happy
  - value restriction: only
- Class: MotherOfOne
  EquivalentTo: Mother and
  hasChild exactly 1
- Class: Bigamist
  EquivalentTo: hasSpouse min 2
  - number restriction: exactly, min, max
- Class: Narcissist
  EquivalentTo: loves some Self

Inverse, symmetric and transitive roles

- **Class: Child**
  EquivalentTo:
  Human and inverse hasChild some owl:Thing
- **Class: hasParent**
  EquivalentTo: inverse hasChild
- **ObjectProperty: hasSibling**
  Characteristic: Symmetric
- **ObjectProperty: hasAncestor**
  Characteristic: Transitive
- inverse role: **inverse**
  - symmetric role:
    Characteristic: SymmetricProperty
  - transitive role:
    Characteristic: TransitiveProperty