INFO216:
Advanced Modelling

Theme, spring 2018:
Modelling and Programming the Web of Data

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Session S12: 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

- 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*:
  - `∀x.(Woman(x) ⇔ Human(x) ∧ Female(x))`
- *Description logics* are about *concepts*:
  - `Woman ≐ Human ⊓ 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

- $\mathbf{Mother} \doteq \mathbf{Female} \sqcap \exists\, \mathbf{hasChild}.\top$
- $\mathbf{Bachelor} \doteq \mathbf{Male} \sqcap \neg\exists\, \mathbf{hasSpouse}.\top$
- $\mathbf{Uncle} \doteq \mathbf{Male} \sqcap \exists\, \mathbf{hasSibling.Parent}$
  - roles: **hasChild, hasSibling...**
  - universal concept ("top"): $\top$
  - existential restriction: $\exists$
- $\mathbf{Grandparent} \doteq \mathbf{Human} \sqcap \exists\, \mathbf{hasChild.Parent}$
- $\mathbf{Grandparent} \doteq \mathbf{Human} \sqcap \exists\, \mathbf{hasChild}.\exists\, \mathbf{hasChild}.\top$
- **Uncle** $\doteq$ ..((without Parent))..

Roles

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  - universal concept ("top"): $\top$
  - existential restriction: $\exists$
- **Grandparent** $\doteq$ **Human** $\sqcap$ $\exists$ **hasChild.Parent**
- **Grandparent** $\doteq$ **Human** $\sqcap$ $\exists$ **hasChild**.$\exists$ **hasChild**.$\top$
- **Uncle** $\doteq$ **Male** $\sqcap$ $\exists$ **hasSibling**.$\exists$ **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

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

More about roles

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- **MassMurderer ≐ (≥4 hasKilled).Human**
- **SelfHater** ≐ ??

More about roles

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  - 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: $\mathbf{hasParent}^{*}$
- $\mathbf{Niece} \doteq$??

Inverse and transitive roles

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

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  - **`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)`**

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

TBox

- *Acyclic TBoxes:*
  - contains only definitions
  - subsumption axioms can (sometimes) be removed:
    - $T \sqsubseteq C$ is transformed into $T \doteq \overline{T} \sqcap C$
    - *when only a single l.h.s. term*
  - 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*)
  - the TBox can (sometimes) be emptied

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: **C ⊑ D**
  - equivalences: **C ≡ D**

    corresponds to: **C ⊑ D, D ⊑ C**
  - definitions: A ≐ **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 ($\mathcal{K} \vDash$ **C ⊑ D**)?
  - are C and D *consistent* ($\mathcal{K} \vDash$ **a:(C ⊓ D)**)?
  - does *a* *belong* to C ($\mathcal{K} \vDash$ **a:C**)?
  - is *a* *R-related* to *b* ($\mathcal{K} \vDash$ **<a,b>:R**)?
- *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

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

Decision problems for concepts

- There are four basic decision problems for concepts:
  - consistency: whether there is an individual $\mathtt{a}$ so that

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

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

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

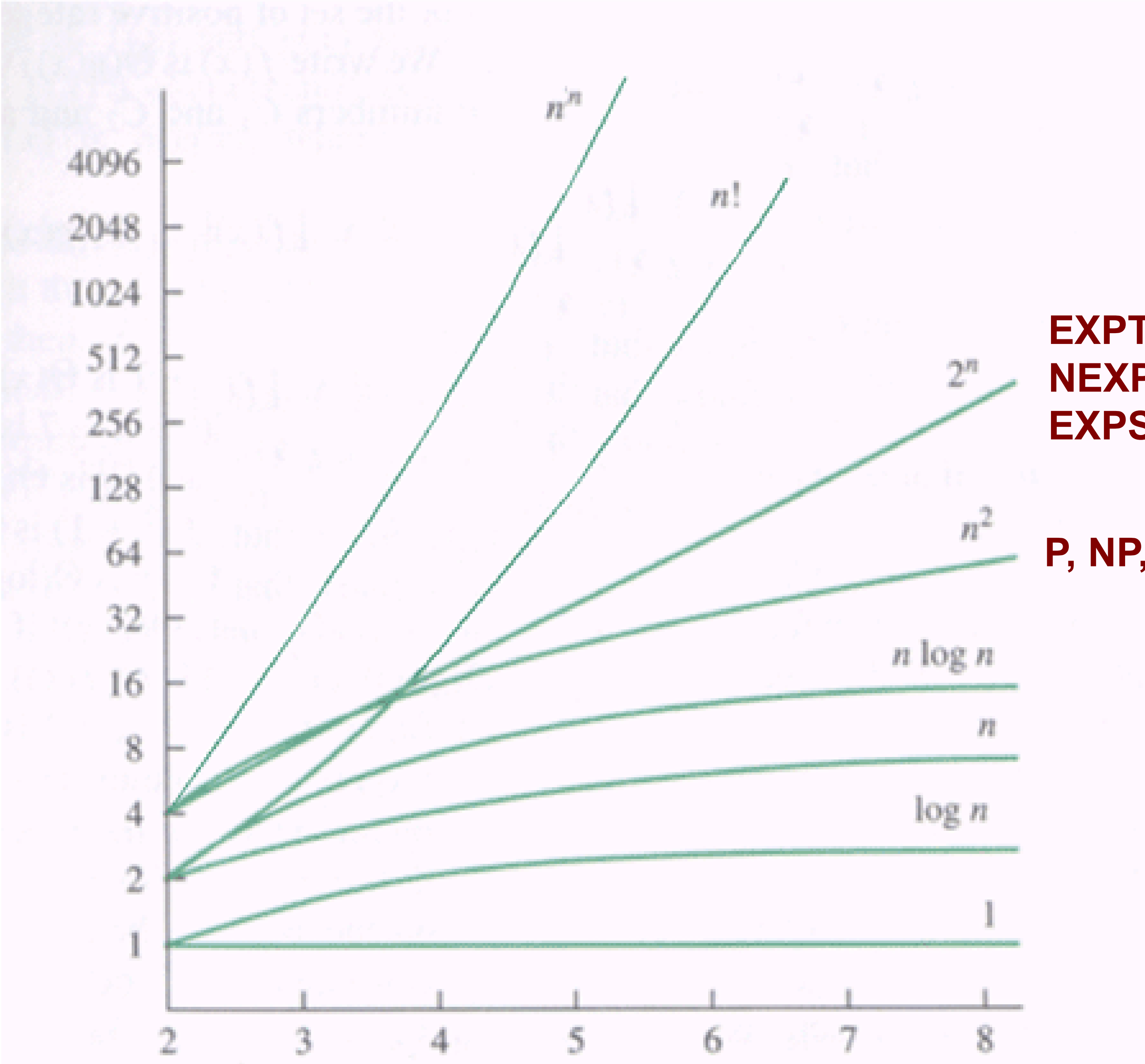
    $\mathcal{T} \models \mathtt{C} \sqsubseteq \mathtt{D}$, $\mathtt{D} \sqsubseteq \mathtt{C}$
  - disjunction: $\mathcal{T} \models \mathtt{C} \sqcap \mathtt{D} \sqsubseteq \bot$
- *All four can be reduced to subsumption or consistency!*
- $\mathcal{T}$ can be *emptied*, by expanding all its concepts

Decision problems for individuals

- Decision problems for individuals and roles:
  - instance checking: $\mathcal{A} \vDash$ **a:C**, $\nvDash \mathcal{A} \sqcap \neg$**(a:C)**
    is individual ***a*** *member of class* ***C****?*
  - role checking: $\mathcal{A} \vDash$ **<a,b>:R**, $\nvDash \mathcal{A} \sqcap \neg$**(<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 EL – quick reasoning, fragment of OWL2 DL
    - OWL2 RL – rule language, fragment of OWL2 DL
      - OWL LD – linked data, fragment of OWL2 RL
    - 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

Old Protege-OWL (3.x and older)

- Supported OWL 1.1:
  - used *Jena* internally
  - wrapped Jena's API with a *Protege-OWL API*
    - uses Jena's graph metaphor
    - you “create the ontology as a graph”
  - many plug-ins:
    - SWRL, Jess, reasoning...
  - still available,
    - but not so actively developed

Protege-OWL 4 and later

- Supports OWL 2:
  - complete reimplementation of internals
  - *not* based on Jena
  - offers a dedicated *OWL API* (in Java)
    - description-logic metaphor
    - you “build the ontology from axioms”
  - more and more plug-ins
  - most OWL DL reasoners have moved to the OWL API

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 ≐ Human ⊓ ¬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