Semantic Web Modeling Languages Lecture III: More OWL

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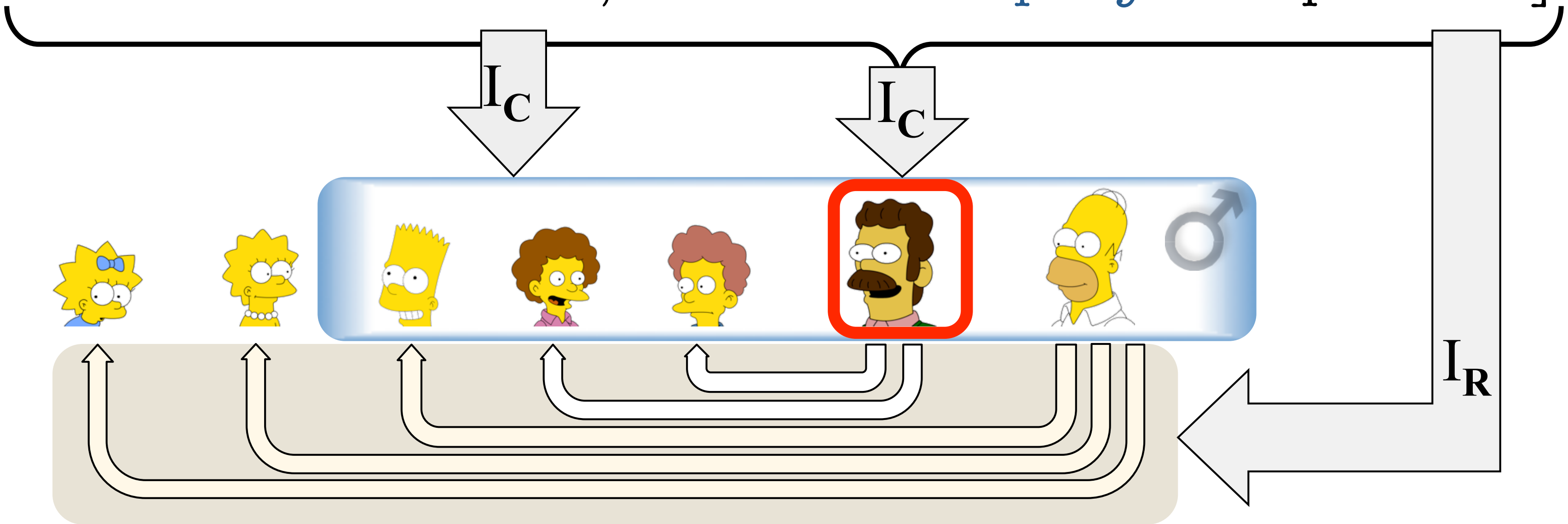
slides available at http://semantic-web-book.org/page/ESSLLI_2009:_Ontology_Modeling_Languages

Outline

- Advanced Features of OWL
  - more class constructors
  - extended property modeling
  - handling of data values

More Complex Classes: Qualified At-Least Restriction

- [rdf:type owl:Restriction ;
  owl:minQualifiedCardinality "*n*"^^xsd:nonNegativeInteger ;
  owl:onProperty *prop* ; owl:onClass *class*]
- $I_C(\ldots) = \{x \mid \#\{\langle x,y\rangle \in I_R(\mathit{prop}) \mid y \in I_C(\mathit{class})\} > n\}$
- Example:
  [rdf:type owl:Restriction ;
  owl:minQualifiedCardinality "2"^^xsd:nonNegativeInteger ;
  owl:onClass ex:Male; owl:onProperty ex:parentOf]



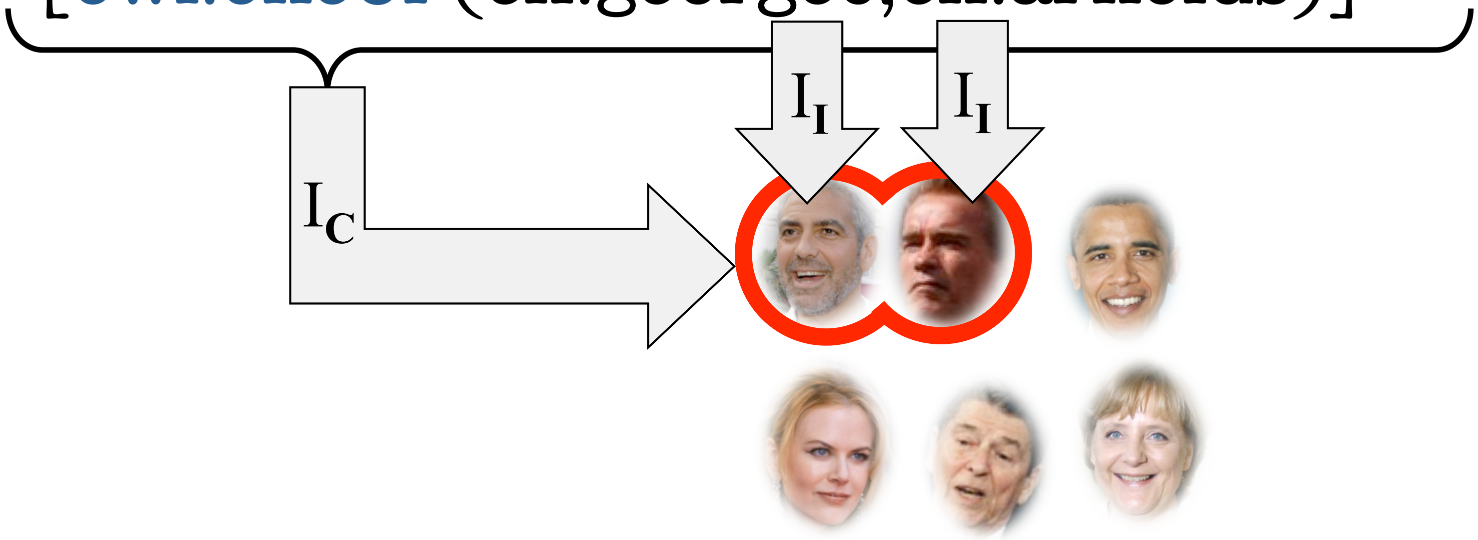
More Qualified Cardinalities

- in analogy to at-least restrictions:
  - at-most:
    owl:maxQualifiedCardinality
  - exact cardinality:
    owl:QualifiedCardinality

More Complex Classes: Enumeration of Individuals

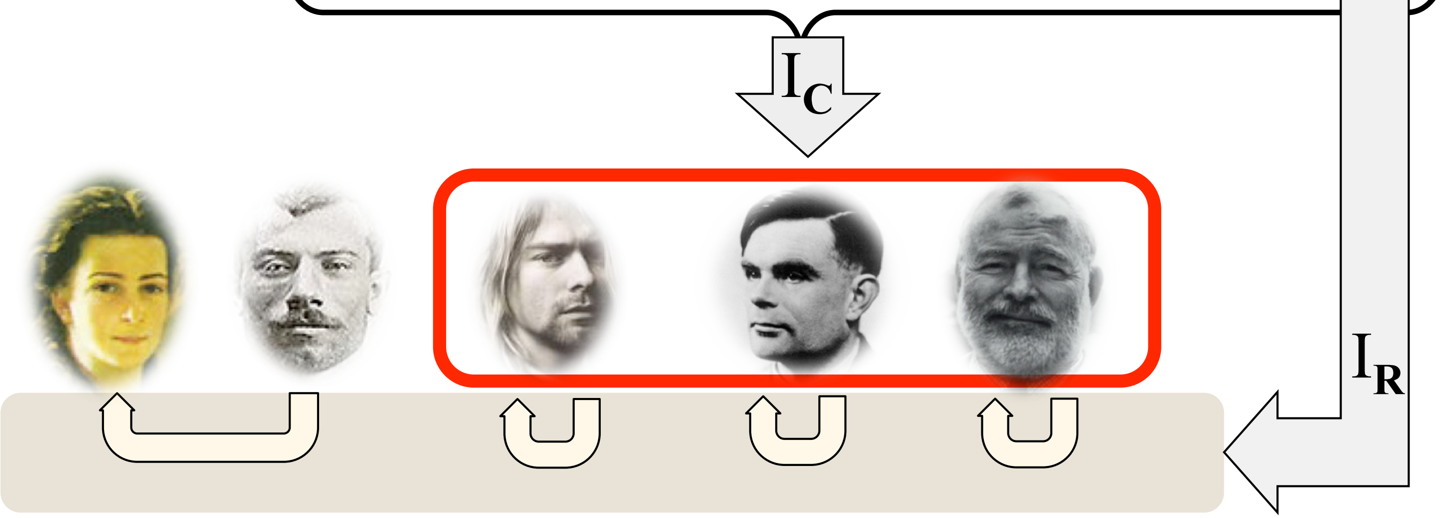
- [owl:oneOf (induri1, …, indurin)]
- I_C([owl:oneOf (induri1, …, indurin)])
  = {I_I(induri1), … , I_I(indurin)}
- Example:

  [owl:oneOf (ex:georgec,ex:arnolds)]



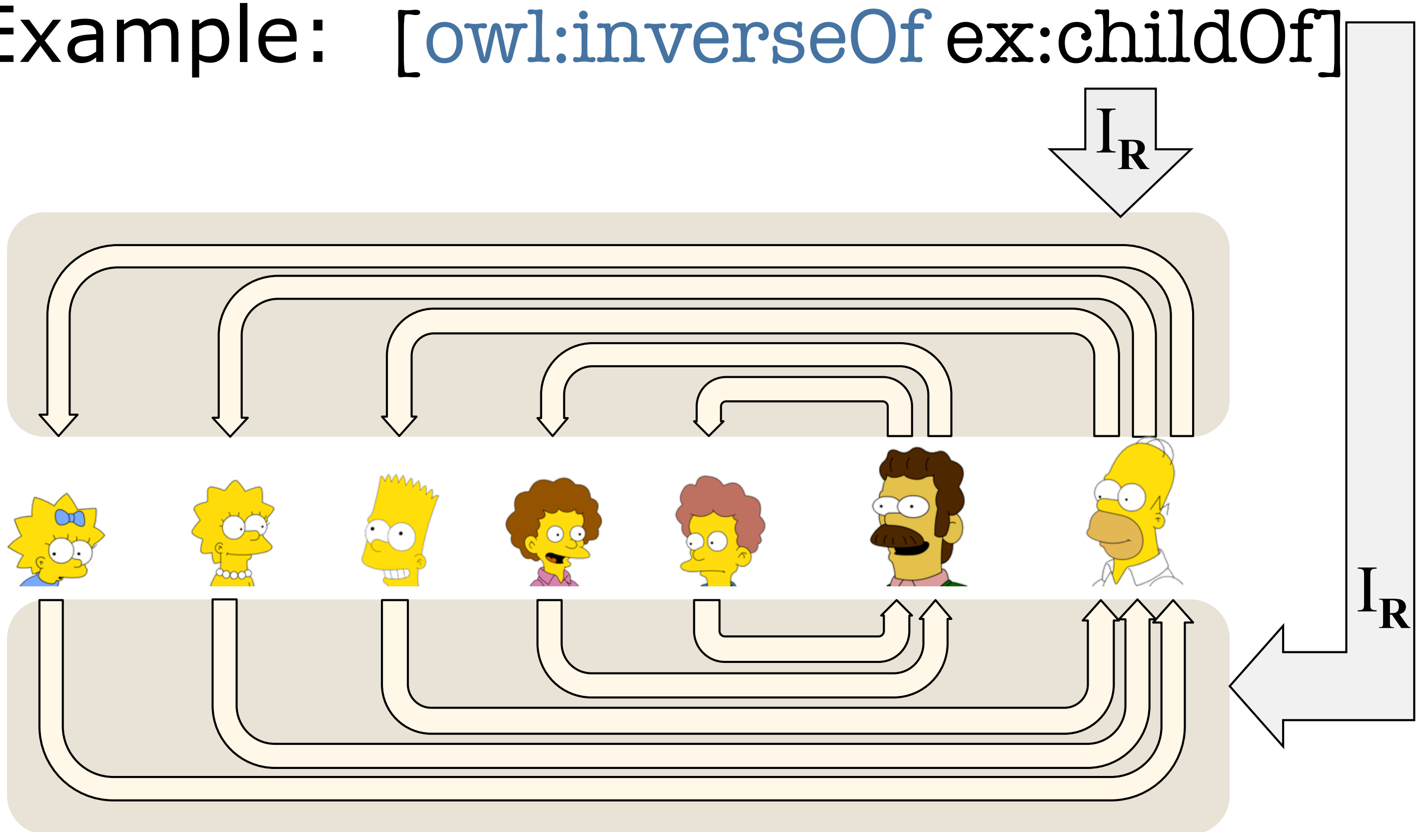
More Complex Classes: Self Restriction

- [rdf:type owl:Restriction ;
  owl:onProperty *prop* ;
  owl:hasSelf "true"^^xsd:boolean]
- $I_C(\ldots)=\{x \mid \langle x,x\rangle \in I_R(prop)\}$
- Example: [rdf:type owl:Restriction ;
  owl:onProperty ex:hasKilled ;
  owl:hasSelf "true"^^xsd:boolean]



Inverse Properties

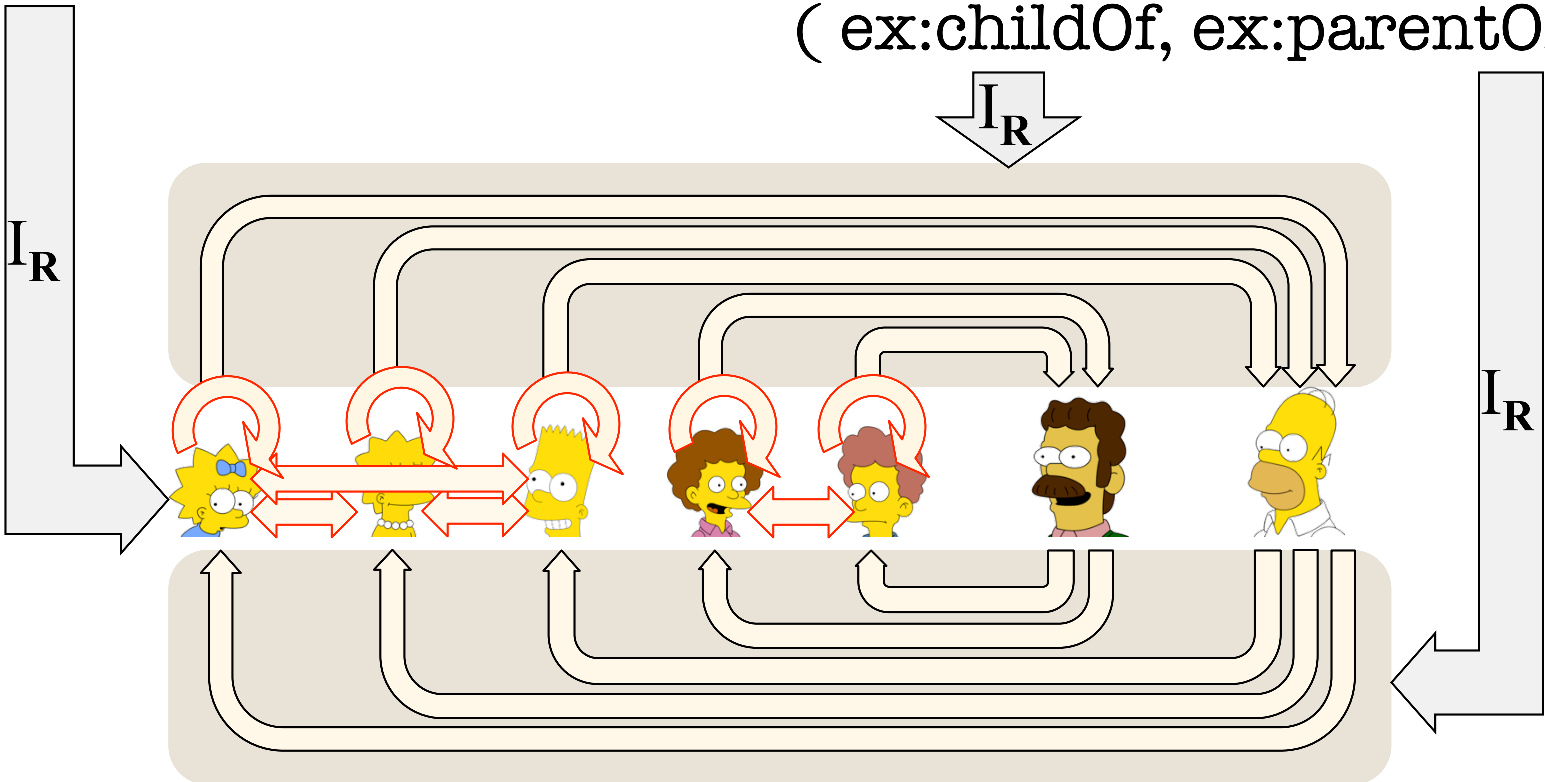
- [owl:inverseOf *prop*]
- I_R([owl:inverseOf *prop*])
  $=\{\langle y,x\rangle \mid \langle x,y\rangle \in I_R(prop)\}$
- Example: [owl:inverseOf ex:childOf]



Property Chain Axioms

- *prop* owl:propertyChainAxiom (*prop1*, ... , *propn*) .
- true in $\mathcal{I}$, if $I_R(prop1) \circ \ldots \circ I_R(propn) \subseteq I_R(prop)$
- Example:

ex:siblingOf owl:propertyChainAxiom
(ex:childOf, ex:parentOf) .



Decidability problems

- role chain axioms can easily lead to undecidability
- in order to retain decidability, two global constraints are imposed on OWL DL ontologies:
  - the set of property chain axioms and subproperty statements must be *regular*
  - properties used in cardinality and self restrictions must be *simple* properties

Property Chain Axioms: Regularity

- in the following , we abbreviate
  R owl:propertyChainAxiom (S_1 … S_n). by $S_1 \circ \ldots \circ S_n \sqsubseteq R$
  S owlrdfs:subPropertyOf R. by $S \sqsubseteq R$
- regularity restriction:
  - there must be a strict linear order $\prec$ on the properties
  - every property chain or subproperty axiom has to have one of the following forms where $S_i \prec R$ for all i= 1, 2, . . . , *n*:

    $R \circ R \sqsubseteq R$ [owl:inverseOf R] $\sqsubseteq R$ $S_1 \circ S_2 \circ \ldots \circ S_n \sqsubseteq R$

    $R \circ S_1 \circ S_2 \circ \ldots \circ S_n \sqsubseteq R$ $S_1 \circ S_2 \circ \ldots \circ S_n \circ R \sqsubseteq R$

- Example 1: $R \circ S \sqsubseteq R$ $S \circ S \sqsubseteq S$ $R \circ S \circ R \sqsubseteq T$
  - regular with order $S \prec R \prec T$
- Example 2: $R \circ T \circ S \sqsubseteq T$
  - not regular because form not admissible
- Example 3: $R \circ S \sqsubseteq S$ $S \circ R \sqsubseteq R$
  - not regular because no adequate order exists

Property Chain Axioms: Simplicity

- combining property chain axioms and cardinality or self restrictions may lead to undecidability
- restriction: use only *simple* properties in cardinality expressions (i.e. those which cannot be – directly or indirectly – inferred from property chains)
- technically:
  - for any property chain axiom $S_1 \circ S_2 \circ \ldots \circ S_n \sqsubseteq R$ with n>1, R is non-simple
  - for any subproperty axiom $S \sqsubseteq R$ with S non-simple, R is non-simple
  - all other properties are simple
- Example:
  $Q \circ P \sqsubseteq R$ $R \circ P \sqsubseteq R$ $R \sqsubseteq S$ $P \sqsubseteq R$ $Q \sqsubseteq S$
  non-simple: R, S simple: P, Q

Property Characteristics

- OWL also allows for specifying that properties are:
  - disjoint from another
  - functional
  - inverse functional
  - transitive
  - symmetric
  - asymmetric
  - reflexive
  - irreflexive

} syntactic sugar w.r.t. already introduced modeling features

Datatypes in OWL

- like in RDF, properties can also be used to associate individuals with data values:

  ex:john ex:hasAge “42“^^xsd:integer .

- those *datatype properties* must not be used as individual-interrelating *object properties* at the same time
- datatypes supported by OWL:

  owl:real, owl:rational, xsd:decimal, xsd:integer, xsd:nonNegativeInteger, xsd:nonPositiveInteger, xsd:positiveInteger, xsd:negativeInteger, xsd:long, xsd:int, xsd:short, xsd:byte, xsd:unsignedLong, xsd:unsignedInt, xsd:unsignedShort, xsd:unsignedByte, xsd:double, xsd:float, xsd:string, xsd:normalizedString, xsd:token, xsd:language, xsd:Name, xsd:NCName, xsd:NMTOKEN, xsd:boolean, xsd:hexBinary, xsd:base64Binary, xsd:anyURI, xsd:dateTime, xsd:dateTimeStamp, rdf:XMLLiteral

Semantic Web Modeling Languages

Lecture 3.2: More OWL

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Slides for remaining lectures at http://semantic-web-book.org/page/ESSLLI_2009

Datatype Ranges

- Property ranges for datatype properties:
  Datatypes (e.g. from XML Schema)
- Example:

```
@prefix xsd: <http://www.w3.org/2001/XMLSchema#> .
...
ex:hasAge  rdfs:range  xsd:integer .
```

- Interpretation of datatypes defined in XML Schema (OWL adds some clarifications, e.g. "Do floating point and integer numbers overlap?")
- Attention: datatypes still have to be explicitly specified in RDF and OWL! Given the above axiom, we find:

```
ex:jean    ex:hasAge  "17"^^xsd:integer .    ← Correct
ex:paul    ex:hasAge  "23"^^xsd:decimal .    ← Correct
ex:claire  ex:hasAge  "42" .                 ← Inconsistent!
```

Defining New Datatypes

- XML Schema has ways of restricting datatypes
  → **datatype facets**
- Example:

```
ex:personAge  owl:equivalentClass
  [ rdf:type  rdfs:Datatype;
    owl:onDatatype  xsd:integer;
    owl:withRestrictions (
       [ xsd:minInclusive  "0"^^xsd:integer ]
       [ xsd:maxInclusive  "150"^^xsd:integer ]
    )
  ] .
```

- Possible facets depend on datatype, some facets restricted in OWL → see specs for details

Simple Data Integration in OWL

- Practical problem: given ontologies from different sources, which URIs refer to the same individuals?
- Typical approaches in OWL:
  - Explicitly specify equality with `owl:sameAs`
  - Use inverse functional properties (“same values → same individual”)
- Problems:
  - `owl:sameAs` requires explicit mappings (rare on the Web)
  - OWL DL disallows inverse functional datatype properties (complicated interplay with datatype definitions!)
  - Only one property used globally for identification, no property combinations (Example: “All ESSLLI participants with the same name and birthday are the same.”)

OWL 2 Keys

OWL 2 provides a way to model
“All ESSLLI students with same name and birthday are the same.“
→ **Keys**

```
ex:ESSLLIStudent  owl:hasKey  (ex:name, ex:birthday) .
```

Restriction: Keys apply only to named individuals – objects of the interpretation domain to which a URI refers.

More explicitly:

If there are two URIs ***u*** and ***v***, and there is some name ***n*** and birthday ***b*** such that

```
u rdf:type ex:ESSLLIStudent; ex:name n ; ex:birthday b .
v rdf:type ex:ESSLLIStudent; ex:name n ; ex:birthday b .
```

then we conclude: `u owl:sameAs v .`

Quo Vadis, OWL Lite?

***OWL Lite* as failure:**

- Defined as fragment of OWL 1 DL, intended to be simpler
- However: almost as complex as OWL DL (ExpTime)
- Complex syntax hides real expressive power
- Current usage in ontologies coincidental rather than intentionally

Original goal: simpler implementation and usage

→ approach in OWL 2: three simpler **language profiles:**

- **OWL 2 QL**
- **OWL 2 EL**
- **OWL 2 RL**

OWL 2 Profiles

Design principle for profiles:
Identify maximal OWL 2 sublanguages that are still implementable in PTime.

Main source of intractability: **non-determinism** (requires guessing/backtracking)

- `owl:unionOf`, or `owl:complementOf` + `owl:intersectionOf`
- Max. cardinality restrictions
- Combining existentials (`owl:someValuesFrom`) and universals (`owl:allValuesFrom`) in superclasses
- Non-unary finite class expressions (`owl:oneOf`) or datatype expressions

→ features that are not allowed in any OWL 2 profile

Many further features can lead to non-determinism – care needed!

OWL 2 EL

OWL profile based on description logic EL++

- Intuition: focus on terminological expressivity used for light-weight ontologies
- Allow `owl:someValuesFrom` (existential) but not `owl:allvaluesFrom` (universal)
- Property domains, class/property hierarchies, class intersections, disjoint classes/properties, property chains, `owl:hasSelf`, `owl:hasValue`, and keys fully supported
- No inverse or symmetric properties
- `rdfs:range` allowed but with some restrictions
- No `owl:unionOf` or `owl:complementOf`
- Various restrictions on available datatypes

OWL 2 EL: Features

- Standard reasoning in OWL 2 EL:
  PTime-complete
- Used by practically relevant ontologies:
  Prime example is SNOMED CT
  (clinical terms ontology with classes and properties in the order of 10^5)
- Fast implementations available:
  full classification of SNOMED-CT in <10min;
  real-time responsivity when preprocessed (modules)

OWL 2 QL

OWL profile that can be used to query data-rich applications:

- Intuition: use OWL concepts as light-weight queries, allow query answering using rewriting in SQL on top of relational DBs
- Different restrictions on subclasses and superclasses of `rdfs:SubclassOf`:
  - subclasses can only be class names or `owl:someValuesFrom` (existential) with unrestricted (`owl:Thing`) filler
  - superclasses can be class names, `owl:someValuesFrom` or `owl:intersectionOf` with superclass filler (recursive), or `owl:complementOf` with subclass filler
- Property hierarchies, disjointness, inverses, (a)symmetry supported, restrictions on range and domain
- Disjoint or equivalence of classes only for subclass-type expressions
- No `owl:unionOf`, `owl:allValuesFrom`, `owl:hasSelf`, `owl:hasKey`, `owl:hasValue`, `owl:oneOf`, `owl:sameAs`, `owl:propertyChainAxiom`, `owl:TransitiveProperty`, cardinalities, functional properties
- Some restrictions on available datatypes

OWL 2 QL: Features

- Standard reasoning in OWL 2 QL:
  PTime, for some cases even LogSpace (<PTime)
- Convenient light-weight interface to legacy data
- Fast implementations on top of legacy database systems (relational or RDF):
  highly scalable to very large datasets

OWL 2 RL

OWL profile that resembles an OWL-based rule language:

- Intuition: subclass axioms in OWL RL can be understood as rule-like implications with head (superclass) and body (subclass)
- Different restrictions on subclasses and superclasses of `rdfs:SubclassOf`:
  - subclasses can only be class names, `owl:oneOf`, `owl:hasValue`, `owl:intersectionOf`, `owl:unionOf`, `owl:someValuesFrom` if applied only to subclass-type expressions
  - superclasses can be class names, `owl:allValuesFrom` or `owl:hasValue`; also max. cardinalities of 0 or 1 are allowed, all with superclass-type filler expressions only
- Property domains and ranges only for subclass-type expressions; property hierarchies, disjointness, inverses, (a)symmetry, transitivity, chains, (inverse)functionality, irreflexivity fully supported
- Disjoint classes and classes in keys need subclass-type expressions, equivalence only for expressions that are sub- and superclass-type, no restrictions on `owl:sameAs`
- Some restrictions on available datatypes

OWL 2 RL: Features

- Standard reasoning in OWL 2 RL: PTime-complete
- Rule-based reading simplifies modeling and implementation: even naïve implementations can be useful
- Fast and scalable implementations exist

Also: possibly useful for combining OWL with rules (see Lecture 5)

Do We Really Need So Many OWLs?

Three new OWL profiles with somewhat complex descriptions … why not just one?

- The union of any two of the profiles is no longer light-weight! QL+RL, QL+EL, RL+EL all ExpTime-hard
- Restricting to fewer profiles = giving up potentially useful feature combinations
- Rationale: profiles are "maximal" (well, not quite) well-behaved fragments of OWL 2
  → Pick suitable feature set for applications
- In particular, nobody is forced to implement *all* of a profile

OWL in Practice: Tools

- Editors (http://semanticweb.org/wiki/Editors)
  - Most common editor: Protégé 4
  - Other tools: TopBraid Composer ($), *NeOn toolkit*
  - Special purpose apps, esp. for light-weight ontologies (e.g. FOAF editors)
- Reasoners (http://semanticweb.org/wiki/Reasoners)
  - OWL DL: Pellet, HermiT, FaCT++, RacerPro ($)
  - OWL EL: CEL, SHER, snorocket ($), *ELLY (*extension of IRIS*)*
  - OWL RL: OWLIM, Jena, Oracle Prime (part of O 11g) ($),
  - OWL QL: Owlgres, QuOnto, Quill
- Many tools use the **OWL API** library (Java)
- Note: many other Semantic Web tools are found online

Non-standard Reasoning in OWL

There is more to do than editing and inferencing:

- **Explanation:** reasoning task of providing axiom sets to explain a conclusion (important for editing and debugging)
- **Conjunctive querying:** check entailment of complex query patterns (cf. Lecture 5)
- **Modularisation:** extract sub-ontologies that suffice for (dis)proving a certain conclusion
- **Repair:** determine ways to repair inconsistencies (related to explanation)
- **Least Common Subsumer:** assuming that class unions are not available, find the smallest class expression that subsumes two given classes
- **Abduction:** given an observed conclusion, derive possible input facts that would lead to this conclusion
- …

→ All implemented, tasks on top common in standard tools today

Overview: Essential OWL Features

Feature	Related OWL vocabulary	FOL	DL
top/bottom class	`owl:Thing/owl:Nothing`	(axiomatise)	$\top/\bot$
Class intersection	`owl:intersectionOf`	$\wedge$	$\sqcap$
Class union	`owl:unionOf`	$\vee$	$\sqcup$
Class complement	`owl:complementOf`	$\neg$	$\neg$
Enumerated class	`owl:oneOf`	(ax. with $\approx$)	{a}
Property restrictions	`owl:onProperty`		
Existential	`owl:someValueFrom`	$\exists y \ldots$	$\exists R.C$
Universal	`owl:allValuesFrom`	$\forall y \ldots$	$\forall R.C$
Min. cardinality	`owl:minQualifiedCardinality` `owl:onClass`	$\exists y1 \ldots yn. \ldots$	$\geq n\ S.C$
Max. cardinality	`owl:maxQualifiedCardinality` `owl:onClass`	$\forall y1 \ldots yn{+}1. \ldots \rightarrow \ldots$	$\leq n\ S.C$
Local reflexivity	`owl:hasSelf`	R(x,x)	$\exists R.Self$

Overview: Essential OWL Features

Feature	Related OWL vocabulary	DL
Property chain	`owl:propertyChainAxiom`	$\circ$
Inverse	`owl:inverseOf`	R^-
Key	`owl:hasKey`	rule, see Lecture 5
Property disjointness	`owl:propertyDisjointWith`	Dis(R,S)
Property characteristics	`rdf:hasType`	
Symmetric	`owl:SymmetricProperty`	Sym(R)
Asymmetric	`owl:AsymmetricProperty`	Asy(R)
Reflexive	`owl:ReflexiveProperty`	Ref(R)
Irreflexive	`owl:IrreflexiveProperty`	Irr(R)
Transitivity	`owl:TransitiveProperty`	Tra(R)

Subclass	`rdfs:subClassOf`	$\forall x.C(x) \rightarrow D(x)$	$C \sqsubseteq D$
Subproperty	`rdfs:subPropertyOf`	$\forall x,y.R(x,y) \rightarrow S(x,y)$	$R \sqsubseteq S$

Summary and Outlook

- OWL: expressive ontology language with practical impact
- Structurally representable in RDF (e.g. using Turtle syntax)
- Reasoning typical based on extensional (“direct”) semantics:
  - closely related to description logics and first-order logic (with equality)
  - different from RDF semantics, but compatible for many purposes
- Various flavours for different applications:
  - OWL Full provides RDF-based semantics (undecidable)
  - OWL DL decidable but complex (N2ExpTime)
  - OWL profiles for light-weight reasoning (in PTime)

Version 2 of the Web Ontology Language almost complete:

Official specification expected by Oct 2009

Further Reading

- P. Hitzler, S. Rudolph, M. Krötzsch: **Foundations of Semantic Web Technologies.** CRC Press, 2009. (Chapter 4 and 5 closely related to this lecture)
- W3C OWL Working Group: **OWL 2 Web Ontology LanguageDocument Overview.** See http://www.w3.org/TR/owl2-overview/. W3C Working Draft, Jun 11 2009. (overview of official OWL 2 documents)
- P. Hitzler, M. Krötzsch, B. Parsia, P.F. Patel-Schneider, S. Rudolph (editors): **OWL 2 Web Ontology Language Primer.** See http://www.w3.org/TR/owl2-primer/. W3C Working Draft, Jun 11 2009. (informative introduction to OWL 2)
- B. Motik, B. Cuenca Grau, I. Horrocks, Z. Wu, A. Fokoue, C. Lutz: **OWL 2 Web Ontology Language Profiles.** See http://www.w3.org/TR/owl2-profiles/. W3C Candidate Recommendation, Jun 11 2009. (definition of OWL 2 profiles)

Selected research articles:

- I. Horrocks, O. Kutz, U. Sattler: **The even more irresistible SROIQ.** In Proc. of the 10th Int. Conf. on Principles of Knowledge Representation and Reasoning (KR 2006). AAAI Press, 2006.
- F. Baader, S. Brandt, C. Lutz: **Pushing the EL envelope.** In Proc. of the 19th Joint Int. Conf. on Artificial Intelligence (IJCAI 2005), 2005. (paper introducing description logic EL++ underlying OWL EL)
- B. Grosof, I. Horrocks, R. Volz, S. Decker: **Description Logic Programs: Combining Logic Programs with Description Logic.** In Proc. of the 12th Int. World Wide Web Conference (WWW 2003), Budapest, Hungary, 2003. (rule-based description logic fragment that influenced OWL RL)
- H. J. ter Horst: **Completeness, decidability and complexity of entailment for RDF Schema and a semantic extension involving the OWL vocabulary.** J. of Web Semantics 3(2–3):79–115, 2005. (rule-based implementation of parts of OWL Full, considerations that influenced the design of OWL RL)
- D. Calvanese, G. de Giacomo, D. Lembo, M. Lenzerini, R. Rosati: **Tractable Reasoning and Efficient Query Answering in Description Logics: The DL-Lite Family.** J. of Automated Reasoning 39(3):385–429, 2007 (introduction of DL-Lite, the description logic that inspired OWL QL)