# OWL

## *an Ontology Language for the Semantic Web*

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# Talk Outline

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## The Semantic Web

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- The Semantic Web
- Web Ontology Languages

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- Reasoning with OWL
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- Reasoning with OWL
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- Research Challenges

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  - **TCP/IP** for transporting bits down a wire
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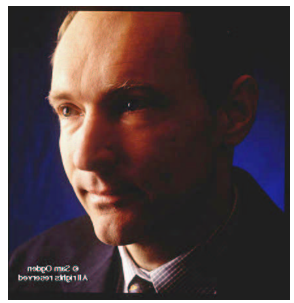

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- Increased formality and regularity facilitates machine understanding
- Ontologies can be used, e.g.:
  - To facilitate agent-agent communication in **e-commerce**
  - In semantic based **search**
  - To provide richer **service descriptions** that can be more flexibly interpreted by intelligent agents

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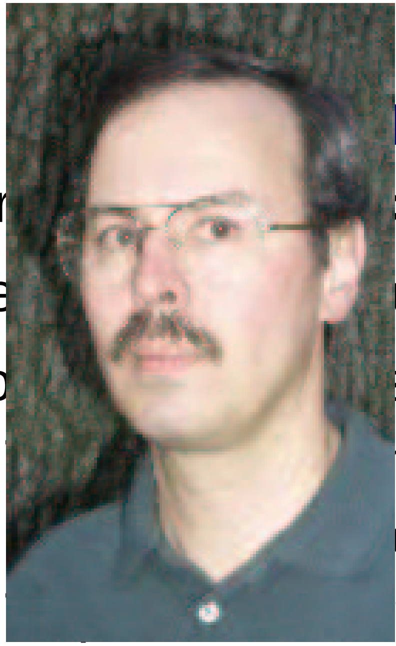

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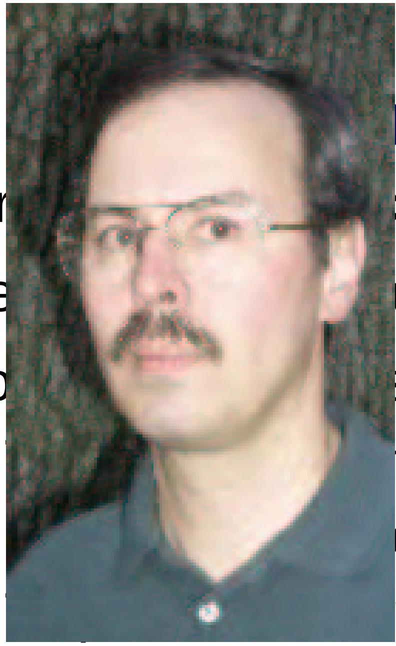

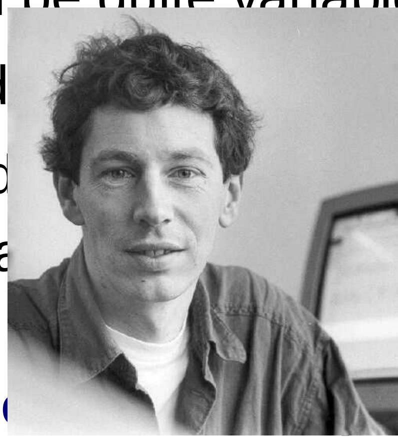

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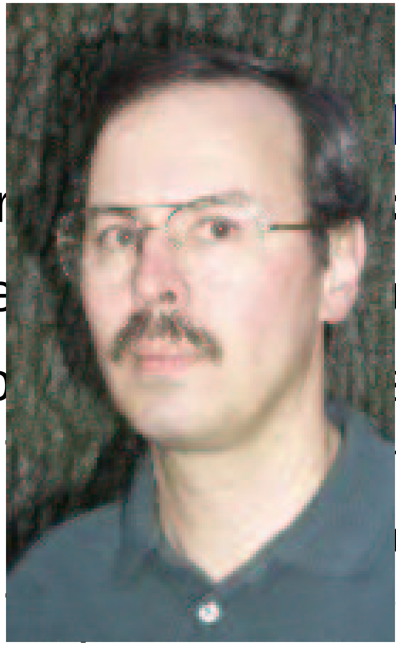

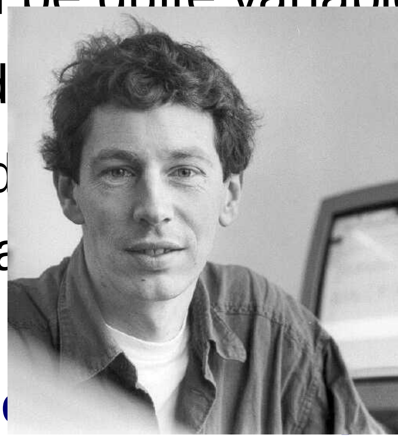

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- But RDFS not a suitable foundation for Semantic Web
  - **Too weak** to describe resources in sufficient detail
- Requirements for web ontology language:
  - **Compatible** with existing Web standards (XML, RDF, RDFS)
  - **Easy to understand** and use (based on familiar KR idioms)
  - **Formally specified** and of “adequate” expressive power
  - Possible to provide **automated reasoning** support

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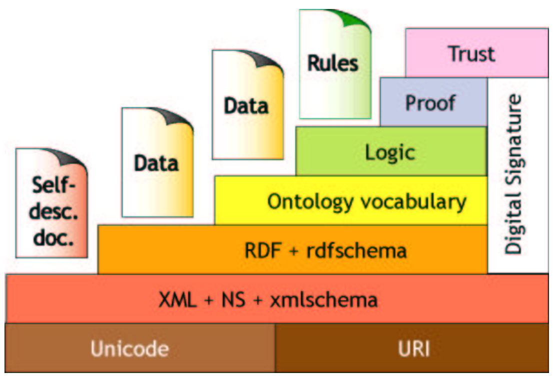

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  - E.g., Person **subclass of** Animal whose parents are all Persons

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  - E.g., Person **subclass of** Animal whose parents are all Persons
- Uses RDF for class/property membership assertions (ground facts)
  - E.g., john **instance of** Person; $\langle \text{john}, \text{mary} \rangle$ instance of parent

# OWL Language

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- OWL DL based on $\mathcal{SHIQ}$ **Description Logic**
- Benefits from many years of DL research
  - Well defined **semantics**
  - **Formal properties** well understood (complexity, decidability)
  - Known **reasoning algorithms**
  - **Implemented systems** (highly optimised)

# OWL Class Constructors

| Constructor | DL Syntax | Example | (Modal Syntax) |
|---|---|---|---|
| intersectionOf | $C_1 \sqcap \ldots \sqcap C_n$ | Human $\sqcap$ Male | $C_1 \wedge \ldots \wedge C_n$ |
| unionOf | $C_1 \sqcup \ldots \sqcup C_n$ | Doctor $\sqcup$ Lawyer | $C_1 \vee \ldots \vee C_n$ |
| complementOf | $\neg C$ | $\neg$Male | $\neg C$ |
| oneOf | $\{x_1 \ldots x_n\}$ | {john, mary} | $x_1 \vee \ldots \vee x_n$ |
| allValuesFrom | $\forall P.C$ | $\forall$hasChild.Doctor | $[P]C$ |
| someValuesFrom | $\exists P.C$ | $\exists$hasChild.Lawyer | $\langle P \rangle C$ |
| maxCardinality | $\leqslant n P$ | $\leqslant 1$hasChild | $[P]_{n+1}$ |
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- XMLS **datatypes** as well as classes in $\forall P.C$ and $\exists P.C$
  - E.g., $\exists$hasAge.nonNegativeInteger
- Arbitrarily complex **nesting** of constructors
  - E.g., Person $\sqcap$ $\forall$hasChild.(Doctor $\sqcup$ $\exists$hasChild.Doctor)

# RDFS Syntax

```
<owl:Class>
  <owl:intersectionOf rdf:parseType="collection">
    <owl:Class rdf:about="#Person"/>
    <owl:Restriction>
      <owl:onProperty rdf:resource="#hasChild"/>
      <owl:toClass>
        <owl:unionOf rdf:parseType="collection">
          <owl:Class rdf:about="#Doctor"/>
          <owl:Restriction>
            <owl:onProperty rdf:resource="#hasChild"/>
            <owl:hasClass rdf:resource="#Doctor"/>
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☞ Semantics defined by **interpretations**: $\mathcal{I} = (\Delta^{\mathcal{I}}, \cdot^{\mathcal{I}})$

- concepts $\longrightarrow$ subsets of $\Delta^{\mathcal{I}}$
- roles $\longrightarrow$ binary relations over $\Delta^{\mathcal{I}}$ (subsets of $\Delta^{\mathcal{I}} \times \Delta^{\mathcal{I}}$)
- individuals $\longrightarrow$ elements of $\Delta^{\mathcal{I}}$

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☞ Interpretation function $\cdot^{\mathcal{I}}$ **extended** to concept expressions

- $(C \sqcap D)^{\mathcal{I}} = C^{\mathcal{I}} \cap D^{\mathcal{I}}$ $\quad (C \sqcup D)^{\mathcal{I}} = C^{\mathcal{I}} \cup D^{\mathcal{I}}$ $\quad (\neg C)^{\mathcal{I}} = \Delta^{\mathcal{I}} \setminus C^{\mathcal{I}}$
- $\{x_n, \ldots, x_n\}^{\mathcal{I}} = \{x_n^{\mathcal{I}}, \ldots, x_n^{\mathcal{I}}\}$
- $(\exists R.C)^{\mathcal{I}} = \{x \mid \exists y. \langle x, y \rangle \in R^{\mathcal{I}} \wedge y \in C^{\mathcal{I}}\}$
- $(\forall R.C)^{\mathcal{I}} = \{x \mid \forall y. (x, y) \in R^{\mathcal{I}} \Rightarrow y \in C^{\mathcal{I}}\}$
- $(\leqslant nR)^{\mathcal{I}} = \{x \mid \#\{y \mid \langle x, y \rangle \in R^{\mathcal{I}}\} \leqslant n\}$
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| subClassOf | $C_1 \sqsubseteq C_2$ | Human $\sqsubseteq$ Animal $\sqcap$ Biped |
| equivalentClass | $C_1 \equiv C_2$ | Man $\equiv$ Human $\sqcap$ Male |
| disjointWith | $C_1 \sqsubseteq \neg C_2$ | Male $\sqsubseteq$ $\neg$Female |
| sameIndividualAs | $\{x_1\} \equiv \{x_2\}$ | {President_Bush} $\equiv$ {G_W_Bush} |
| differentFrom | $\{x_1\} \sqsubseteq \neg\{x_2\}$ | {john} $\sqsubseteq$ $\neg${peter} |
| subPropertyOf | $P_1 \sqsubseteq P_2$ | hasDaughter $\sqsubseteq$ hasChild |
| equivalentProperty | $P_1 \equiv P_2$ | cost $\equiv$ price |
| inverseOf | $P_1 \equiv P_2^-$ | hasChild $\equiv$ hasParent$^-$ |
| transitiveProperty | $P^+ \sqsubseteq P$ | ancestor$^+$ $\sqsubseteq$ ancestor |
| functionalProperty | $\top \sqsubseteq \leqslant 1 P$ | $\top \sqsubseteq \leqslant$1hasMother |
| inverseFunctionalProperty | $\top \sqsubseteq \leqslant 1 P^-$ | $\top \sqsubseteq \leqslant$1hasSSN$^-$ |

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☞ $\mathcal{I}$ **satisfies** $C_1 \sqsubseteq C_2$ iff $C_1^{\mathcal{I}} \subseteq C_2^{\mathcal{I}}$; satisfies $P_1 \sqsubseteq P_2$ iff $P_1^{\mathcal{I}} \subseteq P_2^{\mathcal{I}}$

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| inverseOf | $P_1 \equiv P_2^-$ | hasChild $\equiv$ hasParent$^-$ |
| transitiveProperty | $P^+ \sqsubseteq P$ | ancestor$^+$ $\sqsubseteq$ ancestor |
| functionalProperty | $\top \sqsubseteq \leqslant 1 P$ | $\top \sqsubseteq \leqslant$1hasMother |
| inverseFunctionalProperty | $\top \sqsubseteq \leqslant 1 P^-$ | $\top \sqsubseteq \leqslant$1hasSSN$^-$ |

- $\mathcal{I}$ **satisfies** $C_1 \sqsubseteq C_2$ iff $C_1^{\mathcal{I}} \subseteq C_2^{\mathcal{I}}$; satisfies $P_1 \sqsubseteq P_2$ iff $P_1^{\mathcal{I}} \subseteq P_2^{\mathcal{I}}$
- $\mathcal{I}$ satisfies ontology $\mathcal{O}$ (is a **model** of $\mathcal{O}$) iff satisfies every axiom in $\mathcal{O}$

# Reasoning with OWL DL

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    - Determine if set of facts are consistent w.r.t. ontologies
    - Determine if individuals are instances of ontology classes
    - Retrieve individuals/tuples satisfying a query expression
    - Check if one class subsumes (is more general than) another w.r.t. ontology
    - ...

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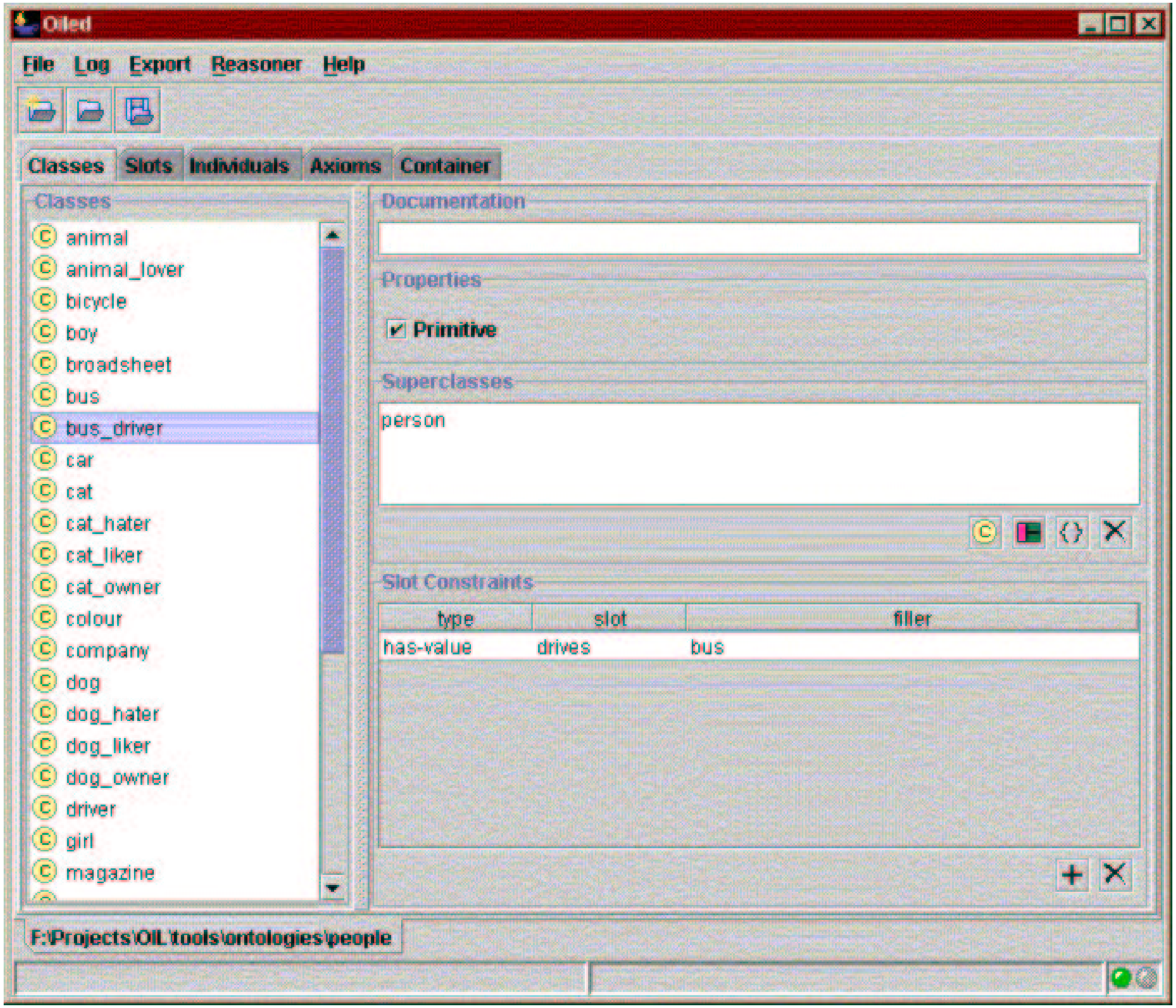
# Reasoning Support for Ontology Design: OilEd



# Description Logic Reasoning

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- ☞ Optimised **subsumption** testing (search for models)
  - Normalisation and simplification of concepts
  - Absorption (simplification) of general axioms
  - Davis-Putnam style semantic branching search
  - Dependency directed backtracking
  - Caching of satisfiability results and (partial) models
  - Heuristic ordering of propositional and modal expansion
  - ...

# Research and Implementation Challenges

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- ☞ **Challenges** remain
  - Reasoning with nominals
  - (Convincing) demonstration(s) of scalability
  - New reasoning tasks

# Acknowledgements

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  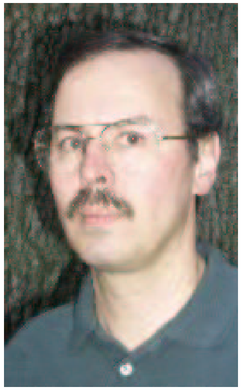

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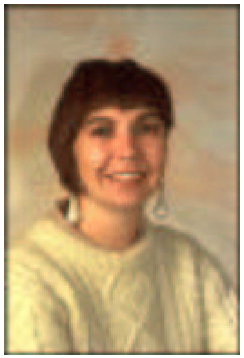
- Members of the Information Management, Medical Informatics and Formal Methods Groups at the University of Manchester



# Resources

Slides from this talk

`http://www.cs.man.ac.uk/~horrocks/Slides/ilash.pdf`

FaCT system (open source)

`http://www.cs.man.ac.uk/FaCT/`

OilEd (open source)

`http://oiled.man.ac.uk/`

W3C Web-Ontology (WebOnt) working group (OWL)

`http://www.w3.org/2001/sw/WebOnt/`

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