Knowledge Representation and Reasoning for the Semantic Web

PD Dr. Pascal Hitzler
AIFB, Universität Karlsruhe (TH)

Presentation at University of St. Andrews, January 2009

ACTIVE KNOWLEDGE-POWERED ENTERPRISE

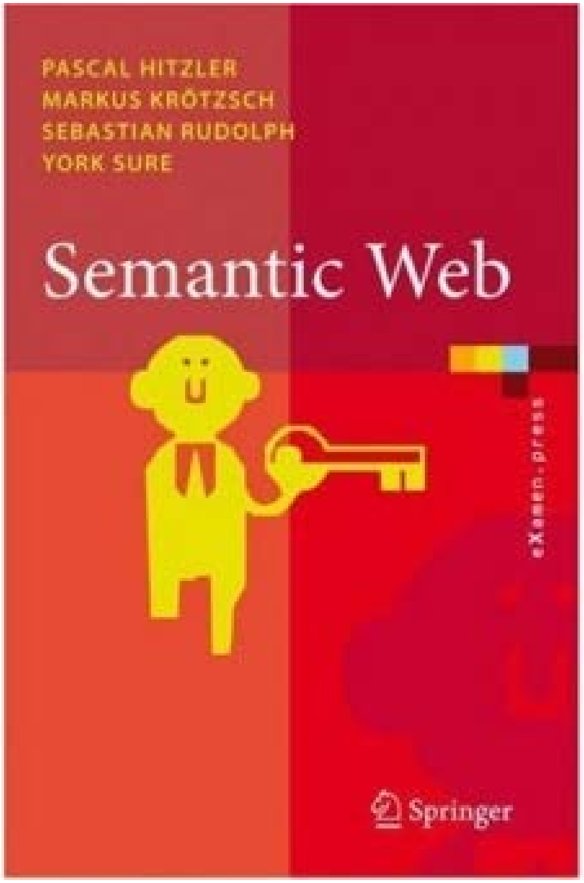
SOA4ALL

NeOn

X-MEDIA

ReaSem

- Hitzler, Krötzsch, Rudolph, Sure
  Semantic Web – Grundlagen.
  Springer, 2008.
  24,95 €



- First German Textbook on Foundations of Semantic Web.

Available from »June 2009

- Hitzler, Krötzsch, Rudolph
  Foundations of Semantic Web Technologies.
  Chapman & Hall/CRC Press

- RDF(S) Syntax and Semantics
  OWL 1+2 Syntax and Semantics
  Tractable Fragments (Profiles)
  Rules and OWL
  Query Languages
  Ontology Engineering
  Applications

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Contents

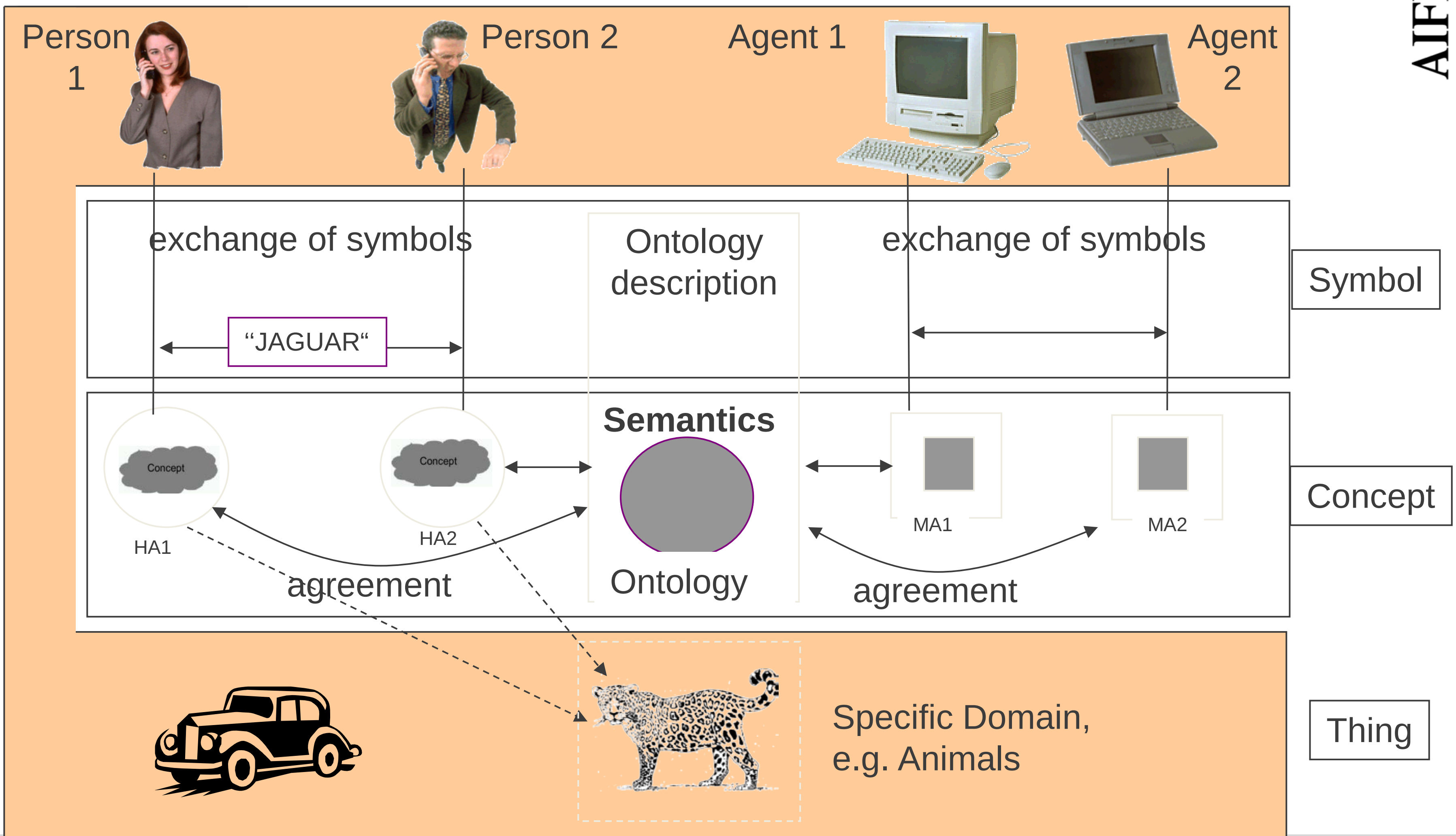
1. **The Semantic Web Idea**
2. Use cases and applications
3. Knowledge Representation for the Semantic Web
4. Bridging OWL and Rules
5. Other Challenges
6. Conclusions

The current (World Wide) Web

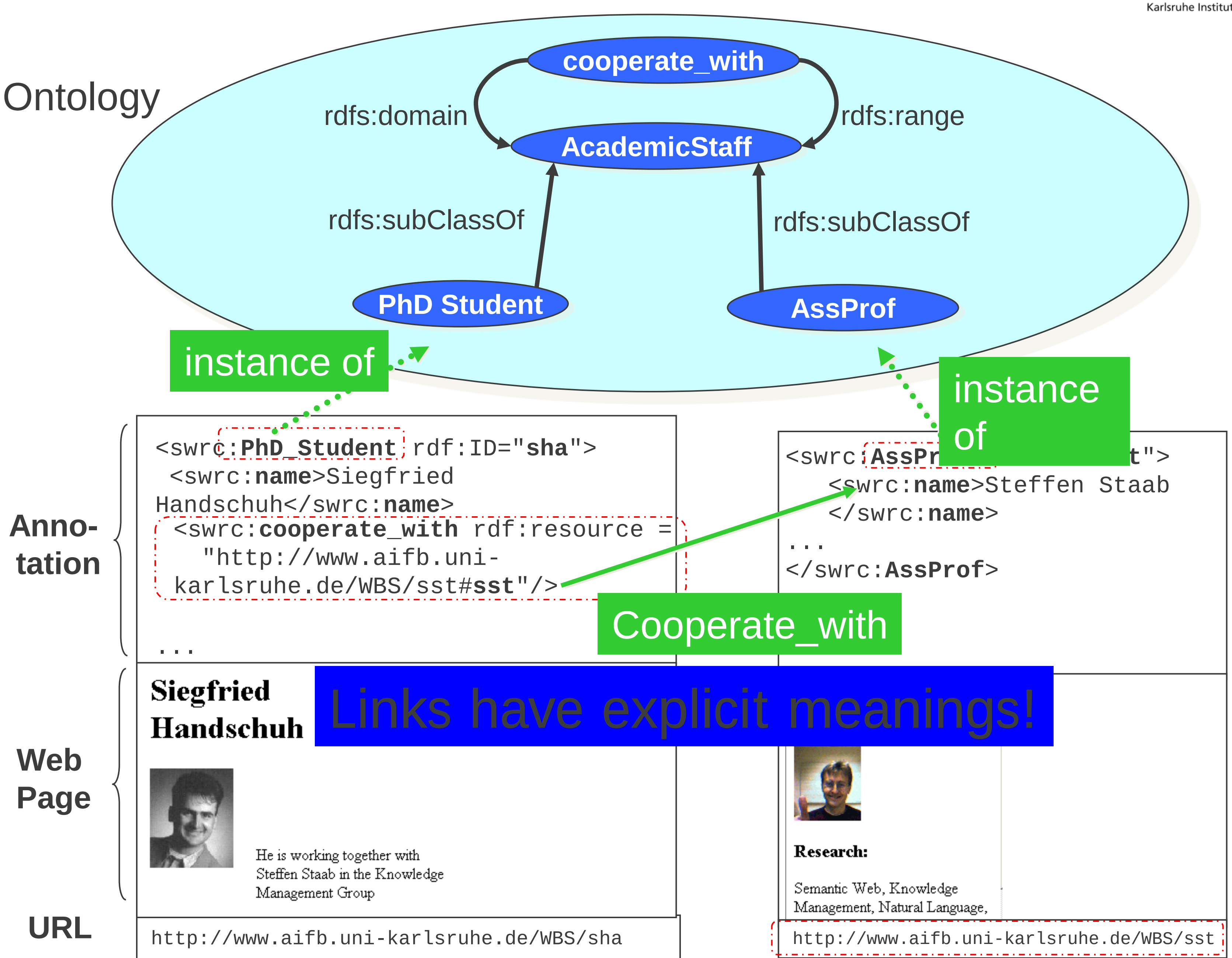
- Immensely successful.
- Huge amounts of data.
- Syntax standards for transfer of structured data.
- Machine-processable, human-readable documents.

- Content/knowledge cannot be accessed by machines.
  Meaning (semantics) of transferred data is not accessible.

Semantic Web – Main Idea



Ontologies & Metadata

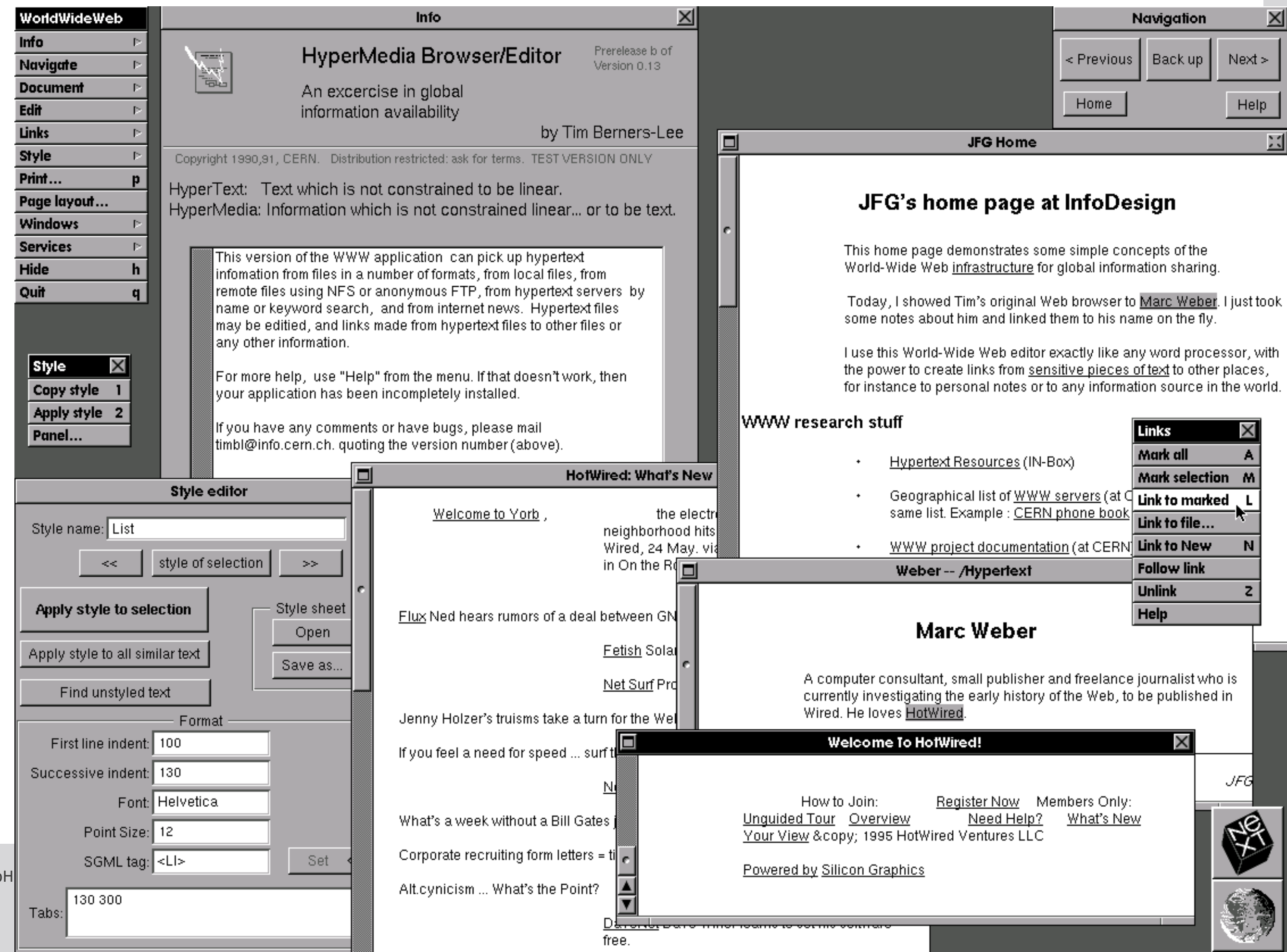


1992: Internet release (CERN)

Basic ideas for the *Web* were fixed 1989 by Tim Berners-Lee.

Ideas for the (today so-called) *Semantic Web* have already been part of the initial ideas!

The Semantic Web Idea is not new!



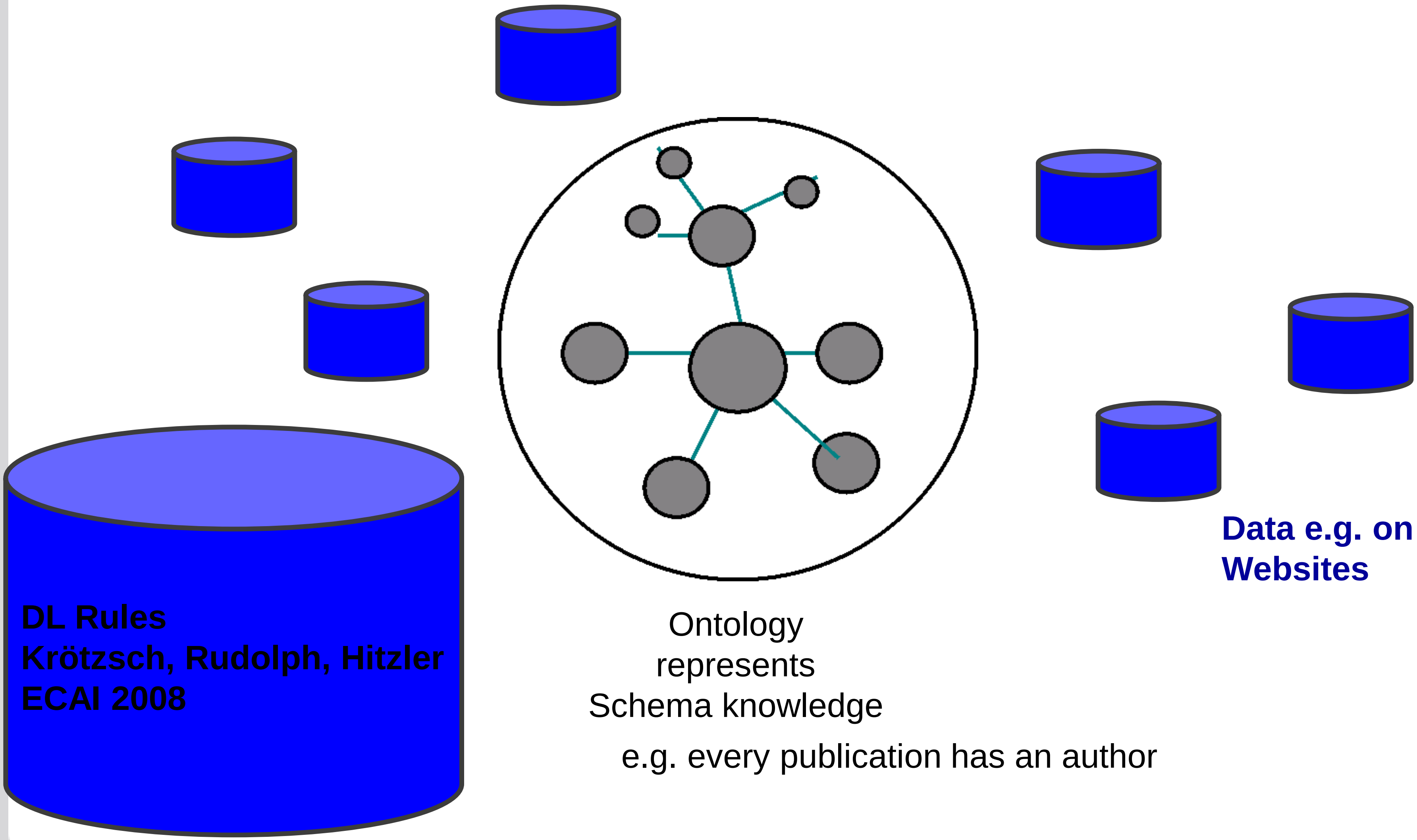
First browser by TBL 1991/92

Very brief history of the Semantic Web

- invented ca. 1989.
- 1990s: W3C metadata activity (lead to RDF(S))
- W3C semantic web activity: chartered 2001.

- USA: DAML-Programme 2000-2005 approx. 70M€.
- Many large scale EU projects since 2002 and ongoing.
  ! FP6/FP7

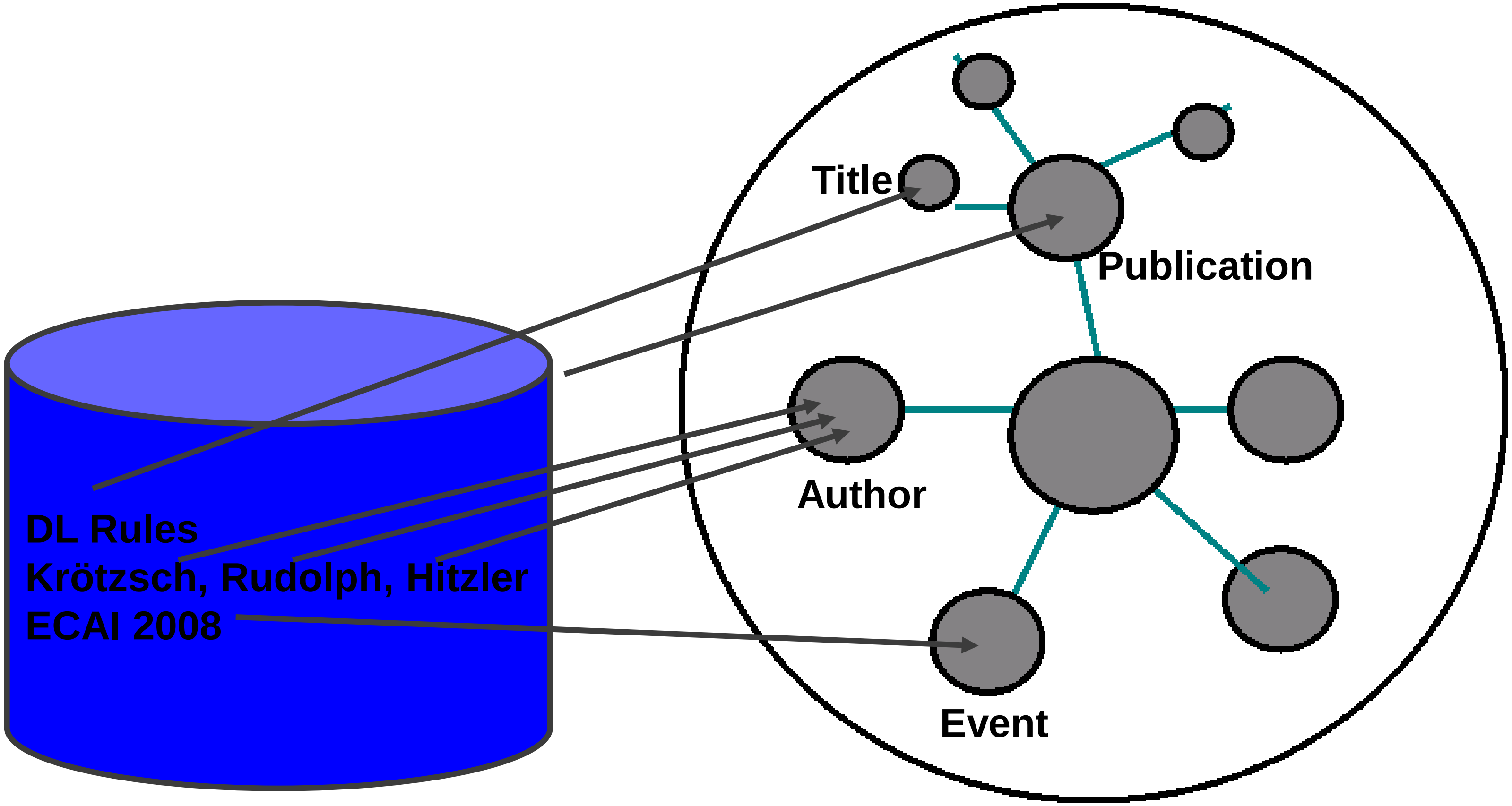
Basic Idea of the Semantic Web



Ontology
represents
Schema knowledge

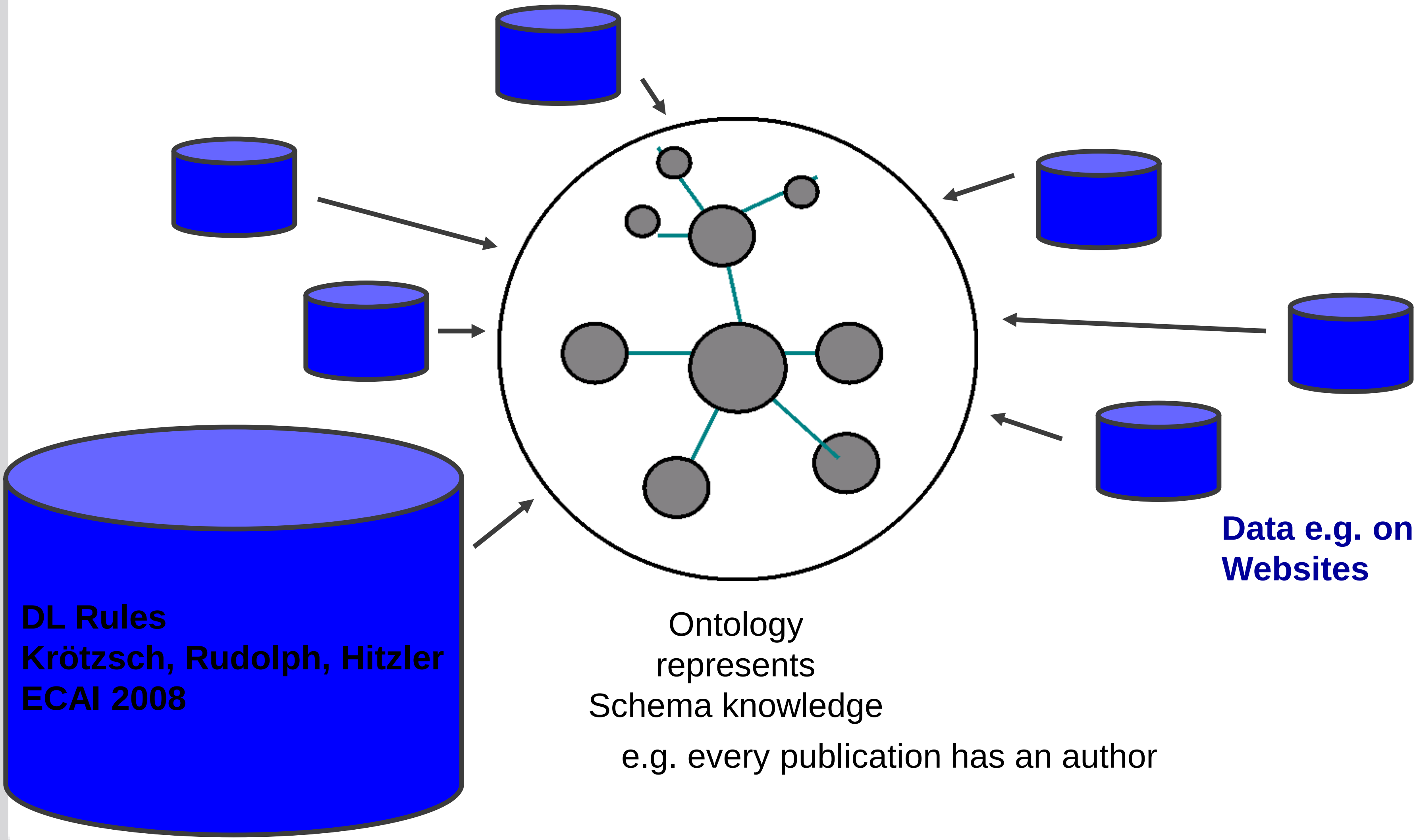
e.g. every publication has an author

Basic Idea of the Semantic Web



e.g. every publication has an author

Basic Idea of the Semantic Web



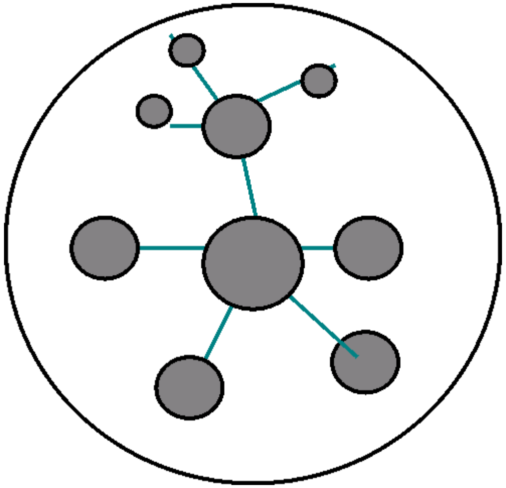
Data e.g. on Websites

Ontology
represents
Schema knowledge

e.g. every publication has an author

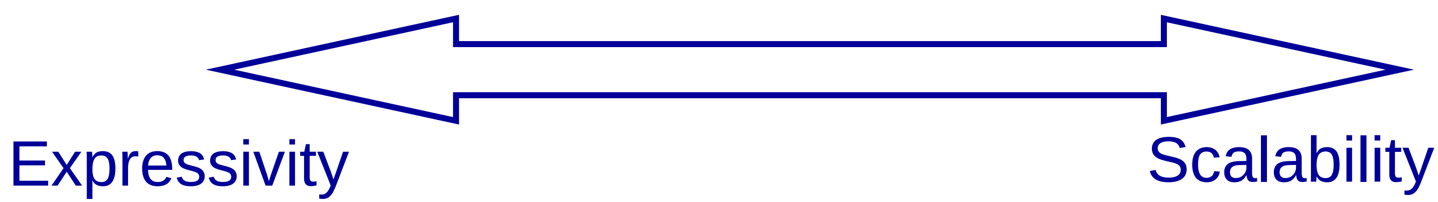
Ontologies as core technology

- Disambiguation of knowledge
- Linking of knowledge
- Provide background knowledge
- Access to implicit knowledge
- Formal Semantics
- Can be shared e.g. over the Web
- Integration of knowledge



Ontology languages

- Of central importance for the realisation of Semantic Technologies are suitable representation languages.
- Meaning (semantics) provided via logic and deduction algorithms.
- Scalability is a challenge.



Key Topics in our Group

- Ontology Management (Tools, Infrastructures, Processes)
- Ontology Learning (mainly from texts)
- Ontology Reasoning (accessing implicit knowledge)
- Semantic Web Services (enabling access to IT services)

- Also: multimedia content management, Web 2.0 (collaborative Web), Business Process Management, internet economy, etc. ...

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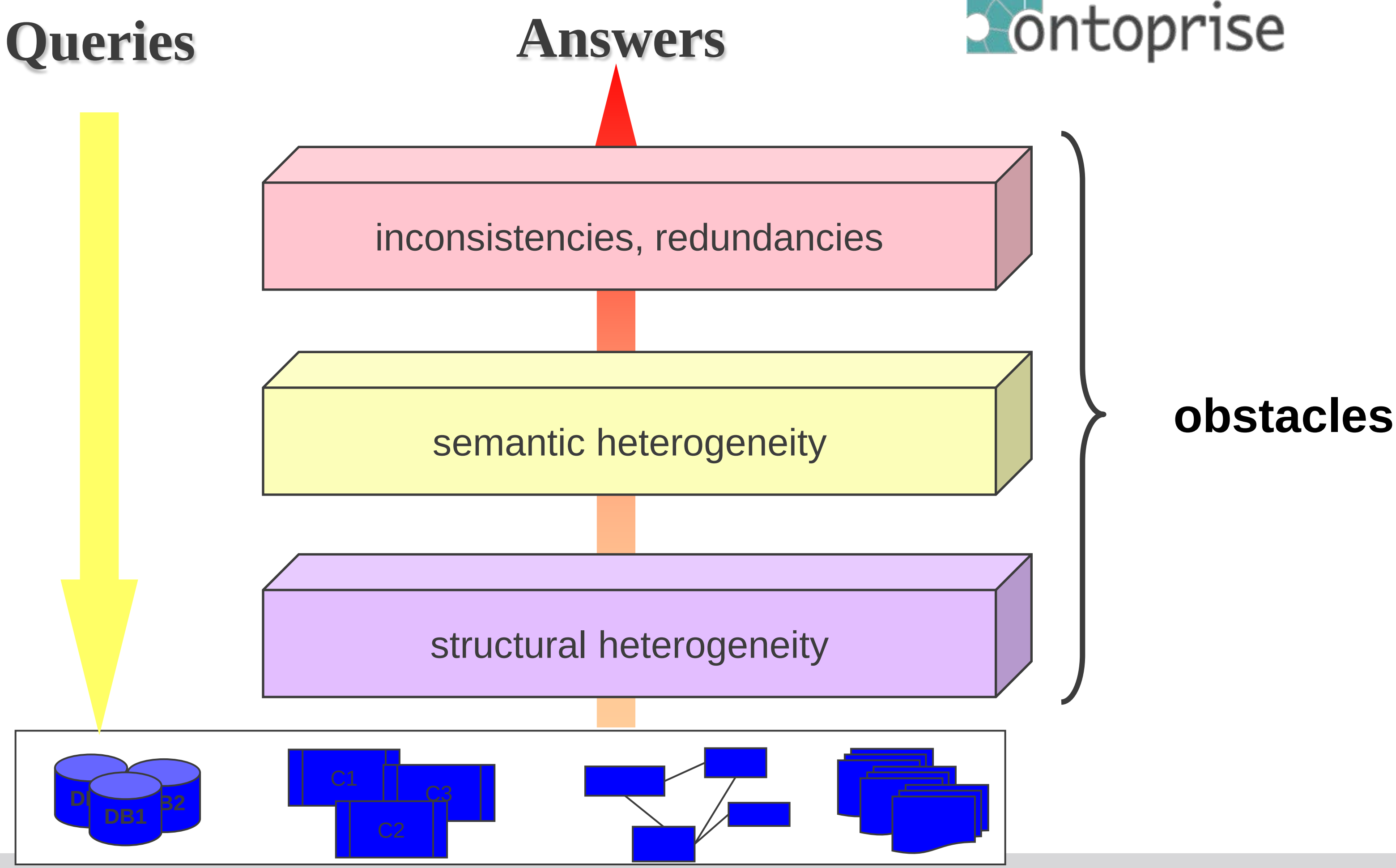
Semantic Technolgies

- Same techniques and methods
- Usage not on the web
  - content management
  - data integration
  - intelligent systems
  - ambient intelligence
  - software engineering
  - etc.

- likely to have huge impact on industrial developments in the near future

Enterprise Information Integration



Semantic Search with context information

ontoprise

KUKA Xpert :: Suche / Anzeige :: Erweiterte Suche — eingeloggt als

- Suche / Anzeige
  - Dokumentensuche
  - Erweiterte Suche
  - Historie
- Explorer / Übersicht
- Redaktion
- Modell
- Administration
- Auswertungen
- Top Tipps
- Mein Konto
- Hilfe
- Kontakt
- Abmelden

Robotertyp: KR30/1 :: **Steuerung:** KRC3 :: **Software:** KRC 1.1.10b :: **Applikation:** Fräsen ::
Suchbegriff: grundachse leckt

Suche verändern
Neue Suche

Fehler (6)	Fehlermeldung	Treffer	Nutzen	Ranking
F_M_004	Leckage an Grundachse A2	Meldung	76	2.87
F_M_006	Öl im Armgehäuse	Meldung	78	1.00
OH_2873	LTC: Initialisierung fehlgeschlagen (Grund: %1)	Meldung		0.90
OH_2899	Start blockiert (Steuerung: %1, Grund: %2)	Meldung		0.90
F_M_007	Druckverlust Hydropneumatischer GWA	Meldung	82	0.87
F_M_008	Druckverlust Gas-GWA	Meldung	37	0.87

Application Scenario: Rolls Royce

- Manufacturer of turbines and propelling devices
- Rolls Royce needs solutions for the supervision of product lifecycles based on multimedial data.

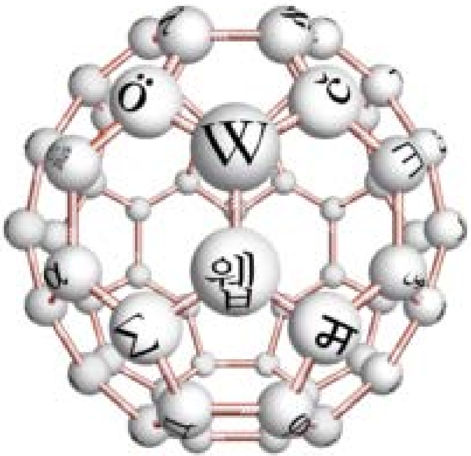
  - EU IST IP X-Media

Application Scenario: UN Food and Agriculture Organisation (FAO)

- FAO is the single institution world wide with knowledge about the global fish stock situation
- FAO needs solutions for the management of huge amounts of data about fishery
- One of the goals: Development of a ontology-based stock overfishing warning system
  - EU IST IP NeOn

Semantic MediaWiki

- Extension of the Wikipedia Software
- Idea: Wiki-internal links are *typed*
  - e.g. Link from *Publication* to *Author* is typed *hasAuthor*
- This enables e.g.
  - Wiki-internal search with metadata
  - flexible creation of lists
  - internal structuring
  - inter-Wiki consistency
  - external reuse of contents



A Wikipedia Problem

- Reuse of content on other pages can only be done manually.
- Wikipedia is full of manually created lists with overlapping content.
- Enormous overhead to maintain the lists and to ensure quality and consistency.

- Semantic Technologies are made to resolve such issues.

article | discussion | edit this page | history

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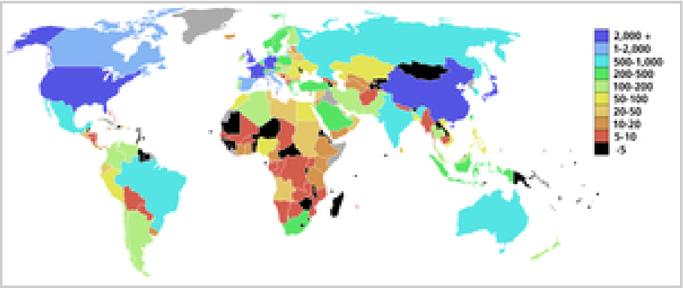
List of countries by GDP (nominal)

From Wikipedia, the free encyclopedia

This article includes a **list of countries of the world sorted by their gross domestic product (GDP)**, the value of all final goods and services produced within a nation in a given year. The GDP dollar estimates presented here are calculated at market or government official exchange rates.

The table below includes data for the year 2005 for all 181 members of the International Monetary Fund, for which information is available. **Data are in millions of current United States dollars.**

It should be noted these figures do not include Somalia, Cuba, North Korea, Iraq, and several small states in Europe (Andorra, Monaco, San Marino, Liechtenstein, Vatican City, Greenland) and the Pacific (Palau, Marshall Islands, Micronesia, Nauru and Tuvalu).

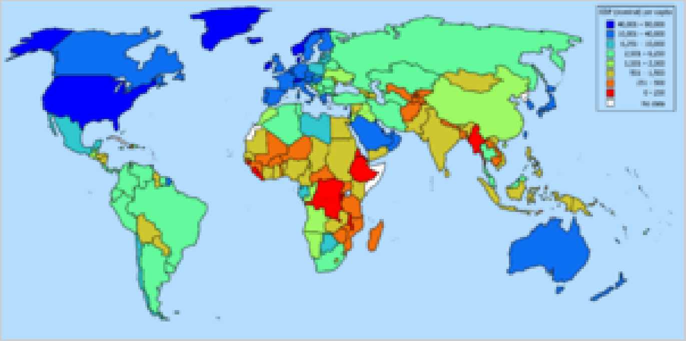


Countries by nominal GDP.
Source: IMF (2005)

Rank	Country	GDP (millions of USD)
—	***World***	**44,454,843**
—	*European Union*	13,502,800
1	United States	12,455,825
2	Japan	4,567,441
3	Germany	2,791,737
4	People's Republic of China [2]	2,234,133
5	United Kingdom	2,229,472
6	France	2,126,719
7	Italy	1,765,537

List of countries by GDP (nominal) per capita

From Wikipedia, the free encyclopedia



Map of countries by GDP (nominal) per capita. *Source: IMF (2005)*

This article includes a **list of countries of the world sorted by their Gross Domestic Product (nominal) per capita**, the value of all final goods and services produced within a nation in a given year, divided by the average population for the same year.

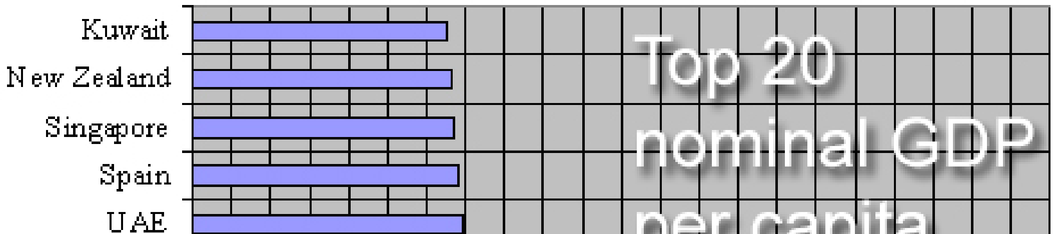
The figures presented here do not take into account differences in the cost of living in different countries, and the results can vary greatly from one year to another based on fluctuations in the exchange rates of the country's currency. Such fluctuations may change a country's ranking a great deal from one year to the next, even though they often make little or no difference to the standard of living of its population. Therefore these figures should be used with caution.

Comparisons of national wealth are also frequently made on the basis of purchasing power parity (PPP), to adjust for differences in the cost of living in different countries (*See* List of countries by GDP (PPP) per capita). PPP largely removes the exchange rate problem, but has its own drawbacks. It does not reflect the value of economic output in international trade, and it also requires more estimation than GDP per capita. On the whole PPP per capita figures are more narrowly spread than GDP per capita figures.

Great care should be taken when using either set of figures to compare the wealth of two countries. Often people who wish to promote or denigrate a country will use the figure that suits their case best and ignore the other one, which may be substantially different, but a valid comparison of two economies should take both rankings into account, as well as utilising other economic data to put an economy in context.

The table below includes data for the year 2005 for all 180 members of the International Monetary Fund, for which information is available. Data are in United States dollars.

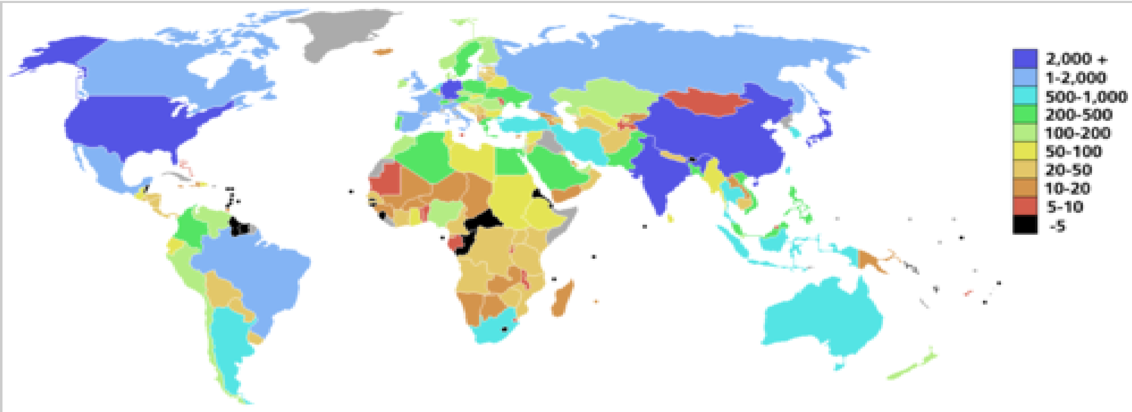
Rank	Country	GDP per capita
1	Luxembourg	80,288
2	Norway	64,193



List of countries by GDP (PPP)

From Wikipedia, the free encyclopedia

There are three **lists of countries of the world sorted by their gross domestic product** (GDP) (the value of all final goods and services produced within a nation in a given year). The GDP dollar estimates given on this page are derived from Purchasing Power Parity (PPP) calculations. Using a PPP basis is arguably more useful when comparing differences in living standards because PPP takes into account the relative cost of living and the inflation rates of the countries, rather than using just exchange rates which may distort the real differences in income. The Market Exchange Rate (MER) GDP is more useful for understanding the international economic purchasing power and the total value of tradeable goods and services of different countries.



Map of world GDP (PPP) by country using the IMF list for 2005

- The first table includes data for the year 2005 for all 180 members of the International Monetary Fund, excluding East Timor for which information is not available, and the unranked entities: world and European Union. Data is in millions of international dollars and is calculated by the International Monetary Fund.
- The second table shows 162 national entities as well as figures for the European Union and the World. This list was compiled by the World Bank. Data is for the year 2005, with figures in millions of international dollars.
- The third table is a tabulation of the CIA World Factbook data update of April 2006, according to the data provided by the CIA. Figures are estimates in millions of international dollars, for various years ranging from 1993 to 2005 (most figures are however for the year 2005).

List by the International Monetary Fund

Rank	Country	GDP (PPP) $m
—	**World**	**61,027,505**
—	European Union	12,427,413
1	United States	12,277,583

List by the World Bank

Rank	Country	GDP (PPP) $m
—	**World**	**61,006,604**
—	European Union	12,626,921
1	United States	12,409,465

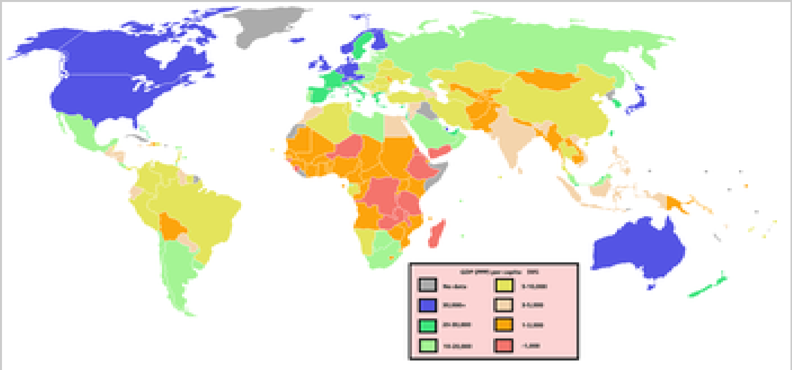
List by the CIA World Factbook

Rank	Country	GDP (PPP) $m
—	**World**	**60,630,000**
1	United States	12,310,000
—	European Union	12,180,000

List of countries by GDP (PPP) per capita

From Wikipedia, the free encyclopedia

This article includes a **list of countries of the world sorted by their gross domestic product (GDP) at purchasing power parity (PPP) per capita**, the value of all final goods and services produced within a nation in a given year divided by the average population for the same year.



Map of countries by GDP (PPP) per capita, based on the 2005 IMF data.

GDP dollar estimates here are derived from purchasing power parity (PPP) calculations. Such calculations are prepared by various organisations, including the International Monetary Fund, the University of Pennsylvania, and the World Bank. As estimates and assumptions have to be made, the results produced by different organisations for the same country tend to differ, sometimes substantially. PPP per capita figures are estimates rather than hard facts, and should be used with caution.

Comparisons of national wealth are also frequently made on the basis of nominal GDP, which does not reflect differences in the cost of living in different countries. (*See* List of countries by GDP (nominal) per capita.) The advantages of using nominal GDP figures include that less estimation is required, and that they more accurately reflect the participation of the inhabitants of a country in the global economy. On the whole PPP per capita figures are more narrowly spread than GDP per capita figures.

Great care should be taken when using either set of figures to compare the wealth of two countries. Often people who wish to promote or denigrate a country will use the figure that suits their case best and ignore the other one, which may be substantially different, but a valid comparison of two economies should take both rankings into account, as well as utilising other economic data to put their economies into context.

The table below includes data for the year 2005 for all 181 members of the International Monetary Fund, for which information is available. Data are in International dollars. The table excludes Bermuda which is one of the British overseas territories. Bermuda has the highest GDP PPP in the world at $69,900 (2004 est.) according to the CIA Worldfact book.

Rank	Country	GDP (PPP) $ per capita
1	Luxembourg	69,800
2	Norway	42,364
3	United States	41,399

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Semantic Web

Tim Berners-Lee

Sir Tim Berners-Lee is the inventor of the Web and the director of W3C. Moreover, he holds a chair at CSAIL (MIT). If you do not know about Sir Tim Berners-Lee, you should probably look him up in Wikipedia.

Timothy Berners-Lee	vCard
timbl@w3.org	
Affiliation:	W3C
Homepage:	at w3c
See also:	FOAF

Category: Person

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special

Browse wiki

Tim Berners-Lee

Affiliation	W3C +
Email	timbl@w3.org +
Foaf:mbox	timbl@w3.org +
Homepage	http://www.w3.org/People/Berners-Lee/ +
Member of	W3C + , CSAIL + , MIT +
Name	Timothy Berners-Lee +
See also	http://www.w3.org/People/Berners-Lee/card +
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Property:Has author

The property **has author** relates a paper or similar publication to each of its authors. Its inverse is property:wrote or property:writing for work still in progress.

Subproperties

This property has the following 2 subproperties.

A

- Author

W

- Written by

(previous 25) (next 25)

Pages using the property "Has author"

Showing 25 pages using this property.

A

A Survey of the Web Ontology Landscape +	Taowei Wang +, Bijan Parsia +, Jim Hendler +
AceRules +	Tobias Kuhn +
AceWiki +	Tobias Kuhn +, Loic Royer +
ActiveRDF +	Eyal Oren +
Artificial Memory +	Lars Ludwig +

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The Semantic Web

The Semantic Web is an article written by Tim Berners-Lee, James Hendler and Ora Lassila published in the May 2001 issue of Scientific American. It describes how the Web of the future will cope with meaning and offers a number of scenarios.

It is the canonical citation for the Semantic Web.

Link

[edit]

- Read the paper
- German translation

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Semantic Web

Editing The Semantic Web

```
'''The Semantic Web''' is an article written by [[Has author::Tim Berners-Lee]],
[[Has author::James Hendler]] and [[Has author::Ora Lassila]] published in the
May 2001 issue of [[published in::Scientific American]]. It describes how the Web
of the future will cope with meaning and offers a number of scenarios.

It is the canonical citation for the [[about::Semantic Web]].

== Link ==

* [http://www.sciam.com/article.cfm?articleID=00048144-10D2-1C70-84A9809EC588EF21
Read the paper]
* [http://www.spektrum.de/artikel/827866&_z=798888 German translation]
```

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papers authored by Jim Hendler

[edit]

```
{{#ask: [[Has author::Jim Hendler]]
| ?Has author
| ?accepted by
}}
```

	Has author	Accepted by
A Survey of the Web Ontology Landscape	Taowei Wang Bijan Parsia Jim Hendler	ISWC2006
The Semantic Web	Tim Berners-Lee Jim Hendler Ora Lassila	

papers authored by Jim Hendler and Bijan Parsia

[edit]

```
{{#ask: [[Has author::Jim Hendler]] [[Has author::Bijan Parsia]]
| ?Has author
| ?accepted by
}}
```

	Has author	Accepted by
A Survey of the Web Ontology Landscape	Taowei Wang Bijan Parsia Jim Hendler	ISWC2006

Semantic Web reasoners with stable releases

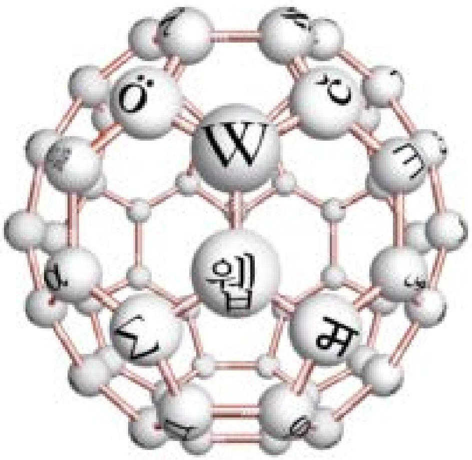
[edit]

```
{{#ask: [[Category:Reasoner]] [[Status::stable]]
| ?Category
| ?Release date = Released
| ?License
| ?Affiliation=By
}}
```

	Category	Released	License	By
AllegroGraph	RDF store Reasoner	19 May 2008	Pay Licensed Closed Source	Franz Inc
FaCT++	Reasoner	28 March 2008	GPL	University of Manchester
Internet Business Logic	Ontology engineering tool Business Rule Ontology editor Ontology language Artificial Intelligence Query language Reasoner Semantic wiki	30 April 2008	Webapp, free shared use, also commercial subscription	Reengineering LLC
KAON2	Reasoner	14 January 2008	Pay Licensed Closed Source	University of Manchester FZI AIFB
OWLIM	Reasoner	10 September 2007		Ontotext
Pellet	Reasoner	1 May 2008	MIT license	Clark & Parsia
RacerPro	Reasoner	5 December 2005	Pay Licensed Closed Source	Racer Systems

Semantic MediaWiki

- Open Source. Used in many wikis world-wide
  - Psychology Wiki (911905 pages)
  - Recipies Wiki (141909 pages)
  - ...
- Ready-to-use for large-scale applications



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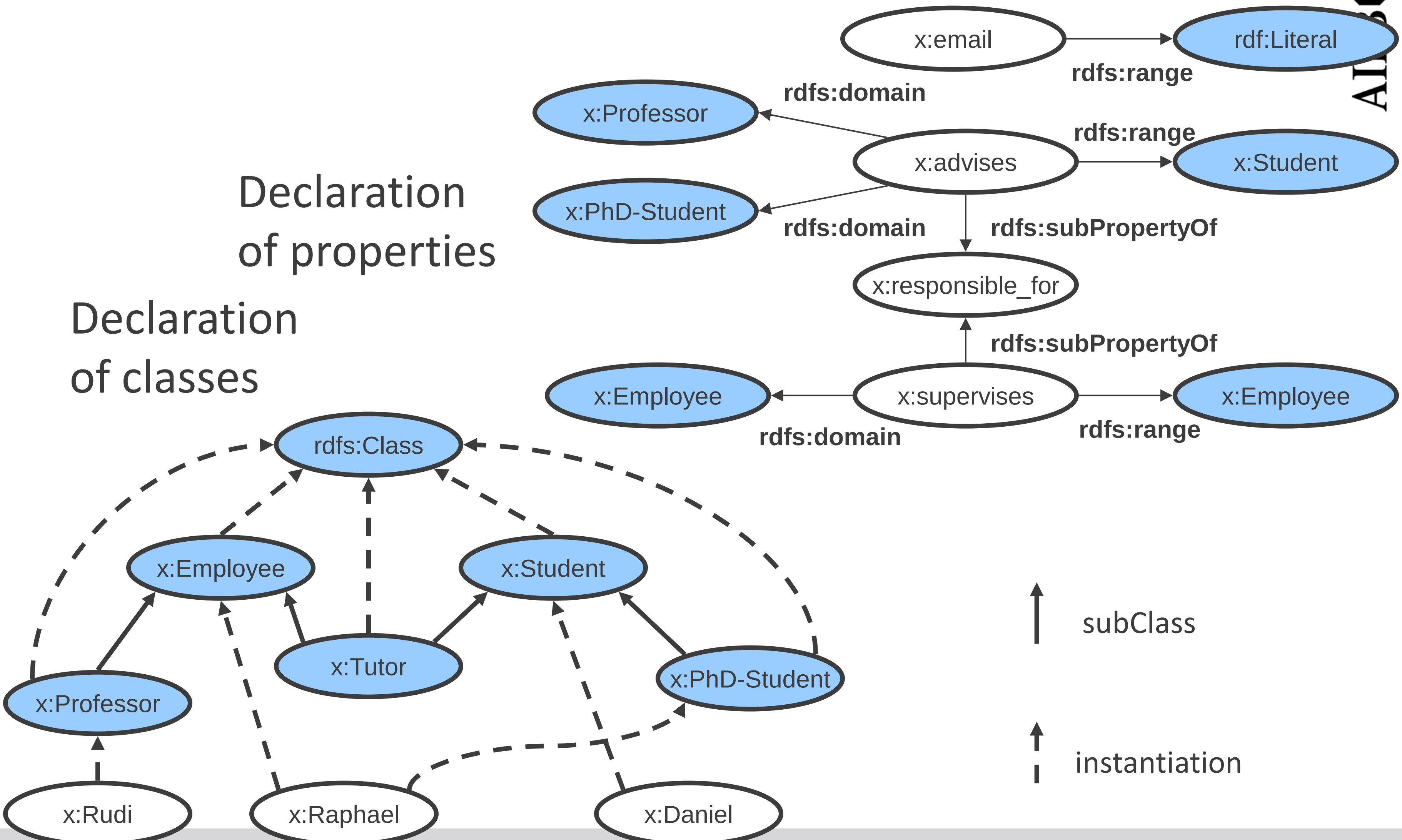
RDF Schema – Example



RDF/RDF Schema (Resource Description Framework)

- W3C standard since April 2004.
- XML Syntax for expressing very simple ontologies.

- Classes (unary predicates), subClassOf relation
- Properties (binary predicates), subPropertyOf relation
- RDF statements are triples (Object, Property, Object)
  - Objects can be
    - **URIs**
    - **Classes**
    - **Properties**
    - **or triples(!)**

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Web Ontology Language OWL

- More expressive than RDFS.
- W3C recommendation April 2004.
- OWL DL: Fragment of 1st order predicate logic.
- OWL Full: OWL DL plus RDFS

- OWL DL:
  - **Description Logic SHOIN**(D).
  - decidable.
  - largely compatible with RDFS.

OWL DL simple example

TBox: human v 9hasParent.>

orphan ´ human u :9hasParent.alive

Translation to FOL:

(8X) (human(X) ! (9Y) hasParent(X,Y))

(8X) (orphan(X) $

(human(X) Æ :(9Y) (hasParent(X,Y) Æ alive(Y)))

ABox: orphan(harrypotter)

hasParent(harrypotter,jamespotter)

OWL 2

- Web Ontology Language
  - OWL (1.0): W3C recommended standard 2004
  - OWL 2: Forthcoming revision (early 2009)

- OWL 2 DL is essentially a web-enabled syntax for the description logic **SROIQ**(D)

Professor v Human u 9hasAffiliation.University

SROIQ (aka OWL 2)

Class expressions

class names	A, B
conjunction	$C \sqcap D$
disjunction	$C \sqcup D$
negation	$\neg C$
exist. role restr.	$\exists R.C$
univ. role restr.	$\forall R.C$
Self	$\exists S.\mathrm{Self}$
atleast	$\geq n\, S.C$
atmost	$\leq n\, S.C$
nominal	$\{a\}$

Roles

role names	R, S, T
simple roles	S, T
inverse roles	R^-
universal role	U

Tbox (Class axioms)

inclusion	$C \sqsubseteq D$
equivalence	$C \equiv D$

Rbox (Role axioms)

inclusion	$R_1 \sqsubseteq R_2$
RIA	$R_1^{(-)} \circ \ldots \circ R_n^{(-)} \sqsubseteq R$
transitivity	$\mathrm{Tra}(R)$
symmetry	$\mathrm{Sym}(R)$
reflexivity	$\mathrm{Ref}(R)$
irreflexivity	$\mathrm{Irr}(S)$
disjointness	$\mathrm{Dis}(S, T)$

Abox (Facts)

class membership	$C(a)$
role relation	$R(a, b)$
neg. role relation	$\neg S(a, b)$
equality	$a \approx b$
inequality	$a \not\approx b$

OWL 2 and DLs

Description Logic Research traditionally uses analyses of computational complexities as integral part.

- DLs are usually decidable

1. Extend a DL / identify some fragment of a DL
2. Investigate computational complexity
3. If favourable, algorithmise
4. Implement and apply

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Rules

- Rules (mainly, logic programming) as alternative ontology modelling paradigm.
- At least same tradition, and still in use (e.g. F-Logic)

- Ongoing: W3C RIF working group
  - Rule Interchange Format
  - based on Horn-logic
  - language standard forthcoming 2009

Horn Rules

$(8\mathbf{x}_1)\ldots(8\mathbf{x}_{n+1})\ (p_1(\mathbf{x}_1)$ Æ $p_n(\mathbf{x}_n)$! $p_{n+1}(\mathbf{x}_{n+1}))$

- $\mathbf{x}_1, \ldots, \mathbf{x}_{n+1}$ are *tuples* of variables
- consequent (head, right-hand side) missing: *integrity constraint*
- antecedent (body, left-hand side) missing: *fact*
- no negation: basis for Prolog
- semi-decidable (Turing equivalent)
- no function symbols: Datalog (decidable)

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Datalog

- decidable
- polynomial data complexity (number of facts)
- combined (overall) complexity: ExpTime
- combined complexity is P if the number of variables per rule is globally bounded

- Relation of Datalog to OWL?
- Can we identify interesting (decidable, tractable) sublanguages or extensions of sublanguages of OWL?

DLP (Description Logic Programs)

- intuitively, the fragment of OWL DL which can be naively transformed into Datalog

- what is "naively"?

- Is C t D v E in DLP?
  - first attempt: (8x) (C(x) Ç D(x) ! E(x)) (no)
  - second attempt: (8x) (C(x) ! E(x))
    (8x) (D(x) ! E(x)) (yes)
- Is every inconsistent OWL KB in DLP?

DLP

- different versions possible, depending on the sophistication of the translation algorithm
- Grosof et al., WWW2003; Volz Dissertation 2004
- decidable
- polynomial combined complexity

- of limited usefulness, despite serious attempts: the language is not expressive enough

DLP – Example

Man t Woman v Adult

Grownup v human u Adult

Woman u 9childOf¯.> v Mother

Orphan v 8childOf.(Dead u Human)

LonelyChild v :9siblingOf.>

AIFBResearcher v 9employedBy.{UKARL}

parentOf ´ childOf¯

> v 8ancestorOf.Human

> v ·1fatherOf¯

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Horn-SHIQ

- Employs a sophisticated (ExpTime) translation of the TBox into Datalog
- polynomial data complexity
- ExpTime combined complexity

- based on Boris Motik's KAON2 algorithms
- HermiT reasoner (Motik) particularly efficient

Horn-SHIQ – Example

Parent ´ 9hasChild.>

Person v childOf.Person

ManyChildren v ¸2hasChild.>

NoSiblings v Person u 8childOf.(·hasChild.>)

childOf ´ hasChild¯

Horn-SHIQ

$$\mathbf{C}_1^+ \leftarrow \top \mid \bot \mid \neg\mathbf{C}_1^- \mid \mathbf{C}_1^+ \sqcap \mathbf{C}_1^+ \mid \mathbf{C}_0^+ \sqcup \mathbf{C}_1^+ \mid \exists\mathbf{R}.\mathbf{C}_1^+ \mid \forall\mathbf{S}.\mathbf{C}_1^+ \mid \forall\mathbf{R}.\mathbf{C}_0^+ \mid \; \mid {\geq}n\,\mathbf{R}.\mathbf{C}_1^+ \mid {\leq}1\,\mathbf{R}.\mathbf{C}_0^- \mid \mathbf{A}$$

$$\mathbf{C}_1^- \leftarrow \top \mid \bot \mid \neg\mathbf{C}_1^+ \mid \mathbf{C}_0^- \sqcap \mathbf{C}_1^- \mid \mathbf{C}_1^- \sqcup \mathbf{C}_1^- \mid \exists\mathbf{S}.\mathbf{C}_1^- \mid \exists\mathbf{R}.\mathbf{C}_0^- \mid \forall\mathbf{R}.\mathbf{C}_1^- \mid \; \mid {\geq}2\,\mathbf{R}.\mathbf{C}_0^- \mid {\leq}n\,\mathbf{R}.\mathbf{C}_1^+ \mid \mathbf{A}$$

$$\mathbf{C}_0^+ \leftarrow \top \mid \bot \mid \neg\mathbf{C}_0^- \mid \mathbf{C}_0^+ \sqcap \mathbf{C}_0^+ \mid \mathbf{C}_0^+ \sqcup \mathbf{C}_0^+ \mid \forall\mathbf{R}.\mathbf{C}_0^+$$

$$\mathbf{C}_0^- \leftarrow \top \mid \bot \mid \neg\mathbf{C}_0^+ \mid \mathbf{C}_0^- \sqcap \mathbf{C}_0^- \mid \mathbf{C}_0^- \sqcup \mathbf{C}_0^- \mid \exists\mathbf{R}.\mathbf{C}_0^- \mid \mathbf{A}$$

Table 1. A grammar for defining Horn-$\mathcal{SHIQ}$. **A**, **R**, and **S** denote the sets of all concept names, role names, and simple role names, respectively. The presentation is slightly simplified by exploiting associativity and commutativity of $\sqcap$ and $\sqcup$, and by omitting ${\geq}1\,R.C$ if $\exists R.C$ is present. The grammar for Horn-$\mathcal{SHIN}$ is obtained by replacing the qualifying class by $\top$ in all number restrictions.

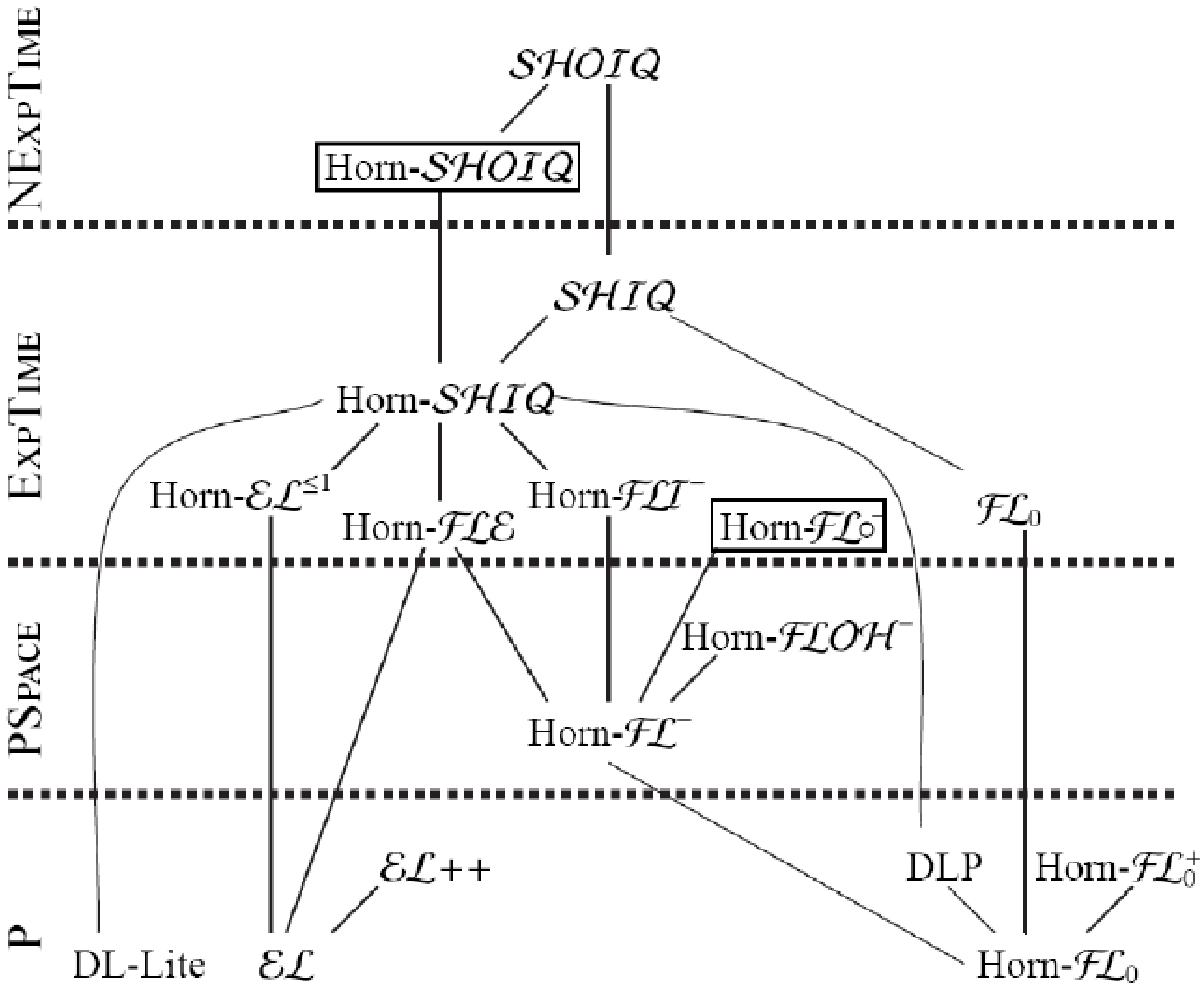
Allowed concept inclusions: C_0^-v C_1^+ and C_1^-v C_0^+

Krötzsch, Rudolph, Hitzler AAAI07

Horn DLs

- generalisation of Horn-SHIQ to other DLs around OWL and OWL 2
- Krötzsch, Rudolph, Hitzler, AAAI07

Horn-DLs: combined complexities



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DL Rules

- Can we push the Horn (Rules) aspect?
- Idea: Allow Datalog rules in addition to DL axioms

- Keep DL (i.e. FOL) semantics.
- Identify decidable such "hybrid" languages.
- Identify tractable such "hybrid" languages.

- In a sense, we step outside the traditional DL perspective, but we stay close to the spirit and the semantics.

DL Rules

- formulae of the form (8**x**) ÆB ! ÆH
  B, H sets of role and (complex) concept atoms
  x vector of all variables in B and H
  - for any u that is not initial in B, there is a path from exactly one initial t to u in B
  - for any t,u, there is at most one path from t to u
  - if H contains an atom of the form C(t) or R(t,u), then t is initial in B
- essentially, the rules must be *tree-shaped*
- we will omit the 8 quantifier when writing the rules

DL Rules – Examples

worksAt(x,y) Æ University(y) Æ supervises (x,z) Æ PhDStudent(z) ! profOf(x,z)

trusts(x,y) Æ Doctor(y) Æ recommends(y,z) Æ Medicine(z) ! buys(x,z)

Woman(x) Æ hasChild(x,y) ! motherOf(x,y)

Man(x) Æ hasBrother(x,y) Æ hasChild(y,z) ! Uncle(x)

marriedTo(x,y) Æ loves(x,y) ! Happy(x)

Elephant(x) Æ Mouse(y) ! biggerThan(x,y)

kills(x,x) ! suicide(x)

ThaiCurry(x) ! 9contains.FishProduct(x)

SROIQ Rules

- SROIQ is essentially OWL 2
- OWL DL plus
  - qualified number restrictions
    HappyFather v ¸2hasChild.female
  - role composition
    hasParent ± hasBrother v hasUncle

SROIQ

Class expressions

class names	A, B
conjunction	$C \sqcap D$
disjunction	$C \sqcup D$
negation	$\neg C$
exist. role restr.	$\exists R.C$
univ. role restr.	$\forall R.C$
Self	$\exists S.\mathrm{Self}$
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simple roles	S, T
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Tbox (Class axioms)

inclusion	$C \sqsubseteq D$
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inclusion	$R_1 \sqsubseteq R_2$
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irreflexivity	$\mathrm{Irr}(S)$
disjointness	$\mathrm{Dis}(S, T)$

Abox (Facts)

class membership	$C(a)$
role relation	$R(a, b)$
neg. role relation	$\neg S(a, b)$
equality	$a \approx b$
inequality	$a \not\approx b$

SROIQ Rules

- i.e. SROIQ extended by the rules as defined

- SROIQ rules can be polynomially reduced to SROIQ!
  - transformation is sometimes "weird", i.e. modelling is unintuitive
  - SROIQ rules are supported by all OWL 2 reasoners

SROIQ Rules – Example reduction to SROIQ

All elephants are bigger than all mice.

- informally: elephant £ mouse v biggerThan
  but cartesian product not part of SROIQ

SROIQ Rule:

elephant(x) Æ mouse(y) ! biggerThan(x,y)

in SROIQ:

elephant ´ 9$R_{elephant}$.Self

mouse ´ 9R_{mouse}.Self

$R_{elephant}$± U ± R_{mouse} v biggerThan

DLP 2

- Naive Datalog fragment of OWL 2, extended by corresponding DL Rules.
- polynomial combined complexity

- body concepts may contain nominals, u, 9, >, ?
- head concepts may contain nominals, u, 8, >, ?

- plus suitable RBox statements

EL++

- tractable fragment (profile) of OWL 2: OWL 2 EL
- CEL reasoner (Dresden)
- prestigous application: classification of SNOMED

SROIQ

Class expressions

class names	A, B
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disjunction	$C \sqcup D$
negation	$\neg C$
exist. role restr.	$\exists R.C$
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class membership	$C(a)$
role relation	$R(a, b)$
neg. role relation	$\neg S(a, b)$
equality	$a \approx b$
inequality	$a \not\approx b$

EL++ aka OWL 2 EL

Class expressions

class names A, B

conjunction $C \sqcap D$

exist. role restr. $\exists R.C$

nominal $\{a\}$

Roles

role names R, S, T

Tbox (Class axioms)

inclusion $C \sqsubseteq D$

equivalence $C \equiv D$

Rbox (Role axioms)

inclusion $R_1 \sqsubseteq R_2$

RIA $R_1 \circ \ldots \circ R_n \sqsubseteq R$

transitivity $\mathrm{Tra}(R)$

Abox (Facts)

class membership $C(a)$

role relation $R(a, b)$

equality $a \approx b$

inequality $a \not\approx b$

EL++ Rules

- can be transformed polynomially into a normal form:
  - no complex classes in bodies
  - all head variables appear in the body
  - heads are of one of the forms A(x), 9R.A(x), R(x,y)

- polynomial combined complexity
- i.e. a tractable DL which contains EL++

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ELP

- combines (roughly)
  - EL++ Rules
    extended in the way that safe variables can occur in the place of individuals
  - DL-safe Datalog rules where predicates are atomic classes or roles
- contains EL++ Rules and DLP (with full semantics)
- polynomial combined complexity (if number of variables in Datalog rules globally bounded)
  - polynomial transformation to Datalog exists
- Implementation forthcoming

ELP – Example

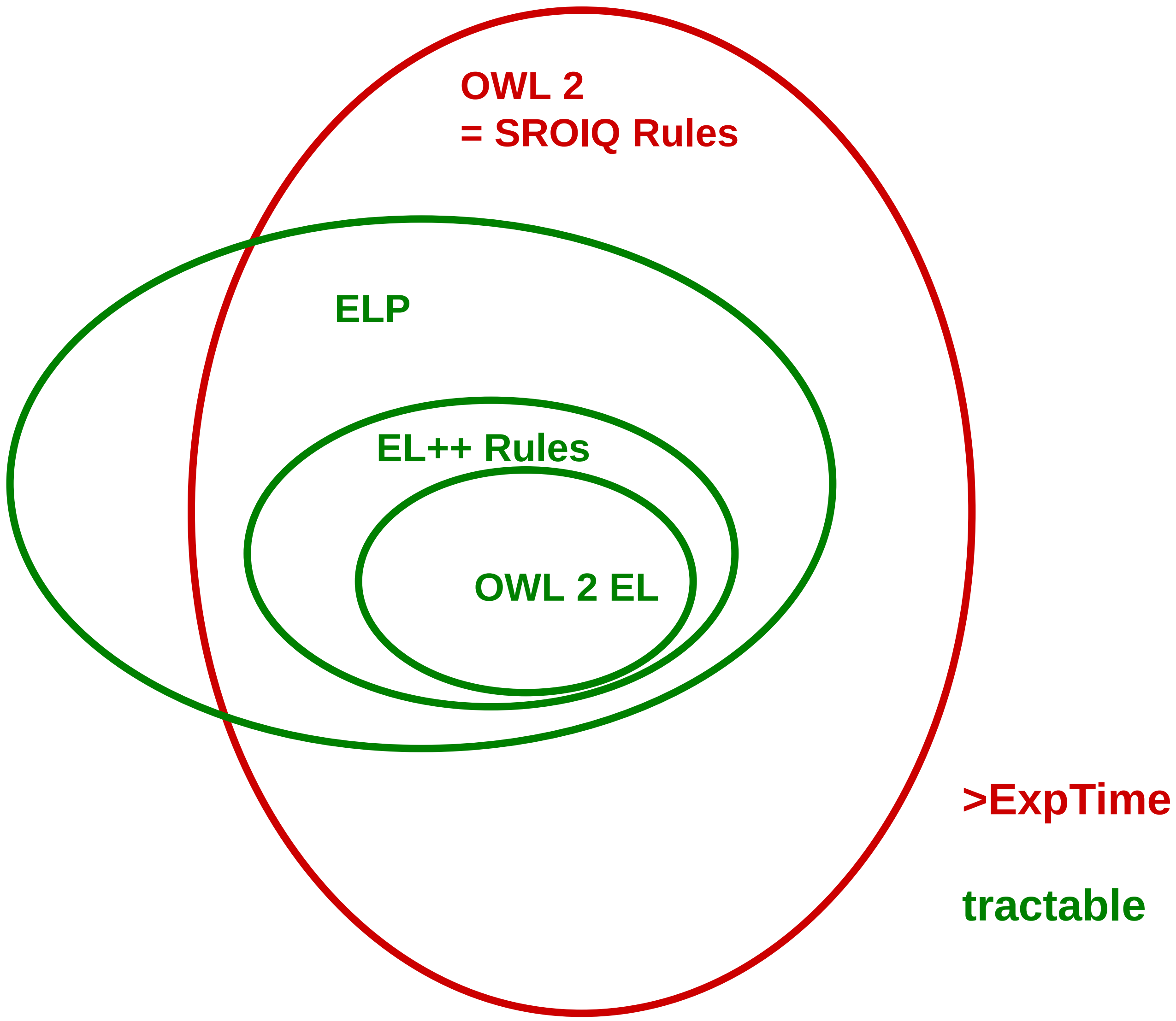
$$
\begin{array}{lr}
(1) & \text{NutAllergic}(x) \wedge \text{NutProduct}(y) \rightarrow \text{dislikes}(x,y) \\
(2) & \text{Vegetarian}(x) \wedge \text{FishProduct}(y) \rightarrow \text{dislikes}(x,y) \\
(3) & \text{orderedDish}(x,y) \wedge \text{dislikes}(x,y) \rightarrow \text{Unhappy}(x) \\
(4) & \text{dislikes}(x,v) \wedge \text{Dish}(y) \wedge \text{contains}(y,v) \rightarrow \text{dislikes}(x,y) \\
(5) & \text{orderedDish}(x,y) \rightarrow \text{Dish}(y)
\end{array}
$$

$$
\begin{array}{ll}
(6) & \text{ThaiCurry}(x) \rightarrow \text{contains}(x, \text{peanutOil}) \\
(7) & \text{ThaiCurry}(x) \rightarrow \exists\text{contains.FishProduct}(x)
\end{array}
$$

$$
\begin{array}{ll}
(8) & \rightarrow \text{NutProduct}(\text{peanutOil}) \\
(9) & \rightarrow \text{NutAllergic}(\text{sebastian}) \\
(10) & \rightarrow \exists\text{orderedDish.ThaiCurry}(\text{sebastian}) \\
(11) & \rightarrow \text{Vegetarian}(\text{markus}) \\
(12) & \rightarrow \exists\text{orderedDish.ThaiCurry}(\text{markus})
\end{array}
$$

(v is a safe variable)

Overview



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Hybrid MKNF knowledge bases

- Due to Motik & Rosati, IJCAI-07

- Idea: Take DL *D* and add rules which include autoepistemic operators *K* and *not*. More precisely:

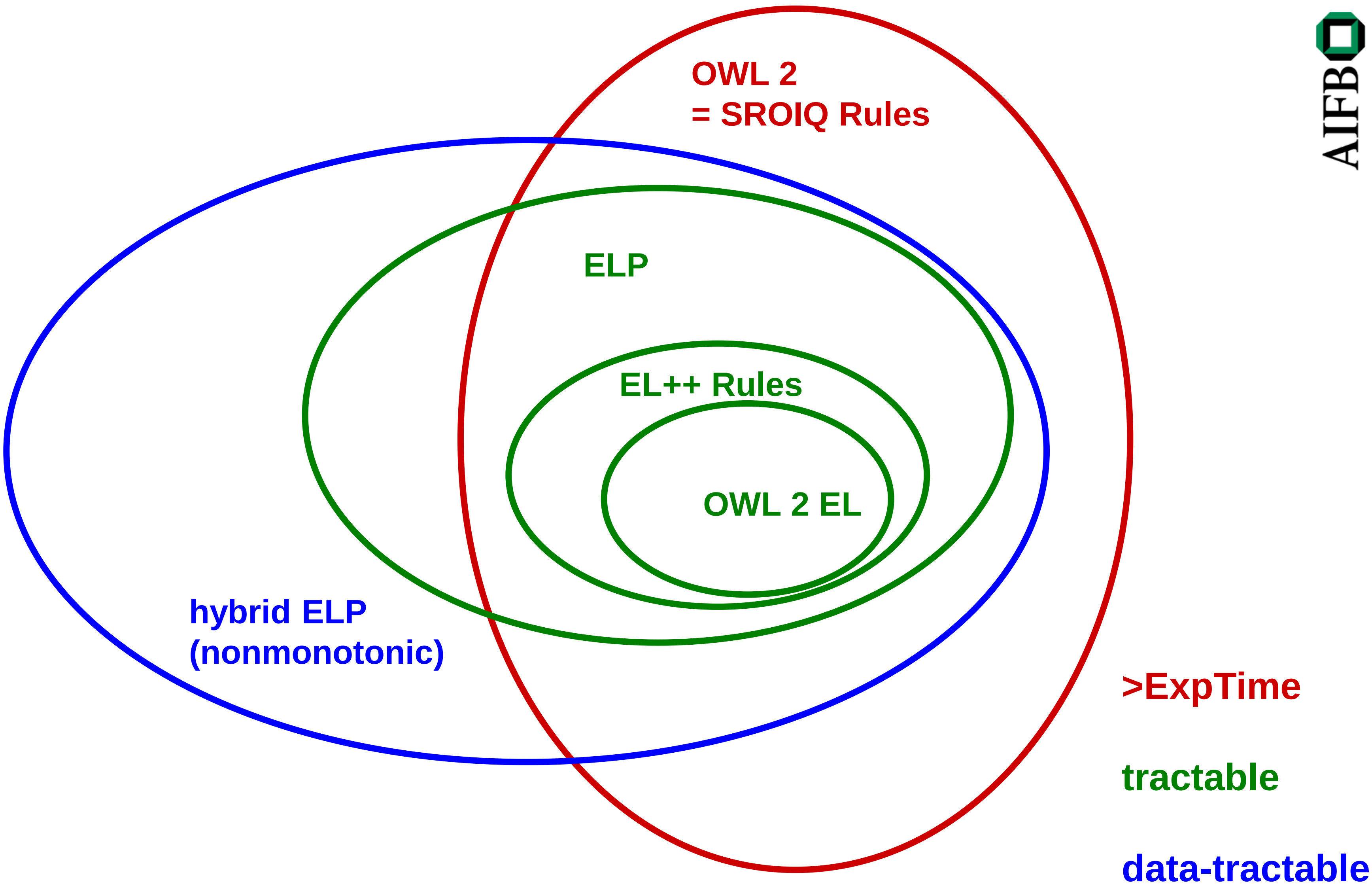
  *K*A Ã *K*A_1 Æ ... Æ *K*A_n Æ *not* B_1 Æ ... Æ *not* B_m

- Rules are DL-safe.
- Original version allows disjunctive heads.

Hybrid MKNF knowledge bases

- Motik & Rosati define a stable-model semantics.
  - data complexity at least NP^{P^C}, where C is data complexity of underlying DL
- [Knorr et al. ECAI08] define well-founded semantics.
  - via alternating fixpoint construction
  - data complexity P^C, where C is data complexity of underlying DL
- In particular: data complexity $P^P=P$ for tractable DLs
  - Forthcoming: investigate hybrid EL++ and/or ELP
  - make use of Datalog transformation

Overview



OWL 2
= SROIQ Rules
ELP
EL++ Rules
OWL 2 EL
hybrid ELP
(nonmonotonic)
>ExpTime
tractable
data-tractable

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    2. Pragmatics
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Realising Semantic Web Reasoning Applications

I see two major obstacles for realising applications for reasoning on the Semantic Web

1. Scalability
2. Pragmatics

Scalability

- KR is computationally tough: Complexities generally P or higher. Often > EXPTIME
- The web is huge. Semantic Web applications have to deal with enormous amounts of data.

- Is there any way to solve this?
  Improvement of algorithms and reasoner performance helps but cannot be sufficient.

Scalability

- Emerging trend:
  - Approximate reasoning, i.e. trade correctness for speed
- Billion Triple Challenge @ ISWC08
  - SAOR: Approximate OWL reasoning with forward chaining rules
  - MARVIN: Approximate massively parallel RDF reasoning
- Non-standard reasoning techniques like machine learning or evolutionary algorithms [d'Amato et al., Oren et al. ISWC08]
- Approximating bottlenecks in proof algorithms [Tserendorj et al. RR08]

Approximate Reasoning

- Suitable for use case scenarios e.g. with human end-recipient
- Important: Quality measures for approximations
  - soundness + completeness are not enough
  - also need to look at precision + recall

- Some harcore AR people have difficulties accepting the necessity
- In the general SW community the trend is emerging

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Reasoning Pragmatics

- Largely ignored so far
  - but Semantic Web necessitates it
- How to make reasoning fit for real applications?
- Logic alone won't answer this question
  - Indeed, focussing mainly on logic is likely to be counterproductive
  - though it certainly doesn't mean to give up on logic
  - but we have to give up some idealism.

Reasoning Pragmatics

- Where does reasoning fit into workflows?
- How much reasoning do we really need?
- Realistic data is noisy and inconsistent (and not necessarily in the logical sense)
- Realistic data is constantly changing.
- How to interface with domain experts (i.e. non-logicians)?
- What support tools are needed for building applications?

Reasoning Pragmatics

- Many of these questions are as old as symbolic AI.
- Still, they have not really been addressed.
- Logicians have been hiding in their ivory tower.

- *We don't even know what the right questions are!*

Reasoning Pragmatics

We don't even know what the right questions are!

Which problems do we really need to solve to make reasoning applications possible on the Semantic Web?

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Conclusions

- Recent progress on OWL + Rules
  - SROIQ Rules
    - can be translated to SROIQ
    - a rules paradigm for OWL 2
  - DLP 2
    - In the spirit of DLP
    - but can do much more
  - ELP Rules
    - Expressive fragment of OWL 2 + SWRL
    - Allows flexible modelling with DLs and rules
    - contains EL++ and DLP
    - tractable (polynomial)
  - Tractable nonmonotonic DL under way ...
- But the real challenges are about pragmatics!

Thanks!

Some details have been omitted to ease the presentation. For exact results, see

- Markus Krötzsch, Sebastian Rudolph, Pascal Hitzler, **ELP: Tractable Rules for OWL 2.** In: Proceedings ISWC2008.
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