Breeding Environments, Dynamic Virtual Organizations, and Professional Virtual Communities.

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Ontologies, Semantic Web and Virtual Enterprises

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Sixth Framework Programme

Information Society Technologies

Agenda

- Motivation
- Ontologies
- Semantic Web
- Selected Applications
  - Semantic Search
  - Semantic Integration
  - Semantic Web Services
- Summary

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Motivation

- Virtual Enterprise
  - "…is a temporary alliance of enterprises that come together to **share skills or core competencies and resources** in order to better respond to business opportunities, and whose cooperation is **supported by computer networks**… "
  - Communication (=knowledge/information exchange and sharing) is necessary
  - We need more from computers than just data exchange

Motivation

- Transportation chain case study (US Army)
  – Involving different companies around the world
  – Transportation of containers weighing tons worked well
  – **Information** about what is in these containers **was not transferred** – manual repacking needed!
    - Source of the problem: Interfaces between manufacturing companies, airlines, shipping and trucking companies – their systems were not made to work together

Motivation

- Exchanging information
  - Physical layer – message must be transported
  - Syntactical layer – recipient must parse (recognize symbols in) the message
  - **Semantical layer** – recipient must understand the message (i.e., know the meaning of the symbols in the message)
    - **Semantics (partially) captured in ontology**

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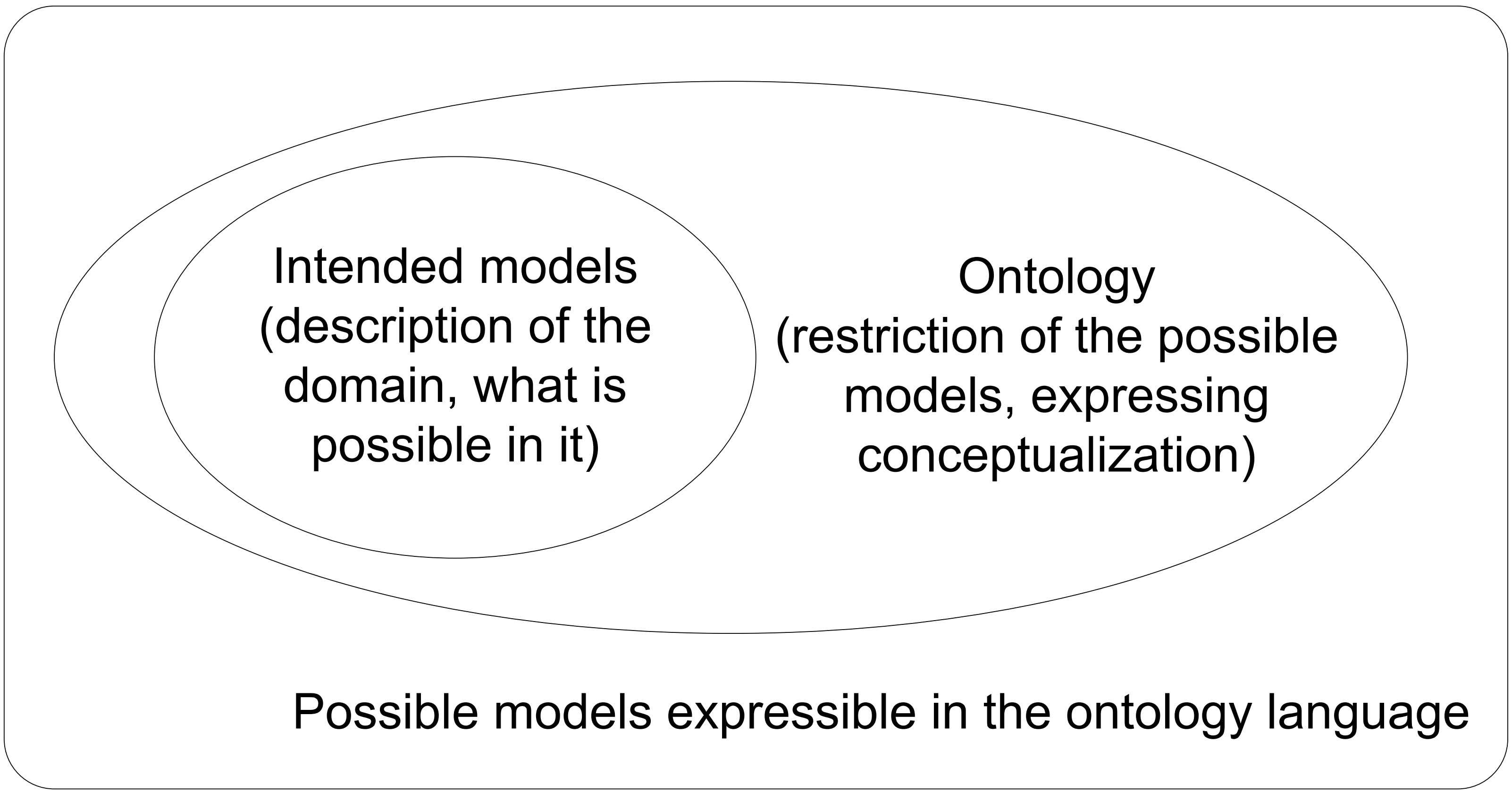
Ontology

- Ontology – description of a domain
  - Not changing (or changing rarely)
  - Engineering artifact: classes of objects, properties, relationships, restrictions…
  - what can and what cannot exist; what we can conclude from a state of affairs
  - Example: City, FlightConnection, destination
- Knowledge base – particular state of affairs
  - Example: Prague is destination of FlightConnection OK0103

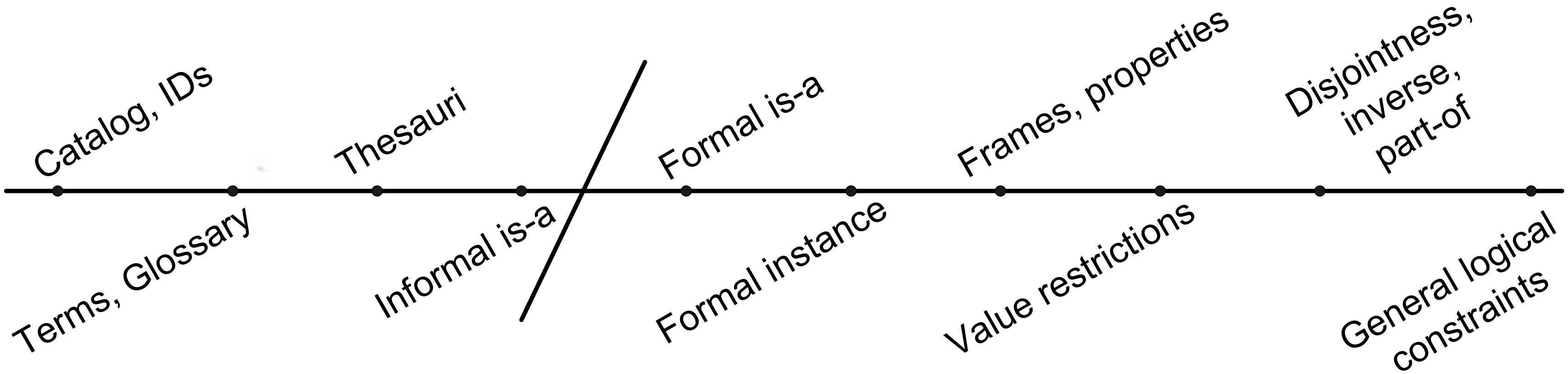
Ontology

- Formal explicit specification of conceptualization



Formality of Ontology

- Formality/usability



- Description Logics
  - Rich enough for practical applications
  - Computationally tractable
  - Semantic web ontologies, tool support

Description Logics

- Formal description of concepts and roles
  - from semantic networks + frame based systems
- Attributive language $\mathcal{AL}$

Syntax	Semantics	Comment
A	$A^{\mathcal{I}} \subseteq \Delta^{\mathcal{I}}$	atomic concept
R	$R^{\mathcal{I}} \subseteq \Delta^{\mathcal{I}} \times \Delta^{\mathcal{I}}$	atomic role
$\top$	$\Delta^{\mathcal{I}}$	top (most general) concept
$\bot$	$\emptyset$	bottom (most specific) concept
$\neg A$	$\Delta^{\mathcal{I}} \setminus A^{\mathcal{I}}$	atomic negation
$C \sqcap D$	$C^{\mathcal{I}} \cap D^{\mathcal{I}}$	intersection
$\forall R.C$	$\{a \in \Delta^{\mathcal{I}} \mid \forall b.(a,b) \in R^{\mathcal{I}} \Rightarrow b \in C^{\mathcal{I}}\}$	value restriction
$\exists R.\top$	$\{a \in \Delta^{\mathcal{I}} \mid \exists b.(a,b) \in R^{\mathcal{I}}\}$	limited existential quantification

$\mathsf{Person} \sqcap \neg\mathsf{Female}$ $\mathsf{Person} \sqcap \exists\mathsf{hasChild}.\top$ $\mathsf{Person} \sqcap \forall\mathsf{hasChild}.\mathsf{Female}$

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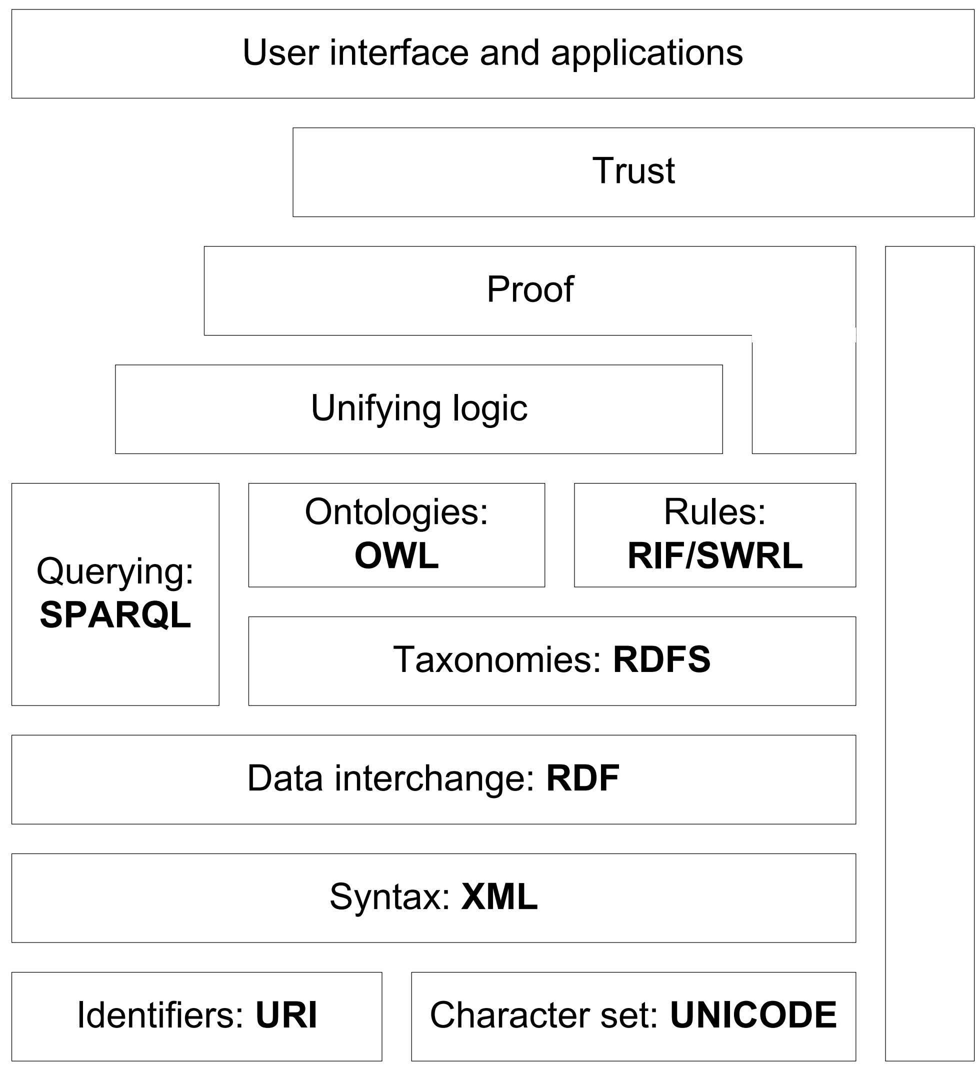
Semantic Web

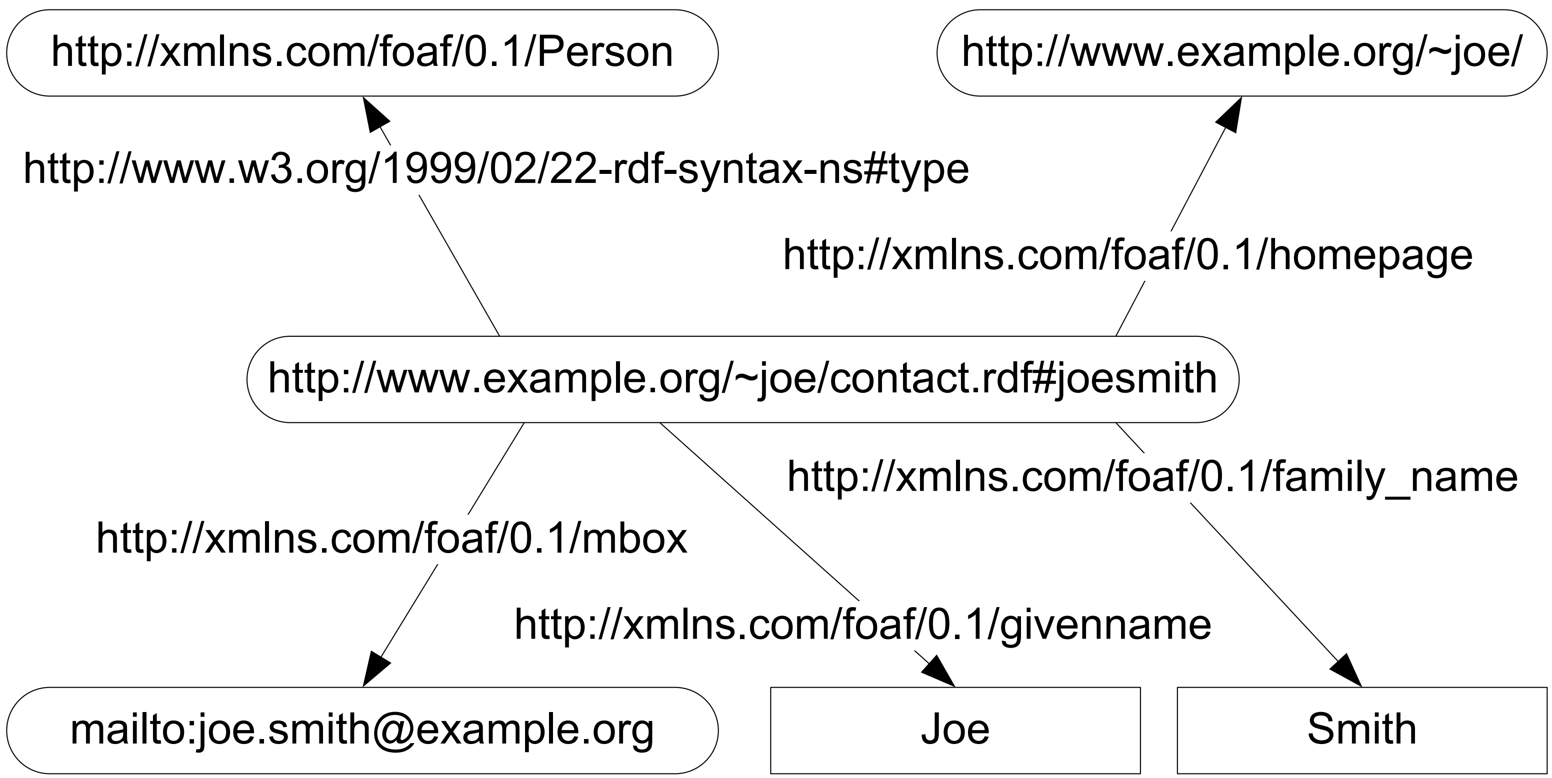
- Semantic Web
  - "provides a common **framework that allows data to be shared and reused across application, enterprise, and community boundaries**. It is a collaborative effort led by W3C (World Wide Web Consortium)…"
- "Classical" Web: computers deliver documents (text, multimedia…)
- Semantic Web: let computers process (interpret, combine, select, judge) and deliver information

Semantic Web



RDF

- Resource Description Framework (RDF)
  - triples object-predicate-subject



RDF Serialization

- RDF/XML
  - XML form, standard for exchange between machines
- N3, TURTLE
  - More readable (and writeable) by humans

```
:joesmith a foaf:Person ;
   foaf:givenname "Joe" ;
   foaf:family_name "Smith" ;
   foaf:homepage
        <http://www.example.org/~joe/> ;
   foaf:mbox
        <mailto:joe.smith@example.org> .
```

RDFS

- RDF Schema (RDFS)
  - Vocabulary for RDF – taxonomies of classes and properties, domain, range, …

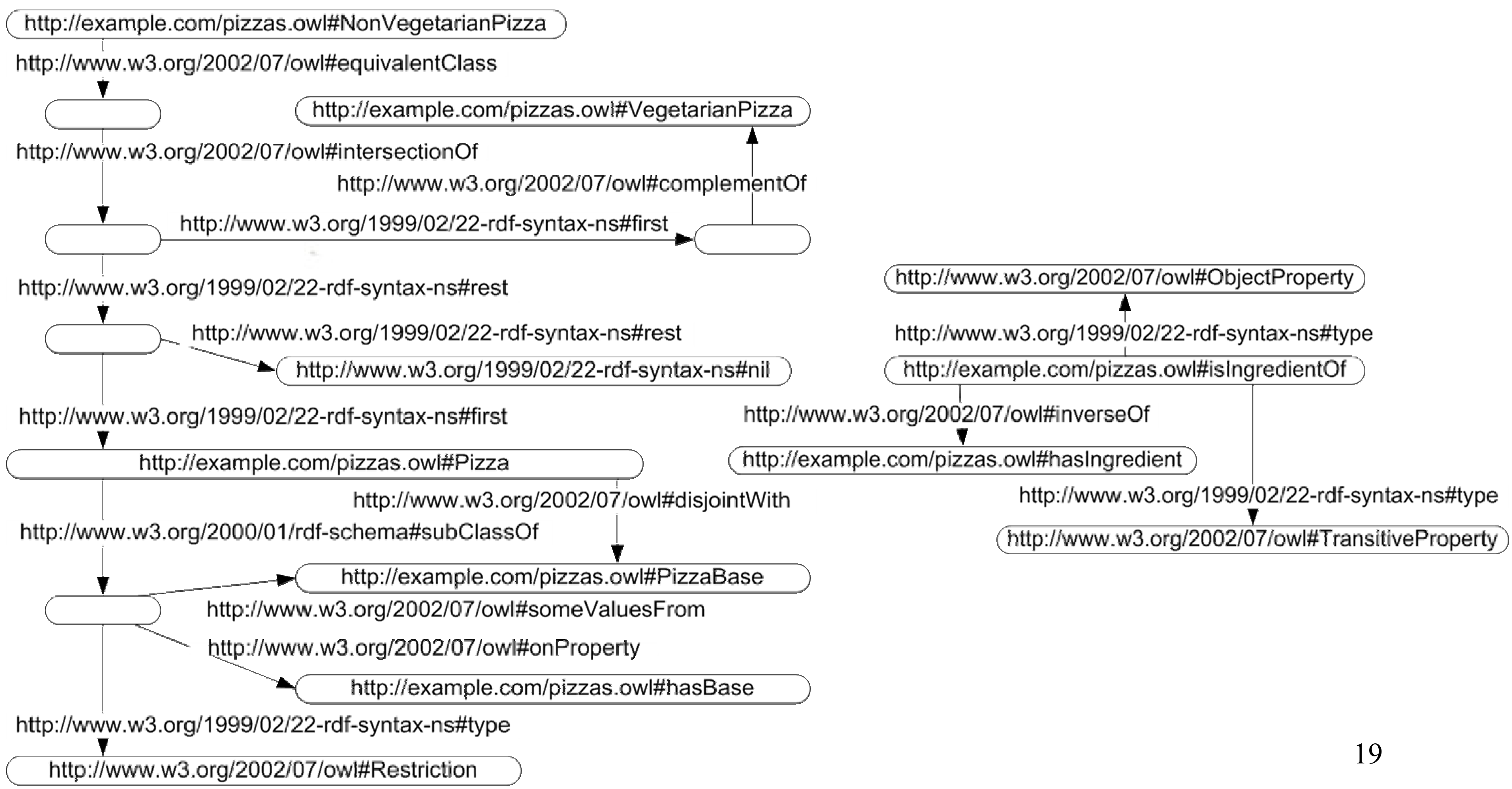
```
:Dog rdfs:subClassOf :Animal.
:Person rdfs:subClassOf :Animal.
:hasChild rdfs:range :Animal;
          rdfs:domain :Animal.
:hasSon rdfs:subPropertyOf :hasChild.

:Max a :Dog.
:Abel a :Person.
:Adam a :Person;
      :hasSon :Abel.
```

OWL

- Web Ontology Language (OWL)
  - Description logic syntactically embedded into RDF(S)
    - OWL Lite – simple constraints, description logic $\mathcal{SHIF}$
    - **OWL DL** – description logic $\mathcal{SHOIN}$
    - OWL Full – no restrictions to RDF
- Example

$$\textsc{Pizza} \sqsubseteq \exists \mathsf{hasBase}.\textsc{PizzaBase}$$
$$\textsc{Pizza} \sqcap \textsc{PizzaBase} \equiv \bot$$
$$\textsc{NonVegetarianPizza} \equiv \textsc{Pizza} \sqcap \neg\textsc{VegetarianPizza}$$
$$Tr(\mathsf{isIngredientOf})$$
$$\mathsf{isIngredientOf} \equiv \mathsf{hasIngredient}^{-}$$

OWL as RDF graph



OWL Reasoning Examples

- Transportation system - nodes, conveyor belts, ...

:targetNode rdfs:subPropertyOf :connectedTo.
- "node TN is target node of a conveyor belt CB" entails "TN and CB are connected"

:connectedTo a owl:SymmetricProperty.
- "X is connected to Y" entails "Y is connected to X"

:targetNode a owl:FunctionalProperty.
- Commercial dept.: "Node Z1 is target node of conveyor belt BE"
- Router supplier: "Router R5 is target node of conveyor belt BE"
- …entails "Node Z1 and Router R5 is the same thing" (can be explicitly stated using owl:sameIndividualAs)

:contains a owl:TransitiveProperty.
- "A contains B" and "B contains C" entails "A contains C"

SPARQL

- Simple Protocol and RDF Query Language
  - SQL like language for RDF querying

```
SELECT ?name ?mbox
WHERE { ?x foaf:name ?name .
        ?x foaf:mbox ?mbox . }
```

  - graph matching/construction
  - SELECT, CONSTRUCT, DESCRIBE, ASK
  - ORDER BY, DISTINCT, OFFSET, LIMIT
- Operates on any RDF graph
  - i.e., including RDFS/OWL

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Semantic Search

- One of the primary goals of semantic web
  – Not only keyword full-text search
  – Query includes relations between resources
  – Connecting data: mash-up from different sources
- Also needed for search within enterprise or enterprises
  – Relevant research: "semantic desktop" – semantic search within data in a single PC

Web versus Enterprise

- Where to get annotations?
  - Let users make them
    - Extra time needed, may require additional knowledge if annotation needs to be perfect
  - Generate them from data context
    - Data exist in some context that can be used to generate metadata for search (class, relations, …)
- Can we trust data providers?
  - Within enterprise there are not so many attempts to cheat as on the web

Semantic Search: Example

- Industrial domain: Assembly line search
  - Data in many formats – ladder logic in controllers, HMI panels, …
  - Structured data with annotations are stored in RDF form -> following queries can be formulated
    - Find ladder code rungs containing XIO instructions referring tags StartCycle and StopCycle
    - Find all the text objects with background color navy that have “axis" in their caption

Semantic Search: Example

- Find ladder code projects that have a tag used in a Gauge control on any HMI display

```
SELECT ?exp ?hmifile ?ladderfile WHERE {
  [ a file:File;
    file:hasFileName ?hmifile;
    gen:contains
    [ a hmi:Gauge.
      gen:contains
      [ hmi:hasTagName ?exp; ] ] ]
  [ a file:File;
    file:hasFileName ?ladderfile;
    gen:contains
    [ a ladder:tag;
      ladder:hasName ?exp; ] ] }
```

Semantic Search

- Both in enterprise/desktop search and in semantic web
  - "Enrichment of the current web" versus "Web of Data"
    - First option is more used for popularizing
    - Second option has made more progress and currently has bigger potential
  - Not surprising, because large part of web is generated from databases

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Semantic Integration

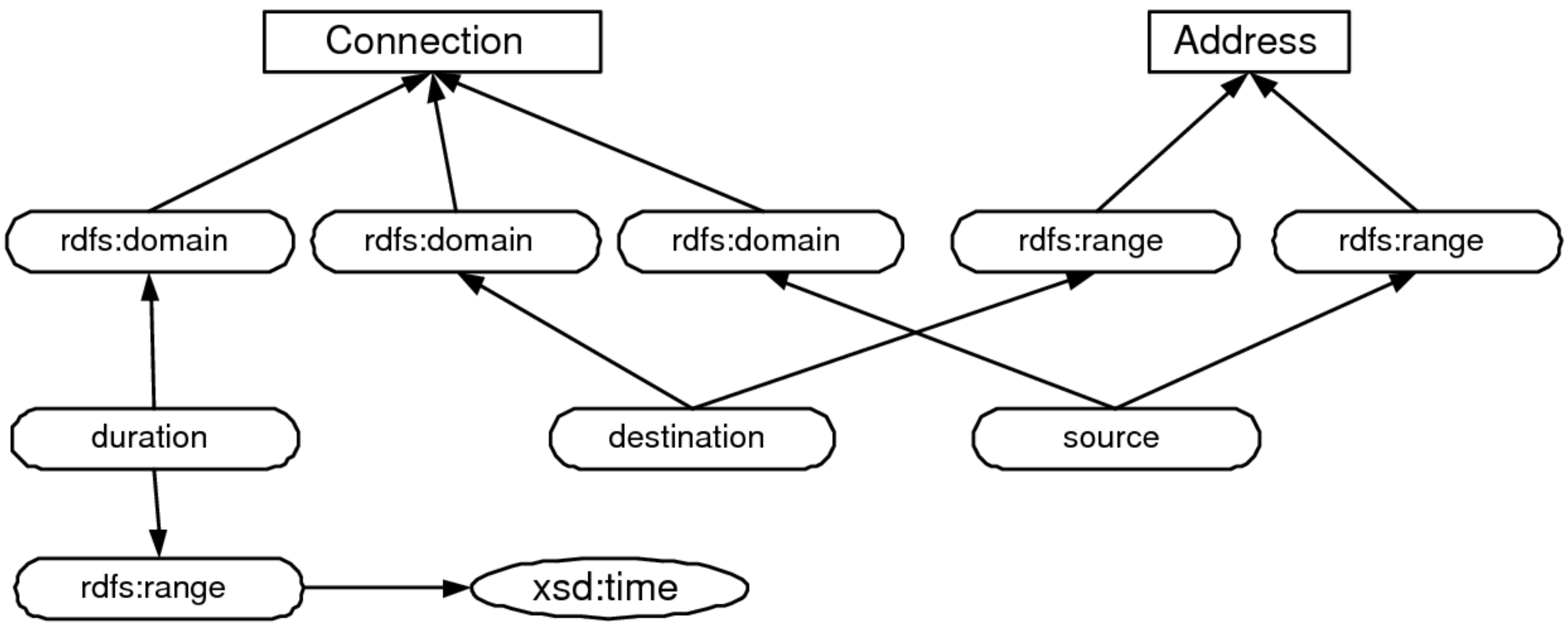
- Communication between enterprises or even within single enterprise
  - Even when using the same ontology language, ontologies are different
  - There is no one ontology that would satisfy all needs for everyone and forever
- Need to deal with multiple ontologies

Communication

- Possible model of communicating enterprises
  - Multi-agent or holonic system
- Only what is expressed in ontology
  - Can be stored in agent's knowledge base
  - Can be communicated between agents
- Agents with different ontologies
  - Need of translation of messages between different ontologies during communication
- Example
  - transportation domain, ontologies expressed in OWL

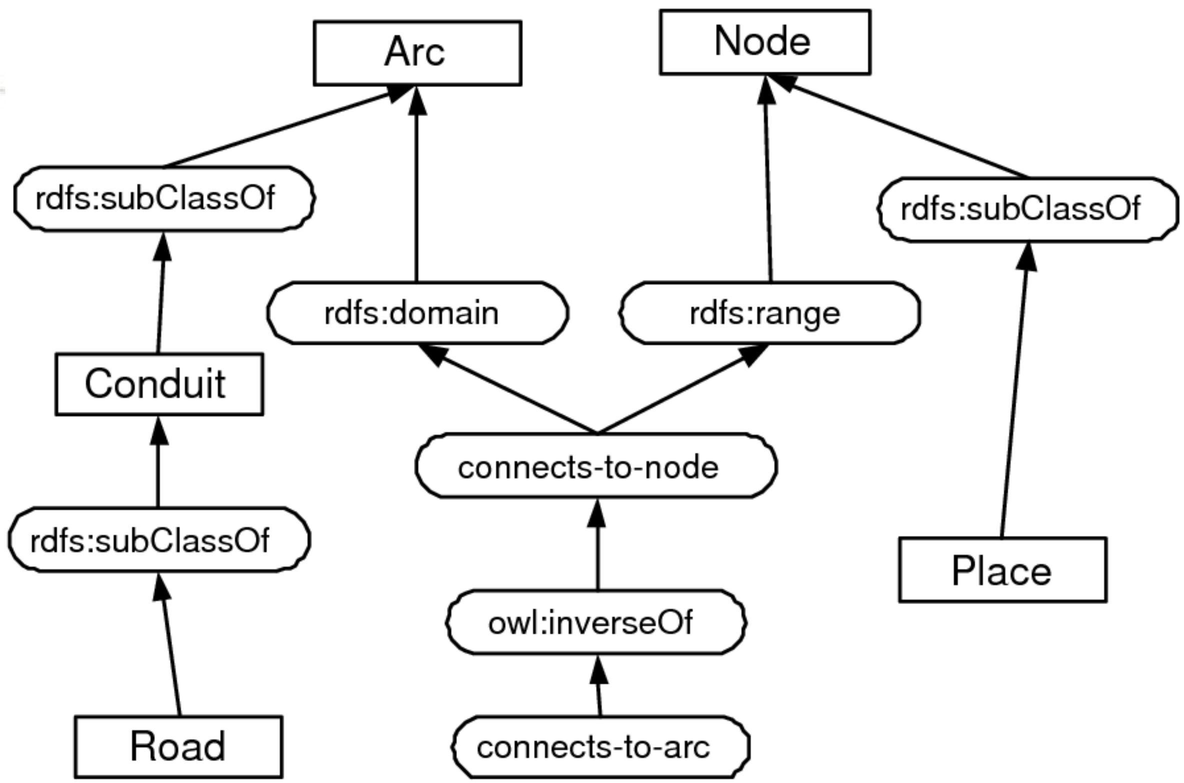
"Berlin" Ontology

- Berlin local transport service



"Boeing" Ontology

- Graph ontology used for modeling infrastructure; further specializing details



Translation

- One needs to know how ontology elements are related mapping between ontologies can be expressed in OWL

$$
\begin{aligned}
\textsc{boeing:Place} &\equiv \textsc{berlin:Address} \\
\textsc{boeing:Conduit} &\equiv \textsc{berlin:Connection} \\
\mathsf{boeing{:}connects\text{-}to\text{-}node} &\equiv \mathsf{berlin{:}destSrc} \equiv \mathsf{berlin{:}destination} \sqcup \mathsf{berlin{:}source}
\end{aligned}
$$

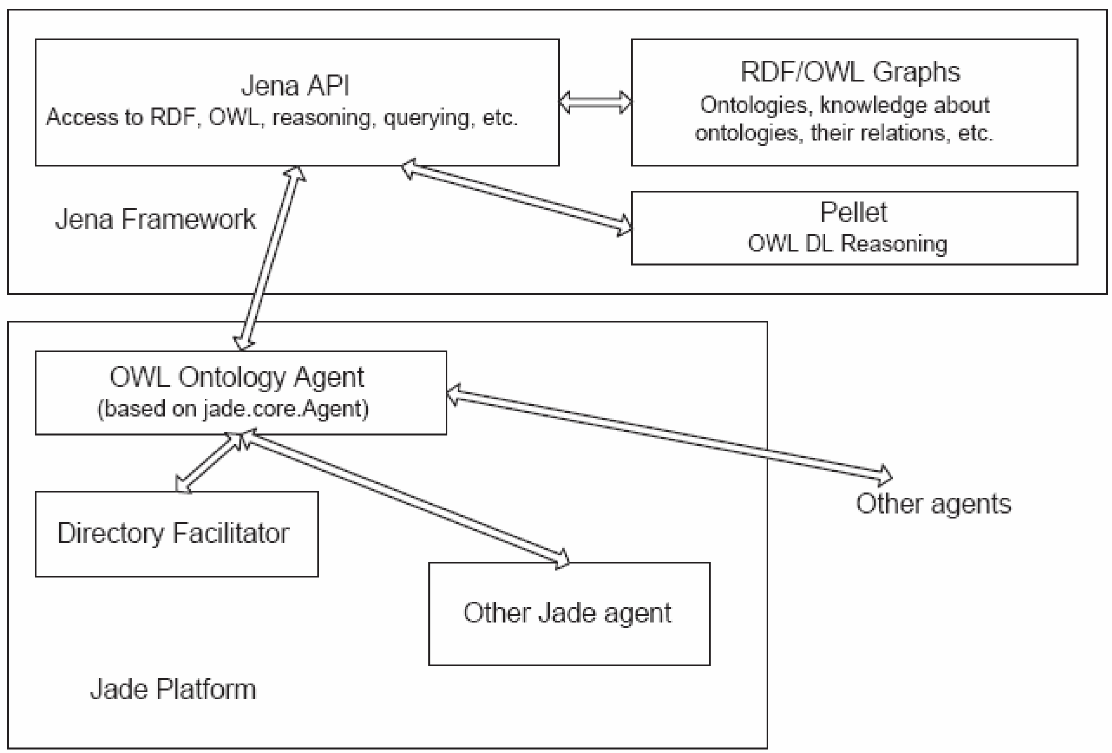
- This information is used to translate messages – OWL reasoning is used, deductions contain translation

$$
\begin{aligned}
&\textsc{boeing:Place}(placeA) \\
&\textsc{boeing:Conduit}(path1) \\
&\mathsf{boeing{:}connects\text{-}to\text{-}node}(path1, placeA)
\end{aligned}
$$

$$
\begin{aligned}
&\textsc{berlin:Address}(placeA) \\
&\textsc{berlin:Connection}(path1) \\
&\mathsf{berlin{:}destSrc} \equiv \mathsf{berlin{:}destination} \sqcup \\
&\qquad\qquad\qquad \mathsf{berlin{:}source} \\
&\mathsf{berlin{:}destSrc}(path1, placeA)
\end{aligned}
$$

Ontology Service

- Helps with translation and other ontological tasks
  - implemented as agent, but similar service can be also embedded into SOA container as a special mediator



Translation – Architecture

- All agents handle translation themselves
  - Agents are aware of ontologies, know all the implications of translation
  - Agents do not rely on anything else
- Specialized agent handles translation
  - Agents need to be aware of translation, but a specialized ontology agent/service handles it
  - Agents can focus on their tasks
- Transparent translation
  - Translation handled directly in multi-agent (or SOA) platform
  - Agents do not have to be aware of ontologies
  - Agent's preferred ontology needs to be supplied

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Services

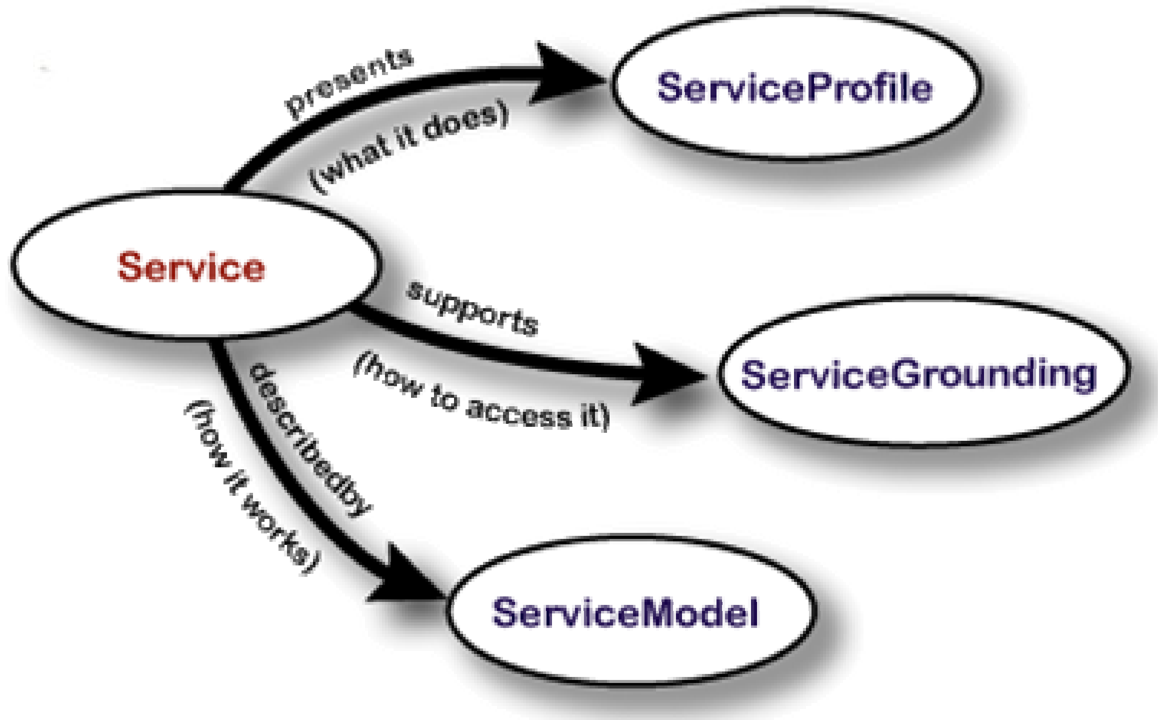
- Virtual Enterprises, Agents, Services in SOA, …
  - Distributing tasks, finding appropriate services
- Web services (“Web API”)
  - Standards for syntactic interoperability:
  - SOAP – protocol for accessing a service
    - Call a service; return result
  - WSDL – description of a service
    - Endpoints (ports), interface (parameters for a message)
  - UDDI – metadata about web services
    - White (contact), yellow (categorization), green (technical information) pages

Semantic Web Services

- Semantic enrichment of Web Services
  – i.e., not replacement
- Semantic interoperability
  – WSDL – available messages, data structures – but not their meaning (semantic constraints)
  – For automated discovery, composition and execution
  – Special ontologies developed for the description of services: OWL-S, WSMO, …

OWL-S

- OWL ontology for describing services
- Top level:



OWL-S Matchmaking

- Description of input and output conditions as a concept
  - In service advertisement and service request
  - E.g., price, provided by, delivery date, …
- Entailment relationship between concepts expressing the description is verified
  - Advertisement versus request (OWL reasoning)
  - Exact, plugin (advertisement is more general), subsume (request is more general), intersection (partially satisfiable), disjoint

Semantic Web Services

- Semantics necessary for realizing SOA vision
  - Situation today
    - Rather tightly coupled (not really loosely coupled) services
    - Programmers design and implement service calls
- Finding, composing and executing services
  - Core of virtual enterprises
  - Not possible in heterogeneous environment without semantic description

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Summary

- Ontologies and Semantic Web
  - Essential for achieving truly **computer supported** VE
  - Expressing meaning (semantics) for computers
- Illustrated on selected applications critical for VE
  - Semantic Search – enrichment of data by generated semantic annotation to perform more precise search
  - Semantic Integration – translation between different ontologies to work in heterogeneous environment
  - Semantic Web Services – service matchmaking to allow service discovery, composition and execution

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Thanks for your attention

Questions, comments?