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TRIPLE – an RDF Rule Language with Context and Use Cases

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Motivation: Why Rule Languages for the Web

- "Rule Languages for Interoperability" or "Rule Language Interoperability"?
  - Focus on the former
- More and more data becomes available – Interoperability required
  Need for:
  - Querying
  - Integration
  - Transformation

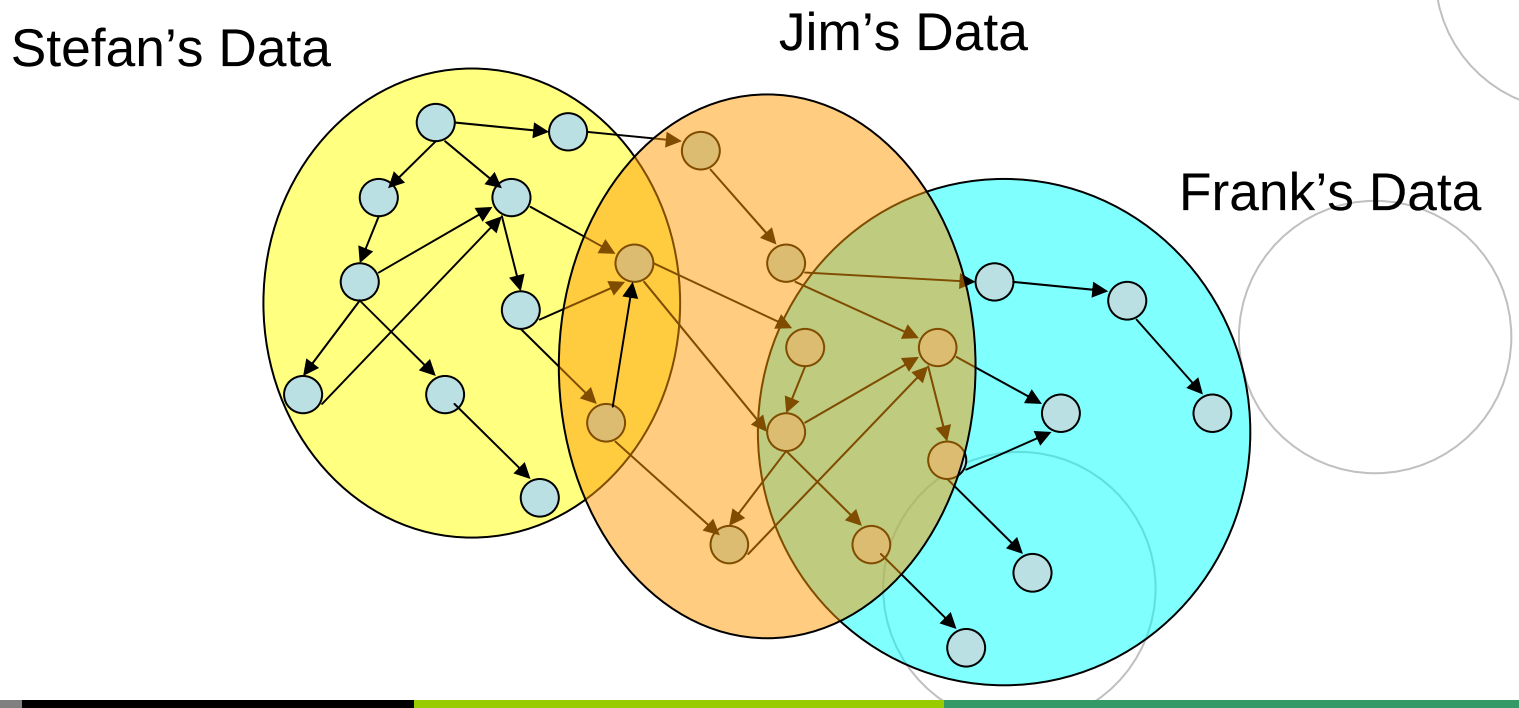
  => "*Time to Market*": Faster to write rules than code for transformation, integration

Guiding Requirements for an RDF Rule Language

- Support RDF (graph-structured data)
- Handle multiple modeling semantics
  - (OWL, UML, ER, TopicMaps, XML-Schema, Relational Data, special purpose data models)
  - Special query systems for all of them?
- Distributed, heterogeneous data sources
  - Not all data is created equal

RDF Contexts (e.g., Named Graphs)

- Support for RDF *contexts*
  - Source (is a restaurant vegetarian or not?)
  - Time stamps (e.g., sensor data)
  - Location (geospacial),
  - Culture (content rating)
  - …



TRIPLE: Brief Language Overview

- Native support
  - for Resources & namespaces,
  - Abbreviations
  - Object invention
  - Contexts (sets of RDF statements)
  - Reification
- Rules with expressive bodies (full FOL syntax)
- Inspired by F-Logic:
  - *subject*[*predicate*→*object*] ("molecule")
- Extended by: context, context expressions, parameterized contexts:
  - *s*[*p*→*o*]@*m* "triple <*s*,*p*,*o*> in model *m*"
  - *s*[*p*→*o*]@(*m1* ∩ *m2*) context intersection, union, diff
  - *s*[*p*→*o*]@sf(m1, X, Y) Skolem function

Example: Querying and Inferencing Dublin Core with Object Invention

namespace abbreviations

dc := “http://purl.org/dc/elements/1.0/”.
deri := “http://www. deri.ie/”.
....

model block

@deri:documents {

fact

deri:d_01_01 [
dc:title → TRIPLE;
dc:creator → “Stefan Decker”;
dc:subject → RDF;
dc:subject → triples; ...].

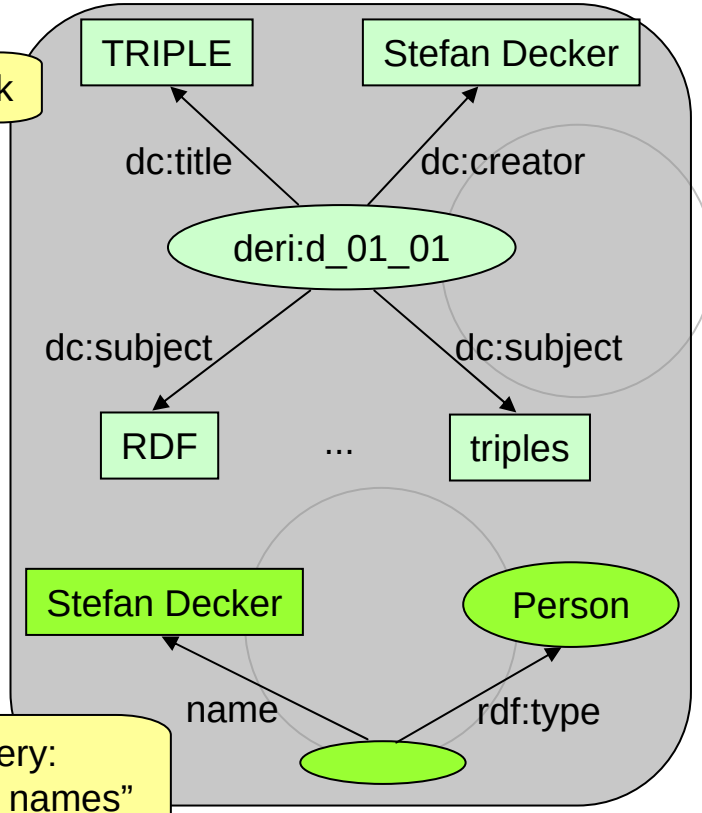
rule

∀N p(N)[rdf:type → xyz:Person;
xyz:name → N] ←
∃D D[dc:creator → N].

}

query:
“find all names”

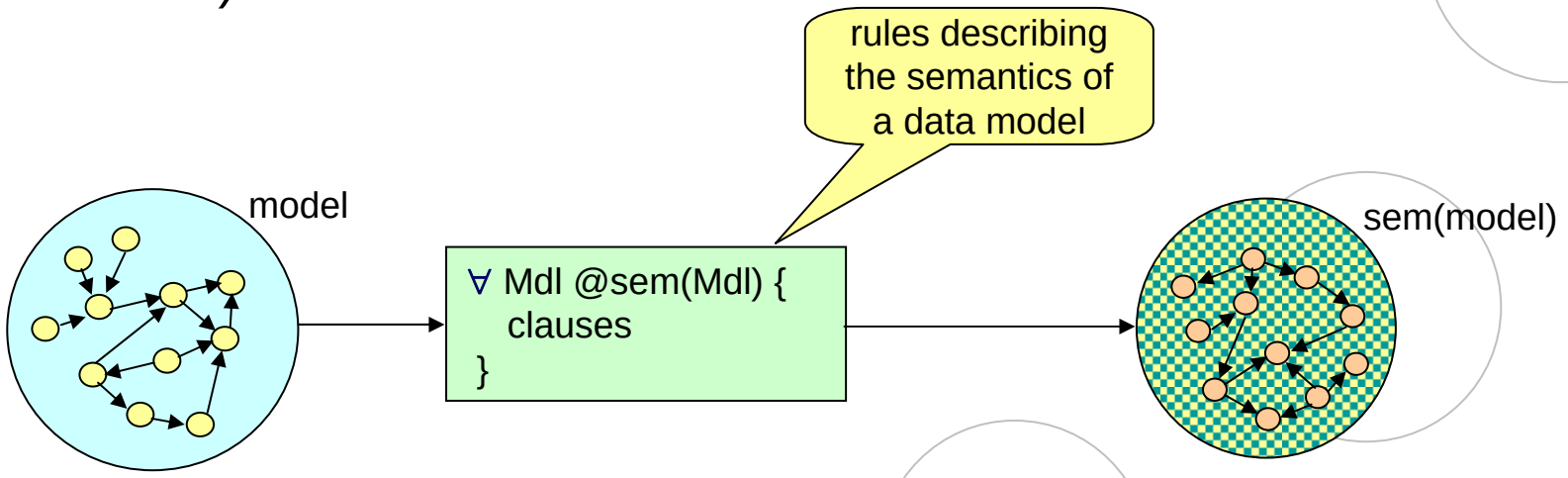
∀N ← ∃P P[rdf:type → xyz:Person;
xyz:name → N]@deri:documents.



N = “Stefan Decker”

Semantic Spaces: Specifying Semantics via Parameterized Contexts

- RDF Schema, UML (and other frame/OO systems): semantics can be *directly* defined in TRIPLE as a parameterized context
- OWL (i.e., expressive ontology languages, DL): requires interaction with *foreign* reasoning components (e.g., DL classifier)



Example: RDF Schema Semantic Space


```
rdf := 'http://www.w3.org/...rdf-syntax-ns#'.
rdfs := 'http://www.w3.org/.../PR-rdf-schema-...#'.
type := rdf:type.
subPropertyOf := rdfs:subPropertyOf.
subClassOf := rdfs:subClassOf.

FORALL Mdl @rdfschema(Mdl) {

  FORALL O,P,V   O[P->V] <-
     O[P->V]@Mdl.

  FORALL O,V   O[subClassOf->V] <-
   EXISTS W   (O[subClassOf->W]
                AND W[subClassOf->V]).

  …
}
```

namespace abbreviations

resource abbreviations

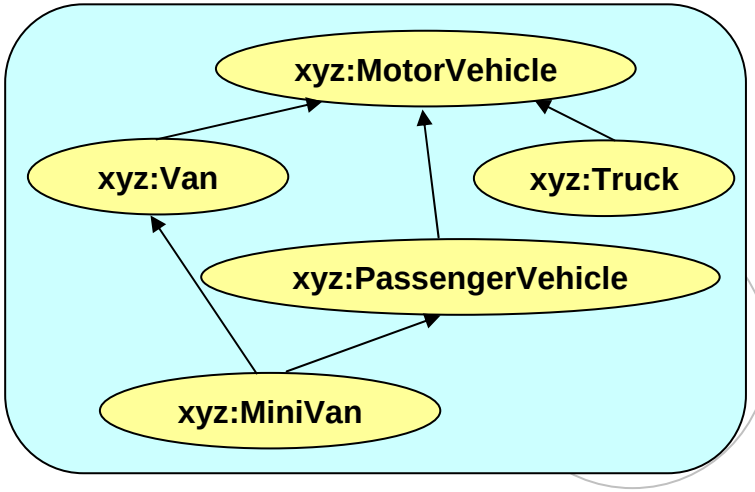
model block

"copy" triples from *Mdl*

Transitivity of subClassOf

Example: Cars Ontology


```
@cars {
  xyz:MotorVehicle[rdfs:subClassOf -> rdfs:Resource].
  xyz:PassengerVehicle[rdfs:subClassOf ->
    xyz:MotorVehicle].
  xyz:Truck[rdfs:subClassOf -> xyz:MotorVehicle].
  xyz:Van[rdfs:subClassOf -> xyz:MotorVehicle].
  xyz:MiniVan[
    rdfs:subClassOf -> xyz:Van;
    rdfs:subClassOf -> xyz:PassengerVehicle].
}
```




```
FORALL X <-
    X[rdfs:subClassOf -> xyz:MotorVehicle]@cars.
```

X = xyz:Van
X = xyz:Truck
X = xyz:PassengerVehicle

```
FORALL X <-
    X[rdfs:subClassOf ->xyz:MotorVehicle]@rdfschema(cars).
```

X = xyz:Van
X = xyz:Truck
X = xyz:PassengerVehicle
X = xyz:MiniVan

Example: UML Semantic Space

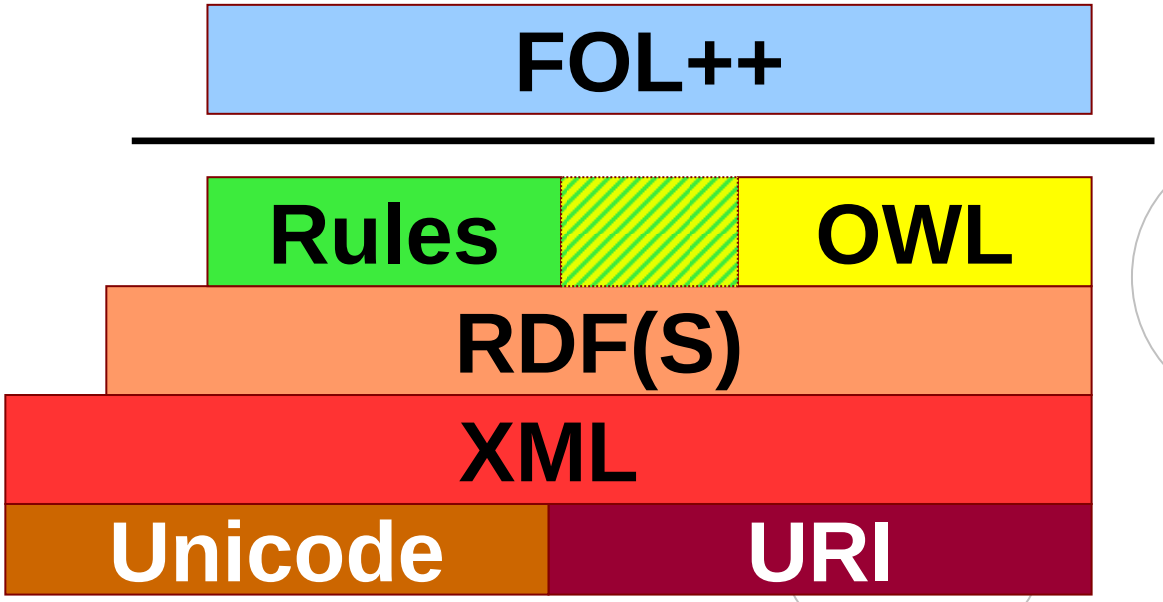

```
rdf := 'http://www.w3.org/...rdf-syntax-ns#'.
uml := 'http://www.omg.org/uml/1.3/'.

FORALL Mdl @uml(Mdl) {

  FORALL O,P,V   O[P->V] <-
     O[P->V]@Mdl.

  FORALL X,Z   g(X,Z)[rdf:type->uml:Generalization;
                      uml:'Generalization.child'->X;
                      uml:'Generalization.parent'->Z]<-
         EXISTS Y,G1,G2
             G1[uml:'Generalization.child'->X; uml:'Generalization.parent'->Y]
                AND
             G2[uml:'Generalization.child'->Y; uml:'Generalization.parent'->Z] .
…
}
```

Transitivity of Generalization

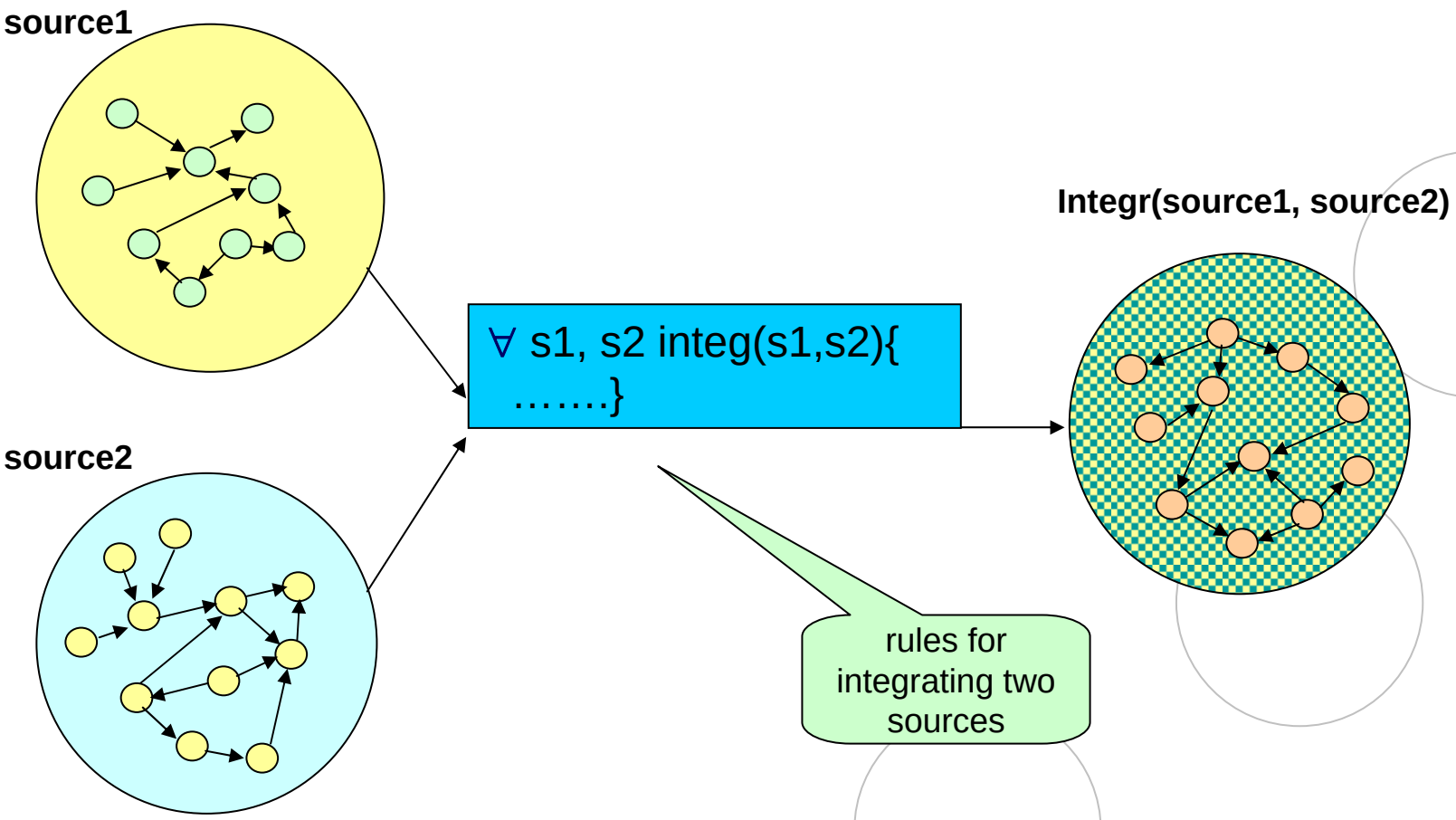
OWL Semantic Space

OWL can be handled by

- Vocabulary only
- DLP (only for the intersection between Horn and DL)
- Connection to an external OWL reasoner
  - Ship RDF to reasoner
  - Import result RDF back within the OWL Semantic Space



Example: Integrate Information from several Sources



Compilation to Horn logic + NAF

- First implementation (and informal semantics) by mapping to Horn Logic / XSB system (Prolog with tabled resolution)
- Lloyd-Topor transformation for quantifiers etc.
- RDF-specific transformations given as rewrite rules:

$$
\begin{array}{rcl}
A : N & \longrightarrow & \text{resource}(A, N) \\
O[P \rightarrow V] & \longrightarrow & \text{statement}(O, P, V) \\
S@M & \longrightarrow & \text{true}(S, M) \quad \text{for statements } S \\
<S> & \longrightarrow & S \quad \text{for statements } S \\
O[P_1 \rightarrow V_1; P_2 \rightarrow V_2; \ldots]@M & \longrightarrow & O[P_1 \rightarrow V_1]@M \ \wedge \\
 & & O[P_2 \rightarrow V_2]@M \ \wedge \ \ldots \\
\text{true}(S, M_1 \cap M_2) & \longrightarrow & \text{true}(S, M_1) \ \wedge \ \text{true}(S, M_2) \\
\text{true}(S, M_1 \backslash M_2) & \longrightarrow & \text{true}(S, M_1) \ \wedge \ \neg \ \text{true}(S, M_2) \\
X \ := \ Y.\ S(X) & \longrightarrow & \forall\, X \ \ (X = Y \ \wedge \ S(X)) \\
 & & \text{for clause sequences } S(X)
\end{array}
$$

Projects involving TRIPLE

- Conflict Analysis and Model Transformation based on TRIPLE (TU Berlin)
- Ontology Management with TRIPLE (Fraunhofer, Berlin)
- Ontology based matchmaking on the Grid (University of Southern California)
- Goods movement planning problems (University of Southern California)
- Personalization Services for the Semantic Web with TRIPLE (University of Hannover)
- Querying Semantic Web Resources Using TRIPLE Views (Technical University of Vienna)
- SmartWeb - Multi-modal access to the Semantic Web (DFKI)

Conclusions

- RDF data is contextualized and rule language need primitives to deal with context
- RDF as a Semantic Web foundation needs to express data with different semantics
- The TRIPLE context mechanism provides a flexible means to handle context

- Prototype available at http://triple.semanticweb.org

Syntax and Semantics Definition (for Peter)

Definition 1 (Alphabet) The *alphabet* of aTRIPLE-language, $\mathcal{L}$, consists of

- a set of *resource constructors*, $\mathcal{F}$ [1];
- an infinite set of *variables*, $\mathcal{V}$;
- an infinite set of *strings*, $\mathcal{H}$ [2];
- a set $\mathcal{E}$ of language identifiers[3] plus a single identifier 'NULL';
- auxiliary symbols, such as,(,),[,],:,<,>,→, ::, XML; and
- usual logical connectives and quantifier, ∧,∨, ¬,←,→,↔,∀, ∃.

Definition 2 (Terms) Terms are defi

- A variable $v \in \mathcal{V}$ is a term.
- A constant (a resource constructor with arity 0) is a term.
- For all $s \in \mathcal{H}$, $e \in \mathcal{E}$, s, $s :: e$, $XMLs$, and $XMLs :: e$ are terms, also called *literals*.
- If f is an n-ary function symbol ($n > 0$) in $\mathcal{F}$, and $t_1, \ldots, t_n$ are terms, then $f(t_1, \ldots, t_n)$ is a term.
- If n and l are terms, then $n : l$ is a term, also called a *resource-id*. The term n is called the *namespace part* of the resource-ids, the term l is called the *localname part* of the resource-id.
- If s, p, and o are terms, then $< s[p \rightarrow o] >$ is a term, also called a *statement-id*. A statement-id is also a resource-id.
- These are all terms.

Definition 4 (Context Expressions) *Context expressions* are defined inductively as follows:

- A term is a context expression.
- Given two context expressions m_1 and m_2, then
  - $m_1 \cup m_2$ (Union of two contexts),
  - $m_1 \cap m_2$ (Intersection of two contexts), and
  - $m_1 \backslash m_2$ (Set difference of two contexts)

  are also context expressions.
- These are all context expressions.

are also context expressions.

- These are all context expressions.

Definition 5 (Molecular Formulae) Given a statement $< s[p \rightarrow o] >$ and a context expression m, the expression $< s[p \rightarrow o] > @m$ is called a molecule.

As a notional convention the angle brackets around the statement in a molecular formulae are usually omitted. General formulae are built from the molecular formulae by means of logical connectives and quantifiers:

Definition 6 (Complex Formulae) Formulae are defined as follows:

- A molecular formula is a formula.
- If φ and ψ are formulae, then so are $\varphi \vee \psi$, $\varphi \wedge \psi$, $\varphi \rightarrow \psi$, $\varphi \leftarrow \psi$, $\varphi \leftrightarrow \psi$, $\neg\varphi$, and (φ).
- If X is a variable, and φ is a formula, then $\forall X \varphi$ and $\exists X \varphi$ are formulae.
- These are all formulae.

Model Structure

Definition 7 (T-structures) Given a TRIPLE-language $\mathcal{L}$, a *T-structure* $\mathcal{T}$ is a tuple $< \mathcal{U}, \mathcal{R}, \mathcal{J}, \mathcal{S}, \mathcal{C}, \mathcal{M}, \mathcal{I} >$. The set $\mathcal{U}$ is called the *Constant Universe*, $\mathcal{R}$ is a set of *Resources*. $\mathcal{J}$ is the set of 3-tuples, defined as $\mathcal{H} \times \mathcal{E} \times \{true, false\}$ (as in definition 1), $\mathcal{S}$ is constructed inductively as follows:

- $\mathcal{S}_0 = \mathcal{R} \times \mathcal{R} \times (\mathcal{R} \cup \mathcal{H})$
- $\mathcal{S}_{n+1} = (\mathcal{R} \cup \mathcal{S}_n) \times (\mathcal{R} \cup \mathcal{S}_n) \times (\mathcal{R} \cup \mathcal{H} \cup \mathcal{S}_n)$ for $n \geq 0$.

Then $\mathcal{S}$ is defined as $\bigcup_{i=0}^{\omega} S_i$.

$\mathcal{C}$ is a mapping from $(\mathcal{U} \cup \mathcal{R} \cup \mathcal{S} \cup \mathcal{J}) \times (\mathcal{U} \cup \mathcal{R} \cup \mathcal{S} \cup \mathcal{J})$ to $\mathcal{R}$. $\mathcal{M}$ is a mapping from $\mathcal{R} \cup \mathcal{S}$ to $2^{\mathcal{S}}$. $\mathcal{I}$ is an *interpretation function* defined as follows:

- Every constant $c \in \mathcal{F}$ is mapped to an element $c' \in \mathcal{U}$ from the universe (noted as $\mathcal{I}(c) = c'$);
- every n-ary ($n > 0$) resource constructor is mapped to an n-ary function $f' : \mathcal{U}^n \mapsto \mathcal{U}$ (noted as $\mathcal{I}(f) = f'$);
- every statement-id $< s[p \rightarrow o] >$ is mapped to a 3-tuple $\langle \mathcal{I}(s), \mathcal{I}(p), \mathcal{I}(o) \rangle \in \mathcal{S}$ (noted as $\mathcal{I}(< s[p \rightarrow] >= \langle \mathcal{I}(s), \mathcal{I}(p), \mathcal{I}(o) \rangle)$;
- every literal l is mapped to an element of $\mathcal{J}$ as follows:
  - if $l = XMLs :: e$ then $\mathcal{I}(l) =< s, e, true >$
  - if $l = s :: e$ then $\mathcal{I}(l) =< s, e, false >$
  - if $l = XMLs$ then $\mathcal{I}(l) =< s, null, true >$
  - if $l = s$ then $\mathcal{I}(l) =< s, null, false >$

Definition 8 (Variable Assignment) A *variable assignment* for a TRIPLE-language $\mathcal{L}$ and a T-structure $\mathcal{T}$ is a mapping $B : \mathcal{V} \mapsto (\mathcal{U} \cup \mathcal{R} \cup \mathcal{S} \cup \mathcal{J})$, which maps a variable to either an element of the universe, to a resource, or to a literal.

A variable assignment extends to terms in the usual way:

Definition 9 (Term Denotation) The denotation of a TRIPLE-term t with respect to a T-structure $\mathcal{T}$ and a variable assignment B (noted as $t^{\mathcal{T},B}$) is defined as follows:

- $v^{\mathcal{T},B} = B(v)$, for all $v \in \mathcal{V}$;
- $c^{\mathcal{T},B} = \mathcal{I}(c)$, for all constants $c \in \mathcal{F}$;
- $f(t_1, \ldots, t_n)^{\mathcal{T},B} = \mathcal{I}(f)(t_1^{\mathcal{T},B}, \ldots, t_n^{\mathcal{T},B})$, for all terms $t_1, \ldots, t_n$ and all $f \in \mathcal{F}$;
- $(n : l)^{\mathcal{T},B} = \mathcal{C}(n^{\mathcal{T},B} : l^{\mathcal{T},B})$ for all resource-ids $n : l$;
- $< s[p \rightarrow o] >^{\mathcal{T},B} = \mathcal{I}(< s^{\mathcal{T},B}[p^{\mathcal{T},B} \rightarrow o^{\mathcal{T},B}] >)$ for all statement-ids $< s[p \rightarrow o] >$;
- $l^{\mathcal{T},B} = \mathcal{I}(l)$ for literals l

Semantics

Definition 10 (Molecular Satisfaction) The satisfaction of a molecular formula with respect to a T-structure $\mathcal{T}$ and a variable assignment B is defined as follows:

- $\mathcal{T}, B \models < s[p \rightarrow o] > @m$ iff $< s[p \rightarrow o] >^{\mathcal{T},B} \in \mathcal{M}(m^{\mathcal{T},B})$ if m is a resource-id;
- $\mathcal{T}, B \models < s[p \rightarrow o] > @m_1 \cup m_2$ iff $\mathcal{T}, B \models < s[p \rightarrow o] > @m_1$ or $\mathcal{T}, B \models < s[p \rightarrow o] > @m_2$;
- $\mathcal{T}, B \models < s[p \rightarrow o] > @m_1 \cap m_2$ iff $\mathcal{T}, B \models < s[p \rightarrow o] > @m_1$ and $\mathcal{T}, B \models < s[p \rightarrow o] > @m_2$;
- $\mathcal{T}, B \models < s[p \rightarrow o] > @m_1 \backslash m_2$ iff $\mathcal{T}, B \models < s[p \rightarrow o] > @m_1$ and $\mathcal{T}, B \not\models < s[p \rightarrow o] > @m_2$

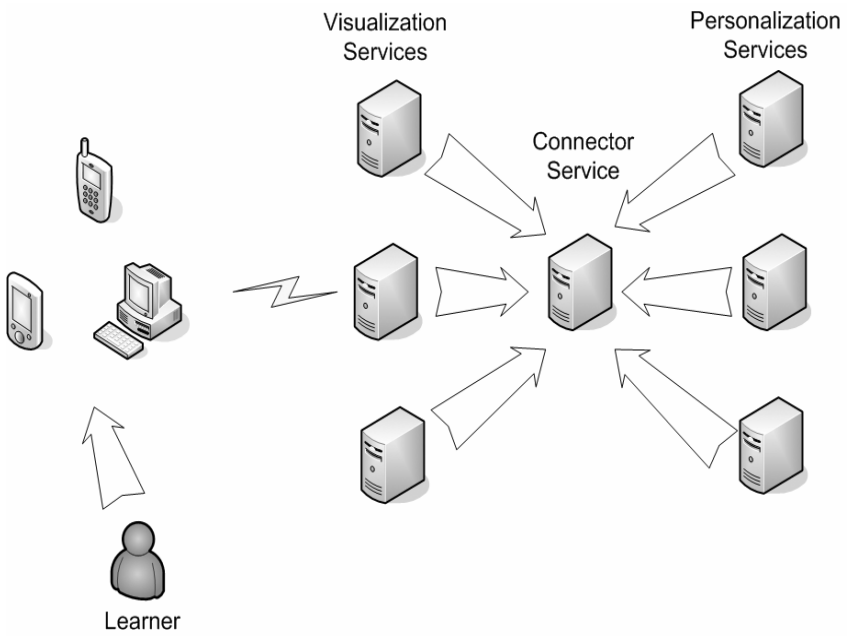
Definition 11 (Formula Satisfaction) Given formulae φ, ψ and a variable x, the satisfaction of a non-molecular formula with respect a T-structure $\mathcal{T}$ a variable assignment B is defined as follows:

- $\mathcal{T}, B \models \varphi \wedge \psi$ iff $\mathcal{T}, B \models \varphi$ and $\mathcal{T}, B \models \psi$;
- $\mathcal{T}, B \models \varphi \vee \psi$ iff $\mathcal{T}, B \models \varphi$ or $\mathcal{T}, B \models \psi$;
- $\mathcal{T}, B \models \varphi \rightarrow \psi$ iff if $\mathcal{T}, B \models \varphi$ then also $\mathcal{T}, B \models \psi$;
- $\mathcal{T}, B \models \varphi \leftarrow \psi$ iff if $\mathcal{T}, B \models \psi$ then also $\mathcal{T}, B \models \varphi$;
- $\mathcal{T}, B \models \varphi \leftrightarrow \psi$ iff $\mathcal{T}, B \models \varphi$ if and only if $\mathcal{T}, B \models \psi$;
- $\mathcal{T}, B \models \neg\varphi$ iff $\mathcal{T}, B \not\models \varphi$;
- $\mathcal{T}, B \models (\varphi)$ iff $\mathcal{T}, B \models \varphi$;
- $\mathcal{T}, B \models \forall x\varphi$ iff for all $d \in \mathcal{U} \cup \mathcal{R} \cup \mathcal{S} \cup \mathcal{H}$ $\mathcal{T}, B_x^d \models \varphi$, where

$$B_x^d(y) := \begin{cases} d & \text{if } x = y \\ B(y) & \text{otherwise} \end{cases}$$

- $\mathcal{T}, B \models \exists x\varphi$ iff there exists $d \in \mathcal{U} \cup \mathcal{R} \cup \mathcal{S} \cup \mathcal{H}$ $\mathcal{T}, B_x^d \models \varphi$, with B_x^d defined as above.

Use-Case: Personalization Services for the Semantic Web



Approach

- Personalization rules reason over distributed resources: TRIPLE
- Personalization functionalities are encapsulated in Web services
- Available personalization services are registered in a Web service registry
- Connector service orchestrates communication
- Visualization services syndicate results according to currently used device

Problem

- Personalization functionality is not reusable but hidden in applications
- currently: no plug & play approaches offering dynamically personalized services
- to reach this goal: distributed sources (user profiling, context detection, resource usage, etc.) have to be collected and evaluated accordingly

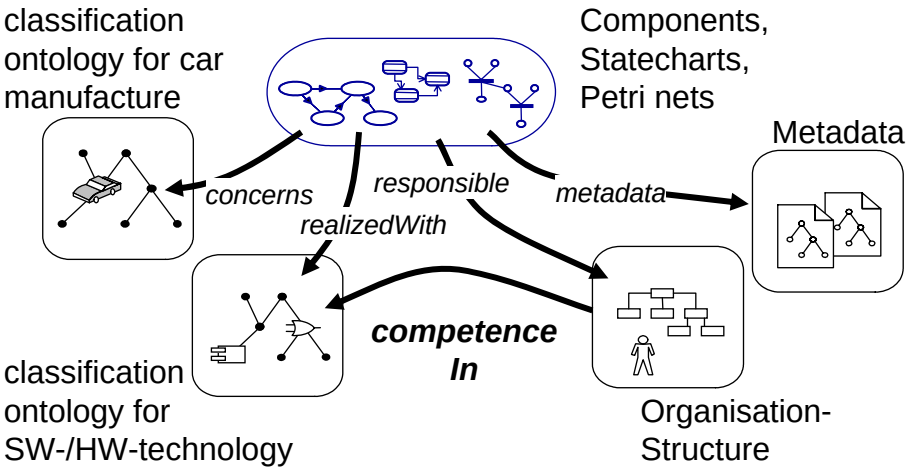
Results

- Realized Personal Readers:
  - e-Learning: for Java, and Semantic Web
  - Personal Publication Browser for the NoE REWERSE – Reasoning on the Web
- Prototypes available at
  - www.personal-reader.de

N. Henze: “Personal Readers: Personalized Learning Object Readers for the Semantic Web” (AIED'05)
R. Baumgartner, N. Henze, M. Herzog: “The Personal Publication Reader: Illustrating Web Data Extraction, Personalization, and Reasoning for the Semantic Web” (ESWC'05)

Nicola Henze, L3S, Hannover

Use Case: Ontology Management



Goal: integrative management and usage of *domain artefacts*

Approach

- Using ***TRIPLE/RDF*** to represent *classes*, instances and their interrelations as *first class objects*
- Using ***TRIPLE contexts*** to partition the artefact set (req. 1)
- Using ***TRIPLE rules*** for derivations (req. 2)
- Using ***TRIPLE parameterized contexts*** to support transformations (req. 3)

Requirements

A repository language has to support

1.Partitioning of the whole artefact set into artefact groups

2.Deriving of new artefact relations (***competenceIn***)

3.Transformation between the elements of the artefact groups

Results

- ***Repository prototype ODIS*** at Fraunhofer ISST (available on demand)
- ***Enhancements*** of ***TRIPLE***:
  - reintroduction of the ***multi-value-construct*** (~ F-Logic)
  - enabling ***mapping-chains*** ((a <- b) <- c)
  - distinction between ***intensional*** and ***extensional statements*** (~ deductive DB)

Andreas Billig, Fraunhofer, Berlin