Semantic Data Exchange

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Motivation

- Interchange data among applications
  - Cooperate, interact, …
  - Fundamental for e-Commerce apps
- 1/2/02, how can I interpret this?

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Contextual information is required

Fundamental Semantic Heterogeneity

- Instance/entity identification problem
  - When two different information sources store information on an identical object, but do not share enough common information attributes to identify the object as the same
  - It cannot be solved algorithmically

Fundamental Semantic Heterogeneity (2)

- Two descriptions in different data sources have a similar meaning, but are quite the same
  - Neither data source (and schema) contains enough information to resolve the problem
    - E.g. prices in one DB include sales tax, while in a different DB do not
  - If data sources do not contain information to clarify the discrepancy, it cannot be resolved programmatically

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Structural Semantic Heterogeneity

- When the same information is represented in two separate Apps in structurally different but formally equivalent ways. Two main reasons:
  - Normally, consequence of independent creation, design and evolution of autonomous Apps
  - Other reason, rich set of modeling constructors
- Spectrum of heterogeneity
  - Domain conflicts
  - Naming conflicts
  - Type conflicts
  - Structural conflicts

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Domain conflicts

- Metadata specification differs and consequently conceptual schemas are different
  - The same entity is described differently in different domains
  - E.g. Paul is known as p123 in domain A and paul in domain B

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Naming conflicts

- Objects may be represented in a different manner
  - The same attribute has different labels
  - E.g. Attribute name versus lastname

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Type conflicts

- Systems represent low level atomic values differently
- Different types are used to describe related entities
- E.g. temperature may be of type integer in one system and of type float in another

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Structural conflicts

- Data may be managed by different DBMSs
- A different data organization or structure is used to represent the same concepts
- E.g. An address type is represented as a structure or as a single attribute of type string

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Overcoming Semantic Heterogeneity

- These heterogeneities can be overcome when
  - there is enough information in the metadata to clarify the meaning of each of the objects within the data source
- If it's not the case
  - Resolving these conflicts become difficult
  - and sometimes impossible

Overcoming: Domain conflicts

- By using semantic dictionaries
  - Must contain mapping between domains
    - Dictionary entry with
      - paul identifies p123 in domain A
      - p123 identifies paul in domain B
  - When objects cannot be mapped 1:1 across domains, a more complicated mapping mechanism must be used
    - This can result in information loss
    - E.g. Representation of grades and marks
      - Out of ten and A, B, C, … +, -

Overcoming: Naming conflicts

- Require mapping functions which simply change the labels of the attributes
  - Easy to overcome
- A naming conflict can be mistaken for a structural conflict
  - E.g. An attribute price may or may not include taxes

Overcoming: Type conflicts

- Usually can be resolved by applying conversion functions
- E.g. Programming languages provide functions for converting strings to integers

Overcoming: Structural confl.

- Involves decomposition or composition
  - E.g. The address type
    - represented in a structure composed into a single attribute
    - represented in a single string decomposed into a structure

Overcoming Semantic Heter.

- Ambiguity of data
  - Looking at data and metadata is sometimes not enough to fully understand its meaning
  - Completely removing ambiguity is unrealistic
- Semantic values
  - Facilitate integration of heterogeneous data
  - Help resolve many ambiguities in data

Data Integration - Issues

- Data from different sources/components is represented differently
- Different organizations/departments use different units and representation formats
- Many of the underlying assumptions about the meaning of a given data object are only implicit
- Context information is left implicit and consequently it is lost when crossing institutional boundaries

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Why Semantic Metadata?

- The Internet as a global marketplace
- Business-to-Consumer:
  - interactive "point-and-click"
- Business-to-Business:
  - proprietary protocols
- Business-to-Business-to-Consumer:
  - need to extract and consolidate data for further electronic processing

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Example

Netscape: travel.html

Availability for FRANKFURT (FRA) to KENNEDY–NEW YORK (JFK)
Saturday, June 06 2000

Select	Airline	Flight	Departing		Arriving		Stops	Meal
			City	Time	City	Time		
	LH	400	FRA	10:35	JFK	13:00	0	S L

Price Per Adult (Economy Class): DEM 1826

Netscape: telep.html

Direct flight on **Saturday June 6, 2000**
Departing: FRA **Frankfurt**, Frankfurt Germany
Arriving at: JFK **John F. Kennedy Int'l Airport**, New York New York
Lufthansa, flight number **400**, departing **10:35** AM, arriving **1:00 PM**
Class: **Y** – Economy Coach; Flight Dist.: **3850 Miles**

You can reserve this/these flight(s) at a fare of **$ 830** for one adult, incl. taxes.

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The MIX Model

- **MIX**:

  *"**M**etadata based **I**ntegration model for data **X**-change"*

- Combines two aspects:
  - *representation of data plus additional semantic metadata*
  - *flexible, self-describing data model for the representation of semi-structured data*

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Ontology

An ontology is a formal specification
of a shared conceptualization
of a domain of interest

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Ontologies in MIX

- Set of concepts and their relationships that model a given domain
- Ontology concept:
  - *is an abstraction of a set of real world phenomena*
  - *has a representation type associated that determines the physical representation of data of a given concept*
- Should be based on existing standards, but must be extensible

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Simple Semantic Object

- A data item with additional metadata to support its interpretation:

< Distance, 3850, {<Unit,"mile">, <Scale, 1>} >

  - ***3850*** is the recorded data value
  - ***Distance*** denotes the ontology concept
  - ***{<Unit,"mile">, <Scale, 1>}*** represents the interpretation context of the value 3850

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Complex Semantic Object

- A heterogeneous collection of semantic objects grouped under a corresponding concept

```
< FlightOffer, {
  < ClassOfService,        "Economy",        {<ClassOfServiceCode,
    "FullServiceClassName">} >,
  < Price,          1826,   {<Currency, "DEM">, <Scale, 1>} >,
  < FlightSegment, {
    < FlightNumber,        400 >,
    < AirlineIdentifier,   "LH",     {<AirlineIdentifierCode,
    "TwoLetterAirlineCode">} >,
    < DepartureDate,       "Jun 06 2000",     {<DateFormat, "Mon DD
    YYYY">} >,
    < DepartureTime,       "10:35",  {<TimeFormat, "HH:MM">} >,
    < DepartureAirport,    "FRA",    {<AirportIdentifierCode,
    "ThreeLetterAirportCode">} >,
    ...
    < Service,      "S",     {<ServiceCode, "OneLetterServiceCode">} >,
    < Service,      "L",     {<ServiceCode, "OneLetterServiceCode">} >      }
    >   } >
```

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Conversion Function

- A function that converts semantic objects between different contexts

$\varphi_{Currency}$(*{ <Currency,"USD">}, < Price, 1826, {<Currency, "DEM">} >*)

= < Price, 830, {<Currency, "USD">} >

with "1 USD = 2.2 DEM"

- Provide a prerequisite for the integration of data from different sources

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Semantic Equivalence

- Semantically equivalent objects represent the same information

  *< Distance, **3.850**, {<Unit, "mile">, <Scale,1000>} >*
  *< Distance, **3850**, {<Unit, "mile">, <Scale,1 >} >*

- Determined through conversion to a common context and the comparison of their data values
- Depends in general on the context and conversion function used

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Semantic Equivalence

- Semantically equivalent objects represent the same information

  *< Distance, **3850**, {<Unit, "mile">, <Scale,1>} >*

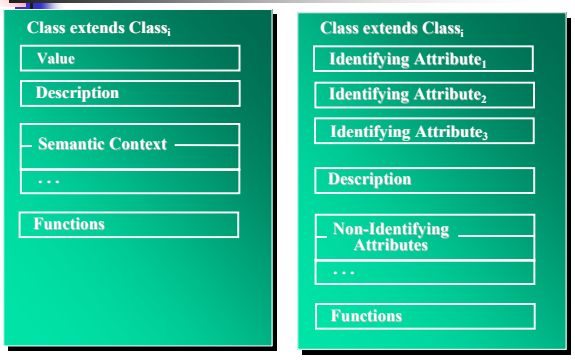
  *< Distance, **3850**, {<Unit, "mile">, <Scale,1>} >*

- Determined through conversion to a common context and the comparison of their data values
- Depends in general on the context and conversion function used

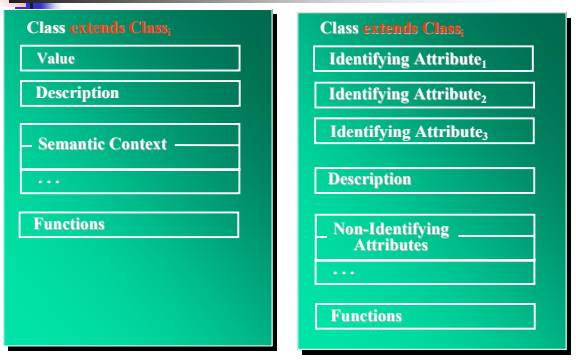
Semantic Identity

- Semantically identical objects represent information about the same real world object
- Complex objects: if all identifying attributes are semantically identical (recursive)
- Simple objects: if they are semantically equivalent

Representing Ontology Concepts



Representing Ontology Concepts



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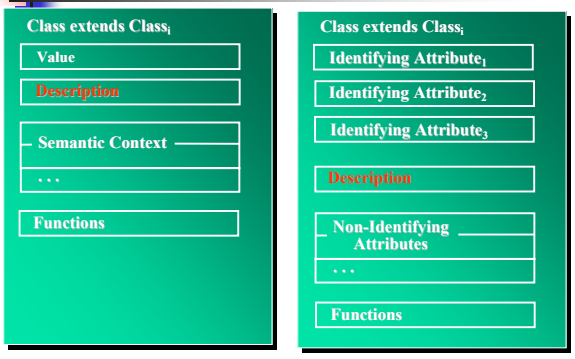

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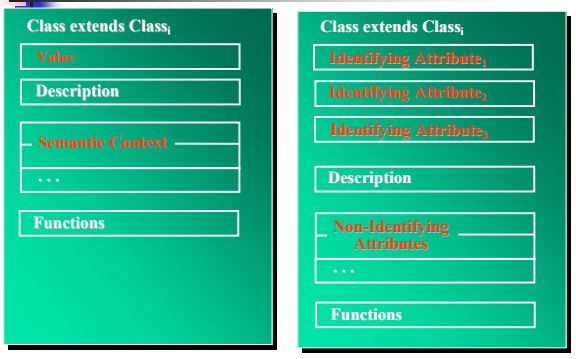

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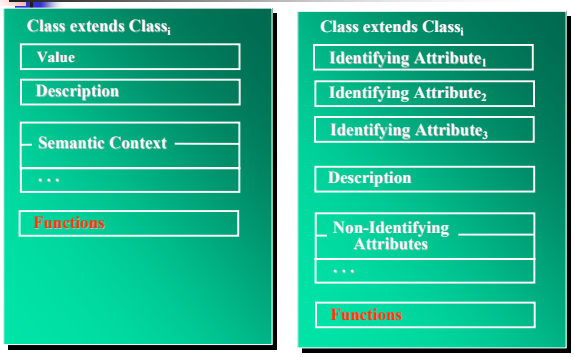

Simple Semantic Objects Complex Semantic Objects

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Representation & Domain-specific Ontologies

- Representation Ontologies
  - domain-independent physical representation basis
  - enables exchange and reuse of concepts
  - contains concepts like Numeric-Value, or Character-String
- Domain-specific Ontologies
  - refer to a concrete subject domain
  - provide a consistent conceptualization of this domain
  - contains concepts like FlightOffer, or Distance

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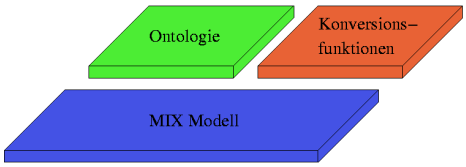
Abstract Model



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Representing Ontology Concepts

- Advantages of using Java for the representation of ontology concepts:
  - it avoids any impedance mismatch between programming and ontology specification language
  - making concepts available as pre-compiled classes allows their shipping, and that of the corresponding data objects, between different platforms

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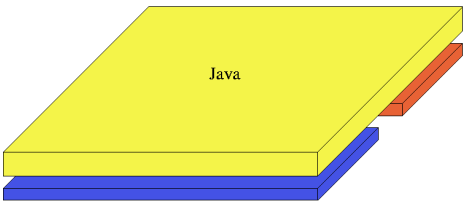
Java Implementation (MIBIA)



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Representing Ontology Concepts

- Disadvantages of using Java for the representation of ontology concepts:
  - Only Java programs can manipulate concepts
    - Representation dependency
  - It is not easy to
    - Identify instances
    - Share context among instances
    - Make relationships among concepts explicit

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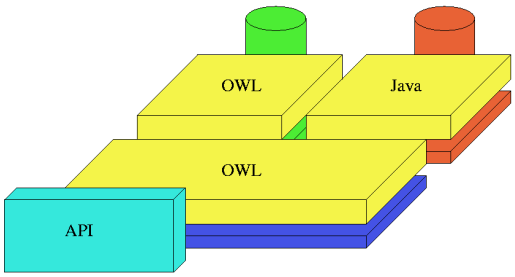
Representation

- Description of semantic objects using OWL (Web Ontology Language)
  - Candidate Recommendation of the W3C
  - Based on XML and therefore programming language and platform independent
  - Use of URI as global identifiers (needed for context-sharing)

Current Implementation



OWL Representation - Sample

```
<owl:Thing rdf:ID="Price1">
  <mix:type>Simple</mix:type>
  <mix:concept>EngMath#Price</mix:concept>
  <rep:value>
      <xsd:string rdf:value="99.95"/>
  </rep:value>
  <rep:semanticContext
  rdf:resource="#CurrencyContext"/>
</owl:Thing>
```


OWL Representation – … Sample

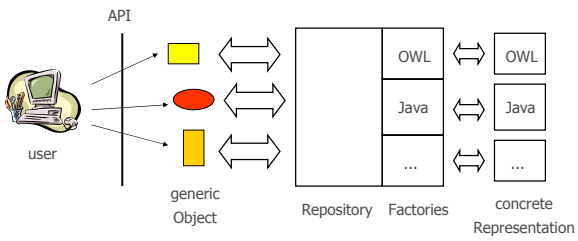
```
<rep:SemanticContext rdf:ID="CurrencyContext">
  <rep:aspect rdf:resource="#EuroCurrency"/>
</rep:SemanticContext>

<owl:Thing rdf:ID="EuroCurrency">
  <mix:type>Simple</mix:type>
  <mix:concept>EngMath#Currency</mix:concept>
  <rep:value>
      <xsd:string rdf:value="Euro"/>
  </rep:value>
</owl:Thing>
```

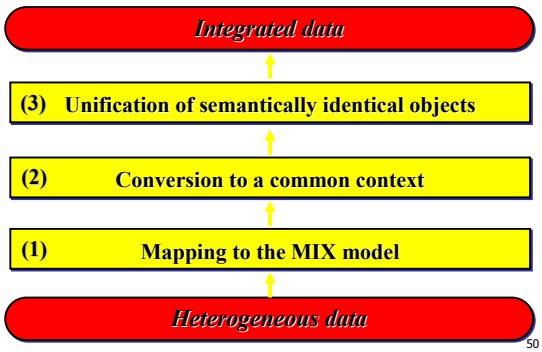

Current API

- Generic objects abstract from its representation
- Access and manipulation through a clean interface
- Store and load by using the repository
- Serialization and desearialization using factories

Current Implementation



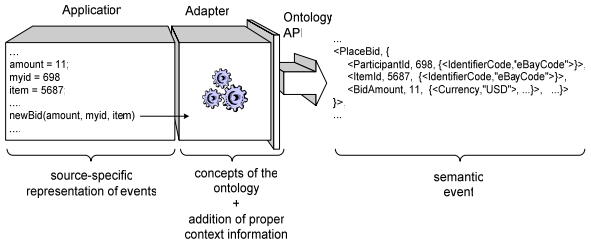
Data Integration based on MIX



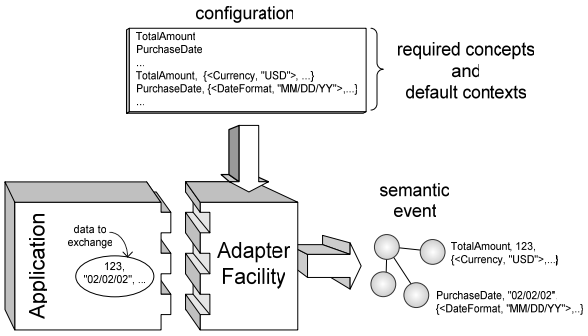
Ontology-based Infrastructure

- In loosely-coupled (component-based) systems interfaces should consider the issues related with data interpretation
  - Specification of arguments must allow the inclusion of metadata in order to correctly interpret them
    - Calculate(<Price, 21000, {<Currency, "EUR">}>)
  - Arguments can be converted to the target context before using them

Adapters / Wrappers



Adapters / Wrappers (cont.)

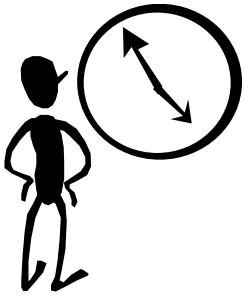


Sem. Data Exchange - Summary

- Common interpretation basis for data
- Implicit modeling assumptions have to be made explicit
- Business-to-Business-to-Consumer:
  - need to extract, prepare and consolidate data for further electronic processing

Sem. Data Exchange – Summary (2)

- MIX:
  - allows to make explicit data semantics by using ontologies and metadata
  - supports integration, and automatic processing of Internet data
  - representation of data plus additional semantic metadata
  - flexible, self-describing data model for the representation of semi-structured data
  - conversion functions



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