Coordination in Open and Dynamic Environments with TuCSoN Semantic Tuple Centres

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Outline

Engineering Today's Software Systems

- Today's software systems like pervasive systems, internet applications, and Web-service-based systems, are mainly characterised by two main features:
  - distribution (of control, spatial, and temporal)
  - openness—dynamism and heterogeneity
- Linda tuple-space model as basic coordination abstraction [Gelernter, 1985].
  - Tuple space as a coordination medium.
  - Communication based on tuples, templates, and a tuple matching mechanism.
  - Operations out, in, and rd as coordination language.

Towards Semantic Tuple Spaces

- Current research trends in the area of coordination middleware propose semantic tuple space computing which enriches tuple spaces semantically to cope with heterogeneity of the structure of the exchanged tuples [Nixon et al., 2008].
- Semantic description of information – tuple content – through an ontology language.
- Logical reasoning over such descriptions to support information matching—matching between tuples and tuple templates

Outline

Aim

- Take tuple centre [Omicini and Denti, 2001b] as a coordination model since it provides programmable tuple spaces.
- Differently from the current appoaches [Nixon et al., 2008], to enrich the tuple centre model semantically maintaining the model identity without any assumption about the application domain.
- Implement semantic tuple centres in TuCSoN [Omicini and Zambonelli, 1999]—a coordination infrastructure providing tuple centres distributed over the network.

Semantic Tuple Centre Model

- Domain ontology allowing to interpret the semantics associated to the knowledge (set of tuples) stored into a tuple centre.
- Domain objects – represented by tuples – described so that they can be interpreted in a semantic way, by means of the domain ontology.
- Semantic tuple templates as descriptions of a domain object set.
- Semantic tuple matching mechanism providing the domain objects – tuples – described through templates.

Ontologies and Individuals in Tuple Centres

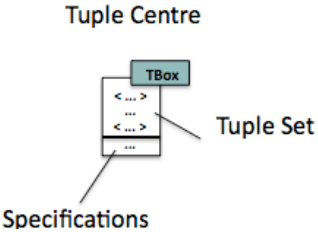
- SHOIN(D) Description Logic formalism [Baader et al., 2003, Horrocks et al., 2003] to describe domain ontologies and objects.
  - Good compromise between expressiveness and complexity.
  - Theoretical counterpart of OWL DL, that is one of the three species of W3C OWL. OWL being a standard, it well fits the openness requirement.

Domain Ontology I

- Described in the form of a terminology through a so called TBox—a set of concept and role descriptions.
- Through a set of constructors described in [Horrocks et al., 2003] (Union $C \sqcap D$, Intersection $C \sqcup D$, Negation $\neg C$, Exists $\exists R.C$, etc.).
- Through the operators $\sqsubseteq$ (Inclusion) and $\equiv$ (Equality), in order to define a taxonomy of concepts or roles.

Domain Ontology II

- Each tuple centre is associated to a specific TBox describing the semantics of stored information, i.e. of tuples.
- For the TBox definition in tuple centres an OWL-DL ontology document [Horrocks et al., 2003].

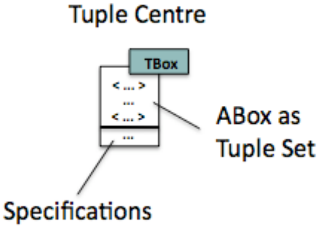


Domain Individuals I

- Described through a so called ABox—a set of assertions about the individuals and roles, in terms of the terminology defined through the TBox.
- ABox defines two kinds of assertion: $C(a)$ and $R(b,c)$.

Domain Individuals II

- Each tuple stored in a tuple centre is described as an ABox individual specifying the following information:
  - name of the individual we want to describe
  - concept to which the individual belongs
  - set of roles in which the individual is involved



Domain Individuals III

- A possible SHOIN(D)-like description language for semantic tuples:

Individual ::= Iname : Descr

Descr ::= Cname | Cname (F)

F ::= Pname : V | Pname in (Vset) | F , F

Vset ::= V | V , Vset

V ::= Iname | N | S

Cname ::= <atom , in Prolog style >

Iname ::= <atom , in Prolog style >

Pname ::= <atom , in Prolog style >

N ::= <number >

S ::= <atom , in Prolog style >

- We can obtain the following semantic tuple:

f550 : 'Car' (hasMaker : ferrari, hasMaxSpeed : 285, hasColour in (red, black))

Semantic Tuple Templates I

- Tuple templates become specifications of set of domain individuals described by the domain ontology.
  - $\Rightarrow$ A tuple template becomes a description, in TBox formalism, of the set of individuals one is interested in.
- In order to describe a tuple template in a semantic way, we need a SHOIN(D)-like description language to express a tuple template as a description in the TBox formalism.

Semantic Tuple Templates II

- A possible SHOIN(D)-like description language for semantic tuple templates:

```
C ::= all | none | Cname | C , C | C ; C |
      not C | R | { Iset } | Cname ( R ) |
      ( C )

R ::= F | exists F | only F | M

F ::= P in C | P : Iname | P : D

M ::= # Msymb PosInt : P

D ::= Msymb N | = S

P ::= Pname | Pname / Binding

Msymb ::= > | < | >= | <= | =

Iset ::= Iname | Iname , Iset

Cname ::= <atom , in Prolog style >

Iname ::= <atom , in Prolog style >

Pname ::= <atom , in Prolog style >

Binding ::= <variable , in Prolog style >

N ::= <number >

PosInt ::= <positive integer number >
```

```
'Car' ; 'Vehicle'(hasMaker in (hasCountry :  italy),
            hasPrice < 15000)
```

Semantic Tuple Matching Mechanism

- Semantic matching mechanism amounts to look for the individuals (in the ABox) which are instances of the given concept, namely, which tuples match the semantic template.
- Description Logic reasoners can be used to perform this kind of reasoning.

Semantic Tuple Centre Primitives

- In a semantic view, tuple centre primitives (in, rd, and out) represent the language whereby system components can read, consume, and write knowledge described by means of a domain ontology.
- Each primitive can fail in case of non-consistency with the TBox.

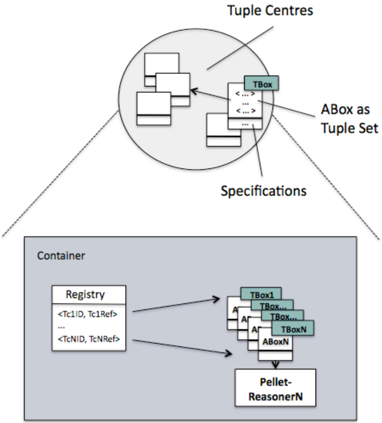
⇒ Differently from the original tuple centre semantic, the out can fail in case the related tuple is not consistent with the domain ontology.

Extending TuCSoN I

- Tuple centres are provided in each TuCSoN node by a container.
- The container represents the manager of the tuple centre life-cycle and provides the API to create, access, and use them.

⇒ The container has to provide the API to:

  - create a tuple centre associated with a specified TBox and a reasoner
  - set and obtain the TBox related to a particular tuple centre



Extending TuCSoN II

- We adopted the Pellet OWL reasoner [Sirin et al., 2007] because:
  - it is easy to integrate it with TuCSoN since it is open-source and it is written in java
  - it is a complete OWL-DL reasoner with good performance
  - it is based on the expressive SPARQL query language
- When the container creates a new tuple centre:
  - by exploiting the Pellet API, a new instance of the ontology is created from a specified OWL file and provided to the tuple centre
  - a new instance of the Pellet reasoner is created and provided to the tuple centre

Extending TuCSoN III

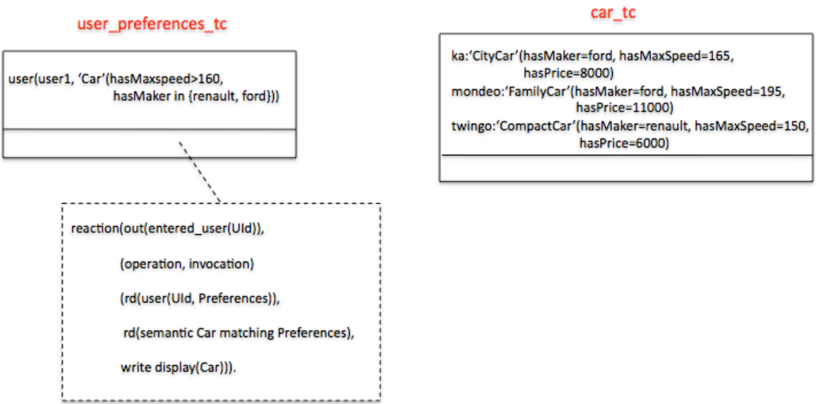
- In face of an out primitive:
  - the individual expressed by the received semantic tuple is interpreted
  - by exploiting the Pellet reasoner, the individual consistency with the ontology is checked
  - the individual is inserted in the ABox
- In face of a in or rd primitive:
  - the concept specification expressed by the received semantic tuple template is interpreted
  - by exploiting the Pellet reasoner the concept specification is checked against the ontology
  - the concept specification is interpreted and converted in SPARQL query
  - the first individual obtained by the reasoner is converted in a tuple
  - the obtained individual is unified with the tuple template

Extending TuCSoN IV

- Besides semantic tuples, tuple templates, and tuple matching mechanism, in a semantic tuple centre it is useful to preserve the possibility of using standard syntactic tuples and templates

  ⇒ No semantic tuples, tuple templates, and tuple matching mechanism are useful to realise coordination mechanisms in tuple centres.

Simple Example



- When an operation like `out(entered_user(user1))` is executed on the user_preferences_tc tuple centre, for example the command `write_display(ka:'Car'(hasMaker=ford, hasMaxSpeed=165, hasPrice=8000))` is executed.

Outline

Conclusions

- Semantic tuple centres was implemented in TuCSoN; a prototype was realised as an open source branch of TuCSoN in http://tucson.svn.sourceforge.net/viewvc/tucson/branches/.
- Future work:
  - Study the semantic tuple centre performance.
  - Test the semantic tuple centre model in pervasive computing applications.
  - Extend the semantic tuple centre model in order to support a fuzzy semantic matching.

Outline

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