A Framework for Semantic Discovery on the Web of Things

Victor Charpenay, Sebastian Käbisch, Harald Kosch
SSN 2018, Monterey, September 2018
def overflow = GET coap://example.org/wt/o
if (overflow)
then PUT coap://example.org/v/s 0x01
Related Work

**SSN**

**eCl@ssOWL**

(and other domain models)

**Thing Description**
### Related Work

<table>
<thead>
<tr>
<th>Web linking</th>
<th>CRUD management</th>
<th>RDF data model</th>
<th>Compact messages</th>
<th>Vocabulary integration</th>
</tr>
</thead>
<tbody>
<tr>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td></td>
<td></td>
</tr>
<tr>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td></td>
<td>✓</td>
</tr>
<tr>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
</tbody>
</table>
Preliminaries

Description Logic (DL)
A DL knowledge base $\mathbf{KB}$ is a set of $\text{subClassOf}$ and $\text{subPropertyOf}$ axioms between DL concept expressions like $C$, $\{a\}$, $(r \text{ some } C)$, $(s \text{ only } D)$. $C, D$ are concept names, $a$ is a named individual and $r, s$ are role names.

Boolean conjunctive query (BCQ)
A BCQ $Q$ is a conjunction of DL axioms with variables. A solution to $Q$ against $\mathbf{KB}$ is a set of axioms $S$ s.t. for every axiom $\alpha$ in $S$, $\mathbf{KB} \models \alpha$ and there exists a mapping $\mu$ from variables to concept, role or individual names in $\mathbf{KB}$. We also denote $S$ as $\mu(Q)$. 
Preliminaries

Query Abduction
Let $\mathbf{KB}$ be a knowledge base and $\mathbf{Q}$ a BCQ. Abduction is the problem of finding a knowledge base $\mathbf{KB}'$ s.t. there exists a mapping $\mu$ where, $\mathbf{KB} \cup \mathbf{KB}' \models \alpha$ but $\mathbf{KB} \not\models \alpha$, for every $\alpha$ in $\mu(\mathbf{Q})$.

Integrity constraint
Let $\mathbf{Q}, \mathbf{Q}'$ be BCQs. An integrity constraint for an abduction problem is a rule $\mathbf{Q} \rightarrow \mathbf{Q}'$, which is said to be met if, for every solution $\mu(\mathbf{Q})$ against $\mathbf{KB} \cup \mathbf{KB}'$, $\mathbf{KB} \cup \mathbf{KB}' \models \alpha'$ ($\alpha'$ in $\mu(\mathbf{Q})$).
Semantic Discovery Framework

Semantic Discovery for the Web of Things

Let $A_1, A_2, \ldots, A_n$ be (ABox) Thing Descriptions and $C$ be an arbitrary set of DL (CBox) axioms. WoT semantic discovery is the abduction problem where

\[ KB = A_1 \cup A_2 \cup \ldots \cup A_n \cup C, \]

\[ Q = \{ ?a \} \text{ subClassOf System and} \]

\[ \text{only ABox axioms are abducible} \]

\[ \text{against a set of integrity constraints } IC. \]
Example

Valve Control subClassOf
(hasSubSystem some Valve) and
(hasSubSystem some Overflow sensor)

C
SSN, eCl@ssOWL

A1
Thing Description

A2
Thing Description

KB'(discovery result)
An Abductive Logic Programming Approach (I)

Restricted to the DL family $\text{EL}^{++}$ (OWL EL):

- Classification in polynomial time by constructing two mappings $S, R$ s.t.:
  - if $D$ in $S(C)$, then $\text{KB} \models C \sqsubseteq \text{subClassOf} \ D$
  - if $(C, D)$ in $R(r)$, then $\text{KB} \models C \sqsubseteq \text{subClassOf} \ (r \text{ some } D)$

- Possible formulation in terms of logic programming
  - By defining an embedding $\tau$ to turn DL axioms into FOL
  - Abduction based on the Abductive Logic Programming (ALP) framework
Experiments
## Experiments

<table>
<thead>
<tr>
<th>System type</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Valve control</td>
<td>An open/close or proportional valve is coupled to a water level sensor to avoid overflow. When water level in a tank goes above a certain threshold, the valve opens.</td>
</tr>
<tr>
<td>Pump control</td>
<td>A water pump is coupled to a water level sensor to refill a tank when necessary. When water level in a tank goes below a certain threshold, the pump starts.</td>
</tr>
<tr>
<td>Heater control</td>
<td>A temperature sensor is coupled to a heater to maintain water at a stable temperature by turning on and off heating (thermostat).</td>
</tr>
<tr>
<td>Circuit anomaly detection</td>
<td>A flow meter and a valve are synchronously monitored to detect potential anomaly in a circuit, e.g. when the measured flow is not null but the valve is closed.</td>
</tr>
<tr>
<td>Water circulation</td>
<td>A pump and a valve are synchronously activated to keep water flowing in a closed loop, e.g. for cleaning purposes.</td>
</tr>
</tbody>
</table>
**Experiments**

Size of $A_i$ for every device $i$

Size of $E_i$ for every device $i$
An Abductive Logic Programming Approach (II)

A knowledge base $KB$ with fresh named entities can also be interpreted as a BCQ, which we then denote $Q_{KB}$.

**Theorem**

If $KB'$ is a solution to an abduction problem over $A_1 \cup A_2 \cup \ldots \cup A_n \cup C$, then there exists $KB^*$, solution over $C$ only s.t. $KB' = \mu(Q_{KB^*})$.

SPARQL optimization techniques can then be leveraged:
1. Run ALP on $C$ only;
2. Turn every intermediary solution $KB^*$ into a SPARQL query $Q_{KB^*}$;
3. Find every mapping $\mu$ for $Q_{KB^*}$ and construct $KB'$ as $\mu(Q_{KB^*})$. 
Experiments

LSTW abduction benchmark (derived from LUBM)
Conclusion

- Reasoning on top of WoT discovery platforms
- Supports the vision of WoT as a large-scale multi-agent system for automation applications
- Addresses scalability too
- Issue: sharing of system specifications (OWL)
Contact

Victor Charpenay
PhD Candidate
Corporate Technology / Germany / CT RDA IOT EWT-DE
Otto-Hahn-Ring 6
81739 Munich
Phone: +49 89 636-631529
E-mail: victor.charpenay@siemens.com