Automated Alignment of Data Models in Energy Informatics
Ilona-Dewi Kusardi
Motivation

- Different data models for management systems
- Interoperability needs to be ensured
- Currently mapping are carried out manually
- Propose methodology to automate Signal Mapping
Agenda

- International Electrotechnical Commission Data Models
  - IEC 61850
  - IEC Common Information Model
- Problem of Model Alignment
- Proposed Methodology
  - Generate Ontologies
  - Ontology Matching System
  - Processing Alignments
- Experimental Results
- Summary
- Conclusion
- References
International Electrotechnical Commission

- International Electrotechnical Commission (IEC)
  - international standards organization
  - publishes International Standards in the area of electrotechnology
  - IEC 61850
  - IEC Common Information Model

- IEC Technical Committee (IEC TC)
  - Develops and maintains international standards
  - IEC TC 57: Power systems management and associated information exchange
IEC 61850

- Communication Networks and Systems for Power Utility Automation
- Developed to standardize substation automation
- Extended to standardize the communication between power system devices
- Two data models: LN model and SCL model
IEC 61850 - LN Model

- Semantics of run-time signals between logical devices
- Described in text tables

Concept:
- Physical device represents physical IEDs
- Logical Devices (LD) virtually represent IEDs
- Logical Node (LN) represent specific function in LD
- Data Objects (DO) represent groups of attributes included in LN
- Data Attributes (DA) are endpoints of LN model

http://slideplayer.com/slide/10674295/
IEC 61850 - LN Model

- Path: Physical Device LD / LN.DO.DA

<table>
<thead>
<tr>
<th>Physical Device</th>
<th>Logical Device</th>
<th>Logical Node</th>
<th>Data Object</th>
<th>Data Attribute</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>prefix</td>
<td>LN class</td>
<td>suffix</td>
</tr>
</tbody>
</table>

- Example
  - Physical Device = C1
  - Breaker prefix = QA1
  - modelling breaker = XCBR
  - Suffix = 1

C1IED1/QA1XCBR1.Pos.stVal

http://slideplayer.com/slide/10674295/
IEC 61850 - SCL Model

- Substation Configuration Language (SCL)
  - Defines concept for configuring automation systems and includes concept to represent LN signals allocated in IEDs

- XML Schema Definition Language (XSD)

```xml
<Header id="None" nameStructure="IEDName">...</Header>
<Substation name="S12">
  <PowerTransformer xmlns:xsi="http://www.iec.ch/61850/2003/SCLcoordinates" type="PTR" xsi:x="339" xsi:y="180">
  ...
  <VoltageLevel xmlns:xsi="http://www.iec.ch/61850/2003/SCLcoordinates" xsi:x="150" xsi:y="44" name="D1">...
  <VoltageLevel xmlns:xsi="http://www.iec.ch/61850/2003/SCLcoordinates" xsi:x="148" xsi:y="266" name="E1">...
</Substation>
<Communication>...
</Communication>
<IED name="D1Q1SB1">
  <Services>...
  <AccessPoint name="S1">...
</AccessPoint>
</IED>
<IED name="D1Q1SB4">...
</IED>
<IED name="E1Q2SB1">...
</IED>
<IED name="E1Q1SB1">...
</IED>
<IED name="E1Q3SB1">...
</IED>
<IED name="A1KA1">...
</IED>
<DataTypeTemplates>...
</DataTypeTemplates>
```

https://www.iit.comillas.edu/santodomingo/
IEC Common Information Model

- Common Information Model: “One of the core standards of the future Smart Grid” [UST+12]

- Defined within three IEC Standards
  - IEC 61970 Application integration at electric utilities – Energy management system application program interface (EMS-API)
  - IEC 61968 Application integration at electric utilities – System interfaces for distribution management
  - IEC 62325 Standards related to energy market models & communications
IEC Common Information Model

- Unified Modelling Language (UML)
  
  *cim:*Descrete and *cim:*Analog represent measurements,
  *cim:*Measurement.measurementType represents type

```xml
<!--BAY D1Q1-->
<cim:Bay rdf:ID="D1Q1">
  <cim:IdentifiedObject.name>Q1</cim:IdentifiedObject.name>
  <cim:Bay.VoltageLevel rdf:resource="#D1"/>
</cim:Bay>
<cim:Breaker rdf:ID="D1Q1QA">
  <cim:IdentifiedObject.name>QA</cim:IdentifiedObject.name>
  <cim:Equipment.EquipmentContainer rdf:resource="#D1Q1"/>
  <cim:Switch.normalOpen rdf:datatype="&xsd:boolean">false</cim:Switch.normalOpen>
</cim:Breaker>
<cim:Terminal rdf:ID="D1Q1AT1">
  <cim:IdentifiedObject.name>D1Q1AT1</cim:IdentifiedObject.name>
  <cim:Terminal.sequenceNumber rdf:datatype="&xsd;integer">1</cim:Terminal.sequenceNumber>
  <cim:Terminal.ConductingEquipment rdf:resource="#D1Q1QA"/>
  <cim:Terminal.ConnectivityNode rdf:resource="#D1Q1L1"/>
</cim:Terminal>
```

https://www.iit.comillas.edu/santodomingo/
Problem of Model Alignment

- CIM and SCL developed by groups of IEC TC 57
- Both have ability to exchange configuration information
- CIM based on UML; no limit modelling equipment
- SCL hierarchical described in XSD; limited on exchange of substation equipment related data
Problem of Model Alignment

For example:
Physical device C1
Logical device IED1

In SCL file:
C1IED1/QA1CSWI1.Pos.stVal

In CIM file:
cim:DiscreteValue.value
Can lead to many different values

[San13]
Proposed Methodology: Definitions

Ontology

„An ontology is an explicit specification of a conceptualization“ [Gru93]

Ontology Matching

„Ontology matching is the process of automatically finding the relationship between the elements [...] of two or more formal ontologies.“ [Hus12]

Jena Rule Language

Language for representing transformation rules
Proposed Methodology

3 steps to automate the mapping of LN Signals and CIM Measurements:

1. Generating Ontologies from standard data models

2. Creating alignment between these ontologies

3. Processing alignments to get signal mappings
Generating Ontologies

SCL OWL with xsd2owl

CIM OWL with uml2owl

Simplified LN OWL:
- \textit{ln:Signal61850}
  - \textit{ln:path} and \textit{ln:value}
- \textit{ln:DataTypeMapping}
  - \textit{ln:Equivalence}, \textit{ln:DataConversion} and \textit{ln:ComplexMapping}
Ontology Matching

CIMMappingBench
schema-based system combining different matching methods

SCL-CIM Alignment
translating files between SCL and CIM

SCL-LN Alignment
get the in:Signal61850 instances

LN-CIM Alignment
get the Data Type Conversion

Domain Ontologies
Ontology Matching System
Ontology Editor
 Alignments SCL-CIM, SCL-LN, LN-CIM
Excursus: Electropedia

- Online version of International Electrothechnical Vocabulary (IEV)

- Global unification of terminologies

<table>
<thead>
<tr>
<th></th>
<th>en</th>
<th>fr</th>
<th>ar</th>
<th>de</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>circuit-breaker</td>
<td>disjoncteur, m</td>
<td>قاطع دارة</td>
<td>Leistungsschalter, m</td>
</tr>
<tr>
<td></td>
<td>mechanical switching device, capable of</td>
<td>appareil mécanique de connexion capable</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>making, carrying and breaking currents</td>
<td>d'établir, de supporter et d'interrompre</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>under normal circuit conditions and</td>
<td>des courants dans les conditions</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>also making, carrying for a specified</td>
<td>normales du circuit, ainsi que d'établir,</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>duration and breaking currents under</td>
<td>de supporter pendant une durée</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>specified abnormal circuit conditions</td>
<td>spécifiée et d'interrompre des courants</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>such as those of short circuit</td>
<td>dans des conditions anormales</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>spécifiées du circuit</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>telles que celles du court-circuit</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

[www.electropedia.com]
Processing Alignments

Processing Alignments to get signal mappings

Proposed methodology to automatically create signal mapping from 3 alignments and SCL and CIM files
Processing Alignments

Electronical System Ontologies Data Translator (ESODAT)

- Put in SCL-CIM Alignment
- Put in SCL File
- Translates SCL File into CIM

[San13]
Processing Alignments

Topology Matcher:
- Creates graphs from SCL-to-CIM translation and CIM File
- Uses graph-based method
  - Descendant’s Similarity Inheritance (DSI)
  - Siblings’ Similarity Contribution (SSC)
Excursus: Descendant’s Similarity Inheritance

\[
\sigma - g(n1, n2) \\
= MCP \cdot \sigma - l(n1, n2) + \frac{2 \cdot (1 - MCP)}{m \cdot (m + 1)} \cdot \sum_{i=1}^{m} (m + 1 - i) \cdot \sigma \\
- l(parenti(n1), parenti(n2))
\]

\(\sigma - g(n1, n2)\) = global similarity
\(\sigma - l(n1, n2)\) = local similarity

Main Contribution percentage (MCP)  
MCP = 0.75

\(path\_len\_root(n)\) = number of arcs between a node \(n\) and it’s root
\(m=\) minimum value from \(path\_len\_root(n1)\) and \(th\_len\_root(n2)\)

\(parenti(n) = i\text{-th parent node of a node } n\)

\[
\sigma - g(E1, E2) \\
= 0.75 \cdot \sigma - l(E1, E2) + 0.167 \cdot \sigma - l(B1, B2) + 0.083 \cdot \sigma - l(A1, A2)
\]

\[\text{San13_1}\]
Excursus: Sibling’s Similarity Contribution

\[
\sigma - g(n_1, n_2) \\
= MCP * \sigma - l(n_1, n_2) + \frac{1 - MCP}{m_1} \\
\times \sum_{i=1}^{m_1} \max(\sigma - l(S_i(n_1), S_i(n_2)), \ldots, (\sigma - l(S_i(n_1), S_{m_2}(n_2)))
\]

\(\sigma - g(n_1, n_2)\) = global similarity
\(\sigma - l(n_1, n_2)\) = local similarity
Main Contribution percentage (MCP)
MCP = 0.75
\(S_i(n_1)\) = i-th sibling of \(n_1\)
\(m_1\) = number of siblings of node \(n_1\)
Processing Alignments

Topology Matcher:
- Graph-based method: Descendant’s Similarity Inheritance (DSI) and Siblings’ Similarity Contribution (SSC)
- Get matrix with similarities
- Mapping Algorithm: Maximum Weight Bipartite Graph
Excursus: Maximum Weight Bipartite Graph

- Get column minimum
- Subtract it from every element of that column
- At least one 0 in every column
- Get row minimum
- Subtract it from every element of that row
- Get combination, so that there is exactly one 0 in every row and column
Processing Alignments

Jena Reasoner

Signal Matcher: Compares the two CIM Measurement from SCL file and CIM file

Signal Mapping Extraction
Processing Alignments

Excel:
Signal Mapping has to be carried out manually

Jena Rule Language:
Jena Reasoner could carry out bi-directional translations between LN signals and CIM measurements
### Experimental Results

Comparison between mappings from implementation and reference mappings

Recall = ratio of correct mappings to reference mappings  
Precision = ratio of correct mappings to total mappings from implementation  
Accuracy = Recall*(2 - 1/Precision)

<table>
<thead>
<tr>
<th></th>
<th>Recall</th>
<th>Precision</th>
<th>Accuracy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Radial</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Type_1</td>
<td>0.628</td>
<td>0.700</td>
<td>0.359</td>
</tr>
<tr>
<td>Type_2</td>
<td>0.604</td>
<td>0.577</td>
<td>0.161</td>
</tr>
<tr>
<td>Type_3</td>
<td>0.693</td>
<td>0.700</td>
<td>0.396</td>
</tr>
<tr>
<td>Average</td>
<td>0.731</td>
<td>0.744</td>
<td>0.479</td>
</tr>
</tbody>
</table>

Values: [San13_2]
Summary

- Generating Ontologies
- Creating Alignments by using CIMMappingBench
- Obtaining Signal Mappings from SCL and CIM Files by processing the Alignments

[San13]
Conclusion

- Interoperability of the different systems need to be ensured
- Reduces integration effort
- No manual mapping needed anymore
References


[San13_1] Santodomingo, Rafael. „Using Semantic Web Resources to achieve metadata interoperability in the scope of future smart grids“. April 2013


References

[CS08] Sunna/Cruz. „Structure-based Methods to Enhance Geospatial Ontology Alignment“.
[San13_2] Santodomingo, Rafael. „Ontologies, Alignments and Configuration Files for Evaluation“. 2013.
Combining different matching methods:

- linguistic-based method
- language-based method
- string-based method
- constraint-based method

[San13_1]
# AgreementMaker

“one of the best generic ontology matchers” - Ontology Alignment Evaluation Initiative (OAEI)

## Type_1-Type_3

Defines by a Spanish electricity company

<table>
<thead>
<tr>
<th>Recall</th>
<th>CIMMappingBench</th>
<th>Agreement Maker</th>
</tr>
</thead>
<tbody>
<tr>
<td>Simple</td>
<td>0.893</td>
<td>0.385</td>
</tr>
<tr>
<td>Radial</td>
<td>0.589</td>
<td>0.222</td>
</tr>
<tr>
<td>Type_1</td>
<td>0.492</td>
<td>0.203</td>
</tr>
<tr>
<td>Type_2</td>
<td>0.59</td>
<td>0.203</td>
</tr>
<tr>
<td>Type_3</td>
<td>0.639</td>
<td>0.203</td>
</tr>
<tr>
<td>Average</td>
<td>0.641</td>
<td>0.243</td>
</tr>
</tbody>
</table>

[Values:San13]