Functional Metadata Scheme for Engineering Knowledge Management

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Needs: Design Knowledge Management

- Recent situation of engineering
  - Rapid changes of technology
  - Life-long learning
  - Global collaboration

- Needs: Knowledge management
  - Sharing of knowledge among engineers
    - To share knowledge across countries, product life-cycle phases, engineering domains, company divisions, etc…
  - IT-based support for knowledge management
    - It boosts the daily design/production/maintenance activity.
    - e.g., CAD/CAE, Product Data Management (PDM), Product Life-cycle Management (PLM), Collaborative Product Commerce (CPC), Computer-supported Collaborative Work/Design (CSCW), Document management systems (search engines)
Current problems

- Typical situations in industry
  - Most of the know-how is hidden in engineer’s head.
  - Most of the technical reports are written in jargons of each domain
  - It is hard to retrieve related documents by keyword search. Thus, most of them are sleeping in DBs.

- Q: Is “to weld” a function as keyword?

  - Feature of “how to achieve”
    - “To weld” pieces of metal
    - The pieces are joined
    - Metal parts are fused

  - Commonality

Needs and current state of the art

- Reasons of the lack of interoperability of documents
  - Lack of “concepts” of function for relationship
    - Common vocabulary for sharing functional knowledge in a community
      - Not just vocabulary level but conceptual level
      - Conceptual schema to capture the target world from the functional viewpoint
  - Clear relationship of function with task-oriented concepts
    - e.g., failure mode and negation of function
      - Ontology of function
  - Research on functional representation and design
    - Functional Representation [Gero 90, Chandrasekaran 93, Lind 94, Umeda 96, Chittaro 98], Engineering Design [Pahl & Beitz 88, Hubka 98], Value Engineering [Miles 61], NIST’s functional basis [Hirtz 02]
    - Difficulties in capturing functions still remain.
Our Approach

- Engineering Knowledge Management based on Functional Ontologies
  - Ontology as meta-knowledge to capture functionality of artifacts
- Knowledge model approach
  - Explicit knowledge extraction from documents/engineers
  - Sharing of generic knowledge in DBs
  - Successful deployment in a manufacturing company
- Document-centric approach (ongoing research)
  - Meta-data annotation for documents in Semantic Web
  - From heavy-weight knowledge to light-weight knowledge authoring
  - Share of different knowledge forms using functional metadata
  - Transformation of rich knowledge contents
Ontology-based Functional model & Knowledge

Introduction of “way”
- Way of function achievement
  - The background knowledge of functional decomposition such as physical principles as the basis of achievement
  - Such knowledge is implicit in conventional knowledge [Paul and Beitz 88]
  - Similar to “means” [Malmqvist 97, Bracewell & Wallace 2001].
- Effect
  - To detach “how to achieve” (way) from “what is achieved” (function)
  - This increases generality and capability to cover wider range of ways

Conventional functional decomposition
A functional concept ontology

- About 230 generic functions for engineering devices
  - Operational definitions with behaviors
  - More comprehensive than NIST’s functional basis [Hirtz 02]

Heat exchange between two different medium flows (behavior) plus teleological focus on the medium releasing heat and no necessity of heat (two functional toppings)

Implementation using HOZO

Functional concepts (ontology)

Definition of concept

Description of generic ways (knowledge)
Ontology-based modeling framework

- Functional concept ontology
- Ontology of function and device
- Ad hoc trees of ways (specific to viewpoint)
- Ontology of function and device
- Is-a relationships among functions with ways
- Guide-lines
- Target artifact
- Modeling step

(a) Function decomposition tree
(b) General function decomposition tree
(c) The generic ways of function achievement

Knowledge sharing software SOFAST®

- Sharing functional models over network
- Traditional server-client system
Deployment in a manufacturing company

- **Target**: production systems of semiconductor ingots etc
  - Sumitomo Electric Industries Ltd., Japan since December 2001.
- **A knowledge sharing software SOFAST ®**
  - Used by other 13 companies.
- **Successful effects in various engineering tasks**

<table>
<thead>
<tr>
<th>Problem solved</th>
<th>Effect in daily activities</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Resolution of problems with poor quality</td>
<td>* Resolved by the same engineer in 3 (2) weeks. Left unsolved for 5 (4) months. (Another case)</td>
</tr>
<tr>
<td>2. Fast and efficient design review</td>
<td>* 3 times =&gt; once</td>
</tr>
<tr>
<td>3. Speeded up patent writing</td>
<td>* 3 - 4 weeks =&gt; 1 week</td>
</tr>
<tr>
<td>4. Extension of claim items in patents</td>
<td>* 3 items =&gt; 7 items on average</td>
</tr>
<tr>
<td>5. Fault diagnosis</td>
<td>* Resolved in 5 days. Left unsolved for 3 months</td>
</tr>
<tr>
<td>6. Fast development of new machines by novices</td>
<td>* System development within 3 days by a novice reusing KB. The job usually needs 2 weeks by an expert</td>
</tr>
<tr>
<td>7. Improvements of machines</td>
<td>* Many examples</td>
</tr>
</tbody>
</table>

Document-Centric Approach
**Funnotation: Ontology-based Functional Metadata Annotation**

- **Functional ontologies**
- **Separate property**
- **RDF**
- **OWL**
- **Metadata schema**
- **Web documents (HTML)**

**Funnotation framework**

- **Ontology/Schema level (OWL, classes)**
- **Meta-data level (RDF, statements)**
- **Data level (HTML documents)**

- **An Ontology of Device and Function (F-Core schema)**
- **Functional concept ontology**
- **Ontology (F-Vocab schema)**
- **Knowledge (F-Ways)**
- **Design documents about functionality**
- **Usual design documents**

- **Task-dependent forms**
  - e.g., FMEA sheets

- **Transform**

- **Ontology mapping knowledge**

- **Task-dependent ontologies**

- **FTA ontology**
- **FMEA ontology**
- **An Ontology of Device and Function (F-Core schema)**

- **Ontology/Schema level (OWL, classes)**
- **Meta-data level (RDF, statements)**

- **Design documents**
  - (structural models, behavioral models)
- **Usual design documents**

- **Task-dependent forms**
  - e.g., FMEA sheets

- **Competent**
- **Function**
- **Failure mode**
- **Cause**
- **Action**

- **Tables**:
  - **Failure modes**
  - **Failure mode**
  - **Frequency**
  - **Severity**
  - **Remedial actions**

**Graphical representation of the Funnotation framework**

- Node labels: Concepts like "function", "class", "property".
- Edge labels: Actions like "extract", "filter", "refine", "distill".
- Diagram includes elements like "instances", "Metadata", "Web documents (HTML)", and "Usual design documents".

**Key concepts**

- **Funnotation framework**: A process for functional metadata annotation using ontologies.
- **Functional concept ontology**: Classes of functional concepts.
- **Ontology/Schema level**: OWL classes.
- **Meta-data level**: RDF statements.
- **Data level**: HTML documents.
- **Task-dependent forms**: Design documents about functionality.
**Funnnotation schema** - A functional meta-data schema

- A tag set for metadata representing functionality of devices
  - Layer structure. Partial commitment.
  - Interoperability to other schemata

![Diagram of Funnnotation schema]

**F-Core schema**

![Diagram of F-Core schema]
F-Core Schema

Class

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>entity</td>
<td>Physical entity</td>
</tr>
<tr>
<td>function</td>
<td>Interpretation of behavior under a goal</td>
</tr>
<tr>
<td>way</td>
<td>Way of function achievement: conceptualization of the principle essential to the achievement of the parent (goal) function by the sub(part)-functions</td>
</tr>
</tbody>
</table>

Property

<table>
<thead>
<tr>
<th>Name</th>
<th>Domain</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>agent</td>
<td>function</td>
<td>entity</td>
</tr>
<tr>
<td>part_function</td>
<td>function</td>
<td>function</td>
</tr>
<tr>
<td>possible_way</td>
<td>function</td>
<td>way</td>
</tr>
<tr>
<td>method_function</td>
<td>way</td>
<td>function</td>
</tr>
</tbody>
</table>

Example of functional metadata

Document (adapted from http://www.fine-yasunaga.co.jp/english/home/wiresaw/index.htm)

What is Wire Saw?......A wire (a piano wire of 0.08 to 0.16mm) is wound around several hundred times along the groove of guide roller. Free abrasive grains (a mixture of grains and cutting oils) are applied to the wire while it keeps running. The abrasive grains rolled on the wire work to enable cutting of a processing object into several hundred slices at one time. It is mostly used to cut electronic materials.

Functional metadata

```xml
<funnotation:device rdf:about="http://ex.org/ex1.html#wire-saw">
  <funnotation:has_function>
    <funnotation:split_entity rdf:about="http://ex.org/ex1.html#cut">
      <funnotation:selected_way rdf:about="http://ex.org/ex1.html#grains">
        <funnotation:fricitional_way/>
      </funnotation:selected_way>
    </funnotation:split_entity>
  </funnotation:has_function>
</funnotation:device>
```

The wire-saw has a splitting function with a frictional way of achievement
Implementation using Hozo
Exported to a schema in OWL

A wire 0.08 to 0.16mm wound around free abrasive grains are applied to keep running object. Several hundred slices cut impart fine destruction.

Annotation using OntoMat
OntoMat-Annotizer http://annotation.semanticweb.org/ontomat/index.html

http://www.fine-yasunaga.co.jp/english/home/iesaw/index.htm
Bridging Heterogeneous Knowledge Forms by Ontology-based Transformation

Possible failure and preventive func.
- Function to prevent possible failures (abnormal)
  - Possible failures
    - Causative chain for malfunction and its effects
  - Function to avoid the malfunction
Knowledge transformation

- Knowledge concerning functional defects in extended functional model includes a part of knowledge described in FMEA sheet.

FMEA (Failure Mode and Effect Analysis)
- The technique widely used for prevention and detection of a failure trouble in the production systems.

Extended functional model

- Possible to transform from extended functional model to FMEA sheet semi-automatically.

<table>
<thead>
<tr>
<th>Component</th>
<th>Function</th>
<th>Failure mode</th>
<th>Cause</th>
<th>Occurrence</th>
<th>Action</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wire</td>
<td>Make frictional force</td>
<td>Snap of wire</td>
<td>frictional heat</td>
<td>Mal-function of wire-saw</td>
<td>Remove heat</td>
</tr>
<tr>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
</tbody>
</table>

Ontology alignment between the extended functional ontology and the FMEA ontology

As a result of ontology alignment, ambiguity of the concept was turned out.

For knowledge transformation, the concepts are redefined with clear relationship with the extended functional ontology.

FMEA ontology based on practical FMEA sheets

Definition of failure mode: “the manner by which a failure is observed” [MIL-STD-1629A]

Failure mode of a filter: *blocked*

Failure model of a valve: *stick*
Knowledge transformation system

(a). Extended functional ontology
(b). FMEA ontology
(c). Ontology mapping Knowledge
(d). Extended functional model
(e). FMEA sheet

Input
Output

Summary

- **Engineering Knowledge Management based on Functional Ontologies**
  - Ontology as meta-knowledge to capture functionality of artifacts
- **Knowledge model approach**
  - Explicit knowledge extraction from documents/engineers
  - Sharing of generic knowledge in DBs
  - Successful deployment in a manufacturing company
- **Document-centric approach (ongoing research)**
  - As a Semantic Web application