Practical experiences with multi-level modeling using FMML*: A hierarchy of domain-specific modeling languages in support of life-cycle assessment

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Life-Cycle Assessment (LCA) as a well-acknowledged approach for Sustainable Development (SD) of Organizations

- Standardized approach (ISO 14040 ff.) to assess potential environmental impacts (similar used for social impacts)
  - Global Warming Potential (GWP)
  - Photochemical Ozone Creation Potential (POCP)
  - Resource Depletion Potential (RDP)
  - ...

- of product systems through their life-cycle (e.g. from cradle-to-grave)

- Can be used
  - for comparative assessment → e.g. a substitution strategy
  - Discursive decision making (e.g. minimizing waste) → e.g. efficiency strategy
ISO 14040 ff. structures the discourse, but results in several challenges

- **Selected concepts proposed in ISO 14040 for LCA**

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>product</td>
<td>“collection of unit processes with elementary and product flows, performing one or more defined functions, and which models the life cycle of a product” [p. 11]</td>
</tr>
<tr>
<td>system</td>
<td>“set of criteria specifying which unit processes are part of a product system” [p. 11]</td>
</tr>
<tr>
<td>sys. boundary</td>
<td>“quantified performance of a product system for use as a reference unit” [p. 10]</td>
</tr>
<tr>
<td>impact</td>
<td>“class representing environmental issues of concern to which life cycle inventory results may be assigned” [p. 13]</td>
</tr>
<tr>
<td>category</td>
<td>“attribute or aspect of natural environment, human health, or resources, identifying an environmental issue giving cause for concern” [p. 12]</td>
</tr>
<tr>
<td>endpoint</td>
<td>“primary or secondary material that is used to produce a product” [p. 9]</td>
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</table>

- **Current challenges of ISO 14040 ff.**
  - Gernic concepts need to be refined to (i) industrial domain (ii) field of interest
    - Impact Category: Global Warming Potential vs. Child Labour
    - Category Endpoint: Forest Stand vs. Population European Dark Bee
  - Many methods that are tool supported (LCA Software)
  - Results of LCA studies
    - Results (reports) are complex
    - Not easy to communicate
    - Not easy to trace
ISO 14040 ff. structures the discourse, but results in several challenges

Selected concepts proposed in ISO 14040 for LCA

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<td>sys. boundary</td>
<td>“set of criteria specifying which unit processes are part of a product system” [p. 11]</td>
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<td>functional unit</td>
<td>“quantified performance of a product system for use as a reference unit” [p. 10]</td>
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<tr>
<td>impact category</td>
<td>“class representing environmental issues of concern to which life cycle inventory analysis results may be assigned” [p. 13]</td>
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<tr>
<td>category endpoint</td>
<td>“attribute or aspect of natural environment, human health, or resources, identifying an environmental issue giving cause for concern” [p. 12]</td>
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<tr>
<td>raw material</td>
<td>“primary or secondary material that is used to produce a product” [p. 9]</td>
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Current challenges of ISO 14040 ff.

- Gernic concepts need to be refined to (i) industrial domain (ii) field of interest
  - Impact Category: Global Warming Potential vs. Child Labour
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- Many methods that are tool supported (LCA Software)

Need for multiple perspectives on the subject ➔ suggests the use of different models and corresponding modeling languages.
Two modeling languages based on LCA with two fundamental differences based on a two-level paradigm

<table>
<thead>
<tr>
<th>Purpose</th>
<th>TracyML [BFO17]</th>
<th>ImpactML [NK17]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Social impacts (e.g. Child Labour)</td>
<td>Ecological impacts (e.g. Global Warming Pot.)</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>ISO: ProcessUnit</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="activity_diagram.png" alt="Activity diagram" /></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>ISO: Location</th>
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</thead>
<tbody>
<tr>
<td><img src="site_location_diagram.png" alt="SiteLocation diagram" /></td>
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</table>

<table>
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<tr>
<th>Range of Reuse</th>
<th>High</th>
<th>Low</th>
</tr>
</thead>
<tbody>
<tr>
<td>Productivity</td>
<td>Low</td>
<td>High</td>
</tr>
</tbody>
</table>
Challenges in a two-level paradigm

- **DSML design conflict:** support of range of reuse vs. modeling productivity

- A design of a modeling language in a two-level paradigm characterized by:
  - Workarounds
  - Overloaded levels
  - Model redundancy
  - Accidental complexity  
  
  [AK08,dLC14]
Propose a hierarchy of DSMLs that facilitates the accumulation and communication of information necessary to support the SD of organizations based on LCA.
Propose a hierarchy of DSMLs that facilitates the accumulation and communication of information necessary to support the SD of organizations based on LCA.

Expected Benefits for the LCA community:
- Reuse of knowledge on higher abstraction levels
- Enable a new generation of tools allowing users to find and refine concepts appropriate for their specific usage scenario
- Support for communication of results
An excerpt of the created multi-level model
Challenges during selection of an approach

- No common terminology → hard to compare various approaches and tools

- Reasons for using FMML\textsuperscript{x} und XModeler
  - Important subject of the research group needing further assessment and development
  - Offers a common representation of model and code

R5: Equipping models and their elements with behavior
  - Provide support for computational analysis
  - Using data from external data sources
Challenges during the initial phase of model creation

- Lack of guidance and heuristics
  - Amount of levels for the whole hierarchy
  - Assigning the concepts to the adequate classification level is challenging
  - → pragmatic approach to cope with the situation
    - Mixed top-down and bottom up approach (dominant): LCA ↔ Scenarios
    - Trial and error → bad feeling

- Lack of satisfactory tool support for the initial phase of model creation
  - No change-propagation algorithms → Frustation
  - Sheet of paper was to small
  - Switching tools (Visio; JavaScript based application)
Challenges during the initial phase of model creation

Selection of an MLM approach → Model creation → Model presentation

Recommendation

• Process models & guidelines that support language designers
  • Support for the exploratory modeling ([AKG11], e.g. suggested concepts by using classes with similar attributes)
  • Clarification of the notion of 'level'

Recommendation

• A change propagation algorithm should be available and interactive: asking the user what (s)he wants to change/ how it should be accounted for in the model
• Assign properties to usage scenarios / perspectives → generate different views
• Possibility to document the decision-making process (notes or comments)
Challenges during the phase of model creation

- dealing with classes having an invariant instantiation level through their entire lifetime.
  - FMMLx requires to keep the amount of levels within a hierarchy in balance

- Example:
Challenges during the phase of model creation

- dealing with classes having an invariant instantiation level through their entire lifetime.
  - FMML requires to keep the amount of levels within a hierarchy in balance

**Recommendation**

**Workaround**

- Selection of an MLM approach
- Model creation
- Model presentation
Challenges during the phase of model creation

- dealing with classes having an invariant instantiation level through their entire lifetime.
  - FMMLx requires to keep the amount of levels within a hierarchy in balance

**Recommendation**

- Introduction of means to build unbalanced models e.g. **leap potency** [dLG14] or **contingent instantiation levels**.
Challenges during the presentation & usage of the model

- Unsatisfactory support for the concrete syntax design in FMMLx

- Inadequate mechanisms for complexity management
  - Human cognitive capabilities are limited
    - Construction: coverage of several domains for LCA
    - Interpretation & usage: Understandability of models

- Foreseeable for LCA: Other kinds of representing the model content
  - Tables
  - Sankey Diagrams
Challenges during the presentation & usage of the model

Selection of an MLM approach → Model creation → Model presentation

Recommendation
Providing an adequate concrete syntax: adjusted / refined on each level of a hierarchy to different industries and enterprises

Recommendation
- Take *understandability* of models‘ and ’cognitive load‘ into account
  - Current work on understandability of ’traditional models‘ as a starting point.
  - A dedicated research on understandability/cognitive load of multi-level models required

- Foreseeable for LCA: Other kinds of representing the model content
  - Tables
  - Sankey Diagrams
Flow diagram: Width of the arrows proportionally to the flow quantity
Is Multi-Level Modeling appropriate for LCA?

Advantages

- Reuse of knowledge on higher abstraction levels
- Avoid 'oversimplifications' & accidental complexity
- Integration of different assessments

Challenges

- Lack of guidance and heuristics
- A lack of satisfactory support for the initial phase of model creation
- Dealing with unbalanced hierarchies and contingent classifications
- Insufficient expressiveness and problems in defining multi-level constraints
- Unsatisfactory support for concrete syntax design in FMMLx
- Inadequate mechanisms for complexity management
Limitations

■ Work presented here
  - No 'systematic assessment'
  - Mainly based on FMMLx / XModeler
  - Model proposed is based on a few scenarios only

■ Life-Cycle Assessment
  - Boundary issues & subjectivity
  - Uncertainty regarding ecological causes and effects
  - Greenwashing / 'opportunistic self-representation'
    → conceptual models might produce more opacity
  - Artificial concepts where shared attributes are not explicitly specified

Next Step:
Discuss the idea of multi-level modeling with LCA Experts in order to extend the hierarchy to address their needs to a higher extent
Literature (1)


### Overview of the scenario used for the Multi-Level model

<table>
<thead>
<tr>
<th></th>
<th>Company T</th>
<th>Company S</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Product</strong></td>
<td>T-Shirts</td>
<td>Shelves</td>
</tr>
<tr>
<td><strong>raw material</strong></td>
<td>natural fiber (avg. and sales price; recycling code)</td>
<td>wood (avg. and sales price; recycling code)</td>
</tr>
<tr>
<td><strong>endpoint</strong></td>
<td>soil of farms (location; fertility; erosion)</td>
<td>forest stands (location; grade closeness to nature; commercial forest); mines (location; downhole; expected closure; year open cut starting)</td>
</tr>
<tr>
<td><strong>impact</strong></td>
<td>resource depletion natural fiber (kind of fiber; renewal rate; consumption worldwide; stock worldw.); virtual water (volume freshwater; location consumption)</td>
<td>resource depletion wood (kind of fiber; renewal rate; consumption worldwide; stock worldw.); resource depletion metals (kind of metal; consumption worldw.; stock worldw.; sum known resources); pot. social and environmental impacts (affected stakeholder / group)</td>
</tr>
<tr>
<td><strong>Resources</strong></td>
<td>Stocks of different kinds of natural fiber, e.g. cotton, linen (global and local)</td>
<td>Stocks different kinds of wood, e.g. birch, spruce (global and local); Stocks of different kinds of metal, e.g. aluminum</td>
</tr>
<tr>
<td><strong>level of detail</strong></td>
<td>typical / average information; specific stocks of resources</td>
<td>typical / average information; specific stocks of resources; individual product dependent information for certificates demanded by customers</td>
</tr>
<tr>
<td><strong>individual quality interests</strong></td>
<td>elasticity (value in Giga Pascal [GPa]); tensile strength (value in Mega Pascal [MPa]) Code DIN 60001-1 (e.g. CO for cotton)</td>
<td>branchiness (high, average, low); durability class (1=very durable - 5=non-durable)</td>
</tr>
</tbody>
</table>
Requirements for the Multi-Level Model in support of LCA

- R1: Accounting for a hierarchy of professional terminology reflected in a hierarchy of DSMLs
- R2: Facilitating integration and avoiding redundancy
- R3: Providing support for productivity of modeling and reuse
- R4: Incorporating relevant knowledge within the language
- R5: Equipping models and their elements with behavior
- R6: Ensuring extensibility and adaptability of the hierarchy without loosing a corresponding tool support

<table>
<thead>
<tr>
<th>Req.</th>
<th>Evaluation and scenario-dependent solution</th>
</tr>
</thead>
<tbody>
<tr>
<td>R1: Hierarchy of professional terminology</td>
<td>Concepts relevant for SD, i.e. LCA can be refined to domain specific concepts (e.g., Raw Material to Natural Fiber Sheet) up to enterprise specific concepts (types of Cotton Sheet) and instances.</td>
</tr>
<tr>
<td>R2: Integration, avoiding redundancy</td>
<td>Domain-dependent attributes like recycling codes for Raw Material can be set once. Derived concepts on deeper levels are related to this information, but can be extended, as the vertical integration of Raw Material shows.</td>
</tr>
<tr>
<td>R3: Productivity and reuse</td>
<td>By offering concepts on different classification levels we support both productivity and reuse at the same time (e.g., we offer both an abstract concept Resource as well as a set of its specific types and instances ready to be used).</td>
</tr>
<tr>
<td>R4: Incorporating knowledge</td>
<td>Thanks to relaxed type-instance dichotomy we may assign state to classes, and thus, e.g., state what is the recycling code for a Plate of Wood.</td>
</tr>
<tr>
<td>R5: Equipping models with behavior</td>
<td>As in FMML^x a class is an object [12], operations can be not only specified for classes but also executed on them (e.g., calculateConsumptionWoW()).</td>
</tr>
<tr>
<td>R6: Extensibility, tool support</td>
<td>Thanks to a common representation of model and code provided by XModeler [12], a multi-level model may be extended without a need for recompilation.</td>
</tr>
</tbody>
</table>
Impact on understandability of models

**Intrinsic cognitive load**
Complexity of information that should be understood <- model-based metrics, content of the labels, characteristics of the comprehension task

**Extraneous cogn. Load**
Influenced by changes in the visual presentation (~Moody 2009)

**Germaine cogn. Load**
Actual processing of the information and the construction of mental structures that organize elements of information into patterns.

- label design (➔ extraneous cogn. load)
  - Longer labels hamper understandability
  - Comprehension accuracy is higher the more abstract labels are (no text)
- naming conventions (➔ intrinsic cogn. load)
  - syntactic like using a verb-object label style for activities
  - semantic like using a domain-specific vocabulary, avoiding homonyms...
- size measures (➔ intrinsic cogn. load)
  - Number of elements shown in a diagram
- appropriateness of redundant elements (➔ intrinsic cogn. load)

(Sweller 1988, Figl 2017)
TracyML: A Modeling Language for Social Impacts of Product Life Cycles

- Excerpt Meta Model TracyML

- Exemplary Diagram

- Excerpt Meta Model ImpactM

- Exemplary Diagram

<table>
<thead>
<tr>
<th>Substance</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Halon 1301</td>
<td>kg CBrF₃</td>
</tr>
<tr>
<td>Trichlorofluoromethane</td>
<td>kg CCl₃F</td>
</tr>
<tr>
<td>Nitrogen dioxide</td>
<td>kg NO₂</td>
</tr>
<tr>
<td>Carbon Dioxide</td>
<td>kg CO₂</td>
</tr>
</tbody>
</table>

- Ozone depletion potential (ODP): kg CCl₃F equiv.
- Depletion of stratospheric ozone layer
- Carcinogenic
- Higher UV-B radiation
- Melting of polar ice
- Global warming (GWP): kg CO₂ equiv. (310, 4000, 12)
- Increasing av. temp. of troposphere
- IPCC Report: Myhr et al.; 2013, p. 733

Kaczmarek-Heß et al. | Practical experiences with multi-level modeling using FMMLx | MULTI 2018 | Copenhagen, October 16th, 201
Constructive vs. Exploratory modeling

- **Constructive Modeling**
  - Goal: „create a complete, definite description of all the **types** in a system (...) so that instances from them can be generated at runtime.“ [AKG11, p. 3]
  - ~ prescriptive

- **Exploratory Modeling**
  - Goal: „develop types that characterize the **objects** populating a domain of interest.“ [AKG11, p. 4]
  - ~ descriptive

- **Focus:** Condition when a model is complete / valid (not purpose) [AKG11]

**Notes:**
A model can from our viewpoint never be (holistically) complete or valid.
- Complete → containing all aspects of interest (that might change over time)
- Valid → Legitimated by all persons concerned (Ramage, Ship 2009, p. 164)

This is why we follow the general idea (Christensen 2002)
Sustainable Development

Brundtland-Report

“Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs.”

→ Balance between economic, environmental and social aspects

[Br97, p. 41]

Debates about Dev. countries

Contested concept

Social SD might be related to develop Capabilities of individuals

[El02; Ha97]
Why not specialize the mine?

Because in case of the “additional” mine level

- we are not only interested in adding new features of interest that would be applicable to lower levels,
- but we also want to “instantiate” some attributes
- and be able to execute some operations there, and some of those have been defined one level above only.

→ So we cannot specialize the concept from one level above (and stay within the same level and in this way avoid being “unbalanced”) — as then we will just “inherit” the structure but not be able to assign straight values and execute operations. **In order to do the latter, indeed we needed to instantiate the concept and introduce yet additional classification level.**