Domain Specific Language for Modeling Waste Management Systems

In order to develop sustainable waste management systems with considering life cycle perspective, scientists and domain experts in environmental science require readily applicable tools for modeling and evaluating the life cycle impacts of the waste management systems. Practice has proved that modeling these systems with general-purpose tools is a cumbersome task. On one hand, the scientists have to spend considerable amount of time to understand these tools in order to develop their models. On another hand, integrated assessments are becoming gradually common in environmental management and therefore scientists are also faced with the problem of integrating models across scales and domains, which is not a straightforward process.

Domain-Specific Languages (DSLs) are languages which are specialized for a specific application domain and they promise to increase developer productivity by raising the level of abstraction. They allow domain experts, who are non-programmers, to directly encode their domain knowledge about what a system under development should do. In this thesis, we utilize domain-specific languages, on the basis of the flow-based programming (FBP) paradigm, to model and evaluate environmental technologies i.e. solid waste management systems. Flow-based programming is used to support concurrent execution of the processes, and provides a model-integration language for composing processes from homogeneous or heterogeneous domains. And a domain-specific language is used to define atomic processes and domain-specific validation rules for composite processes. We call these DSLs, which are based on FBP paradigm, domain-specific flow based languages and we provide a formal framework to develop them. To this end, we advocate aspect-oriented concepts to FBP to separate cross-cutting concerns, by providing an extension called AOFBP. Afterwards, we propose the framework based on this extension, and we use a formal language called ForSpec, which is an extension of FORMULA, to formally specify the structural and behavioral semantics of the sub-languages proposed in this framework. Finally, we propose a domain specific language for modeling of waste-management systems on the basis of our framework. We evaluate the language by providing a set of case studies. The contributions of this thesis are; addressing separation of concerns in Flow-based programming and providing the formal specification of its syntax and semantics; a formal language and framework to specify domain-specific flow based languages; design and develop domain specific languages for waste management modeling; and finally our work also can be considered as another case study for structural and behavioral semantics specifications in ForSpec and FORMULA.
An institution for object-Z with inheritance and polymorphism

Large software systems are best specified using a multi-paradigm approach. Depending on which aspects of a system one wants to model, some logic formalisms are better suited than others. The theory of institutions and (co)morphisms between institutions provides a general framework for describing logical systems and their connections. This is the foundation of multi-modelling languages allowing one to deal with heterogeneous specifications in a consistent way. To make Object-Z accessible as part of such a multi-modelling language, we define the institution OZS for Object-Z. We have chosen Object-Z in part because it is a prominent software modelling language and in part because it allows us to study the formalisation of object-oriented concepts, like object identity, object state, dynamic behaviour, polymorphic sorts and inheritance.

Capabilities for modelling of conversion processes in LCA

Life cycle assessment was traditionally used for modelling of product design and optimization. This is also seen in the conventional LCA software which is optimized for the modelling of single materials streams of a homogeneous nature that is assembled into a final product. There has therefore been little focus on the chemical composition of the functional flows, as flows in the models have mainly been tracked on a mass basis, as focus was on the function of the product and not the chemical composition of said product.

Conversely modelling environmental technologies, such as wastewater treatment and waste management, the material being addressed is of a very heterogeneous nature. Between treatment facilities receiving materials with different compositions, but also at the individual treatment facility where the temporal composition of a treated material varies considerably. To address this, EASETECH (Clavreul et al., 2014) was developed which integrates a matrix approach for the functional unit which contains the full chemical composition for different material fractions, and also the number of different material fractions present in the overall mass being handled. These chemical substances can then be traced through the different processes similar to substance flow assessment, but with the added options to address emissions and material and energy usage through each process step.
However, it was found that further capabilities were needed as in some technologies even the chemical substances themselves change through a process chain. A good example of this is bio-refinery processes where different residual biomass products are converted through different steps into the final energy product. Here it is necessary to know the stoichiometry of the different products going in, and being able to set constraints for a possible flow on basis of other flows, and also do return flows for some material streams. We have therefore developed a new editor for the EASETECH software, which allows the user to make specific process modules where the actual chemical conversion processes can be modelled and then integrated into the overall LCA model. This allows for flexible modules which automatically will adjust the material flows it is handling on basis of its chemical information, which can be set for multiple input materials at the same time. A case example of this was carried out for a bio-refinery process.

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Capabilities For Modelling Of Conversion Processes In Life Cycle Assessment
Life cycle assessment was traditionally used for modelling of product design and optimization. This is also seen in the conventional LCA software which is optimized for the modelling of single materials streams of a homogeneous nature that is assembled into a final product. There has therefore been little focus on the chemical composition of the functional flows, as flows in the models have mainly been tracked on a mass basis, as emphasis was the function of the product and not the chemical composition of said product. Conversely, in modelling of environmental technologies, such as wastewater treatment and waste management, the material being addressed is of a very heterogeneous nature. This heterogeneity is seen both between treatment facilities receiving materials with different compositions, but also at the individual treatment facility where the temporal composition of a treated material varies considerably. To address this, EASETECH (Clavreul et al., 2014) was developed which integrates a matrix approach for the reference flow which contains the full chemical composition for different material fractions, and also the number of different material fractions present in the overall mass being handled. These chemical substances can then be traced through the different processes similarly to substance flow assessment, but with the added options to address emissions, material and energy usage through each process step. However, it was found that further capabilities were needed, when considering how the biochemical parameters change through a process chain. A good example of this is bio-refinery processes where different residual biomass products are converted through different steps into the final energy product. Here it is necessary to know the stoichiometry of the different products going in, and being able to set constraints for a possible flow on basis of other flows, and also do return flows for some material streams. We have therefore developed a new editor for the EASETECH software, which allows the user to make specific process modules where the actual chemical conversion processes can be modelled and then integrated into the overall LCA model. This allows for flexible modules which automatically will adjust the material flows and the conversion takes places in processes on basis of its chemical information, which can be set for multiple input materials at the same time. A case example of this was carried out for a bio-refinery process, and the result of this case studied will be used to exemplify the use of the new process editor.

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Towards Separation of Concerns in Flow-Based Programming

Flow-Based Programming (FBP) is a programming paradigm that models software systems as a directed graph of predefined processes which run asynchronously and exchange data through input and output ports. FBP decomposes software systems into a network of processes. However, there are concerns in software systems which do not fit this dominant decomposition. In this paper, we address the cross-cutting-concerns in FBP by using some examples and propose an aspect-oriented extension to FBP.

An environmental assessment system for environmental technologies

A new model for the environmental assessment of environmental technologies, EASETECH, has been developed. The primary aim of EASETECH is to perform life-cycle assessment (LCA) of complex systems handling heterogeneous material flows. The objectives of this paper are to describe the EASETECH framework and the calculation structure. The main novelties compared to other LCA software are as follows. First, the focus is put on material flow modelling, as each flow is characterised as a mix of material fractions with different properties and flow compositions are computed as a basis for the LCA calculations. Second, the tool has been designed to allow for the easy set-up of scenarios by using a toolbox, the processes within which can handle heterogeneous material flows in different ways and have different emission calculations. Finally, tools for uncertainty analysis are provided, enabling the user to parameterise systems fully and propagate probability distributions through Monte Carlo analysis. © 2014 Elsevier Ltd.
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Design of a Domain-Specific Language for Material Flow Analysis using Microsoft DSL tools: An Experience Paper

Material Flow Analysis (MFA) is the procedure of measuring and assessing the mass flows of matter (solid waste, water, food...) and substances (carbon, phosphorus ...) within a process or a system for the period of time. In this paper we propose a Domain-Specific Language (DSL) to model MFA in a waste management modeling context. The result is that we integrate the DSL within a waste management modeling software called EASETECH and we show how the proposed DSL allows the domain experts to extend the software without involving of software developers.

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EASETECH – A LCA model for assessment of environmental technologies

EASETECH is a new model for the environmental assessment of environmental technologies developed in collaboration between DTU Environment and DTU Compute. EASETECH is based on experience gained in the field of waste management modelling over the last decade and applies the same concepts to systems with different kinds of material flows, such as sludge, wastewater, biomass for energy production and treatment of contaminated soil. The primary aim of EASETECH is to perform life cycle assessment (LCA) of complex systems handling heterogeneous material flows. The main novelties of the model compared to other LCA software are as follows. The focus is put on material flow modelling. This means that each material flow is characterized as a mix of material fractions with different properties. Flows in terms of mass and composition are computed throughout the integrated system including rejects, slags, ashes and products as a basis for the LCA calculations. These flows are handled as a matrix of waste fractions and material properties, and each fraction can be handled independently or grouped based on general similarity (e.g. PE bottle and plastic waste) in different processes. This is very important because different materials have different chemical compositions, and the optimal treatment for one material fraction might be suboptimal for another fraction. It is therefore critical that the starting point of the modelling process is a composition matrix where each material fraction is specified in terms of chemical, as well as fraction-specific parameters (e.g. water content, heating value).

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LCA of waste management systems: Development of tools for modelling and uncertainty analysis

Since the late 1990s, life cycle assessment (LCA) has been increasingly applied to waste management to quantify direct, indirect and avoided impacts from various treatment options. The construction of inventories for waste management systems differs from classical product-LCAs in that (1) these systems usually handle a heterogeneous mix of different waste fractions, (2) optimal treatments differ for these various fractions due to their chemical and physical properties and (3) emissions from final disposal places may occur over a very long time, depending on technology choice, and thus they have to be modelled rather than monitored as in classical LCA (e.g. landfilling or the application of processed waste on agricultural land). Therefore LCA-tools are needed which specifically address these issues and enable practitioners to model properly their systems. In this thesis several pieces of work are presented. First a review was carried out on all LCA studies of waste management systems published before mid-2012. This provided a global overview of the technologies and waste fractions which have attracted focus within LCA while enabling an analysis of methodological tendencies, the use of tools and databases and the application of uncertainty analysis methods.

The major outcome of this thesis was the development of a new LCA model, called EASETECH, building on the experience with previous LCA-tools, in particular the EASEWASTE model. Before the actual implementation phase, a design phase involved a thorough analysis of requirements and the implementation of a conceptual model as a computational prototype, to ensure the feasibility of the model. During the development process, focus has been primarily placed on:

• Providing a toolbox of processes to model the different transfer functions found in waste treatment technologies. These material transfer functions specify how substances in input flows are transferred to output flows and environmental compartments and include for example processes for anaerobic digestion or landfill gas generation.
• Offering a flexible user interface where the user can connect freely all processes and combine them to build new treatment technologies and eventually scenarios.
• Keeping track of waste flows, throughout entire scenarios, as matrixes of fractions and chemical and physical properties. Displaying the time dimension of flows when needed, e.g. for gas and leachate emissions from landfill.
• Offering import functions which enable the use of newly released databases and life cycle impact assessment methods.
• Providing tools for uncertainty analysis. Furthermore, as the review pointed out the lack of quantitative assessment of uncertainties in waste-LCA studies, a systematic approach was developed which includes several steps: sensitivity analysis, uncertainty propagation, uncertainty contribution analysis and combined sensitivity analysis. The result from each proposed step narrows the scope of the following step while producing a communicable outcome for decision makers. This method permits an analysis of the system at different scopes, from the largest picture with all processes and impact categories to a more detailed analysis of the reasons and probability for a shift in rankings between scenarios. To help practitioners in the screening of sources of uncertainty, a description of all uncertainties usually encountered in waste-LCAs was also provided. Finally, an insight into uncertainty representation was presented which highlighted the importance of the choice of uncertainty representation, by comparing the propagation of probability distributions and fuzzy sets in a case study. A method was suggested whereby the practitioner is invited to choose one of the two representation types for each parameter, based on the level of information available, and all parameter uncertainties are propagated jointly. The use of the new EASETECH model on two case studies has demonstrated the transparency of the model (allowing for a clear overview of all flows and data inputs), its flexibility (through the modelling of a full wastewater treatment plant) and the usefulness of the uncertainty analysis methods implemented. Further developments will focus on tools for economic analysis, an improved graphical display of results, the design of new process templates, the provision of an external editor of process templates and the development of new functionalities for the impact assessment phase.
Modelling sensitivity and uncertainty in a LCA model for waste management systems - EASETECH

In the new model, EASETECH, developed for LCA modelling of waste management systems, a general approach for sensitivity and uncertainty assessment for waste management studies has been implemented. First general contribution analysis is done through a regular interpretation of inventory and impact assessment results. Based on findings from this step, the user can carry out sensitivity analysis on numerous key parameters through the use of parameters at most input places. For every parameter the users can then specify a list of values, termed a numberlist, to represent different values for each parameter, that is then propagated throughout the model. This means that all results are obtained in the form of numberslists. In the next step, uncertainty propagation is done through the use of single probability distributions in lieu of the parameters. Uncertainty contribution analysis can next be generated based on the results of steps 1 & 2. The 4th step of combined sensitivity analysis can currently not be carried out graphically in the model, but can be performed by calculating in EASETECH for two scenarios’ results for different combinations of values for two parameters and extrapolating the results to delimitate the space of predominance of each scenario.

On the dimensions of software documents — An idea for framing the software engineering process.

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Organisations: Department of Informatics and Mathematical Modeling, Computer Science and Engineering, Software Engineering
Authors: Kindler, E. (Intern), Baumeister, H. (Intern), Haxthausen, A. E. (Intern), Kiniry, J. (Intern)
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Modelling the CoCoME with the Java/A Component Model

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Organisations: Software Engineering, Department of Informatics and Mathematical Modeling, Ludwig-Maximilians-Universität, University of Edinburgh
Authors: Knapp, A. (Ekstern), Janisch, S. (Ekstern), Hennicker, R. (Ekstern), Clark, A. (Ekstern), Gilmore, S. (Ekstern), Hacklinger, F. (Ekstern), Baumeister, H. (Intern), Wirsing, M. (Ekstern)
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UML-Based Web Engineering: An Approach Based on Standards

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Algebraic specification in CASL

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Organisations: Software Engineering, Department of Informatics and Mathematical Modeling
Authors: Baumeister, H. (Intern), Bert, D. (Ekstern)
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CASL Semantics

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**Domain Specific Languages for Waste Management Modelling**
Department of Applied Mathematics and Computer Science
Period: 15/12/2012 → 12/12/2016
Number of participants: 5
Phd Student:
Zarrin, Bahram (Intern)
Main Supervisor:
Baumeister, Hubert (Intern)
Examiner:
Kindler, Ekkart (Intern)
Mosses, Peter David (Ekstern)
Wirsing, Martin (Ekstern)

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Name of research programme: Institut stipendie (DTU) Samf.
Project: PhD

**Behavioural Modelling and Model-based Development of Protocol Software**
Department of Applied Mathematics and Computer Science
Period: 01/03/2011 → 21/11/2014
Number of participants: 6
Phd Student:
Simonsen, Kent Inge (Intern)
Supervisor:
Kristensen, Lars Michael (Ekstern)
Main Supervisor:
Kindler, Ekkart (Intern)
Examiner:
Baumeister, Hubert (Intern)
Daniel, Moldt (Ekstern)
Meling, Hein (Ekstern)

Financing sources
Source: Internal funding (public)
Name of research programme: Stipendie fra udlandet
Project: PhD

Flexible model structure for waste-LCA modelling - The next generation of the EASEWASTE model
Department of Environmental Engineering
Period: 01/01/2010 → 18/09/2013
Number of participants: 6
Phd Student:
Clavreul, Julie (Intern)
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Baumeister, Hubert (Intern)
Main Supervisor:
Christensen, Thomas Højlund (Intern)
Examiner:
Astrup, Thomas (Intern)
Eriksson, Ola Norman (Ekstern)
Kirkeby, Janus Søgaard (Intern)

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Source: Internal funding (public)
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Integrating Design Decision Management with Model-based Software Development
Department of Informatics and Mathematical Modeling
Period: 01/02/2008 → 01/06/2011
Number of participants: 6
Phd Student:
Könemann, Patrick (Intern)
Supervisor:
Baumeister, Hubert (Intern)
Main Supervisor:
Kindler, Ekkart (Intern)
Examiner:
Störrle, Harald (Intern)
Babar, Muhammad Ali (Ekstern)
Paige, Richard F. (Ekstern)

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Name of research programme: Institut stipendie (DTU)
Project: PhD

Secure Communication Protocols
Department of Informatics and Mathematical Modeling
Period: 01/09/2004 → 29/05/2008
Number of participants: 5
Phd Student:
Gao, Han (Intern)
Main Supervisor:
Nielsen, Hanne Riis (Intern)
Examiner:
Baumeister, Hubert (Intern)
Cortesi, Agostino (Ekstern)
Gilmore, Stephen (Ekstern)

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