An Integrated Framework to Specify Domain-Specific Modeling Languages

In this paper, we propose an integrated framework that can be used by DSL designers to implement their desired graphical domain-specific languages. This framework relies on Microsoft DSL Tools, a meta-modeling framework to build graphical domain-specific languages, and an extension of ForSpec, a logic-based specification language. The drawback of MS DSL Tools is it does not provide a formal and rigorous approach for semantics specifications. In this framework, we use Microsoft DSL Tools to define the metamodel and graphical notations of DSLs, and an extended version of ForSpec as a formal language to define their semantics. Integrating these technologies under the umbrella of Microsoft Visual Studio IDE allows DSL designers to utilize a single development environment for developing their desired domain-specific languages.

General information
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Organisations: Department of Applied Mathematics and Computer Science, Embedded Systems Engineering, Software Engineering
Authors: Zarrin, B. (Intern), Baumeister, H. (Intern)
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Publication date: 2018

Blockchains for Business Process Management - Challenges and Opportunities

Blockchain technology offers a sizable promise to rethink the way inter-organizational business processes are managed because of its potential to realize execution without a central party serving as a single point of trust (and failure). To stimulate research on this promise and the limits thereof, in this paper we outline the challenges and opportunities of blockchain for Business Process Management (BPM). We first reflect how blockchains could be used in the context of the established BPM lifecycle and second how they might become relevant beyond. We conclude our discourse with a summary of seven research directions for investigating the application of blockchain technology in the context of BPM.

General information
State: Published
Organisations: Department of Applied Mathematics and Computer Science, Software Engineering, Vienna University of Economics and Business, University of New South Wales, Eindhoven University of Technology, University of Liechtenstein, Politecnico di Milano, IT University of Copenhagen, University of Tartu, Technische Universität Wien, Technion-Israel Institute of Technology, Data61, IBM Research, Vrije Universiteit Amsterdam, Universität Stuttgart, University of Ulm, University of Vienna, Queensland University of Technology, North Carolina State University, University of Copenhagen, Humboldt-University of Berlin, Universität Potsdam
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Journal: ACM Transactions on Management Information Systems
Volume: 9
Issue number: 1
Clinical Processes - The Killer Application for Constraint-Based Process Interactions

For more than a decade, the interest in aligning information systems in a process-oriented way has been increasing. To enable operational support for business processes, the latter are usually specified in an imperative way. The resulting process models, however, tend to be too rigid to meet the flexibility demands of the actors involved. Declarative process modeling languages, in turn, provide a promising alternative in scenarios in which a high level of flexibility is demanded. In the scientific literature, declarative languages have been used for modeling rather simple processes or synthetic examples. However, to the best of our knowledge, they have not been used to model complex, real-world scenarios that comprise constraints going beyond control-flow. In this paper, we propose the use of a declarative language for modeling a sophisticated healthcare process scenario from the real world. The scenario is subject to complex temporal constraints and entails the need for coordinating the constraint-based interactions among the processes related to a patient treatment process. As demonstrated in this work, the selected real process scenario can be suitably modeled through a declarative approach.

General information
State: Accepted/In press
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Process flexibility, Declarative process model, Healthcare process, Temporal constraints
Source: PublicationPreSubmission
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Smart grid communication infrastructure comparison-for distributed control of distributed energy resources using internet of things devices

Communication between distributed energy resources and aggregators is necessary to improve the efficiency of power use and solve stability issues. For the communication, the probability of delivery for measurements and control commands, determines the possible power system services. The probability of delivery is determined by the processing units, data connection, middleware, and serialization. The comparison is made based on multiple experimental setups to test the performance of different middleware and serialization with different processing units and data connections in a Smart Grid context. The hardware includes Beagle Bones, Raspberry Pi's, and Dell laptops processing units, and the data connection bandwidths include 1, 10, 100 and 1000 Mbit/s. The results show that there are better alternatives to XMPP and Web Services middleware and XML serialization as advocated for by the prevalent communication standards. The paper gives guidance in choosing the best software and hardware for communication depending on the use case.

General information
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Streaming Process Discovery and Conformance Checking

Streaming process discovery, streaming conformance checking, and streaming process mining in general (also known as online process mining) are disciplines which analyze event streams to extract a process model or to assess their conformance with respect to a given reference model. The main characteristic of this family of techniques is to analyze events immediately as they are generated (instead of storing them in a log for late processing). This allows to drastically reduce the latency among phases of the BPM lifecycle (cf. Dumas et al (2013)), thus allowing faster process adaptations and better executions.

General Information
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Authors: Burattin, A. (Intern)
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Publication: Research - peer-review › Encyclopedia chapter – Annual report year: 2018

Time and activity sequence prediction of business process instances
The ability to know in advance the trend of running process instances, with respect to different features, such as the expected completion time, would allow business managers to timely counteract to undesired situations, in order to prevent losses. Therefore, the ability to accurately predict future features of running business process instances would be a very helpful aid when managing processes, especially under service level agreement constraints. However, making such accurate forecasts is not easy: many factors may influence the predicted features. Many approaches have been proposed to cope with this problem but, generally, they assume that the underlying process is stationary. However, in real cases this assumption is not always true. In this work we present new methods for predicting the remaining time of running cases. In particular we propose a method, assuming process stationarity, which achieves state-of-the-art performances and two other methods which are able to make predictions even with non-stationary processes. We also describe an approach able to predict the full sequence of activities that a running case is going to take. All these methods are extensively evaluated on different real case studies.
Time Prediction on Multi-perspective Declarative Business Processes

Process-aware information systems (PAISs) are increasingly used to provide flexible support for business processes. The support given through a PAIS is greatly enhanced when it is able to provide accurate time predictions which is typically a very challenging task. Predictions should be (1) multi-dimensional and (2) not based on a single process instance. Furthermore, the prediction system should be able to (3) adapt to changing circumstances, and (4) deal with multi-perspective declarative languages (e.g., models which consider time, resource, data and control flow perspectives). In this work, a novel approach for generating time predictions considering the aforementioned characteristics is proposed. For this, first, a multi-perspective constraint-based language is used to model the scenario. Thereafter, an optimized enactment plan (representing a potential execution alternative) is generated from such a model considering the current execution state of the process instances. Finally, predictions are performed by evaluating a desired function over this enactment plan. To evaluate the applicability of our approach in practical settings we apply it to a real process scenario. Despite the high complexity of the considered problems, results indicate that our approach produces a satisfactory number of good predictions in a reasonable time.
Toward an Automated Labeling of Event Log Attributes

Process mining aims at exploring the data produced by executable business processes to mine the underlying control-flow and dataflow. Most of the process mining algorithms assume the existence of an event log with a certain maturity level. Unfortunately, the logs provided by process unaware information systems often do not comply with the required maturity level, since they lack the notion of process instance, also referred in process mining as "case id". Without a proper identification of the case id attribute in log files, the outcome of process mining algorithms is unpredictable. This paper proposes a new approach that aims to overcome this challenge by automatically inferring the case id attribute from log files. The approach has been implemented as a ProM plugin and evaluated with several real-world event logs. The results demonstrate a high accuracy in inferring the case id attribute.

General information
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Organisations: Department of Applied Mathematics and Computer Science, Software Engineering
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Towards Domain-specific Flow-based Languages

Due to the significant growth of the demand for data-intensive computing, in addition to the emergence of new parallel and distributed computing technologies, scientists and domain experts are leveraging languages specialized for their problem domain, i.e., domain-specific languages, to help them describe their problems and solutions, instead of using general purpose programming languages. The goal of these languages is to improve the productivity and efficiency of the development and simulation of concurrent scientific models and systems. Moreover, they help to expose parallelism and to specify the concurrency within a component or across different independent components. In this paper, we introduce the concept of domain-specific flow-based languages which allows domain experts to use flow-based languages adapted to a particular problem domain. Flow-based programming is used to support concurrency, while the domain-specific part of these languages is used to define atomic processes and domain-specific validation rules for composite processes. We propose a modeling language that can be used to develop such domain-specific languages. Since this language allows one to define other languages, we often refer to it as a meta-modeling language.

General information
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Pages: 319-325
Publication date: 2018
A Domain-Specific Language for Generic Interlocking Models and Their Properties
State-of-the-art railway interlocking systems typically adhere to the product line paradigm, where each individual system is obtained by instantiating a generic system with configuration data. In this paper, we present a domain-specific language, IDL, for specifying generic behavioural models and generic properties of interlocking systems. An IDL specification of a generic model consists of generic variable declarations and generic transition rules, and generic properties are generic state invariants. Generic models and generic properties can be instantiated with configuration data. This results in concrete models and concrete properties that can be used as input for a model checker to formally verify that the system model satisfies desired state invariants. The language and a configuration data instantiator based on the semantics have been implemented as components of the RobustRailS tool set for formal specification and verification of interlocking systems. They have successfully been applied to (1) define a generic model and generic safety properties for the new Danish interlocking systems and to (2) instantiate these generic artefacts for real-world stations and lines in Denmark. A novelty of this work is to provide a domain-specific language for generic models and an instantiator tool taking not only configuration data but also a generic model as input instead of using a hard-coded generator for instantiating only one fixed generic model and its properties with configuration data.

A Framework for Online Conformance Checking
Conformance checking – a branch of process mining – focuses on establishing to what extent actual executions of a process are in line with the expected behavior of a reference model. Current conformance checking techniques only allow for a-posteriori analysis: the amount of (non-)conformant behavior is quantified after the completion of the process instance. In this paper we propose a framework for online conformance checking: not only do we quantify (non-)conformant behavior as the execution is running, we also restrict the computation to constant time complexity per event analyzed, thus enabling the online analysis of a stream of events. The framework is instantiated with ideas coming from the theory of regions, and state similarity. An implementation is available in ProM and promising results have been obtained.
Online process mining, Conformance checking, Event stream
Beyond Brainstorming: Exploring Convergence in Teams

Collaborative brainstorming is often followed by a convergence activity where teams extract the most promising ideas on a useful level of detail from the brainstorming results. Contrary to the wealth of research on electronic brainstorming, there is a dearth of research on convergence. We used experimental methods for an in-depth exploration of two facilitation-based interventions in a convergence activity: attention guidance (focusing participants on procedures to execute a convergence task) and discussion encouragement (engaging participants in conversations to combine knowledge on ideas). Our findings show that both attention guidance and discussion encouragement are correlated with higher convergence quality. We argue that attention guidance’s contribution is in its support of coordination, information processing, and goal specification. Similar, we argue that discussion encouragement’s contribution is in its stimulation of idea clarification and idea combination. Contrary to past research, our findings further show that satisfaction was higher after convergence than after brainstorming.

General information
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BFI (2015): BFI-level 2
Scopus rating (2015): CiteScore 4.31 SNIP 2.084 SJR 2.71
BFI (2014): BFI-level 2
Scopus rating (2014): CiteScore 3.8 SNIP 1.928 SJR 2.222
BFI (2013): BFI-level 2
Scopus rating (2013): CiteScore 3.33 SNIP 1.63 SJR 1.767
BFI (2012): BFI-level 2
Scopus rating (2012): CiteScore 2.67 SNIP 1.773 SJR 1.404
BFI (2011): BFI-level 2
Scopus rating (2011): CiteScore 3.29 SNIP 2.359 SJR 1.964
BFI (2010): BFI-level 2
Scopus rating (2010): SNIP 2.421 SJR 2.728
BFI (2009): BFI-level 2
Scopus rating (2009): SNIP 2.191 SJR 2.12
BFI (2008): BFI-level 2
Scopus rating (2008): SNIP 2.14 SJR 1.926
Scopus rating (2007): SNIP 1.906 SJR 2.727
Scopus rating (2006): SNIP 2.403 SJR 2.325
Scopus rating (2005): SNIP 2.337 SJR 1.907
Scopus rating (2004): SNIP 2.611 SJR 2.109
Scopus rating (2003): SNIP 2.855 SJR 2.225
Scopus rating (2002): SNIP 1.928 SJR 1.617
Scopus rating (2001): SNIP 1.227 SJR 0.99
Cheetah Experimental Platform Web 1.0: Cleaning Pupillary Data

Recently, researchers started using cognitive load in various settings, e.g., educational psychology, cognitive load theory, or human–computer interaction. Cognitive load characterizes a tasks’ demand on the limited information processing capacity of the brain. The widespread adoption of eye–tracking devices led to increased attention for objectively measuring cognitive load via pupil dilation. However, this approach requires a standardized data processing routine to reliably measure cognitive load. This technical report presents CEP–Web, an open source platform to providing state of the art data processing routines for cleaning pupillary data combined with a graphical user interface, enabling the management of studies and subjects. Future developments will include the support for analyzing the cleaned data as well as support for Task–Evoked Pupillary Response (TEPR) studies.

General information
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Organisations: Department of Applied Mathematics and Computer Science, Software Engineering, University of Innsbruck
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Compositional Model Checking of Interlocking Systems for Lines with Multiple Stations

In the railway domain safety is guaranteed by an interlocking system which translates operational decisions into commands leading to field operations. Such a system is safety critical and demands thorough formal verification during its development process. Within this context, our work has focused on the extension of a compositional model checking approach to formally verify interlocking system models for lines with multiple stations. The idea of the approach is to decompose a model of the interlocking system by applying cuts at the network modelling level. The paper introduces an alternative cut (the linear cut) to a previously proposed cut (border cut). Powered with the linear cut, the model checking approach is then applied to the verification of an interlocking system controlling a real-world multiple station line.

General information
State: Published
Organisations: Department of Applied Mathematics and Computer Science, Software Engineering
Authors: Macedo, H. D. D. S. (Intern), Fantechi, A. (Intern), Haxthausen, A. E. (Intern)
Compositional Verification of Interlocking Systems for Large Stations

Railway interlocking systems are responsible to grant exclusive access to a route, that is a sequence of track elements, through a station or a network. Formal verification that basic safety rules regarding exclusive access to routes are satisfied by an implementation is still a challenge for networks of large size due to the exponential computation time and resources needed. Some recent attempts to address this challenge adopt a compositional approach, targeted to track layouts that are easily decomposable into sub-networks such that a route is almost fully contained in a sub-network: in this way granting the access to a route is essentially a decision local to the sub-network, and the interfaces with the rest of the network easily abstract away less interesting details related to the external world. Following up on previous work, where we defined a compositional verification method that started considering routes that overlap between sub-networks in interlocking systems governing a multi-station line, we attack the verification of large networks, which are typically those in main stations of major cities, and where routes are very intertwined and can hardly be separated into sub-networks that are independent at some degree. At this regard, we study how the division of a complex network into sub-networks, using stub elements to abstract all the routes that are common between sub-networks, may still guarantee compositionality of verification of safety properties.
Convergence of Crowdsourcing Ideas: A Cognitive Load perspective

Many organizations use crowdsourcing for problem solving, innovation, and consultation. In open innovation and community crowdsourcing initiatives the volume of generated ideas may prevent a careful evaluation if each individual contribution. To overcome this challenge, crowd workers can perform a convergence activity. Convergence involves reducing a large set of ideas to a focused subset of ideas that are worthy of further consideration. While convergence is a critical process for situations were large volumes of ideas must be processed, little is known what affects convergence quality and satisfaction with the convergence process and outcomes. We propose an experimental study that adopts Cognitive Load Theory as its theoretical lens to investigate the effects of task complexity, idea presentation, and instructional guidance on convergence quality and satisfaction. This study has the potential to further our understanding of convergence processes in crowdsourcing and inform the design and guidance of crowdsourcing initiatives.

Convergence on Self-Generated vs. Crowdsourced Ideas in Crisis Response: Comparing Social Exchange Processes and Satisfaction with Process

Social media allow crowds to generate many ideas to swiftly respond to events like crises, public policy discourse, or online townhall meetings. This allows organizations and governments to harness the innovative power of the crowd. As part of this setting, teams that process crowd ideas must engage in social exchange processes to converge on a few promising ideas. Traditionally, teams work on self-generated ideas. However, in a crowdsourcing scenario, such as public participation in crisis response, teams may have to process crowd-generated ideas. To better understand this new practice, it is important to investigate how converging on crowdsourced ideas affects the social exchange processes of teams and resulting outcomes. We conducted a laboratory experiment in which small teams working in a crisis response setting converged on self-generated or crowdsourced ideas in an emergency response context. Our findings suggest that teams converging on self-generated ideas have better social exchange processes in terms of dominance and coordination. We found support that evaluation and coordination positively affect team member satisfaction under both experimental conditions. Implications for research and practice are discussed.

Convergence on Self-Generated vs. Crowdsourced Ideas in Crisis Response: Comparing Social Exchange Processes and Satisfaction with Process

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Cost-effective evolution of research prototypes into end-user tools: The MACH case study

Much of Software Engineering research needs to provide an implementation as proof-of-concept. Often such implementations are created as exploratory prototypes without polished user interfaces, making it difficult to (1) run user studies to validate the tool's contribution, (2) validate the author's claim by fellow scientists, and (3) demonstrate the utility and value of the research contribution to any interested parties. However, turning an exploratory prototype into a "proper" tool for end-users often entails great effort. Heavyweight mainstream frameworks such as Eclipse do not address this issue; their steep learning curves constitute substantial entry barriers to such ecosystems.

In this paper, we present the Model Analyzer/Checker (MACH), a stand-alone tool with a command-line interpreter. MACH integrates a set of research prototypes for analyzing UML models. By choosing a simple command line interpreter rather than (costly) graphical user interface, we achieved the core goal of quickly deploying research results to a broader audience while keeping the required effort to an absolute minimum. We analyze MACH as a case study of how requirements and constraints in an academic environment influence design decisions in software tool development. We argue that our approach while perhaps unconventional, serves its purpose with a remarkable cost-benefit ratio.

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Organisations: Department of Applied Mathematics and Computer Science, Software Engineering
Authors: Störrle, H. (Intern)
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Web of Science (2017): Indexed yes
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Scopus rating (2016): CiteScore 1.36 SJR 0.454 SNIP 1.271
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 2
Scopus rating (2015): SJR 0.442 SNIP 1.182 CiteScore 1.18
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 2
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Web of Science (2014): Indexed yes
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Scopus rating (2013): SJR 0.528 SNIP 1.551 CiteScore 1.3
ISI indexed (2013): ISI indexed yes
Web of Science (2013): Indexed yes
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Scopus rating (2012): SJR 0.626 SNIP 1.85 CiteScore 1.66
ISI indexed (2012): ISI indexed yes
BFI (2011): BFI-level 2
Scopus rating (2011): SJR 0.634 SNIP 1.973 CiteScore 1.81
ISI indexed (2011): ISI indexed yes
BFI (2010): BFI-level 2
Scopus rating (2010): SJR 1.146 SNIP 2.637
Web of Science (2010): Indexed yes
BFI (2009): BFI-level 2
Designing Visual Decision Making Support with the Help of Eye-tracking

Data visualizations are helpful tools to cognitively access large amounts of data and make complex relationships in data understandable. This paper shows how results from neuro-physiological measurements, more specifically eye-tracking, can support justified design decisions about improving existing data visualizations for exploring process execution data. This is achieved by gaining insight into how visualizations are used for decision-making. The presented examination is embedded in the domain of process modeling behavior analysis, and the analyses are performed on the background of representative analytical questions from the domain of process model behavior analysis. We present initial findings on one out of three visualization types we have examined, which is the Rhythm-Eye visualization.

General information

State: Published
Organisations: Department of Applied Mathematics and Computer Science, Software Engineering, University of Duisburg-Essen, University of Innsbruck
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Detection and quantification of flow consistency in business process models

Business process models abstract complex business processes by representing them as graphical models. Their layout, as determined by the modeler, may have an effect when these models are used. However, this effect is currently not fully
understood. In order to systematically study this effect, a basic set of measurable key visual features is proposed, depicting the layout properties that are meaningful to the human user. The aim of this research is thus twofold: first, to empirically identify key visual features of business process models which are perceived as meaningful to the user and second, to show how such features can be quantified into computational metrics, which are applicable to business process models. We focus on one particular feature, consistency of flow direction, and show the challenges that arise when transforming it into a precise metric. We propose three different metrics addressing these challenges, each following a different view of flow consistency. We then report the results of an empirical evaluation, which indicates which metric is more effective in predicting the human perception of this feature. Moreover, two other automatic evaluations describing the performance and the computational capabilities of our metrics are reported as well.

**General information**
State: Published
Organisations: Department of Applied Mathematics and Computer Science, Software Engineering, University of Innsbruck, University of Haifa
Authors: Burattin, A. (Intern), Bernstein, V. (Ekstern), Neurauter, M. (Ekstern), Soffer, P. (Ekstern), Weber, B. (Intern)
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Main Research Area: Technical/natural sciences

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Web of Science (2017): Indexed yes
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Web of Science (2016): Indexed yes
BFI (2015): BFI-level 2
Scopus rating (2015): SJR 0.445 SNIP 1.846 CiteScore 1.53
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 2
Scopus rating (2014): SJR 0.454 SNIP 1.822 CiteScore 1.41
Web of Science (2014): Indexed yes
BFI (2013): BFI-level 2
Scopus rating (2013): SJR 0.778 SNIP 3.148 CiteScore 2.25
ISI indexed (2013): ISI indexed yes
Web of Science (2013): Indexed yes
BFI (2012): BFI-level 2
Scopus rating (2012): SJR 0.935 SNIP 2.503 CiteScore 2.66
ISI indexed (2012): ISI indexed yes
BFI (2011): BFI-level 2
Scopus rating (2011): SJR 0.829 SNIP 2.178 CiteScore 2.28
ISI indexed (2011): ISI indexed no
BFI (2010): BFI-level 2
Scopus rating (2010): SJR 0.946 SNIP 2.311
BFI (2009): BFI-level 2
Scopus rating (2009): SJR 1.051 SNIP 2.414
BFI (2008): BFI-level 2
Scopus rating (2008): SJR 1.501 SNIP 3.344
Scopus rating (2007): SJR 0.928 SNIP 4.07
Scopus rating (2006): SJR 1.455 SNIP 6.799
Original language: English
Business process modeling, Metrics, Visual layout, Qualitative empirical study, Consistency of flow
Electronic versions:
art_10.1007_s10270_017_0576_y.pdf
Digitalising the General Data Protection Regulation with Dynamic Condition Response Graphs

We describe how the declarative Dynamic Condition Response (DCR) Graphs process notation can be used to digitalise the General Data Protection Regulation (GDPR) and make a first evaluation to what extent the formalisation and associated tool for end-user modelling and simulation can be used to clarify the meaning of the GDPR and its consequences for the main business process of a Danish funding agency.

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.
Do we educate engineers that can engineer?
Since 2008, the Bachelor of Engineering education at the Technical University of Denmark has been CDIO-based, including the software technology and IT and economics study lines. Consequently, the study plans of these study lines were revised to include cross-disciplinary CDIO projects in each of the first four semesters. These projects replaced 11 smaller, course-specific projects in the old study plans. The first three semesters contain design-build projects spanning several courses, and the fourth semester centers around a stand-alone CDIO project. These team-based projects aim at training the students’ engineering skills (CDIO competence category 4) and at improving the students’ skills in CDIO competence categories 2 and 3. In the tenth year of operation, we now decided to investigate, how content students and employers are with our students’ engineering skills. To this end we have designed a survey to provide us with insights for improving our study lines and to address the question: "Are we educating engineers who can engineer?" The questionnaire is aligned with the CDIO syllabus and can also serve for surveying other study lines, since it is not study line specific. To obtain meaningful results, we decided to target students who have at least passed the first four terms, and companies that have hosted a significant number of students in the last 3 years in internships or for the final thesis. These companies interact with the students for almost one year at the end of their studies, providing a good foundation for the company supervisors to answer questions about the students’ abilities as an engineer. In this paper, we discuss the design and result of the questionnaire, and the obtained results. As mentioned above, the survey will give us and the CDIO community detailed insights as to how our students and their employers experience the result of our education.

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Effect of Linked Rules on Business Process Model Understanding
Business process models are widely used in organizations by information systems analysts to represent complex business requirements and by business users to understand business operations and constraints. This understanding is extracted from graphical process models as well as business rules. Prior research advocated integrating business rules into business process models to improve the effectiveness of important organizational activities, such as developing shared understanding, effective communication, and process improvement. However, whether such integrated modeling can improve the understanding of business processes has not been empirically evaluated. In this paper, we report on an experiment that investigates the effect of linked rules, a specific rule integration approach, on business process model understanding. Our results indicate that linked rules are associated with better time efficiency in interpreting business operations, less mental effort, and partially associated with improved accuracy of understanding.
ePNK Applications and Annotations

The ePNK is an Eclipse-based framework and platform for developing and integrating Petri net tools and applications. One of its core features is that new types of Petri nets can be realized and plugged into the ePNK without any programming by providing a model of the concepts of the new type, the so-called Petri net type definition (PNTD). Moreover, the ePNK allows developers to customize the graphical appearance of the features of a new Petri net type. The main idea and features of the ePNK have been presented before [1, 2]. One important aspect of the ePNK, however, has not been discussed yet: realizing new applications for the ePNK and, in particular, visualizing the result of an application in the graphical editor of the ePNK by using annotations, and interacting with the end user using these annotations.

In this paper, we give an overview of the concepts of ePNK applications by discussing the implementation of a simulator for YAWL nets [3].


Research on the process of process modeling (PPM) studies how process models are created. It typically uses the logs of the interactions with the modeling tool to assess the modeler’s behavior. In this paper, we suggest introducing an additional stream of data (i.e., eye tracking) to improve the analysis of the PPM. We show that, by exploiting this additional source of information, we can refine the detection of comprehension phases (introducing activities such as “semantic validation” or “problem understanding”) as well as provide more exploratory visualizations (e.g., combined modeling phase diagram, heat maps, fixations distributions) both static and dynamic (i.e., movies with the evolution of the model and eye tracking data on top).
Formal Development and Verification of Safe Railway Control Systems

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Formal modelling and verification of interlocking systems featuring sequential release

In this article, we present a method and an associated toolchain for the formal verification of the new Danish railway interlocking systems that are compatible with the European Train Control System (ETCS) Level 2. We have made a generic and reconfigurable model of the system behaviour and generic safety properties. This model accommodates sequential release - a feature in the new Danish interlocking systems. To verify the safety of an interlocking system, first a domain-specific description of interlocking configuration data is constructed and validated. Then the generic model and safety properties are automatically instantiated with the well-formed description of interlocking configuration data. This instantiation produces a model instance in the form of a Kripke structure, and concrete safety properties expressed as invariants. Finally, using a combination of SMT based bounded model checking (BMC) and inductive reasoning, it is verified that the generated model instance satisfies the generated safety properties. Using this method, we are able to verify the safety properties for model instances corresponding to railway networks of industrial size. Experiments show that BMC is also efficient for finding bugs in the railway interlocking designs. Additionally, benchmarking results comparing the performance of our approach with alternative verification techniques on the interlocking models are presented.

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Lost in Time and Space: States of High Arousal Disrupt Implicit Acquisition of Spatial and Sequential Context Information

Biased cognition during high arousal states is a relevant phenomenon in a variety of topics: from the development of post-traumatic stress disorders or stress-triggered addictive behaviors to forensic considerations regarding crimes of passion. Recent evidence indicates that arousal modulates the engagement of a hippocampus-based “cognitive” system in favor of a striatum-based “habit” system in learning and memory, promoting a switch from flexible, contextualized to more rigid, reflexive responses. Existing findings appear inconsistent, therefore it is unclear whether and which type of context processing is disrupted by enhanced arousal. In this behavioral study, we investigated such arousal-triggered cognitive-state shifts in human subjects. We validated an arousal induction procedure (three experimental conditions: violent scene, erotic scene, neutral control scene) using pupillometry (Preliminary Experiment, n = 13) and randomly administered this method to healthy young adults to examine whether high arousal states affect performance in two core domains of contextual processing, the acquisition of spatial (spatial discrimination paradigm; Experiment 1, n = 66) and sequence information (learned irrelevance paradigm; Experiment 2, n = 84). In both paradigms, spatial location and sequences were encoded incidentally and both displacements when retrieving spatial position as well as the predictability of the target by a cue in sequence learning changed stepwise. Results showed that both implicit spatial and sequence learning were disrupted during high arousal states, regardless of valence. Compared to the control group, participants in the arousal conditions showed impaired discrimination of spatial positions and abolished learning of associative sequences. Furthermore, Bayesian analyses revealed evidence against the null models. In line with recent models of stress effects on cognition, both experiments provide evidence for decreased engagement of flexible, cognitive systems supporting encoding of context information in active cognition during acute arousal, promoting reduced sensitivity for contextual details. We argue that arousal fosters cognitive adaptation towards less demanding, more present-oriented information processing, which prioritizes a current behavioral response set at the cost of contextual cues. This transient state of behavioral perseverance might reduce reliance on context information in unpredictable environments and thus represent an adaptive response in certain situations.

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Measuring and Explaining Cognitive Load During Design Activities: A fine-grained approach
Recent advances in neuro-physiological measurements resulted in reliable and objective measures of Cognitive Load (CL), e.g., using pupillary responses. However, continuous measurement of CL in software design activities, e.g., conceptual modeling, has received little attention. In this paper, we present the progress of our work intended to close this gap by continuously measuring cognitive load during design activities. This work aims at advancing our understanding of WHEN and WHY designers face challenges. For this, we attempt to explore and explain the occurrence of CL using fine-granular units of analysis (e.g., type of subtasks, evolution of design artifact's quality, and manner of technology use). We expect implications for the future development of intelligent software systems, which are aware WHEN a particular designer experiences challenges, but also WHY challenges occur.

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Model Checking Geographically Distributed Interlocking Systems Using UMC
The current trend of distributing computations over a network is here, as a novelty, applied to a safety critical system, namely a railway interlocking system. We show how the challenge of guaranteeing safety of the distributed application has been attacked by formally specifying and model checking the relevant distributed protocols. By doing that we obey the safety guidelines of the railway signalling domain, that require formal methods to support the certification of such products. We also show how formal modelling can help designing alternative distributed solutions, while maintaining adherence to safety constraints.

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Online Conformance Checking for Petri Nets and Event Streams

Within process mining, we can identify conformance checking as the task of computing the extent to which executions of a process model are in line with the reference behavior. Most approaches currently available in the literature (for imperative models, such as Petri nets) perform just a-posteriori analyses. This means that the amount of nonconformant behavior is quantified after the completion of the current execution. The tool presented in this paper, instead, proposes an approach for online conformance checking: not only it is capable of quantifying the deviating behavior on the fly, but the computation complexity is also restricted to a constant complexity per event analyzed. This enables the online analysis of an infinite stream of events. The tool is implemented as a package of the ProM framework and promising results have been obtained and are presented in this paper.

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Smart Grid Communication Comparison: Distributed Control Middleware and Serialization Comparison for the Internet of Things

To solve the problems caused by intermittent renewable energy production, communication between Distributed Energy Resources (DERs) and system operators is necessary. The communication middleware and serialization used for communication are essential to ensure delivery of the messages within the required timeframe, to provide the necessary ancillary services to the power grid. This paper shows that there are better alternatives to using Web Services and XMPP as middleware and that there are better alternatives than using XML for serialization. The paper also gives guidance at choosing the best communication middleware and serialization format/library, aided by the authors' earlier work, which investigates the performance and characteristics of communication middleware and serialization independently. Given the performance criteria of the paper, ZeroMQ, YAMI4, and ICE are the middleware that performs the best, and ProtoBuf (ProtoStuff), and ProtoStuff are the serialization that performs the best.

General information
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Smart Grid, Internet of Things, Communication Middleware, RMI, XML-RPC, CORBA, ICE, Web Services, OPC UA, XMPP, WAMP, YAMI4, ZeroMQ, Serialization, XML, JSON, YAML, FST, Kryo, JAXB, Jackson, XStream, ProtoStuff, Gson, Genson, SnakeYaml, MsgPack, Smile, ProtoBuf, BSON, Hessian, CBOR, Avro
Smart grid communication comparison: Distributed control middleware and serialization comparison for the Internet of Things

To solve the problems caused by intermittent renewable energy production, communication between Distributed Energy Resources (DERs) and system operators is necessary. The communication middleware and serialization used for communication are essential to ensure delivery of the messages within the required timeframe, to provide the necessary ancillary services to the power grid. This paper shows that there are better alternatives to using Web Services and XMPP as middleware and that there are better alternatives than using XML for serialization. The paper also gives guidance at choosing the best communication middleware and serialization format/library, aided by the authors' earlier work, which investigates the performance and characteristics of communication middleware and serialization independently. Given the performance criteria of the paper, ZeroMQ, YAMI4, and ICE are the middleware that performs the best, and ProtoBuf (ProtoStuff), and ProtoStuff are the serialization that performs the best.

General information
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Smart Grid communication middleware comparison distributed control comparison for the Internet of things

Communication between Distributed Energy Resources (DERs) is necessary to efficiently solve the intermittency issues caused by renewable energy, using DER power grid auxiliary services, primarily load shifting and shedding. The middleware used for communication determines which services are possible by their performance, which is limited by the middleware characteristics, primarily interchangeable serialization and the Publish-Subscribe messaging pattern. The earlier paper "Smart Grid Serialization Comparison" (Petersen et al. 2017) aids in the choice of serialization, which has a big impact on the performance of the communication as a whole. This paper identifies the dis-/advantages of the different middleware, shows that there are better alternatives to Web Services and XMPP, and gives guidance in choosing the most appropriate middleware depending on the context. YAMI4 and ZeroMQ are generally the strongest candidates for Smart Grid distributed control, but WAMP should also be considered in the future.

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Smart Grid Serialization Comparison
Communication between DERs and System Operators is required to provide Demand Response and solve some of the problems caused by the intermittency of much Renewable Energy. An important part of efficient communication is serialization, which is important to ensure a high probability of delivery within a given timeframe, especially in the context of the Internet of Things, using low-bandwidth data connections and constrained devices. The paper shows that there are better alternatives than XML & JAXB and gives guidance in choosing the most appropriate serialization format and library depending on the context.

General information
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Organisations: Department of Electrical Engineering, Center for Electric Power and Energy, Energy system operation and management, Department of Applied Mathematics and Computer Science, Software Engineering
Authors: Petersen, B. S. (Intern), Bindner, H. W. (Intern), Poulsen, B. (Intern), You, S. (Intern)
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The Choice Is Yours: The Role of Cognitive Processes for IT-Supported Idea Selection

The selection of good ideas out of hundreds or even thousands has proven to be the next big challenge for organizations that conduct open idea contests for innovation. Cognitive load and attention loss hinder crowds to effectively run their idea selection process. Facilitation techniques for the reduction and clarification of ideas could help with such problems, but have not yet been researched in crowd settings that are prevalent in idea contests. This research-in-progress paper aims to contribute to this research gap by investigating IT-supported selection techniques that differ in terms of selection direction and selection type. A laboratory experiment using eye-tracking will investigate variations in selection type and selection direction. Moreover, the experiment will test the effects on the decision-making process and the number and quality of ideas in a filtered set. Findings will provide explanations why certain mechanisms work for idea selection. Potential implications for theory and practice are discussed.

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Visualization of the Evolution of Layout Metrics for Business Process Models
Considerable progress regarding impact factors of process model understandability has been achieved. For example, it has been shown that layout features of process models have an effect on model understandability. Even so, it appears that our knowledge about the modeler’s behavior regarding the layout of a model is very limited. In particular, research focuses on the end product or the outcome of the process modeling act rather than the act itself. This paper extends existing research by opening this black box and introducing an enhanced technique enabling the visual analysis of the modeler’s behavior towards layout. We demonstrate examples showing that our approach provides valuable insights to better understand and support the creation of process models. Additionally, we sketch challenges impeding this support for future research.

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Algebraic Varieties and System Design
Design and analysis of networks have many applications in the engineering sciences. This dissertation seeks to contribute to the methods used in the analysis of networks with a view towards assisting decision making processes. Networks are
initially considered as objects in the category of graphs and later as objects in the category of hypergraphs. The connection with the category of simplicial pairs become apparent when the topology is analyzed using homological algebra. A topological ranking is developed that measures the ability of the network to stay path-connected. Combined with the analysis of cover ideals of hypergraphs, the topological ranking demonstrates the non-trivial decisions that needs to be considered in system design. All the methods developed here have an underlying common structure, namely that they all appear at solution sets for systems of polynomials. These solution sets are called algebraic varieties.

An approach for activity-based DEVS model specification
Creation of DEVS models has been advanced through Model Driven Architecture and its frameworks. The overarching role of the frameworks has been to help develop model specifications in a disciplined fashion. Frameworks can provide intermediary layers between the higher level mathematical models and their corresponding software specifications from both structural and behavioral aspects. Unlike structural modeling, developing models to specify behavior of systems is known to be harder and more complex, particularly when operations with non-trivial control schemes are required. In this paper, we propose specifying activity-based behavior modeling of parallel DEVS atomic models. We consider UML activities and actions as fundamental units of behavior modeling, especially in the presence of recent advances in the UML 2.5 specifications. We describe in detail how to approach activity modeling with a set of elemental behavioral constructs for atomic DEVS model. We show how Activity models correspond to the atomic DEVS model using an exemplar. We also highlight the complementary roles of Activity and Statecharts models.

Clone Detection for Graph-Based Model Transformation Languages
Cloning is a convenient mechanism to enable reuse across and within software artifacts. On the downside, it is also a practice related to significant long-term maintainability impediments, thus generating a need to identify clones in affected artifacts. A large variety of clone detection techniques has been proposed for programming and modeling languages; yet no specific ones have emerged for model transformation languages. In this paper, we explore clone detection for graph-based model transformation languages. We introduce potential use cases for such techniques in the context of constructive and analytical quality assurance. From these use cases, we derive a set of key requirements. We describe our customization of existing model clone detection techniques allowing us to address these requirements. Finally, we
provide an experimental evaluation, indicating that our customization of ConQAT, one of the existing techniques, is well-suited to satisfy all identified requirements.

Comparing formal verification approaches of interlocking systems

The verification of railway interlocking systems is a challenging task, and therefore several research groups have suggested to improve this task by using formal methods, but they use different modelling and verification approaches. To advance this research, there is a need to compare these approaches. As a first step towards this, in this paper we suggest a way to compare different formal approaches for verifying designs of route-based interlocking systems and we demonstrate it on modelling and verification approaches developed within the research groups at DTU/Bremen and at Surrey/Swansea. The focus is on designs that are specified by so-called control tables. The paper can serve as a starting point for further comparative studies. The DTU/Bremen research has been funded by the RobustRailS project granted by Innovation Fund Denmark. The Surrey/Swansea research has been funded by the SafeCap and the DITTO research projects granted by EPSRC and RSSB. The authors would like to thank Linh Hong Vu for providing the benchmark of scheme plans and the drawings of the track plans.

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Compositional Verification of Multi-Station Interlocking Systems

Because interlocking systems are highly safety-critical complex systems, their automated safety verification is an active research topic investigated by several groups, employing verification techniques to produce important cost and time savings in their certification. However, such systems also pose a big challenge to current verification methodologies, due to the explosion of state space size as soon as large, if not medium sized, multi-station systems have to be controlled.

For these reasons, verification techniques that exploit locality principles related to the topological layout of the controlled system to split in different ways the state space have been investigated. In particular, compositional approaches divide the controlled track network in regions that can be verified separately, once proper assumptions are considered on the way the pieces are glued together.

Basing on a successful method to verify the size of rather large networks, we propose a compositional approach that is particularly suitable to address multi-station interlocking systems which control a whole line composed of stations linked by mainline tracks. Indeed, it turns out that for such networks, and for the adopted verification approach, the verification efforts amount just to the sum of the verification efforts for each intermediate station and for each connecting line.

Defining Effectiveness Using Finite Sets A Study on Computability

This paper studies effectiveness in the domain of computability. In the context of model-theoretical approaches to effectiveness, where a function is considered effective if there is a model containing a representation of such function, our definition relies on a model provided by functions between finite sets and uses category theory as its mathematical foundations. The model relies on the fact that every function between finite sets is computable, and that the finite
composition of such functions is also computable. Our approach is an alternative to the traditional model-theoretical based works which rely on (ZFC) set theory as a mathematical foundation, and our approach is also novel when compared to the already existing works using category theory to approach computability results. Moreover, we show how to encode Turing machine computations in the model, thus concluding the model expresses at least the desired computational behavior. We also provide details on what instances of the model would indeed be computable by a Turing machine.

General information
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Gaussian elimination is not optimal, revisited

We refactor the universal law for the tensor product to express matrix multiplication as the product $MN$ of two matrices $M$ and $N$. Thus making possible to use such matrix product to encode and transform algorithms performing matrix multiplication using techniques from linear algebra. We explore such possibility and show two stepwise refinements transforming the composition $MN$ into the Naïve and Strassen's matrix multiplication algorithms.

The inspection of the stepwise transformation of the composition of matrices $MN$ into the Naïve matrix multiplication algorithm evidences that the steps of the transformation correspond to apply Gaussian elimination to the columns of $M$ and to the lines of $N$ therefore providing explicit evidence on why "Gaussian elimination is not optimal", the aphorism serving as the title to the succinct paper introducing Strassen's matrix multiplication algorithm.

Although the end results are equations involving matrix products, our exposition builds upon previous works on the category of matrices (and the related category of finite vector spaces) which we extend by showing: why the direct sum $(\oplus,0)$ monoid is not closed, a biproduct encoding of Gaussian elimination, and how to further apply it in the derivation of linear algebra algorithms.
How do humans inspect BPMN models: an exploratory study

Even though considerable progress regarding the technical perspective on modeling and supporting business processes has been achieved, it appears that the human perspective is still often left aside. In particular, we do not have an in-depth understanding of how process models are inspected by humans, what strategies are taken, what challenges arise, and what cognitive processes are involved. This paper contributes toward such an understanding and reports an exploratory study investigating how humans identify and classify quality issues in BPMN process models. Providing preliminary answers to initial research questions, we also indicate other research questions that can be investigated using this approach. Our qualitative analysis shows that humans adopt different strategies on how to identify quality issues. In addition, we observed several challenges appearing when humans inspect process models. Finally, we present different manners in which classification of quality issues was addressed.
IT-Supported Formal Control: How Perceptual (in)Congruence Affects the Convergence of Crowd-Sourced Ideas

IT-supported teams face challenges when converging on crowd-sourced ideas. One reason is that teams have difficulties in establishing shared understanding. Enacting formal control has been suggested as a way how to overcome these challenges as they help to develop shared understanding and focus interactions on the team outcome, i.e. the ideas in a converged list. However, it is unclear if formal control can facilitate perceptual congruence and what effect it has on idea quality, e.g., an idea's elaborateness. Perceptual congruence is operationalized by examining the agreement between leaders and team members on depth of interaction to build shared understanding. The findings show that teams receiving formal control outperform self-managed teams in terms of depth of interaction and extent of idea development. Moreover, findings indicate that extent of idea development is high at the extreme ends of perceptual congruence. Perceptual incongruence was found to be detrimental for extent of idea development.

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Large-scale Optimization of Contoured Beam Reflectors and Reflectarrays

Designing a contoured beam reflector or performing a direct optimization of a reflectarray requires a mathematical optimization procedure to determine the optimum design of the antenna. A popular approach, used in the market-leading TICRA software POS, can result in computation times on the order of days, due to the optimization algorithm. The present paper discusses recent improvements, allowing reductions in optimization time by two orders of magnitude or more on several application examples.

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Model Manipulation for End-User Modelers

End-user modelers are domain experts who create and use models as part of their work. They are typically not Software Engineers, and have little or no programming and meta-modeling experience. However, using model manipulation languages developed in the context of Model-Driven Engineering often requires such experience. These languages are therefore only used by a small subset of the modelers that could, in theory, benefit from them.

The goals of this thesis are to substantiate this observation, introduce the concepts and tools required to overcome it, and provide empirical evidence in support of these proposals. To achieve its first goal, the thesis presents the findings of a Systematic Mapping Study showing that human factors topics are scarcely and relatively poorly addressed in model transformation research. Motivated by these findings, the thesis explores the requirements of end-user modelers, and proposes the VM* family of model manipulation languages addressing them. This family consists of the Visual Model Query Language (VMQL), the Visual Model Constraint Language (VMCL), and the Visual Model Transformation Language (VMTL). They allow modelers to specify and execute queries, constraints, and transformations using their modeling notation and editor of choice.

The VM* languages are implemented via a single execution engine, the VM* Runtime, built on top of the Henshin graph-based transformation engine. This approach combines the benefits of flexibility, maturity, and formality. To simplify model editor integration, the VM* Runtime is deployed as a collection of lightweight Web Services. The claim that VM* languages offer end-user modelers superior learnability compared to existing model manipulation languages is verified empirically via user experiments complemented by qualitative evidence.
On the impact of size to the understanding of UML diagrams

Background: Practical experience suggests that usage and understanding of UML diagrams is greatly affected by the quality of their layout. While existing research failed to provide conclusive and comprehensive evidence in support of this hypothesis, our own previous work provided substantial evidence to this effect, also suggesting diagram size as a relevant factor, for a range of diagram types and layouts.

Aims: Since there is no generally accepted precise notion of “diagram size,” we first need to operationalize this concept, analyze its impact on diagram understanding, and derive practical advice from our findings.

Method: We define three alternative, plausible metrics. Since they are all highly correlated on a large sample of UML diagrams, we opt for the simplest one. We use it to re-analyze existing experimental data on diagram understanding.

Results: We find a strong negative correlation between diagram size and modeler performance. Our results are statistically highly significant and exhibit a very large degree of validity. We utilize these results to derive a recommendation on diagram sizes that are, on average, optimal for model understanding. These recommendations are implemented in a plug-in to a widely used modeling tool, providing continuous feedback about diagram size to modelers.

Conclusions: The effect sizes are varying, but generally suggest that the impact of size matches or exceeds that of other factors in diagram understanding. With the guideline and tool, modelers are steered toward avoiding too large diagrams.
On the significance of the noise model for the performance of a linear MPC in closed-loop operation

This paper discusses the significance of the noise model for the performance of a Model Predictive Controller when operating in closed-loop. The process model is parametrized as a continuous-time (CT) model and the relevant sampled-data filtering and control algorithms are developed. Using CT models typically means less parameters to identify. Systematic tuning of such controllers is discussed. Simulation studies are conducted for linear time-invariant systems showing that choosing a noise model of low order is beneficial for closed-loop performance. (C) 2016, IFAC (International Federation of Automatic Control) Hosting by Elsevier Ltd. All rights reserved.

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On the Use of Static Checking in the Verification of Interlocking Systems

In the formal methods community, the correctness of interlocking tables is typically verified by model checking. This paper suggests to use a static checker for this purpose and it demonstrates for the RobustRailS verification tool set that the execution time and memory usage of its static checker are much less than of its model checker. Furthermore, the error messages of the static checker are much more informative than the counter examples produced by classical model checkers.

Pragmatics annotated coloured petri nets for protocol software generation and verification

Pragmatics Annotated Coloured Petri Nets (PA-CPNs) are a restricted class of Coloured Petri Nets (CPNs) developed to support automated generation of protocol software. The practical application of PA-CPNs and the supporting PetriCode software tool have been discussed and evaluated in earlier papers already. The contribution of this paper is to give a formal definition of PA-CPNs, motivate the definitions, and demonstrate how the structure of PA-CPNs can be exploited for more efficient verification.
SaRDIn - A Safe Reconfigurable Distributed Interlocking

Current computer-based interlocking systems most often have a centralized design, with all logic residing in a single computer. Centralized interlockings are complex to design. Following the general trend in Cyber-Physical Systems, the SaRDIn (Safe Reconfigurable Distributed Interlockings) concept promises a radically simpler solution. The novelty of the SaRDIn concept is a fine-grained distribution of the logic over all processors deployed at the sensors and actuators along the track layout, i.e. within the track circuits, point machines, signals, etc. The advantages and drawbacks of such a solution are discussed, together with strategies to address the main challenges introduced by this concept, namely configuration, re-configuration and certification.

General information
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Studying the Creation of Design Artifacts

As software and information systems (IS) increase in functional sophistication, perceptions of IS quality are changing. Moving beyond issues of performance efficiency, essential qualities such as fitness for purpose, sustainability, and overall effectiveness become more complex. Creating software and information systems represents a highly interconnected locus in which both the generative processes of building design artifacts and articulating constructs used to evaluate their quality take place. We address this interconnectedness with an extended process-oriented research design enabling multi-modal neurophysiological data analyses. We posit that our research will provide more comprehensive assessments of the efficacy of design processes and the evaluation of the qualities of the resulting design artifacts.

The impact of working memory and the "process of process modelling" on model quality: Investigating experienced versus inexperienced modellers

A process model (PM) represents the graphical depiction of a business process, for instance, the entire process from online ordering a book until the parcel is delivered to the customer. Knowledge about relevant factors for creating PMs of high quality is lacking. The present study investigated the role of cognitive processes as well as modelling processes in creating a PM in experienced and inexperienced modellers. Specifically, two working memory (WM) functions (holding and processing of information and relational integration) and three process of process modelling phases (comprehension, modelling, and reconciliation) were related to PM quality. Our results show that the WM function of relational integration was positively related to PM quality in both modelling groups. The ratio of comprehension phases was negatively related to PM quality in inexperienced modellers and the ratio of reconciliation phases was positively related to PM quality in experienced modellers. Our research reveals central cognitive mechanisms in process modelling and has potential practical implications for the development of modelling software and teaching the craft of process modelling.
The innovation element of the diploma (b.Eng.) programs at DTU

In September 2014 the first version of the newly developed CDIO-based diploma (B.Eng) programs were launched at DTU (Nyborg et al., 2015). The programs are the result of a comprehensive merger process of former diploma programs, namely the programs at Engineering College of Copenhagen (now DTU Diploma) and the Technical University of Denmark.

The most significant new activity in the programs is the introduction of a common 10 ECTS compulsory course in innovation in the later part of the programs. The idea behind this course is to give students the opportunity to collaborate on interdisciplinary real-life projects.

This course strengthens not only innovation skills but personal and interpersonal skills as well. In this paper we will discuss the organization of the Innovation Pilot course. In particular we focus on:
- Structure of programmes
- Organization of the Innovation Pilot course
- The didactical considerations
- Scaling up the course from 50 to 500 students

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**VMTL: a language for end-user model transformation**
Model transformation is a key enabling technology of Model-Driven Engineering (MDE). Existing model transformation languages are shaped by and for MDE practitioners—a user group with needs and capabilities which are not necessarily characteristic of modelers in general. Consequently, these languages are largely ill-equipped for adoption by end-user modelers in areas such as requirements engineering, business process management, or enterprise architecture. We aim to introduce a model transformation language addressing the skills and requirements of end-user modelers. With this contribution, we hope to broaden the application scope of model transformation and MDE technology in general. We discuss the profile of end-user modelers and propose a set of design guidelines for model transformation languages addressing them. We then introduce Visual Model Transformation Language (VMTL) following these guidelines. VMTL draws on our previous work on the usability-oriented Visual Model Query Language. We implement VMTL using the Henshin model transformation engine, and empirically investigate its learnability via two user experiments and a think-aloud protocol analysis. Our experiments, although conducted on computer science students exhibiting only some of the characteristics of end-user modelers, show that VMTL compares favorably in terms of learnability with two state-of-the-art model transformation languages: Epsilon and Henshin. Our think-aloud protocol analysis confirms many of the design decisions adopted for VMTL, while also indicating possible improvements.

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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.

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Behavior Modeling -- Foundations and Applications: International Workshops, BM-FA 2009-2014, Revised Selected Papers

This book constitutes revised selected papers from the six International Workshops on Behavior Modelling - Foundations and Applications, BM-FA, which took place annually between 2009 and 2014. The 9 papers presented in this volume were carefully reviewed and selected from a total of 58 papers presented at these 6 workshops. The contributions were organized in topical sections named: modelling practices; new ways of behaviour modelling: events in modelling; and new ways of behaviour modelling: protocol modelling.

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Bx 2015 — Bidirectional Transformations: Proceedings of the 4th International Workshop on Bidirectional Transformations

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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.
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 study will be used to exemplify the use of the new process editor.

**General information**

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**Code Generation from Pragmatics Annotated Coloured Petri Nets**

All electronic communication relies on communication protocols. It is therefore very important that protocols are correct and that protocol implementations are reliable. Coloured Petri Nets (CPNs) have been widely used to model, analyse and verify communication protocols. However, relatively limited work has been done on transforming CPN model to protocol implementations. The goal of the thesis is thus to be able to automatically generate high-quality implementations of communication protocols based on CPN models.

In this thesis, we develop a methodology for generating implementations of protocols using a sub-class of CPNs, called Pragmatics Annotated CPNs (PACPNs). PA-CPNs give structure to the protocol models and allows the models to be annotated with code generation pragmatics. These pragmatics are used by our code generation approach to identify and execute the appropriate code generation templates. The templates hold the information needed to transform the model to a fully working protocol implementation for a target platform. The code generation approach coupled with PA-CPNs provide a flexible way to perform code generation for communication protocols. The code generation approach has been implemented in a prototype tool called PetriCode.

We defined several criteria for our code generation approach, the approach should be scalable so that is can be used to generate code for industrial sized protocols. The models should be verifiable and it should be possible to perform efficient verification on the models. The approach and the models that are employed for code generation should be platform independent in the sense that it should be possible to generate code for a wide range of platforms based on the same model. The generated code should be integrable meaning that it should be able to use different third party libraries and the code should be easily usable by third party code. Finally, the code should be readable by developers with expertise on the considered platforms.

In this thesis, we show that our code generation approach is able to generate code for a wide range of platforms without altering the PA-CPN model that describe the protocol design. The generated code is also shown to be readable and we demonstrate that a generated implementation can be easily integrated with third party software. We also show that our approach scales to industrial sized protocols by applying our approach to generate code for the WebSocket protocol. The WebSocket protocol creates a message-based two-way channel that can be used by web applications. This allows web applications to communicate with the server more much more efficiently than using the traditional request-response pattern for certain application types such as games and rich web applications. Finally, we conclude the evaluation of the criteria of our approach by using the WebSocket PA-CPN model to show that we are able to verify fairly large protocols.
Developing merged CDIO based curricula for diploma (B.Eng.) IT study programs at DTU

Starting 2007, the Danish government drew up a new map of universities through a process of mergers of a number of universities and research institutions (UFM 2007), as part of the national innovation strategy. In the beginning of 2013, the Engineering College Copenhagen (IHK, now DTU Ballerup) merged with the Technical University of Denmark (DTU Lyngby). The goal of the merger was to educate ever more innovative diploma engineers to fulfill the needs by Danish industry through combining a practice-oriented development environment and a research-oriented environment.

Merging a university with an engineering college implies merging two different cultures: established teaching staff, different study lines; a difficult undertaking at best. Existing study lines must be merged, overlaps and differences identified and handled, and in general a common understanding and language must be established.

The two institutions represented before the merger well 3500 B.Eng. students. The goal of the merger was to combine the best of the existing educations rooted in a practice-oriented development environment and a research-oriented environment. At the same time, the merger was supposed to contribute to the national innovation strategy.

In this paper we describe the process of developing new, merged B.Eng curricula in the IT field (Diploma IT), as part of the merger between DTU Lyngby and IHK. Particular attention will be given to the following subjects:

• The design process used to develop the new merged study programs;
• Involvement of stakeholders in designing the new curricula;
• Introduction of a common interdisciplinary innovation course in the programs; and
• Education of teaching staff: Integration into one organization.
Effective and efficient model clone detection

Code clones are a major source of software defects. Thus, it is likely that model clones (i.e., duplicate fragments of models) have a significant negative impact on model quality, and thus, on any software created based on those models, irrespective of whether the software is generated fully automatically ("MDD-style") or hand-crafted following the blueprint defined by the model ("MBSD-style"). Unfortunately, however, model clones are much less well studied than code clones. In this paper, we present a clone detection algorithm for UML domain models. Our approach covers a much greater variety of model types than existing approaches while providing high clone detection rates at high speed.

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Efficient Model Querying with VMQL

Context: Despite model querying being an important practical problem, existing solutions lack either usability, expressiveness, or generality. The Visual Model Query Language (VMQL) is a query by example solution created to satisfy these requirements simultaneously. Objective: In the present paper we study whether VMQL queries can be executed in an efficient way, such that VMQL is suitable for ad-hoc model querying in practical settings involving large models. Method: We study VMQL query execution performance on sets of models ranging over a broad spectrum of sizes and degrees of complexity. The models are based on large and realistic case studies. Results: We observe that our approach exhibits competitive performance, while providing superior usability and generality.

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First International Workshop on Human Factors in Modeling (HuFaMo 2015): Preface

Modeling is a human-intensive enterprise. As such, many research questions related to modeling can only be answered by empirical studies employing human factors. The International Workshop Series on Human Factors in Modeling (HuFaMo) is dedicated to the discussion of empirical research involving human factors in modeling. Our goal is to improve the state of the science and professionalism in empirical research in the Model Based Engineering community. Typical examples of research questions might consider the usability of a certain approach, such as a method or language, or the emotional states or personal judgements of modelers.

While concerned with foundations and framework support for modeling, the community has been somehow neglecting the issue of human factors in this context. There is a growing need from the community concerned with quality factors to understand the best practices and systematic approaches to assert usability in modeling and confirm the claims of productivity. This workshop creates a space for discussion being a get together of both MDE, Usability, Human Interfaces and the Experimental Software engineering community.

HuFaMo expressly focuses on human factors, in order to raise the awareness for these topics and the associated research methods and questions in the modeling community, providing an outlet for research of this type, guaranteeing high quality reviews by people that apply these research methods themselves. Along with fully complete empirical evaluations, the workshop organizers explicitly encouraged researchers new to empirical methods to discuss study designs before conducting their empirical evaluations. The rationale was to create a constructive environment where the HuFaMo participants could contribute to improving the proposed study designs so that stronger (and more easily replicable) empirical designs and results can be obtained. Ultimately, we aim to congregate a community of researchers and practitioners that promotes (possibly independently replicated) empirical assessments on claims related to human factors in modeling.

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Formal Development and Verification of Railway Control Systems - In the context of ERTMS/ETCS Level 2
This dissertation presents a holistic, formal method for efficient modelling and verification of safety-critical railway control systems that have product line characteristics, i.e., each individual system is constructed by instantiating common generic applications with concrete configuration data. The proposed method is based on a combination of formal methods and domain-specific approaches. While formal methods offer mathematically rigorous specification, verification and validation, domain-specific approaches encapsulate the use of formal methods with familiar concepts and notions of the domain, hence making the method easy for the railway engineers to use. Furthermore, the method features a 4-step verification and validation approach that can be integrated naturally into different phases of the software development process. This 4-step approach identifies possible errors in generic applications or configuration data as early as possible in the software
development cycle, and facilitates debugging/troubleshooting if errors are discovered. The proposed method has successfully been applied to case studies of the forthcoming Danish railway interlocking systems that are compatible with the European standardized railway control systems ERTMS/ETCS Level 2. Experiments showed that the method can be used for specification, verification and validation of systems of industrial size.

**General information**

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**Formal Modeling and Verification of Interlocking Systems Featuring Sequential Release**

In this paper, we present a method and an associated tool suite for formal verification of the new ETCS level 2 based Danish railway interlocking systems. We have made a generic and reconfigurable model of the system behavior and generic high-level safety properties. This model accommodates sequential release – a feature in the new Danish interlocking systems. The generic model and safety properties can be instantiated with interlocking configuration data, resulting in a concrete model in the form of a Kripke structure, and in high-level safety properties expressed as state invariants. Using SMT based bounded model checking (BMC) and inductive reasoning, we are able to verify the properties for model instances corresponding to railway networks of industrial size. Experiments also show that BMC is efficient for finding bugs in the railway interlocking designs.

**General information**

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Organisations: Department of Applied Mathematics and Computer Science, Software Engineering, Universität Bremen  
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Model Checking and Model-based Testing in the Railway Domain

This chapter describes some approaches and emerging trends for verification and model-based testing of railway control systems. We describe state-of-the-art methods and associated tools for verifying interlocking systems and their configuration data, using bounded model checking and k-induction. Using real-world models of novel Danish interlocking systems, it is exemplified how this method scales up and is suitable for industrial application. For verification of the integrated HW/SW system performing the interlocking control tasks, a model-based hardware-in-the-loop testing approach is presented. The trade-off between complete test strategies capable of uncovering every error in implementations of a given fault domain on the one hand, and on the other hand the unmanageable load of test cases typically created by these strategies is discussed. Pragmatic approaches resulting in manageable test suites with good test strength are explained. Interlocking systems represent just one class of many others, where concrete system instances are created from generic representations, using configuration data for determining the behaviour of the instances. We explain how the systematic transition from generic to concrete instances in the development path is complemented by associated transitions in the verification and testing paths.

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Organisations: Department of Applied Mathematics and Computer Science, Software Engineering, University of Bremen
Authors: Haxthausen, A. E. (Intern), Peleska, J. (Ekstern)
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Pragmatics Annotated Coloured Petri Nets for Protocol Software Generation and Verification

PetriCode is a tool that supports automated generation of protocol software from a restricted class of Coloured Petri Nets (CPNs) called Pragmatics Annotated Coloured Petri Nets (PA-CPNs). Petri-Code and PA-CPNs have been designed with five main requirements in mind, which include the same model being used for verification and code generation. The PetriCode approach has been discussed and evaluated in earlier papers already. In this paper, we give a formal definition of PA-CPNs and demonstrate how the specific structure of PA-CPNs can be exploited for verification purposes.

General information
State: Published
Organisations: Department of Applied Mathematics and Computer Science, Software Engineering, Bergen University College
Authors: Fagerland Simonsen, K. I. (Ekstern), Kristensen, L. M. (Ekstern), Kindler, E. (Intern)
Pages: 79-98
Publication date: 2015
The Event Coordination Notation: Behaviour Modelling Beyond Mickey Mouse

The Event Coordination Notation (ECNO) allows modelling the desired behaviour of a software system on top of any object-oriented software. Together with existing technologies from Model-based Software Engineering (MBSE) for automatically generating the software for the structural parts, ECNO allows generating fully functional software from a combination of class diagrams and ECNO models. What is more, software generated from ECNO models, integrates with existing software and software generated by other technologies.

ECNO started out from some challenges in behaviour modelling and some requirements on behaviour modelling approaches, which we pointed out in a paper presented at the second BMFA workshop [1]; the integration with pre-
existing software was but one of these requirements.

Different ideas and concepts of ECNO have been presented before – mostly with neat and small examples, which exhibit one special aspect of ECNO or another; and it would be fair to call them “Mickey Mouse examples”.

In this paper, we give a concise overview of the motivation, ideas, and concepts of ECNO. More importantly, we discuss a larger system, which was completely generated from the underlying models: a workflow management system. This way, we demonstrate that ECNO can be used for modelling software beyond the typical Mickey Mouse examples. This example demonstrates that the essence of workflow management – including its behaviour – can be captured in ECNO: in a sense, it is a domain model of workflow management, from which a fully functioning workflow engine can be generated.
Transparent Model Transformation: Turning Your Favourite Model Editor into a Transformation Tool

Current model transformation languages are supported by dedicated editors, often closely coupled to a single execution engine. We introduce Transparent Model Transformation, a paradigm enabling modelers to specify transformations using a familiar tool: their model editor. We also present VMTL, the first transformation language implementing the principles of Transparent Model Transformation: syntax, environment, and execution transparency. VMTL works by weaving a transformation aspect into its host modeling language. We show how our implementation of VMTL turns any model editor into a flexible model transformation tool sharing the model editor’s benefits, transparently.

General information
State: Published
Organisations: Department of Applied Mathematics and Computer Science, Software Engineering, Philipps-Universität Marburg
Authors: Acretoaie, V. (Intern), Störrle, H. (Intern), Strüber, D. (Ekstern)
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Publication: Research - peer-review › Article in proceedings – Annual report year: 2015

A SysML Test Model and Test Suite for the ETCS Ceiling Speed Monitor: Technical report, Work Package 4

In this technical report a detailed model description of a train control system application is given. The application consists of the ceiling speed monitoring (CSM) function for the European Vital Computer which is the main onboard controller for trains conforming to the European Train Control System specification. The model is provided in SysML, and it is equipped with a formal semantics that is consistent with the (semi formal) SysML standard published by the Object Management Group (OMG). The model and its description are publicly available on http://www.mbt-benchmarks.de, a website dedicated to the publication of models that are of interest for the model-based testing (MBT) community, and may serve as benchmarks for comparing MBT tool capabilities. The model described here is of particular interest for analysing the capabilities of equivalence class testing strategies. The CSM application inputs velocity values from a domain which could not be completely enumerated for test purposes with reasonable effort. We describe a novel method for equivalence class testing that – despite the conceptually infinite cardinality of the input domains – is capable to produce finite test suites that are exhaustive under certain hypotheses about the internal structure of the system under test.

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State: Published
Organisations: Department of Applied Mathematics and Computer Science, Software Engineering, University of Bremen, University of Hamburg
Authors: Braunstein, C. (Ekstern), Peleska, J. (Ekstern), Schulze, U. (Ekstern), Hübner, F. (Ekstern), Huang, W. (Ekstern), Haxthausen, A. E. (Intern), Vu, L. H. (Intern)
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Publication: Research - peer-review › Article in proceedings – Annual report year: 2015
A Domain-Specific Language for Railway Interlocking Systems

This paper presents a domain-specific language (DSL) for describing route-based interlocking systems which are compatible with European Train Control System ETCS Level 2. The abstract syntax and static semantics of the language are formally defined using the RAISE Specification Language (RSL). Furthermore, the paper describes an interlocking table generator (ITG) that generates automatically a well-formed interlocking table from a well-formed railway network layout. Experiments with the DSL and ITG using the RAISE tools and the C++ implementation show that the use of the DSL and ITG can increase the productivity and significantly reduce errors in the specifications of railway interlocking systems.

General information
State: Published
Organisations: Department of Applied Mathematics and Computer Science, Software Engineering, University of Bremen
Authors: Vu, L. H. (Intern), Haxthausen, A. E. (Intern), Peleska, J. (Ekstern)
Pages: 200-209
Publication date: 2014

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Editors: Schnieder, E., Tarnai, G.
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Main Research Area: Technical/natural sciences
domain-specific languages, interlocking tables, validation and verification, railway signalling systems, formal methods
Source: PublicationPreSubmission
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Publication: Research - peer-review › Article in proceedings – Annual report year: 2014

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.

General information
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Organisations: Residual Resource Engineering, Department of Environmental Engineering, Department of Applied Mathematics and Computer Science, Software Engineering
Authors: Clavreul, J. (Intern), Baumeister, H. (Intern), Christensen, T. H. (Intern), Damgaard, A. (Intern)
Pages: 18-30
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Supplement info
An Evaluation of Automated Code Generation with the PetriCode Approach

Automated code generation is an important element of model driven development methodologies. We have previously proposed an approach for code generation based on Coloured Petri Net models annotated with textual pragmatics for the network protocol domain. In this paper, we present and evaluate three important properties of our approach: platform independence, code integratability, and code readability. The evaluation shows that our approach can generate code for a wide range of platforms which is integratable and readable.

General information
State: Published
Organisations: Department of Applied Mathematics and Computer Science, Software Engineering, Bergen University College
Authors: Simonsen, K. I. (Intern)
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Source-ID: 101106657
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An Index for Software Engineering Models

General information
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Organisations: Department of Applied Mathematics and Computer Science, Software Engineering, University of Augsburg, Sorbonne Universités
Authors: Störrle, H. (Intern), Hebig, R. (Ekstern), Knapp, A. (Ekstern)
Number of pages: 5
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Series: CEUR Workshop Proceedings
Volume: 1258
ISSN: 1613-0073
BFI conference series: Model Driven Engineering Languages and Systems (5000533)
Main Research Area: Technical/natural sciences
An Institution for Imperative RSL Specifications
The RAISE Specification Language (RSL) is a wide-spectrum specification language having a very complex semantics. This paper defines an institution for an imperative subset RSLI of RSL such that this subset can be given a much simpler semantics in terms of that institution. The subset allows model-oriented type definitions, declaration of state variables, axiomatic specification of values (including functions), and explicit function definitions. Functions may be imperative. The semantics of an RSLI specification is defined to be the loose semantics of a theory presentation consisting of a signature $\Sigma$ and a set of sentences $E$ that can easily be derived from the specification.

General information
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Organisations: Department of Applied Mathematics and Computer Science, Software Engineering
Authors: Haxthausen, A. E. (Intern)
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General information
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Organisations: Department of Applied Mathematics and Computer Science, Software Engineering, Iowa State University
Authors: Ciardo, G. (ed.) (Ekstern), Kindler, E. (ed.) (Intern)
Number of pages: 395
Publication date: 2014

Applied Bounded Model Checking for Interlocking System Designs
In this paper the verification and validation of interlocking systems is investigated. Reviewing both geographical and route-related interlocking, the verification objectives can be structured from a perspective of computer science into (1)
verification of static semantics, and (2) verification of behavioural (operational) semantics. The former checks that the plant model – that is, the software components reflecting the physical components of the interlocking system – has been set up in an adequate way. The latter investigates trains moving through the network, with the objective to uncover potential safety violations. From a formal methods perspective, these verification objectives can be approached by theorem proving, global, or bounded model checking. This paper explains the techniques for application of bounded model checking techniques, and discusses their advantages in comparison to the alternative approaches.

Automated generation of formal safety conditions from railway interlocking tables
This paper describes a tool for extracting formal safety conditions from interlocking tables for railway interlocking systems. The tool has been applied to generate safety conditions for the interlocking system at Stenstrup station in Denmark, and the SAL model checker tool has been used to check that these conditions were satisfied by a model of the relay circuits implementing the interlocking system at Stenstrup station.

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Organisations: Department of Applied Mathematics and Computer Science, Siemens
Authors: Haxthausen, A. E. (Intern), Peleska, J. (Ekstern), Pinger, R. (Ekstern)
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Complete Model-Based Equivalence Class Testing for the ETCS Ceiling Speed Monitor

In this paper we present a new test model written in SysML and an associated blackbox test suite for the Ceiling Speed Monitor (CSM) of the European Train Control System (ETCS). The model is publicly available and intended to serve as a novel benchmark for investigating new testing theories and comparing the capabilities of model-based test automation tools. The CSM application inputs velocity values from a domain which could not be completely enumerated for test purposes with reasonable effort. We therefore apply a novel method for equivalence class testing that, despite the conceptually infinite cardinality of the input domains, is capable to produce finite test suites that are complete (i.e. sound and exhaustive) for a given fault model. In this paper, an overview of the model and the equivalence class testing strategy is given, and tool-based evaluation results are presented. For the technical details we refer to the published model and a technical report that is also available on the same website.

General information
State: Published
Organisations: Department of Applied Mathematics and Computer Science, Software Engineering, University of Bremen
Authors: Braunstein, C. (Ekstern), Haxthausen, A. E. (Intern), Huang, W. (Ekstern), Hübner, F. (Ekstern), Peleska, J. (Ekstern), Schulze, U. (Ekstern), Vu, L. H. (Intern)
Pages: 380-395
Publication date: 2014
Coordinating Interactions: The Event Coordination Notation

The purpose of a domain model is to concisely capture the concepts of an application's domain, and their relation among each other. Even though the main purpose of domain models is not on implementing the application, major parts of an application can be generated from the application’s domain models fully automatically with today’s technologies. The focus of today's code generation technologies, however, is mostly on the structural aspects of the domain; the domain’s behaviour is often not modelled at all, or implemented manually based on some informal models, or the behaviour is modelled on a much more technical level.

The Event Coordination Notation (ECNO) allows modelling the behaviour of an application on a high level of abstraction that is closer to the application's domain than to the software realizing it. Still, these models contain all necessary details for actually executing the models and for generating code from them. In order to be able to model the behaviour of a domain, the ECNO makes the events in which the different elements of the domain could engage explicit. The local behaviour of an element defines at which time an element can engage or participate in an event. The global behaviour of the application results from different elements jointly engaging in such events, which is called an interaction. Which events are supposed to be jointly executed and which elements need to join in is defined by so-called coordination diagrams of the ECNO. Together, the models for the local and the global behaviour define the overall behaviour of the domain.

In this technical report, we discuss the main idea and philosophy of ECNO and its notation as well as all the subtle details and concepts - and we motivate the decisions made for its design. Moreover, we discuss the prototypical implementation of ECNO, which consists of a modelling environment based on Eclipse and the Eclipse Modeling Framework (EMF) and an execution engine, which fully supports all the concepts and features of ECNO discussed in this technical report. All the examples are based on EMF, but the ECNO Engine can be used with different other platforms or object-oriented code across different platforms, once some adapters are provided. Though the focus of this technical report is on the general concepts of ECNO, the examples discussed here work for version 0.3.2 of the ECNO Tool and Framework. The ECNO Tool as well as the examples are available from the ECNO Home page: http://www2.imm.dtu.dk/~ekki/projects/ECNO/.
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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Authors: Zarrin, B. (Intern), Baumeister, H. (Intern)
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Source-ID: 110883488
Publication: Research - peer-review › Article in proceedings – Annual report year: 2015

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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Organisations: Department of Environmental Engineering, Residual Resource Engineering, Department of Applied Mathematics and Computer Science, Software Engineering
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Publication: Research - peer-review › Conference abstract in proceedings – Annual report year: 2014
Efficient Representation of Timed UML 2 Interactions

UML 2 interactions describe system behavior over time in a declarative way. The standard approach to defining their formal semantics enumerates traces of events; other representation formats, like Büchi automata or prime event structures, have been suggested, too. We describe another, more succinct format, interaction structures, which is based on asymmetric event structures. It simplifies the integration of real time, and complex operators like alt and break, and leads to an efficient semantic representation of interactions. We provide the formalism, and a prototypical implementation highlighting the benefits of our approach.
Formal Modeling and Verification of Interlocking Systems Featuring Sequential Release

In this paper, we present a method and an associated tool suite for formal verification of the new ETCS level 2 based Danish railway interlocking systems. We have made a generic and reconfigurable model of the system behavior and generic high-level safety properties. This model accommodates sequential release - a feature in the new Danish interlocking systems. The generic model and safety properties can be instantiated with interlocking configuration data, resulting in a concrete model in the form of a Kripke structure, and in high-level safety properties expressed as state invariants. Using SMT based bounded model checking (BMC) and inductive reasoning, we are able to verify the properties for model instances corresponding to railway networks of industrial size. Experiments also show that BMC is efficient for finding bugs in the railway interlocking designs.

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Publication: Research - peer-review › Article in proceedings – Annual report year: 2014

Formal Verification of the Danish Railway Interlocking Systems

In this paper, we present a method for formal verification of the new Danish railway interlocking systems. We made a generic and reconfigurable model of the behaviors and high-level safety properties of non-collision and nonderailment. This model accommodates sequential release – a new feature in the new Danish interlocking systems. Instantiating the generic model with interlocking configuration data results in a concrete model and high-level safety properties. Using bounded model checking and inductive reasoning, we are able to verify safety properties for model instances corresponding to railway networks of industrial size.

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Authors: Vu, L. H. (Intern), Haxthausen, A. E. (Intern), Peleska, J. (Ekstern)
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Editors: Huisman, M., van de Pol, J.
Series: C T I T Workshop Proceedings Series
Number: WP 14-01
ISSN: 1574-0846
Main Research Area: Technical/natural sciences
From Pen-and-Paper Sketches to Prototypes: The Advanced Interaction Design Environment
Pen and paper is still the best tool for sketching GUIs. However, sketches cannot be executed, at best we have facilitated or animated scenarios. The Advanced User Interaction Environment facilitates turning hand-drawn sketches into executable prototypes.

Hypersonic: Model Analysis and Checking in the Cloud
Context: Modeling tools are traditionally delivered as monolithic desktop applications, optionally extended by plug-ins or special purpose central servers. This delivery model suffers from several drawbacks, ranging from poor scalability to difficult maintenance and the proliferation of 'shelfware'. Objective: In this paper we investigate the conceptual and technical feasibility of a new software architecture for modeling tools, where certain advanced features are factored out of the client and moved towards the Cloud. With this approach we plan to address the above mentioned drawbacks of existing modeling tools.
Method: We base our approach on RESTful Web services. Using features implemented in the existing Model Analysis and Checking (MACH) tool, we create a RESTful Web service API offering model analysis facilities. We refer to it as the Hypersonic API. We provide a proof of concept implementation for the Hypersonic API using model clone detection as our example case. We also implement a sample Web application as a client for these Web services.
Results: Our initial experiments with Hypersonic demonstrate the viability of our approach. By applying standards such as REST and JSON in combination with Prolog as an implementation language, we are able to transform MACH from a command line tool into the first Web-based model clone detection service with remarkably little effort.
Hypersonic - Model Analysis as a Service
Hypersonic is a Cloud-based tool that proposes a new approach to the deployment of model analysis facilities. It is implemented as a RESTful Web service API offering analysis features such as model clone detection. This approach allows the migration of resource intensive analysis algorithms from monolithic desktop modeling tools to a wide range of mobile and Web-based clients. As a technology demonstrator, a Web application acting as a client for the Hypersonic API has been implemented and made publicly available.

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Organisations: Department of Applied Mathematics and Computer Science, Software Engineering
Authors: Acretoaie, V. (Intern), Störrle, H. (Intern)
Number of pages: 5
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Publication date: 2014

Implementing the WebSocket Protocol Based on Formal Modelling and Automated Code Generation
Model-based software engineering offers several attractive benefits for the implementation of protocols, including automated code generation for different platforms from design-level models. In earlier work, we have proposed a template-based approach using Coloured Petri Net formal models with pragmatic annotations for automated code generation of protocol software. The contribution of this paper is an application of the approach as implemented in the PetriCode tool to obtain protocol software implementing the IETF WebSocket protocol. This demonstrates the scalability of our approach to
real protocols. Furthermore, we perform formal verification of the CPN model prior to code generation, and test the implementation for interoperability against the Autobahn WebSocket test-suite resulting in 97% and 99% success rate for the client and server implementation, respectively. The tests show that the cause of test failures were mostly due to local and trivial errors in newly written code-generation templates, and not related to the overall logical operation of the protocol as specified by the CPN model.

**General information**
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Organisations: Department of Applied Mathematics and Computer Science, Software Engineering, Bergen University College
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**Modelling Requirements with RED**

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Organisations: Department of Applied Mathematics and Computer Science, Software Engineering
Authors: Störrle, H. (Intern)
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Series: CEUR Workshop Proceedings
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On the Impact of Diagram Layout: How Are Models Actually Read?
This poster presents the latest results from a very large eye tracking study (n=29) that explores how modelers read UML diagrams. We find that various factors like layout quality, modeler experience, and diagram type lead to significant differences in diagram reading strategies. We derive elements of a theory of diagram reading behavior from our findings. This paper presents only late breaking results: all findings presented, theories constructed, and conclusions drawn are of a preliminary nature. This paper does not present the amount and degree of evidence that would allow us to consider the contents as being scientifically validated, yet.

General information
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Organisations: Department of Applied Mathematics and Computer Science , Software Engineering, Department of Management Engineering, Production and Service Management, Engineering Systems Group, Technical University of Denmark
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On the Impact of Layout Quality to Understanding UML Diagrams: Size Matters
Practical experience suggests that usage and understanding of UML diagrams is greatly affected by the quality of their layout. While existing research failed to provide conclusive evidence in support of this hypothesis, our own previous work provided substantial evidence to this effect. When studying different factors like diagram type and expertise level, it became apparent that diagram size plays an important role, too. Since we lack an adequate understanding of this notion, in this paper, we define diagram size metrics and study their impact to modeler performance. We find that there is a strong negative correlation between diagram size and modeler performance. Our results are highly significant. We utilize these results to derive a recommendation on diagram sizes that are optimal for model understanding.

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Organisations: Department of Applied Mathematics and Computer Science , Software Engineering
Authors: Störrle, H. (Intern)
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Publisher: Springer
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ISBN (Print): 978-3-319-11652-5
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PetriCode: A Tool for Template-Based Code Generation from CPN Models

Code generation is an important part of model driven methodologies. In this paper, we present PetriCode, a software tool for generating protocol software from a subclass of Coloured Petri Nets (CPNs). The CPN subclass is comprised of hierarchical CPN models describing a protocol system at different levels of abstraction. The elements of the models are annotated with code generation pragmatics enabling PetriCode to use a template-based approach to generate code while keeping the models uncluttered from implementation artefacts. PetriCode is the realization of our code generation approach which has been described in previous works.

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State: Published
Organisations: Department of Applied Mathematics and Computer Science, Software Engineering, Bergen University College
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Pragmatics Annotated Coloured Petri Nets for Protocol Software Generation and Verification

This paper presents the formal definition of Pragmatics Annotated Coloured Petri Nets (PA-CPNs). PA-CPNs represent a class of Coloured Petri Nets (CPNs) that are designed to support automated code generation of protocol software. PA-CPNs restrict the structure of CPN models and allow Petri net elements to be annotated with so-called pragmatics, which are exploited for code generation. The approach and tool for generating code is called PetriCode and has been discussed and evaluated in earlier work already. The contribution of this paper is to give a formal definition for PA-CPNs; in addition, we show how the structural restrictions of PA-CPNs can be exploited for making the verification of the modelled protocols more efficient. This is done by automatically deriving progress measures for the sweep-line method, and by introducing so-called service testers, that can be used to control the part of the state space that is to be explored for verification purposes.

General information
State: Published
Organisations: Department of Applied Mathematics and Computer Science, Software Engineering, Bergen University College
Ranking Entities in Networks via Lefschetz Duality

In the theory of communication it is essential that agents are able to exchange information. This fact is closely related to the study of connected spaces in topology. A communication network may be modelled as a topological space such that agents can communicate if and only if they belong to the same path connected component of that space. In order to study combinatorial properties of such a space, notions from algebraic topology are applied. This makes it possible to determine the shape of a network by concrete invariants, e.g. the number of connected components. Elements of a network may then be ranked according to how essential their positions are in the network by considering the effect of their respective absences. Defining a ranking of a network which takes the individual position of each entity into account has the purpose of assigning different roles to the entities, e.g. agents, in the network. In this paper it is shown that the topology of a given network induces a ranking of the entities in the network. Further, it is demonstrated how to calculate this ranking and thus how to identify weak sub-networks in any given network.

General information
State: Published
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Publication: Research › Report – Annual report year: 2014
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Organisations: Department of Applied Mathematics and Computer Science, Software Engineering, Queensland University of Technology, Technion-Israel Institute of Technology
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Scopus rating (2010): SJR 0.907 SNIP 2.251
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Scopus rating (2008): SJR 1.401 SNIP 3.091
Scopus rating (2006): SJR 1.099 SNIP 2.734
The CDIO concept is now well integrated into many curricula at universities around the world and it has meant an increase in the quality of engineering education. However, the main focus has been on design-build projects and less on the ‘C’ and ‘O’ part.

In particular, the ‘O’ part of CDIO has received very little focus, since this is probably the most difficult part to implement in a university environment.

Because of this observation, in 2011 we decided to launch a new elective course, ‘Testing and deployment of software systems (in practice)’, focusing entirely on the ‘O’ part in CDIO.

The aim of this paper is to describe:
• the unified software development process and compare this with CDIO.
• the activities covering the ‘O’ part in software engineering.
• the course structure and schedule.
• the evaluations and comments received from students.

The paper concludes that:
It is possible to give students a realistic experience of the ‘O’ phase of CDIO. The prerequisite for this is that the course’s entry level is a working prototype.
It is very important to identify an actor outside the university, which can act as a client (customer). This gives the students a more realistic environment.
The course also prepares the students for meetings with industry, taking place in the 6th semester, during the students’ internship and later in the exam project in the 7th semester.

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The Requirements Editor RED
Towards a model-based development approach for wireless sensor-actuator network protocols

Model-Driven Software Engineering (MDSE) is a promising approach for the development of applications, and has been well adopted in the embedded applications domain in recent years. Wireless Sensor Actuator Networks consisting of resource constrained hardware and platform-specific operating system is one application area where the advantages of MDSE can be exploited. Code-generation is an integral part of MDSE, and using a multi-platform code generator as a part of the approach has several advantages. Due to the automated code-generation, it is possible to obtain time reduction and prevent errors induced due to manual translations. With the use of formal semantics in the modeling approach, we can further ensure the correctness of the source model by means of verification. Also, with the use of network simulators and formal modeling tools, we obtain a verified and validated model to be used as a basis for code-generation. The aim is to build protocols with shorter design to implementation time and efforts, along with higher confidence in the protocol designed.

Towards Diagram Understanding: A Pilot Study Measuring Cognitive Workload Through Eye-Tracking

We investigate model understanding, in particular, how the quality of the UML diagram layout impacts cognitive load. We hypothesize that this will have a significant impact on the structure and effectiveness of engineers’ communication. In
previous work, we have studied task performance measurements and subjective assessments; here, we also investigate
behavioral indicators such as fixation and pupillary dilation. We use such indicators to explore diagram understanding- and
reading strategies and how such strategies are impacted, e.g. by diagram type and expertise level. In the pilot eye-
tracking experiment run so far, we have only examined a small number of participants (n=4), so our results are preliminary
in nature and do not afford far reaching conclusions. They do, however, corroborate findings from earlier experiments, for
example, showing that layout quality indeed matters and improves understanding. Our results also give rise to a number of
new hypotheses about diagram understanding strategies that we are investigating in an ongoing data acquisition
campaign.

General information
State: Published
Organisations: Department of Management Engineering, Production and Service Management, Engineering Systems
Group, Department of Applied Mathematics and Computer Science , Software Engineering, Technical University of
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Applied Bounded Model Checking for Interlocking System Designs
In this article the verification and validation of interlocking systems is investigated. Reviewing both geographical and route-
related interlocking, the verification objectives can be structured from a perspective of computer science into (1)
verification of static semantics, and (2) verification of behavioural (operational) semantics. The former checks that the
plant model – that is, the software components reflecting the physical components of the interlocking system – has been
set up in an adequate way. The latter investigates trains moving through the network, with the objective to uncover
potential safety violations. From a formal methods perspective, these verification objectives can be approached by
theorem proving, global, or bounded model checking. This article explains the techniques for application of bounded
model checking techniques, and discusses their advantages in comparison to the alternative approaches.
A Rigorous Methodology for Analyzing and Designing Plug-Ins

Today, GUI plug-ins development is typically done in a very ad-hoc way, where developers dive directly into implementation. Without any prior analysis and design, plug-ins are often flaky, unreliable, difficult to maintain and extend with new functionality, and have inconsistent user interfaces. This paper addresses these problems by describing a rigorous methodology for analyzing and designing plug-ins. The methodology is grounded in the Extended Business Object Notation (EBON) and covers informal analysis and design of features, GUI, actions, and scenarios, formal architecture design, including behavioral semantics, and validation. The methodology is illustrated via a case study whose focus is an Eclipse environment for the RAISE formal method's tool suite.

A simulator for high-level Petri nets: An ePNK application

The ePNK is a platform for Petri net tools based on the PNML transfer format. One of its important features is its extensibility, which allows developers to plug in new Petri net types and new functions and applications for different kinds of Petri nets. The basic version of the ePNK provides an editor for high-level Petri nets, but no analysis or simulation functionality. In this paper, we present a simulator for high-level Petri nets, which supports most of the built-in operators of ISO/IEC 15909-2. As an additional feature, this simulator allows the simulation of so-called network algorithms. In this paper, we briefly show how to use this simulator from the end user's point of view. Moreover, we discuss some of the concepts underlying this simulator and its implementation.
Code Generation for Protocols from CPN models Annotated with Pragmatics

Model-driven engineering (MDE) provides a foundation for automatically generating software based on models. Models allow software designs to be specified focusing on the problem domain and abstracting from the details of underlying implementation platforms. When applied in the context of formal modelling languages, MDE further has the advantage that models are amenable to model checking which allows key behavioural properties of the software design to be verified. The combination of formally verified models and automated code generation contributes to a high degree of assurance that the resulting software implementation satisfies the properties verified for the model. Coloured Petri Nets (CPNs) have been widely used to model and verify protocol software, but limited work exists on using CPN models of protocol software as a basis for automated code generation. In this report, we present an approach for generating protocol software from a restricted class of CPN models. The class of CPN models considered aims at being descriptive in that the models are intended to be helpful in understanding and conveying the operation of the protocol. At the same time, a descriptive model is close to a verifiable version of the same model and sufficiently detailed to serve as a basis for automated code generation when annotated with code generation pragmatics. Pragmatics are syntactical annotations designed to make the CPN models descriptive and to address the problem that models with enough details for generating code from them tend to be verbose and cluttered. Our code generation approach consists of three main steps, starting from a CPN model that the modeller has annotated with a set of pragmatics that make the protocol structure and the control-flow explicit. The first step is to compute for the CPN model, a set of derived pragmatics that identify control-flow structures and operations, e.g., for sending and receiving packets, and for manipulating the state. In the second step, an abstract template tree (ATT) is constructed providing an association between pragmatics and code generation templates. The ATT then directs the code generation in the third step by invoking the code templates associated with each node of the ATT in order to generate code. We illustrate our approach using an example of a unidirectional data framing protocol.
Compositional Synthesis of Controllers from Scenario-Based Assume-Guarantee Specifications

Modern software-intensive systems often consist of multiple components that interact to fulfill complex functions in sometimes safety-critical situations. During the design, it is crucial to specify the system's requirements formally and to detect inconsistencies as early as possible in order to avoid flaws in the product or costly iterations during its development.

We propose to use Modal Sequence Diagrams (MSDs), a formal, yet intuitive formalism for specifying the interaction of a system with its environment, and developed a formal synthesis approach that allows us to detect inconsistencies and even to automatically synthesize controllers from MSD specifications. The technique is suited for specifications of technical systems with real-time constraints and environment assumptions. However, synthesis is computationally expensive. In order to employ synthesis also for larger specifications, we present, in this paper, a novel assume-guarantee-style compositional synthesis technique for MSD specifications. We provide evaluation results underlining the benefit of our approach and formally justify its correctness.

Efficient Development and Verification of Safe Railway Control Software

In this book, the authors present current research on the types, design and safety issues of railways. Topics discussed include the acoustic characteristics of noise in train stations; monitoring railway structure conditions and opportunities to use wireless sensor networks as tools to improve the monitoring process; hydraulic absorbers as dampers to dissipate the energy of oscillations in railway electric equipment; development of train fare calculation and adjustment systems using VDM++; efficient development and verification of safe railway control software; and evolution of the connectivity of the Portuguese broad gauge railway network (1948-2012).

Efficient Development and Verification of Safe Railway Control Software

In this book, the authors present current research on the types, design and safety issues of railways. Topics discussed include the acoustic characteristics of noise in train stations; monitoring railway structure conditions and opportunities to use wireless sensor networks as tools to improve the monitoring process; hydraulic absorbers as dampers to dissipate the energy of oscillations in railway electric equipment; development of train fare calculation and adjustment systems using VDM++; efficient development and verification of safe railway control software; and evolution of the connectivity of the Portuguese broad gauge railway network (1948-2012).
Formal Development and Verification of Railway Control Systems

This paper presents work package WP4.1 of the RobustRails research project. The work package aims at suggesting a methodology for efficient development and verification of safe and robust railway control systems.

1 Project background and state of the art

Over the next 10 years all Danish railway signalling systems are going to be completely replaced with modern, computer based railway control systems based on the European standard ERTMS/ETCS [3, 4] by the Danish Signaling Programme [1]. The purpose of these systems is to control the railway traffic such that unsafe situations, like train collisions, are avoided. Central parts of these new systems consist of safety-critical software the functional correctness of which is one of the key requisites for a reliable operation of the traffic and in particular for the safety of passengers. Until now the development of railway control software has typically been done applying conventional methods where requirements and designs are described using natural language, diagrams and pseudo code, and the verification of requirements has been done by code inspection and non-exhaustive testing. These techniques are not sufficient, leading to errors and an ineffective and costly development process. The railway sector and in particular Rail Net Denmark (Banedanmark) therefore call for improved software development methods.

2 Original contribution and expected results

In order to avoid the problems mentioned in previous section, it is strongly recommended by the CENELEC standards [2] for railways to use formal (i.e. mathematical) logic and models for the unambiguous description of requirements and designs as well as for exhaustive verification as they give a higher assurance of safety compared to conventional methods. The use of domain-specific methods is another trend in software development, suggested to make the construction of software more efficient by generating the software automatically from domain-specific descriptions. Hence, to combine these two approaches is expected to be very attractive. The project will examine how domain-specific methods and formal methods can be combined and used for an efficient development and verification of new fail-safe systems. The expected result is a methodology for using domain-specific, formal languages, techniques and tools for more efficient development and verification of robust software for railway control systems. The hypothesis is that domain-specific, model-based system development methods will lead to a more efficient construction with fewer errors and these errors will be found earlier in the system development.

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General information

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Formal Model-Based Validation for Tally Systems

Existing commercial and open source e-voting systems have horrifically poor testing frameworks. Most tally systems, for example, are tested by re-running all past elections and seeing if the new system gives the same answer as an older, perhaps erroneous, system did. This amounts to a few dozen system tests and, typically, few-to-no unit tests. These systems are used today in a dozen countries to determine the outcome of national elections. This state-of-affairs cannot continue because it calls into question the legitimacy of elections in major European and North American democracies. In this work, the ballot counting process for one of the most complex electoral schemes used in the world, Proportional Representation by Single Transferable Vote (PR-STV), is mechanically formally modeled. The purpose of such a formalization is to generate, using an algorithm of our design, a complete set of non-isomorphic test cases per electoral scheme, once and for all. Using such a system test suite, any digital election technology (proprietary or open source) can be rigorously evaluated for correctness. Doing so will vastly improve the confidence experts have-and can only improve the level of trust citizens have-in these digital elections systems.

General information
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Publication: Research - peer-review › Article in proceedings – Annual report year: 2013
Generating Protocol Software from CPN Models Annotated with Pragmatics

Model-driven software engineering (MDSE) provides a foundation for automatically generating software based on models that focus on the problem domain while abstracting from the details of underlying implementation platforms. Coloured Petri Nets (CPNs) have been widely used to formally model and verify protocol software, but limited work exists on using CPN models of protocols as a basis for automated code generation. The contribution of this paper is a method for generating protocol software from a class of CPN models annotated with code generation pragmatics. Our code generation method consists of three main steps: automatically adding so-called derived pragmatics to the CPN model, computing an abstract template tree, which associates pragmatics with code templates, and applying the templates to generate code which can then be compiled. We illustrate our method using a unidirectional data framing protocol.

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Publication: Research - peer-review › Article in proceedings – Annual report year: 2013

How Do Developers Use APIs? A Case Study in Concurrency

With the omnipresent usage of APIs in software development, it has become important to analyse how the routines and functionalities of APIs are actually used. This information is in particular useful for API developers, to make decisions about future updates of the API. However, also for developers of static analysis and verification tools this information is highly important, because it indicates where and how to put the most efficient effort in annotating APIs, to make them usable for the static analysis and verification tools. This paper presents an analysis of the usage of the routines and functionalities of the Java concurrency library java.util.concurrent. It discusses the Histogram tool that we developed for this purpose, i.e., to efficiently analyse a large collection of bytecode classes. The Histogram tool is used on a representative benchmark set, the Qualitas Corpus. The paper discusses the results of the analysis of this benchmark set in detail. This covers both an analysis of the important classes and methods used by the current releases of the benchmark collection, as well as an analysis of the time it took for the Java concurrency library to start being used in released software.

General information
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Organisations: Department of Applied Mathematics and Computer Science, Software Engineering, University of Twente
Authors: Blom, S. (Ekstern), Kiniry, J. (Intern), Huisman, M. (Ekstern)
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Main Research Area: Technical/natural sciences
Improving modeling with layered UML diagrams
Layered diagrams are diagrams whose elements are organized into sets of layers. Layered diagrams are routinely used in many branches of engineering, except Software Engineering. In this paper, we propose to add layered diagrams to UML modeling tools, and elaborate the concept by exploring usage scenarios. We validate the concept by implementation, lab assessments, and field testing. We conclude that layers enhance and complement conventional diagrams and model structuring techniques, are easy to add to existing modeling infrastructure, and are easy to apply to modelers.

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Organisations: Department of Applied Mathematics and Computer Science, Software Engineering
Authors: Störrle, H. (Intern)
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Source: dtu
Source-ID: n::oai:DTIC-ART:compendex/387417477::28879
Publication: Research - peer-review › Article in proceedings – Annual report year: 2013

Improving the Usability of OCL as an Ad-hoc Model Querying Language
The OCL is often perceived as difficult to learn and use. In previous research, we have defined experimental query languages exhibiting higher levels of usability than OCL. However, none of these alternatives can rival OCL in terms of adoption and support. In an attempt to leverage the lessons learned from our research and make it accessible to the OCL community, we propose the OCL Query API (OQAPI), a library of query-predicates to improve the user-friendliness of OCL for ad-hoc querying. The usability of OQAPI is studied using controlled experiments. We find considerable evidence to support our claim that OQAPI facilitates user querying using OCL.

General information
State: Published
Organisations: Department of Applied Mathematics and Computer Science, Software Engineering
Authors: Störrle, H. (Intern)
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Conference: 13th International Workshop on OCL, Model Constraint and Query Languages (OCL 2013), Miami, Florida, United States, 30/09/2013
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MQ-2b-OQAPI.pdf
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http://ceur-ws.org/Vol-1092/
Source: dtu
Source-ID: u::10239
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Integrating Intelligent Electric Devices into Distributed Energy Resources in a Cloud-Based Environment
Until now the main purpose of Distributed Energy Resources (DERs) has been to compliment the power plants. However, if DERs are to play a larger role in the power grid of the future, then improved communication and cooperation between these resources and the system operators is necessary. Cooperation requires intelligence at the level of the DER as well as at the aggregator level, and in order to efficiently facilitate this, communication must be easily achievable.

This project presents a proof-of-concept plug-and-play cloud solution for next generation DERs, built upon the IEC 61850[15] standard, that enable easy communication and cooperation between DERs and system operators.

General information
State: Published
Organisations: Department of Electrical Engineering, Center for Electric Power and Energy, Department of Applied Mathematics and Computer Science, Software Engineering, Energy system operation and management, Technical University of Denmark
Authors: Petersen, B. S. (Intern), Winther, D. (Ekstern), Pedersen, A. B. (Intern), Poulsen, B. (Intern), Træholt, C. (Intern)
Number of pages: 5
Publication date: 2013

Intelligent Electric Vehicle Integration - Domain Interfaces and Supporting Informatics
This thesis seeks to apply the field of informatics to the intelligent integration of electric vehicles into the power system. The main goal is to release the potential of electric vehicles in relation to a reliable, economically efficient power system based on renewables. To make intelligent EV integration a reality, it is prudent to understand the domain in its entirety. In this thesis, this is reflected by a thorough investigation of the stakeholders most relevant to the synergistic relationship between electric vehicle and grid. The first investigation addresses the power market. The market can give system operators access to the flexibility of electric vehicles while at the same time creating an immediate economic incentive for the EV owner. A fleet operator is introduced to allow a fleet of electric vehicles to participate in the markets. Examples are provided on the specific markets and services in which the electric vehicle may be best suited to participate. The next stakeholder investigated is the distribution system operator representing the low voltage grid. The challenge is assessed by considering a number of grid impacts studies. Next, a set of grid congestion mitigation strategies are proposed with a special attention to the impact that congestion would have on the operation of a fleet operator. The third and most important stakeholder is the electric vehicle owner. The emphasis is on the plug in patterns of a number of Danish electric vehicle drivers. The objective is to understand how owner behavior will influence charging flexibility. It is indicated how plug in behavior may be predicted and how the resulting flexibility may be applied to achieve several different goals. After having investigated the aims, constraints and requirements for the above stakeholders, the attention, in the second part of the thesis, is turned to three vital topics within the field of informatics. The first topic is the control architecture that determines the placement and relationship between control systems used to control electric vehicle charging. A centralised market-based architecture is chosen and the functionalities needed by the control logic are demanded. The next informatics topic, communication, describes a set of protocols and standards applicable for electric vehicle integration. The study investigates the IEC 61850 standard and its ability to support smart charging. Finally it is described how considerations to each of the stakeholders can be included in the optimization done by the fleet operator. It is shown how different markets can be considered and how stochastic optimization can be used to model uncertainty in regards to plug in behavior and grid congestion. A large part of the above work have been done as contributions to the EDISON project in which the Thesis Author has participated. During the project the author has built a technical platform for testing several of the technologies mentioned above, against a small fleet of electric vehicles. This thesis is meant as an input for market players, system operators, fleet operators, fellow researchers and anyone with an interest in the role of the electric vehicle in the future power system.

General information
State: Published
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 matrices 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.
**Making sense to modelers: Presenting UML class model differences in prose**

Understanding the difference between two models, such as different versions of a design, can be difficult. It is a commonly held belief in the model differencing community that the best way of presenting a model difference is by using graph or tree-based visualizations. We disagree and present an alternative approach where sets of low-level model differences are abstracted into high-level model differences that lend themselves to being presented textually. This format is informed by an explorative survey to elicit the change descriptions modelers use themselves. Our approach is validated by a controlled experiment that tests three alternatives to presenting model differences. Our findings support our claim that the approach presented here is superior to EMF Compare.

**MOCQL: A Declarative Language for Ad-Hoc Model Querying**

This paper starts from the observation that existing model query facilities are not easy to use, and are thus not suitable for users without substantial IT/Computer Science background. In an attempt to highlight this issue and explore alternatives, we have created the Model Constraint and Query Language (MOCQL), an experimental declarative textual language to express queries (and constraints) on models. We introduce MOCQL by examples and its grammar, evaluate its usability by means of controlled experiments, and find that modelers perform better and experience less cognitive load when working with MOCQL than when working with OCL. While MOCQL is currently only implemented and validated for the different notations defined by UML, its concepts should be universally applicable.
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 numberlists. 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.

PetriCode: A Tool for Template-based Code Generation from CPN Models

Code generation is an important part of model driven methodologies. In this paper, we present PetriCode, a software tool for generating protocol software from a subclass of Coloured Petri Nets (CPNs) that is the realization of previous work [17, 19, 18]. The CPN subclass is comprised of hierarchical CPN models describing a protocol system at different levels of abstraction. The elements of the models are annotated with code generation pragmatics enabling PetriCode to use a template based approach to generate code while keeping the models uncluttered.
**Querying Business Process Models with VMQL**

The Visual Model Query Language (VMQL) has been invented with the objectives (1) to make it easier for modelers to query models effectively, and (2) to be universally applicable to all modeling languages. In previous work, we have applied VMQL to UML, and validated the first of these two claims. In this paper, we apply VMQL to the Business Process Modeling Notation (BPMN) to evaluate the second claim. We explore the adaptations required, and re-evaluate the usability of VMQL in this context. We find similar results to earlier work, thus both supporting our claims and establishing the usability of VMQL beyond the realm of UML.

**General information**

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Authors: Störrle, H. (Intern), Acretoaie, V. (Intern)  
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Model Querying, VMQL, BPMN, OCL, UML, Model Repositories  
DOIs: 10.1145/2492437.2492441  
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Source-ID: u::8264  
Publication: Research - peer-review › Article in proceedings – Annual report year: 2013

**Simulation Tool For Energy Consumption and Production: The development of a simulation tool for measuring the impact of a smart grid on a building**

In order to promote adoption of smart grid with the general public it is necessary to be able to visualize the benefits of a smart home. Software tools that model the effects can help significantly with this. However, only little work has been done in the area of simulating and visualizing the energy consumption in smart homes. This paper presents a prototype simulation tool that allows graphical modeling of a home. Based on the modeled homes the user is able to simulate the energy consumptions and compare scenarios. The simulations are based on dynamic weather and energy price data as well as a controller unit of the user’s choice. The results of the simulations can be compared using a dynamic reporting window that allows the user to create custom charts of the data. The application has been designed such that it can easily be extended with additional controller units, price and weather data as well as appliances and other electrical components used in the modeled homes.

**General information**

State: Published  
Organisations: Department of Applied Mathematics and Computer Science, Software Engineering, Department of Electrical Engineering, Center for Electric Power and Energy, Technical University of Denmark  
Authors: Nysteen, M. (Ekstern), Mynderup, H. (Ekstern), Poulsen, B. (Intern), Træholt, C. (Intern)  
Number of pages: 8  
Publication date: 2013

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Source: dtu  
Source-ID: u::10020  
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**SmartNursing - a mobile application to improve communication in home care**

This paper presents SmartNursing system and discusses how increasing capabilities of smartphone could benefit employees in working environment. A SmartNursing system is developed for home nurses working environment to fulfil
their needs. The solution helps to improve communication among nurses, provide customized information and increase work efficiency. Developed system consists of mobile application, web based server and database. This article discusses the solution SmartNursing from design to implementation.

**General information**
State: Published
Organisations: Department of Applied Mathematics and Computer Science, Software Engineering, Technical University of Denmark
Authors: Nyborg, M. (Intern), Bashir, K. (Ekstern), Maknickaite, A. (Ekstern)
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Home nursing, Public health, Mobile application, Web server

Electronic versions:
Telemed2013SmartNursing.pdf
Source: dtu
Source-ID: u::9072
Publication: Research - peer-review › Article in proceedings – Annual report year: 2013

**The Overture Approach to VDM Language Evolution**
The Overture Language Board (LB) has a strategic role in the development of the VDM-10 Languages, VDM-SL, VDM++ and VDM-RT, and deals in particular with Requests for Modifications (RMs) to the language. Such requests come usually from participants in the Overture project. This paper describes how the LB uses a well-defined process with several phases to deal with the RMs, from when they are requested until they are either rejected or accepted and implemented. The paper also gives an overview of language changes that have been accepted and implemented in the period April 2009 – June 2013.

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Organisations: Department of Applied Mathematics and Computer Science, Software Engineering
Authors: Battle, N. (Ekstern), Haxthausen, A. E. (Intern), Hiroshi, S. (Ekstern), Jørgensen, P. (Ekstern), Plat, N. (Ekstern), Sahara, S. (Ekstern), Verhoef, M. (Ekstern)
Pages: 8-15
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Workshop: 11th Overture Workshop, Aarhus, Denmark, 28/08/2013 - 28/08/2013
VDM, Formal specification languages, Language design, Language modification process, The Overture Language Board
Source: Bibtex
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Publication: Research - peer-review › Article in proceedings – Annual report year: 2013

**Towards a CPN-Based Modelling Approach for Reconciling Verification and Implementation of Protocol Models**
Formal modelling of protocols is often aimed at one specific purpose such as verification or automatically generating an implementation. This leads to models that are useful for one purpose, but not for others. Being able to derive models for verification and implementation from a single model is beneficial both in terms of reduced total modelling effort and confidence that the verification results are valid also for the implementation model. In this paper we introduce the concept of a descriptive specification model and an approach based on refining a descriptive model to target both verification and implementation. Our approach has been developed in the context of the Coloured Petri Nets (CPNs) modelling language. We illustrate our approach by presenting a descriptive specification model of the Websocket protocol which is currently under development by the Internet Engineering Task Force (IETF), and we show how this model can be refined to target both verification and implementation.

**General information**

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Authors: Störrle, H. (Intern), Fish, A. (Forskerdatabase)
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Number: 20
ISSN: 1601-2321
Main Research Area: Technical/natural sciences
Electronic versions:
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Publication: Research › Report – Annual report year: 2013

Towards an Operationalization of the "Physics of Notations" for the Analysis of Visual Languages

We attempt to validate the conceptual framework "Physics of Notation" (PoN) as a means for analysing visual languages by applying it to UML Use Case Diagrams. We discover that the PoN, in its current form, is neither precise nor comprehensive enough to be applied in an objective way to analyse practical visual software engineering notations. We propose an operationalization of a part of the PoN, highlight conceptual shortcomings of the PoN, and explore ways to address them.

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Organisations: Department of Applied Mathematics and Computer Science, Software Engineering, University of Brighton
Authors: Störrle, H. (Intern), Fish, A. (Forskerdatabase)
Utilizing a Flexibility Interface for Distributed Energy Resources Through a Cloud-Based Service

With governments around the world pushing for an ever increasing shift towards renewable energy production, large numbers of controllable distributed energy resources are starting to appear. Already a multitude of proposed control solutions have seen the light of day, but most are focused solely on the control itself and not the more practical network- and data management issues that follows trying to handle such huge portfolios. This paper covers a cloud based solution to the aforementioned issues, greatly aiding aggregators scale to meet future demands. It also includes a flexibility interface that are currently being researched by iPower, that is mapped to the well tested standard of IEC 61850 as additional sub-nodes. By mapping to existing standards, no major changes would be needed to adapt existing systems.

General information
State: Published
Organisations: Department of Electrical Engineering, Center for Electric Power and Energy, Department of Applied Mathematics and Computer Science, Software Engineering, Technical University of Denmark
Authors: Orda, L. D. (Intern), Bach, J. (Ekstern), Pedersen, A. B. (Intern), Poulsen, B. (Intern), Hansen, L. H. (Intern)
Number of pages: 6
Publication date: 2013

CO2NSL (Datalogger)
The following report will describe the development of a computer system, and act as the final exams project for Sune Andersen prepared at Informatics Mathematical Modelling, the Technical University of Denmark acquiring the candidate degree in computer engineering. The project lasts 26 weeks, which must cover analyses, design, implementation and documentation of the project. Risø National Laboratory is getting more and more requests from The danish government on how to save energy. One of the main issue is saving money on power, special when it comes to streetlight. Before the end of the year 2012, 1500 street lamps around Copenhagen will be changed for light sources with low power consumption. Technical and Environmental turn down the energy as a part of Copenhagen goal of reducing the citys CO2 emissions by 20 percent by the end of year 2015. But how much power will the new lamps consume? And can a street lamp produce sufficient power even in Denmark? Here will a low cost & lowpower Datalogger come handy. The data logger is an electronic device that records earthquakes (Sensor network), Wind, daylight, power used/produced on the street lamp over time. Data will then be uploaded via a wireless radio MESH network (868 Mhz) to a database server for later analyze. The Prototype is developed on two microcontrollers (AVR and ARM Cortex-A8) with the low power and with fault tolerant in mind, equipped with extra storage for offline catching (like a uSD (16/32Gb)). The ARM CortexA8-board is running a full version of Ubuntu (OMAP), with Apache-webserver, PHP and MySQL-database for local catching of data, in case of the network is offline. Data will then be sync with the database server then there is connectivity. Controlling the Datalogger device can be done from the control centers webinterface or on the device it self (via Web or SSH). The device can even be used for other purposes like a (MESH) WIFI net, something like freifunk in Berlin & WNDW. In a catastrophe area the
lamp-network will still be running (because it is off-grid), even when the infrastructure is destroyed or very heavy loaded.

**General information**
State: Published
Organisations: IT Service, Department of Applied Mathematics and Computer Science, Software Engineering
Authors: Andersen, S. S. (Intern), Gustafsson, F. (Intern)
Number of pages: 96
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Thesis_public.pdf
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Publication: Research - peer-review › Report – Annual report year: 2012

**MQ-2 A Tool for Prolog-based Model Querying**
MQ-2 integrates a Prolog console into the MagicDraw1 modeling environment and equips this console with features targeted specifically to the task of querying models. The vision of MQ-2 is to make Prolog-based model querying accessible to both student and expert modelers by offering powerful query features and a tight integration with the host modeling environment.

**General information**
State: Published
Organisations: Department of Applied Mathematics and Computer Science, Software Engineering
Authors: Acretoaie, V. (Intern), Störrle, H. (Intern)
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Main Research Area: Technical/natural sciences
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Links:
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Publication: Research - peer-review › Article in proceedings – Annual report year: 2013

**Timing Analysis of Mixed-Criticality Hard Real-Time Applications Implemented on Distributed Partitioned Architectures**
In this paper we are interested in the timing analysis of mixed-criticality embedded real-time applications mapped on distributed heterogeneous architectures. Mixed-criticality tasks can be integrated onto the same architecture only if there is enough spatial and temporal separation among them. We consider that the separation is provided by partitioning, such that applications run in separate partitions, and each partition is allocated several time slots on a processor. Each partition can have its own scheduling policy. We are interested to determine the worst-case response times of tasks scheduled in partitions using fixed-priority preemptive scheduling. We have extended the state-of-the-art algorithms for schedulability analysis to take into account the partitions. The proposed algorithm has been evaluated using several synthetic and real-life benchmarks.

**General information**
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Organisations: Department of Applied Mathematics and Computer Science, Embedded Systems Engineering, Software Engineering, Technical University of Denmark
Authors: Marinescu, S. O. (Ekstern), Tamas-Selicean, D. (Intern), Acretoaie, V. (Intern), Pop, P. (Intern)
Number of pages: 4
An Introduction to Formal Methods for the Development of Safety-critical Applications

This report is a delivery to The Danish Government’s railway authority, Trafikstyrelsen, as a part of the Public Sector Consultancy service offered by the Technical University of Denmark. The purpose of the report is to give the reader an insight into the state-of-the-art of formal methods. The reader is assumed to have some knowledge about software development, but not on formal methods. The background for the railway authorities’ interest in formal methods is the fact that during the next decade a total renewal of the Danish signalling infrastructure is going to take place. Central parts of the new systems will be software components that must fulfill strong safety requirements: in order to get the software certified at the highest Safety Integrity Levels of the European CENELEC standards for railway applications, the software providers are expected to use formal methods.

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Authors: Haxthausen, A. E. (Intern)
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