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Preface

At the end of the seventies, when the GI had just turned 10 years old, about 2000 of its members proclaimed their commitment to the society and most of them were very active: General Assemblies were huge events with hundreds of participants. Especially the 'Fach-ausschüsse' ("Fachbereiche" did not exist yet) could no longer cope with the manifold interests and activities of their members without additional structures. Therefore, the idea was born to create subdivisions with more restricted subject areas, called "Fachgruppen" (special interest groups. Renowned university professors and some leaders from practice founded the first SIGs 'Softwaretechnik' and 'Datenbanksysteme', an unproblematic act, since the promoters were all well-known personalities with a direct line to the GI board.

The EMISA case is quite different. First, the 'Council of Wise Men' did not seem to consider the concerns of information systems to be particularly relevant at that time. For a computer scientist, this was a rather dazzling field in which, on the one hand, non-technical, organizational and design issues had to be dealt with and, on the other hand, modeling and methodology rather than implementation were the focus. Second, the idea to establish such a SIG came from two young assistants who had met at an event, Bernd E. Meyer, and Heinrich C. Mayr. In the back then professorially dominated GI, this undertaking was the rather revolutionary. The resistance of the presidium was correspondingly strong, and it took several presidium meetings and name changes before formal approval was given. To say it right away and full of gratitude: without the massive support of the founders' bosses Peter Lockemann and Hans-Jochen Schneider, EMISA would never have become reality.

The founding event took place from May 24-26, 1979 in Tutzing, Germany. More than one hundred highly interested and discussion-joyful participants met in the dance hall of an old inn with creaking floorboards and a rustic ambience. In the following year we moved on to the Protestant Academy with its wonderful round auditorium 'Rotunde', which almost automatically provokes lively and intensive discussions, as everyone can look everyone in the eye. In addition, the academy is located directly on the western shore of the Starnberger See, where and on which the discussions continue.

It is now 40 years that EMISA has been a platform for industry experts and academics to exchange and discuss the methodical aspects of planning, modeling, developing and running digital ecosystems. While terminology and buzzwords change, many of the questions raised when EMISA was founded still remain challenging, and many new questions came along over the years.

To commemorate the 40th anniversary of the founding event and the conference series, we returned to the original location and organized the "40 Years EMISA" at the Evangelische Akademie Tutzing. Furthermore, for this event we have not only called for the usual submission of papers with corresponding peer review. Rather, we have also invited personalities to keynotes who have contributed significantly to events and the success of EMISA over the past 40 years. And finally, we have invited relevant research groups to present their current projects in a "madness show" and an exhibition. The response was overwhelming: many of the personalities who were approached promised to make a contribution and came to the event, as did all but one of the SIG chairmen.

This led to a very varied programme, which is shown on the pages 195ff. Some reactions from participants:

„Nochmals ganz herzlichen Dank für die schöne Tagung - ein ganz aussergewöhnliches Event!“

„Nicht nur, dass der Ort so schön ist. Auch mit den Leuten war es einfach schön. Das ist die GI, wie ich sie kennengelernt habe...“

„Das war eine tolle Veranstaltung - ich freue mich schon darauf, 45 Jahre wieder in Tutzing zu machen!“

„erlauben Sie mir bitte, Ihnen zu der gelungenen EMISA 40 zu gratulieren. Nie hat mir Frühaufstehen so viel Freunde bereitet... ;-)

„Diese Veranstaltung war äußerst abwechslungsreich, kurzweilig und interessant! Ebenso war es schön, mehreren Informatik-Veteranen, und das meine ich mit allergrößtem Respekt, an einem solch schönen Ort zu begegnen.“

„vielen Dank für die tolle Organisation der Veranstaltung. Ich habe es genossen nach 40 Jahren beruflichem Alltag, mich mit Themen zu beschäftigen, die an den Hochschulen gerade diskutiert werden.“

This LNI volume contains the full papers selected from the submissions through a review process (three peer reviews per paper), shorter and longer contributions from the invited speakers, provided they were willing to provide written material, as well as introduction papers from the research groups that participated in the Madness Show and the exhibition. In this way, the volume draws a vivid picture of the variety of exciting and current topics that are currently dealt with and discussed in the environment of EMISA.

Unfortunately, the conference proceedings could only be published after some delay. The reason for this was mainly due to a serious illness of one of the editors, which came with longer artificial deep sleep, intensive care and a slow recovery process. However, this does not detract from the topicality of the articles in the volume - their topics are also important in and after the times of the corona pandemic.

We would like to thank everyone who contributed to the success of the 40 Years EMISA, especially of course the authors and lecturers, the sponsors, the members of the programme committee and the staff of the Evangelische Akademie Tutzing. We owe special thanks to our invited speakers, who not only accepted our invitation but also paid normal conference fees to support the low-cost strategy of our SIG. We also thank the organizers of the panel discussion, Jan Mendling and Gottfried Vossen, as well as Agnes Koschmider and Matthias Weidlich for the organization of the project group exhibition including the Madness Show. Last but not least we would like to thank our "official" speakers, who did not shy away from the way to EMISA either: Hannes Federrath, the current president of GI, Erhard Rahm, the current chairman of GI TC Databases and Information Systems, and Cornelia Winter, the GI CEO.

Klagenfurt, Wien, Hagen in May 2020

Heinrich C. Mayr, Stefanie Rinderle-Ma and Stefan Strecker

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Fundamental challenges in systems modelling¹

Henderik A. Proper², Marija Bjeković³

Abstract: In the context of information systems, and digital ecosystems at large, many different forms of *systems modelling* are used. This includes: enterprise (architecture) modelling, business process modelling, ontology modelling and information modelling. The resulting models have come to play an important role during all stages of the life-cycle of digital (eco)systems, where we see such systems as being socio-technical systems involving a hybrid of human and digital actors, supported by (other) technologies.

In our view, the key role of models also fuels the need for a more fundamental reflection on core aspects of modelling itself. In line with this, the goal of this paper is to explore some of the underlying fundamental challenges of modelling, and in doing so create awareness for, and initiate discussions on, the need for more foundational research into these challenges.

The discussion of these challenges has been structured in terms of three clusters: the *semiotic foundations*, the *essence of modelling*, and the role of *normative frames* (such as modelling languages).

1 Introduction

Over the past forty years, EMISA's domain of interest has shifted, or rather enlarged, from *information systems* to *digital ecosystems*⁴ at large, where we see such systems as being socio-technical systems involving a hybrid of human and digital actors, supported by (other) technologies. In the context of digital ecosystems, many different forms of (socio-technical) *systems modelling* are in use. This includes: enterprise (architecture) modelling, business process modelling, ontology modelling, soft systems methodology, organisational modelling, and information modelling. The resulting models have come to play an important role during all stages of the life-cycle of digital (eco)systems. This now includes their development, improvement, maintenance, operation (e.g. models at “run time”), and regulation.

As a result, the produced models carry (potentially) valuable knowledge regarding digital (eco)systems and their environment(s), which puts even more stress on the role of systems

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⁴ <https://ae-ainf.aau.at/emisa2019/>

modelling. It is, therefore, no surprise that modelling has always been a central topic in the domain of EMISA.⁵ In line with this, it is also interesting to observe that, for their own institutional information systems, the European Union relies heavily on a model based approach, even resulting in the creation of a dedicated *competence centre for modelling*.⁶

In our view, the key role of models across the life-cycle of digital (eco)systems, fuels the need for more fundamental reflection on modelling itself. This includes e.g. topics such as *the act of modelling*, *the essence of what a model is*, and *the role of (modelling) languages*.

Such fundamental topics have certainly been studied by different scholars (see e.g. [69, 64, 18, 39, 73, 20, 22, 74, 89, 65]), including ourselves (e.g. [33, 60, 34, 12, 11, 10, 88]). In our view, many challenges remain, however.

The amount of research effort that has been put into such fundamental topics, also seems limited in comparison to the quantity of research conducted in specific “applied” domains of modelling, such as information modelling, enterprise (architecture) modelling, (business) rules modelling, and business process modelling. We are certainly not arguing against the importance of research conducted in these “applied” domains of modelling. We do, however, argue that there is a need to find answers to some of the more generic underlying challenges that will lead to generic insights, and results, that can / may be applied across the more specific areas of modelling.

The goal of this discussion paper is therefore to explore some of the fundamental challenges we see. In doing so, we do not claim to be complete, nor do we claim to provide an exhaustive overview of all relevant work related to these challenges. The goal is rather to create awareness for, and initiate discussions on, the need for more foundational research into modelling in the context of digital ecosystems.

We have grouped the challenges, as discussed in this paper, into three main clusters that build on each other:

1. *Semiotic foundations* concerned with the challenges that originate from viewing models as linguistic artefacts.
2. *Essence of modelling* pertaining to challenges related to the role of a model as being a representation of a purposeful abstraction of some domain of modelling.
3. *The role of normative frames* pertaining to the role of different normative frames (including modelling languages in particular) when modelling, and the impact (positively or negatively) these may have.

The remainder of the paper is structured accordingly.

⁵Entwicklungsmethoden für Informationssysteme und deren Anwendung, see <http://emisa.org/index.php/fachgruppe/historie/gruendung-und-entstehung>

⁶https://ec.europa.eu/jrc/sites/jrcsh/files/ccmod_leaflet.pdf

2 Semiotic foundations

The semiotic triangle by Ogden and Richard's [51], depicted in Figure 1, is quite often used as a base to theorise about meaning in the context of language [49, 78, 68, 16], and is essentially a continuation⁷ of the work by Peirce [54].

The semiotic triangle expresses how a person attributes meaning (*thought or reference*) to the *combination* of a *symbol* and a *referent*, where the former is some language utterance, and the latter is something that the person can refer to. The *referent* can be anything, e.g. something in the physical world (tree, car, bike, atom, document, picture, etc) or something in the social world (marriage, mortgage, trust, value, etc). In addition, it can be something in an existing world, or in a desired / imagined world.

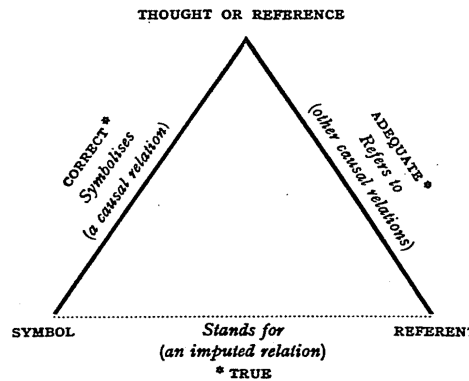


Fig. 1: Ogden and Richard's semiotic triangle [51]

The semiotic triangle is also used directly or indirectly (in terms of the use of semiotics) by several authors to reason about the foundations of (information) systems modelling [70, 39, 37, 42, 22, 73, 75, 9]. In the nineties of the last century, the IFIP 8.1 working group on the *Framework of Information System Concepts* (FRISCO), developed a variation of the triangle in terms of the so-called semiotic tetrahedron [18]. The role of the semiotic triangle in modelling has also been reflected upon explicitly in e.g. [25, 53].

When using the semantic triangle in the context of systems modelling, we essentially end up with the variation as depicted in Figure 2, where a model (as an artefact) is positioned in the role of symbol and the domain that is being modelled in the role of the referent.

Searle [68] added to the above by observing that a language utterance has both a *writer* and a *reader*, which both have their own thoughts about the symbol / utterance, in the context of (possibly) the same referent. If the referent is an existing thing in the physical

⁷We prefer not to simply state *based on*, as there are certainly nuances in the views presented by the involved scholars

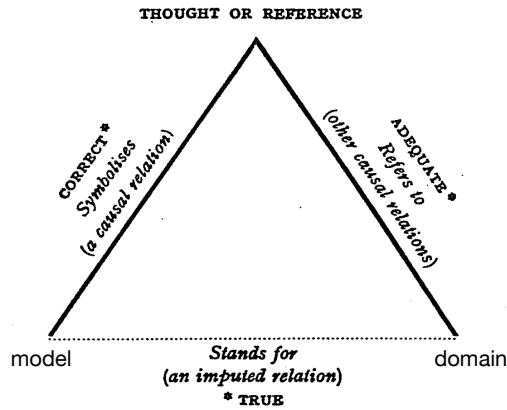


Fig. 2: Ogden and Richard's semiotic triangle applied to modelling

world, humans can apply their senses to “observe” the referent, and as such, have a chance of agreeing that they are indeed looking at the same “thing”. When the referent is part of the social world, it becomes more problematic to validate if the reader and writer are relating their respective thoughts to the same referent, leading to the need for e.g. “semantic reassurance” of a shared understanding by means of, for instance, paraphrasing [32]. When the referent is (in addition) a desired / imagined world this becomes even more problematic.

In our modelling context, we see these issues re-appearing, leading to a first two fundamental challenges (stated in the terms used in Figure 2):

Challenge 1: *How to ensure that different creators / readers of a model relate it to the same domain / referent?*

Challenge 2: *How to ensure that different creators / readers of a model have the same understanding (thought) of the model, assuming they relate it to the same domain / referent?*

The first of these two challenges is an important topic in the context of collaborative modelling, where groups of people are expected to e.g. jointly create an enterprise model [72, 66, 5].

The second challenge relates directly to the question of model understanding. For instance, empirical studies have shown that diagrams can easily be misunderstood [26, 27, 50, 62, 47, 14], which is likely to lead to problems in practical use.

In general, these challenges have also fuelled the work on e.g. the quality of models and modelling. See e.g. [40, 39, 13, 48, 80] to mention but a few. These challenges can also be seen as the major driver on the work towards the use of animation [58], gamification, and natural language verbalisation [63, 23, 30, 45], to increase model understandability, and

increase the chances of achieving a shared understanding. Strategies to measure the latter have e.g. been explored in [44, 35].

On a more fundamental level, these challenges are also related to the concept of *boundary object* [71] from the social sciences: “*They have different meanings in different social worlds but their structure is common enough to more than one world to make them recognizable, a means of translation. The creation and management of boundary objects is key in developing and maintaining coherence across intersecting social worlds.*” The applicability of this concept in the context of systems modelling has been explored in e.g. [1, 2].

3 The essence of modelling

Several scholars within the field (in the broadest sense) of systems modelling have provided definitions of the concept of model [69, 64, 19, 18, 33, 6, 42, 46, 73, 11]. Most of these definitions, indeed, take the considerations of the semiotic triangle as discussed in the previous Section on board.

One of the key sources on the notion of model itself is the work by Stachowiak [69]. Stachowiak makes a distinction between three key features (“*Merkmale*”) of a model. The *representation feature* (“*Abbildungsmerkmal*”) referring to the fact that a model is a representation of some original. The *abstraction feature* (“*Verkürzungsmerkmal*”) concerned with the fact that a model only captures a limited number of properties, with a limited precision, of the properties that are present in the original. The *pragmatic feature* (“*Pragmatisches Merkmal*”) dealing with the fact that the relation between a model, and its original, is related to its usage. In our understanding, in defining the concept of model, Stachowiak also takes the views of e.g. Peirce [54] and Ogden & Richards [51] on board.

In a practical context, such as systems modelling, the *pragmatic feature* of a model will impact the other two features in the sense that a specific usage context of a model, will put requirements on the representation feature (i.e. what should be represented) and the abstraction feature (i.e. what level of detail / specificity / precision is needed). As such the *pragmatic feature* also corresponds directly to the notion of *purpose* of models [36].

One possible way to summarise the above notion of model is to state that a model is [11]: “*an artefact that is acknowledged by an observer as representing some domain for a particular purpose*”, where *observer* refers to the (group of) actor(s) involved in the creation and use of the model, and *domain* can be any “part” or “aspect” of the past / existing / desired / imagined world. As such, the word *domain* as used here, is used in a general sense. This should not be confused with a *specific* use of the concept of domain when e.g. referring to the automotive domain or the genomics domain.

This allows us to highlight some additional fundamental challenges in modelling:

Challenge 3: *How to make the (intended) purpose of a model explicit?*

Challenge 4: *How to tune a model's representation and abstraction features to its (intended) purpose?*

Work into better understanding the usage context has indeed been conducted. The *purpose* of a model is often considered as the main discriminant of the added value of a model [69, 64, 73], while also being a central consideration in e.g. *agile modelling* [3] and the notion of *Return on Modelling Effort* (RoME) [52, Chapter 4].

When discussing the purpose of models in a systems modelling context, it is important to realise that in engineering, software engineering in particular, one has developed the implicit assumption that models are artefacts with a highly controlled structure (syntax) and mathematically defined semantics [24]. There are, however, more, many more, forms of models in use, including informal sketches, textual descriptions, regulatory / legal texts, strategy documents, etc. [55]. One can even go as far as saying that modelling [69, 64, 33, 65] occurs naturally, when people use explicit artefacts (texts, diagrams, sketches, formal descriptions, etc.) that *stand model for* some observed / normative / desired aspect of a part of reality of a (service) system and its environment.

We consider *purpose* as aggregating three (interrelated) key ingredients: (1) the *domain* (of interest) that the model should represent, (2) the intended *usage* of the model by its *audience*, and (3) the *competences* of the (human) actors involved in the creation and use of the model. In our view, the latter is an important, yet sometimes forgotten, aspect of the usage and creation of models [21, 83, 80].

The purpose of a model thus provides the basis for identifying required qualities of the specific model [13, 12] (whereby the qualities may be defined in terms of e.g. the Sequel framework [39]).

When considering the challenges on semiotics, as raised in the previous Section, in the context of collaborative modelling, we are immediately confronted with an additional challenge:

Challenge 5: *How to ensure that all actors involved in the creation and / or use of a model have the same understanding about, and agree to, its purpose?*

As the work reported in [21, 83, 80] illustrates, understanding the competences needed in the creation and use of models are not trivial. So, in this vein, another fundamental challenge we see is:

Challenge 6: *What are the competences that are needed by the creators and users of models?*

In line with the considerations behind the concept of *natural modelling* [11, 88], as also echoed more recently in the ideas on *grassroots* modelling [65], the final challenge we mention in this section concerns:

Challenge 7: *How to support the processes involved in modelling?*

Such support may, for instance, be in terms of explicit strategies for modelling [34, 31], support for step-by-step refinement / specialisation of models [61, 56], more natural notational styles [11, 88], as well as explicitly structured modelling dialogues [31, 15].

4 The role of normative frames

In this final Section, before concluding, we aim to consider some “normative frames” that are likely to influence modelling activities. Again, we do not aim to be complete, but primarily attempt to create awareness for the existence of these frames, and potential influences.

The normative frames as discussed below, leads to four main challenges in modelling:

Challenge 8: *Which normative frames exist?***Challenge 9:** *How to ensure that all actors involved are aware of the role of the normative frame(s)?***Challenge 10:** *What are the positive and / or negative impacts of the normative frame(s) on the resulting models (in relation to its purpose)?***Challenge 11:** *How to manage (mitigate / optimise) these impacts?*

The first main normative frame involves the *philosophical stance* of the actors involved in a modelling process. Even though not all actors involved in modelling may be explicitly aware of their metaphysical position, it will have a clear influence on the model and modelling process if a modeller is essentially an *objectivist*, a *subjectivist*, or a *constructivist*. The role of the philosophical stance of actors involved in (systems) modelling, and its impact on the modelling process, has e.g. been discussed in [18, 53].

Additionally, the differences between these philosophical stances is likely to also influence the orientation of researchers in the field of systems modelling, and as such also influences the appreciation of the challenges presented in this paper so far and the role of normative frames as discussed below.

A second class of normative frames are the *cognitive biases* which the actors involved in modelling may have developed during their professional, educational, and private lives. The work by Lakoff [41] in terms of the *categories* in terms of which we classify the world around us, certainly illustrates this point. Experiments in the context of conceptual modelling also indicate that this potentially plays a role during modelling as well [79, 81].

A third class of normative frames are concerned with the *self interests* which the actors may have regarding the domain being modelled. Depending on an actor’s personal goals /

concerns with a domain being modelled, they will take a specific perspective on the domain, highlighting (or hiding) aspects that impact their interests.

The *design frameworks* we use in the context of system engineering, are a fourth class of normative frames. Different methods [87, 67, 38, 17, 76, 84] for the engineering of information systems, enterprises, etc, each feature their own framework of aspects / abstraction layers to consider when engineering a system representing the “design philosophy” which the respective method is based upon. In doing so, each of these frameworks defines a structure (essentially a mega-model [7]) of different aspects / perspectives to consider, and as such *normatively* defining the scopes of what can / should be modelled about a system. This is clearly a potential benefit in the sense of ensuring all relevant (from the perspective of the respective “design philosophy”) aspects are covered, and a clear line of reasoning is followed [59]. At the same time, however, these frameworks do bring about the risk of essentially creating a “tunnel vision”.

In creating system models, we use different modelling languages, possibly in combination with the above mentioned design frameworks. These languages provide the fifth class of normative frames. The *linguistic structure* of a chosen modelling language, i.e. its meta-model, may not only limit the freedom of what can be expressed in a model. It may even limit, or at least influence, the way in which modellers observe the domain. This may lead to situations where a modelling language may “feel unnatural”, in the sense that the linguistic structure puts too much restriction on a modeller’s “freedom of expression”. At an anecdotal level, this corresponds to the *hammer* and *nail* paradigm. At a more fundamental level, it corresponds to the notion of linguistic relativity [77]⁸ which states that the structure of a language determines, or greatly influences, the modes of thought and behaviour characteristic of the culture / context in which it is spoken. The impact of linguistic relativity in the context of modelling has been explored in e.g. [10, 4].

The potential advantage of creating a model in a well-defined modelling language, is that the transferability of the resulting models over time, and between actors, is likely to increase. Even more, when, for instance, foundational ontologies [22] are applied in the creation of these models, or is even used in shaping the *linguistic structure* of the modelling language itself, the improvement of the transferability is likely to increase even further.

Furthermore, using a modelling language with a formally defined syntax and semantics [29, 28, 24] also enables computer-based manipulation of the models in terms of checking of correctness, possibly animation and simulation, or even execution (depending on the precision at which the semantics has been defined).

This clearly surmounts a trade-off, which has to be made in line with the *purpose* for modelling in a situation at hand [8] as well as the expected *Return on Modelling Effort* (RoME) [52, Chapter 4].

⁸More colloquially also known as the Sapir-Whorf hypothesis.

The role of modelling languages as a normative frame, has certainly sparked a lot of debate in literature as well. For example, Wyssusek's [85] critique on the Bunge-Wand-Weber ontology [82] providing a normative frame on the linguistic structure of a modelling language, resulted in a lively debate (summarised in [86]).

5 Conclusion

The goal of this paper was to explore some of the underlying fundamental challenges of modelling. In line with this, the paper presented 11 challenges, taking us from the *semiotic foundations*, the *essence of modelling*, to the role of *normative frames*. In doing so, we hope to have created more awareness for the need for more foundational research into these challenges.

In the future, we aim to further elaborate these challenges in terms of their underlying understanding and generic solutions / strategies that can be used across different more applied modelling domains, such as such as information modelling, enterprise (architecture) modelling, (business) rules modelling, and business process modelling.

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References

- [1] Abraham, R.: Enterprise Architecture Artifacts As Boundary Objects - A Framework Of Properties. In Proceedings of the 21st European Conference on Information Systems (ECIS 2013), Utrecht, the Netherlands, 2013.
- [2] Abraham, R.; Niemietz, H.; de Kinderen, S.; Aier, S.: Can boundary objects mitigate communication defects in enterprise transformation? Findings from expert interviews. In R. Jung and Reichert (eds.): Proceedings of the 5th International Workshop on Enterprise Modelling and Information Systems Architectures, EMISA 2013. LNI Volume 222, pages 27–40, 2013.
- [3] Ambler, S.W.; Jeffries, R.: Agile Modeling: Effective Practices for Extreme Programming and the Unified Process. John Wiley & Sons, New York, New York, 2002.
- [4] Henderson-Sellers, B.B.; Gonzalez-Perez, C.; Eriksson, O.; Ågerfalk, P. J.; Walkerden, G.: Software modelling languages: A wish list. In 2015 IEEE/ACM 7th International Workshop on Modeling in Software Engineering, pages 72–77, May 2015.
- [5] Barjis, J.: Collaborative, Participative and Interactive Enterprise Modeling. In (Filipe, J.; Cordeiro, eds.): Enterprise Information Systems, Proc. 11th Int. Conference, ICEIS 2009, Milan. LNBIP Vol 24, pages 651–662. Springer, Heidelberg, Germany, 2009.

- [6] Bézivin, J.: On the Unification Power of Models. *Software and Systems Modeling*, 4(2):171–188, May 2005.
- [7] Bézivin, J.; Jouault, F.; Valduriez, P.: On the Need for Megamodels. In *Proceedings of Workshop on Best Practices for Model-Driven Software Development at the 19th Annual ACM Conference on Object-Oriented Programming, Systems, Languages, and Applications.*, Vancouver, British Columbia, Canada, October 2004.
- [8] Bjeković, M.: *Pragmatics of Enterprise Modelling Languages: A Framework for Understanding and Explaining*. PhD thesis, Radboud University, Nijmegen, the Netherlands, 2018.
- [9] Bjeković, M.; Proper, H.A.; Sottet, J.-S.: Towards a coherent enterprise modelling landscape. In (Sandkuhl, K.; Seigerroth, U.; Stirna, J. eds.): *Short Paper Proceedings of the 5th IFIP WG 8.1 Working Conference on the Practice of Enterprise Modeling*, Rostock, Germany, CEUR Workshop Proceedings Vol. 933. CEUR-WS.org, 2012.
- [10] Bjeković, M.; Proper, H.A.; Sottet, J.-S.: Enterprise modelling languages - just enough standardisation? In (Shishkov, B. ed.): *Business Modeling and Software Design - Third International Symposium, BMSD 2013*, The Netherlands, 2013, Revised Selected Papers, LNBIP Vol. 173, pages 1–23, Springer, Heidelberg, Germany, 2014.
- [11] Bjeković, M.; Sottet, J.-S.; Favre, J.-M.; Proper, H.A.: A framework for natural enterprise modelling. In *IEEE 15th Conference on Business Informatics, CBI 2013*, Vienna, Austria, 2013, pages 79–84, IEEE Computer Society Press, Los Alamitos, California, 2013.
- [12] van Bommel, P.; Hoppenbrouwers, S.J.B.A.; Proper, H.A.; Roelofs, J.: Concepts and Strategies for Quality of Modeling. In (Halpin, T.A.; Krogstie, J.; Proper, H.A. eds.): *Innovations in Information Systems Modeling*, chapter 9. IGI Publishing, Pennsylvania, 2008.
- [13] van Bommel, P.; Hoppenbrouwers, S.J.B.A.; Proper, H.A.; van der Weide, Th.P.: QoMo: A Modelling Process Quality Framework based on SEQUAL. In: Proper et al. [57], pages 118–127.
- [14] Caire, P.; Genon, N.; Heymans, P.; D. L. Moody, D.L.: Visual notation design 2.0: Towards user comprehensible requirements engineering notations. In: *21st IEEE International Requirements Engineering Conference (RE2013)*, pages 115–124, 2013.
- [15] Costetchi, E.; Ras, E.; Latour, T.: Automated Dialogue-Based Ontology Elicitation. In: *Proceedings of the 2nd European Future Technologies Conference and Exhibition (FET 11)*, volume 7, pages 185–186, Elsevier, Procedia Computer Science, 2011.
- [16] Cruse, A.: *Meaning in Language, an Introduction to Semantics and Pragmatics*. Oxford University Press, Oxford, UK, 2000.
- [17] Dietz, J.L.G.: *Enterprise Ontology – Theory and Methodology*. Springer, Heidelberg, Germany, 2006.
- [18] Falkenberg, E.D.; Verrijn–Stuart, A.A.; Voss, K.; Hesse, W.; Lindgreen, P.; Nilsson, B.E.; Oei, J.L.H.; Rolland, C.; Stamper, R.K. (eds): *A Framework of Information Systems Concepts*. IFIP WG 8.1 Task Group FRISCO, IFIP, Laxenburg, Austria, 1998.
- [19] Frank, U.: *Evaluating Modelling Languages: Relevant Issues, Epistemological Challenges and a Preliminary Research Framework*. Technical Report 15, University of Koblenz-Landau, Germany, 1998.

- [20] Frank, U.: Multi-perspective Enterprise Modeling (MEMO) - Conceptual Framework and Modeling Languages. In HICSS '02: Proceedings of the 35th Annual Hawaii International Conference on System Sciences (HICSS'02)-Volume 3, page 72, Washington, DC, 2002. IEEE Computer Society Press, Los Alamitos, California.
- [21] Frederiks, P.J.M.; van der Weide, Th.P.: Information Modeling: the process and the required competencies of its participants. *Data & Knowledge Engineering*, 58(1):4–20, July 2006.
- [22] Guizzardi, G.: On Ontology, ontologies, Conceptualizations, Modeling Languages, and (Meta)Models. In (Vasilecas, O.; Eder, J.; A. Caplinskas, A. eds.): *Databases and Information Systems IV - Selected Papers from the 7th International Baltic Conference, DB&IS 2006, Vilnius, Lithuania, volume 155 of Frontiers in Artificial Intelligence and Applications*, pages 18–39, IOS Press, 2006.
- [23] Halpin, T.A.; Harding, J.: Automated Support for Verbalization of Conceptual Schemas. In (Brinkkemper, S.; Harmsen, A.F. eds.): *Proceedings of the Fourth Workshop on the Next Generation of CASE Tools*, pages 151–161, June 1993.
- [24] Harel, D.; Rumpe, B.: Meaningful Modeling: What's the Semantics of "Semantics"? *IEEE Computer*, 37(10):64–72, 2004.
- [25] Henderson-Sellers, B.; Gonzalez-Perez, C.; Walkerden, G.: An application of philosophy in software modelling and future information systems development. In (Franch, X.; Soffer, P. eds.): *Advanced Information Systems Engineering Workshops*, pages 329–340. Springer, Heidelberg, Germany, 2013.
- [26] Hitchman, S.: Practitioner Perceptions On The Use Of Some Semantic Concepts In The Entity Relationship Model'. *European Journal of Information Systems*, 4:31–40, 1995.
- [27] Hitchman, S.: The Details of Conceptual Modelling Notations are Important – A Comparison of Relationship Normative Language. *Communications of the AIS*, 9(10), 2002.
- [28] ter Hofstede, A.H.M.; Proper, H.A.: How to formalize it?: Formalization principles for information system development methods. *Information and Software Technology*, 40(10): 519–540, October 1998.
- [29] ter Hofstede, A.H.M.; van der Weide, Th.P.: Formalisation of techniques: chopping down the methodology jungle. *Information and Software Technology*, 34(1): 57–65, January 1992.
- [30] Hoppenbrouwers, J.J.A.C.; van der Vos, B.; Hoppenbrouwers, S.J.B.A.: NL Structures and Conceptual Modelling: Grammalizing for KISS. *Data & Knowledge Engineering*, 23(1): 79–92, 1997.
- [31] Hoppenbrouwers, S.; Wilmont, I.: Focused Conceptualisation: Framing Questioning and Answering in Model-Oriented Dialogue Games. In *PoEM*, pages 190–204, 2010.
- [32] Hoppenbrouwers, S.J.B.A.: Freezing Language; Conceptualisation processes in ICT supported organisations. PhD thesis, University of Nijmegen, Nijmegen, the Netherlands, 2003.
- [33] Hoppenbrouwers, S.J.B.A.; Proper, H.A.; van der Weide, Th.P.: A fundamental view on the process of conceptual modeling. In (Delcambre, L. et al. eds.): *Conceptual Modeling - ER 2005, 24th Int. Conference on Conceptual Modeling, Klagenfurt, Austria, LNCS Vol. 3716*, pages 128–143, Springer, Heidelberg, Germany, June 2005.

- [34] Hoppenbrouwers, S.J.B.A.; Proper, H.A.; van der Weide, Th.P.: Towards explicit strategies for modeling. In (Halpin, T.A.; Siau, K.; Krogstie, J. eds.): Proceedings of the 10th Workshop on Evaluating Modeling Methods for Systems Analysis and Design (EMMSAD'05), pages 485–492. CEUR-WS.org, 2005.
- [35] Houy, C.; Fettke, P.; Loos, P.: Understanding understandability of conceptual models: What are we actually talking about? In Proc. Conceptual Modeling – 31st Int. Conference, ER 2012 Florence, Italy, LNCS Vol. 7532, pages 64–77. Springer, Heidelberg, Germany, 2012.
- [36] Jeanneret, C.; Glinz, M.; Baar, T.: Modeling the Purposes of Models. In (Sinz, E.J.; Schürr, A. eds.): Modellierung, LNI Vol. 201, pages 11–26. GI, 2012.
- [37] Kecheng, L. et al. eds.): IFIP TC8/WG8.1 Working Conference on Organizational Semiotics – Evolving a Science of Informa-tion Systems. Kluwer, Deventer, the Netherlands, 2002.
- [38] Kosanke, K.; Vernadat, F.; Zelm, M.: CIMOSA: enterprise engineering and integration. Computers in industry, 40(2):83–97, 1999.
- [39] Krogstie, J.: A Semiotic Approach to Quality in Requirements Specifications. In (L. Kecheng, L. et al. eds.): Proceedings of the IFIP TC8 / WG8.1 Working Conference on Organizational Semiotics: Evolving a Science of Information Systems, pages 231–250, Deventer, the Netherlands, 2002. Kluwer.
- [40] Krogstie, J.; Lindland, O.I.; Sindre, G.: Defining Quality Aspects for Conceptual Models. In (Falkenberg, E.D.; Hesse, W.; Olivé, A. eds.): Information System Concepts: Towards a consolidation of views – Proceedings of the third IFIP WG8.1 conference (ISCO–3), pages 216–231, Marburg, Germany, 1995. Chapman & Hall/IFIP WG8.1, London, UK.
- [41] Lakoff, G.: Women, Fire, and Dangerous Things: What Categories Reveal About the Mind. University of Chicago Press, Chicago, Illinois, 1997.
- [42] Lankhorst, M.M. et al.: Foundations. In Enterprise Architecture at Work - Modelling, Communication and Analysis, Fourth Edition [43], pages 41–58.
- [43] Lankhorst, M.M. et al.: Enterprise Architecture at Work - Modelling, Communication and Analysis, Fourth Edition. Springer, Heidelberg, Germany, 4th edition, 2017.
- [44] Laue, R.; Gadatsch, A.: Measuring the understandability of business process models – are we asking the right questions? In (zur Muehlen, M.; Su, J. eds.): Business Process Management Workshops 2010, LNBIP, Vol. 76, pages 37–48. Springer, Heidelberg, Germany, 2011.
- [45] Leopold, H.; Mendling, J.; Polyvyanyy, A.: Supporting process model validation through natural language generation. IEEE Transactions on Software Engineering, 40(8):818–840, August 2014.
- [46] Mahr, B.: On the epistemology of models. In (Abel, G.; Conant, J. eds.): Rethinking Epistemology, pages 1–301. De Gruyter, 2011.
- [47] Masri, K.; Parker, D.; Gemino, A.: Using Iconic Graphics in Entity Relationship Diagrams: The Impact on Understanding. Journal of Database Management, 19(3):22–41, 2008.

- [48] Moody, D.L.: The “Physics” of Notations: Toward a Scientific Basis for Constructing Visual Notations in Software Engineering. *IEEE Transactions on Software Engineering*, 35(6):756–779, 2009.
- [49] Morris, C.: *Signs, Language and Behaviour*. Prentice Hall, Englewood Cliffs, New Jersey, 1946.
- [50] Nordbotten, J.C.; Crosby, M.E.: The effect of graphic style on data model interpretation. *Information Systems Journal*, 9(2):139–155, 1999.
- [51] Ogden, C.K.; Richards, I.A.: *The Meaning of Meaning – A Study of the Influence of Language upon Thought and of the Science of Symbolism*. Magdalene College, University of Cambridge, Oxford, UK, 1923.
- [52] Op ’t Land, M. et. al.: *Enterprise Architecture - Creating Value by Informed Governance*. Springer, Heidelberg, Germany, 2008.
- [53] Partridge, C.; Gonzalez-Perez, C.; Henderson-Sellers, B.: Are conceptual models concept models? In (Ng, W.; Storey, V.C.; Trujillo, J.C. eds.): *Conceptual Modeling. ER 2013, LNCS Vol. 8217*, pages 96–105. Springer, Heidelberg, Germany, 2013.
- [54] Peirce, C.S.: *Volumes I and II – Principles of Philosophy and Elements of Logic*. Collected Papers of C. S. Peirce. Harvard University Press, Boston, Massachusetts, 1969.
- [55] Proper, H.A.: Enterprise architecture: Informed steering of enterprises in motion. In (S. Hammoudi, S. et al. eds.): *Enterprise Information Systems - 15th International Conference, ICEIS 2013, Angers, France, 2013, LNBIP Vol 190*, pages 16–34. Springer, Heidelberg, Germany, 2014.
- [56] Proper, H.A. et al.: Towards a Multi-Stage Strategy to Teach Enterprise Modelling. In *Proceedings of the 8th Enterprise Engineering Working Conference (EEWC 2018)*, Luxembourg, LNBIP. Springer, Heidelberg, Germany, 2018.
- [57] Proper, H.A.; Halpin, T.A.; Krogstie, J. (eds): *Proceedings of the 12th Workshop on Exploring Modeling Methods for Systems Analysis and Design (EMMSAD 2007)*, Trondheim, Norway. CEUR-WS.org, 2007.
- [58] Proper, H.A.; Hoppenbrouwers, S.J.B.A.; Veldhuijzen van Zanten, G.E.: Communication of enterprise architectures. In *Enterprise Architecture at Work - Modelling, Communication and Analysis, Fourth Edition [43]*, pages 59–72.
- [59] Proper, H.A.; Op ’t Land, M.: Lines in the Water – The Line of Reasoning in an Enterprise Engineering Case Study from the Public Sector. In (Harmsen, A.F. et al. eds.): *Proceedings of the 2nd Working Conference on Practice-driven Research on Enterprise Transformation (PRET 2010)*, LNBIP Vol. 69, pages 193–216, Delft, the Netherlands, 2010. Springer, Heidelberg, Germany.
- [60] Proper, H.A.; Verrijn–Stuart, A.A.; Hoppenbrouwers, S.J.B.A.: On utility-based selection of architecture-modelling concepts. In (Hartmann, S.; Stumptner, M. eds.): *Conceptual Modelling 2005, Second Asia-Pacific Conference on Conceptual Modelling (APCCM2005)*, Australia, CRPIT Vol. 43, pages 25–34, 2005, Australian Computer Society.
- [61] Proper, H.A.; van der Weide, Th.P.: Modelling as selection of interpretation. In (Mayr, H.C.; Breu, R. eds.): *Modellierung 2006, LNI Vol P-82*, pages 223–232, Bonn, Germany, 2006.

- [62] Purchase, H.C.; Carrington, D.; Alder, J.-A.: Empirical Evaluation of Aesthetics-based Graph Layout. *Empirical Software Engineering*, 7(3):233–255, 2002.
- [63] Rolland, C.; Proix, C.: A Natural Language Approach For Requirements Engineering. In (Loucopoulos, P. ed.): *Advanced Information Systems Engineering, CAiSE'92*, Manchester, UK, LNCS Vol. 593, pages 257–277. Springer, Heidelberg, Germany, 1992.
- [64] Rothenberg, J.: The Nature of Modeling. In *Artificial intelligence, simulation & modeling*, pages 75–92. John Wiley & Sons, New York, New York, United States of America, 1989.
- [65] Sandkuhl, K. et al.: From Expert Discipline to Common Practice: A Vision and Research Agenda for Extending the Reach of Enterprise Modeling. *Business & Information Systems Engineering*, 60(1):69–80, 2018.
- [66] Sandkuhl, K. et al.: *Enterprise Modeling: Tackling Business Challenges with the 4EM Method*. Springer, Heidelberg, Germany, 2014.
- [67] Scheer, A.-W.: *Architecture of Integrated Information Systems: Foundations of Enterprise Modelling*. Springer, Heidelberg, Germany, Secaucus, New Jersey, 1992.
- [68] Searle, J.R.: A Taxonomy of Illocutionary Acts. In *Expression and Meaning: Studies in the Theory of Speech Acts*. Cambridge University Press, Cambridge, UK, 1979.
- [69] Stachowiak, H.: *Allgemeine Modelltheorie*. Springer, Heidelberg, Germany, 1973.
- [70] Stamper, R.K.: Signs, norms, and information systems. In (Holmqvist, B. ed.): *Signs at Work*, pages 349–397. Walter de Gruyter, Berlin, Germany, 1996.
- [71] Star, S.L.; Griesemer, J.R.: Institutional Ecology, ‘Translations’ and Boundary Objects: Amateurs and Professionals in Berkeley’s Museum of Vertebrate Zoology 1907-39. *Social Studies of Science*, 19(4):387–420, 1989.
- [72] Stirna, J.; Persson, A.: Ten Years Plus with EKD: Reflections from Using an Enterprise Modeling Method in Practice. In Proper et al. [57], pages 97–106.
- [73] Thalheim, B.: The Theory of Conceptual Models, the Theory of Conceptual Modelling and Foundations of Conceptual Modelling. In *Handbook of Conceptual Modeling*, pages 543–577. Springer, Heidelberg, Germany, 2011.
- [74] Thalheim, B.: Syntax, Semantics and Pragmatics of Conceptual Modelling. In (Bouma, G. et al. eds.): *Natural Language Processing and Information Systems - 17th International Conference on Applications of Natural Language to Information Systems, NLDB 2012*, LNCS Vol 7337 pages 1–10. Springer, Heidelberg, Germany, 2012.
- [75] Thalheim, B.: The Conception of the Model. In (Abramowicz, W. ed.): *Business Information Systems - 16th International Conference, BIS 2013*. LNBIP Vol. 157, pages 113–124. Springer, Heidelberg, Germany, 2013.
- [76] The Open Group. *TOGAF Version 9*. Van Haren Publishing, the Netherlands, 2009.
- [77] Tohidian, I.: Examining Linguistic Relativity Hypothesis as One of the Main Views on the Relationship Between Language and Thought. *Journal of Psycholinguistic Research*, 38(1):65–74, 2009.
- [78] Ullmann S.: *Semantics: An Introduction to the Science of Meaning*. Basil Blackwell, Oxford, UK, 1967.

- [79] van der Linden, D.J.T.; Gaaloul, K.; W. A. Molnar, W.A.: Initial Results from a Study on Personal Semantics of Conceptual Modeling Languages. In (Bouma, G. et al. eds.): *Natural Language Processing and Information Systems*, LNCS Vol. 7337, pages 360–365. Springer, Heidelberg, Germany, 2012.
- [80] van der Linden; D.J.T; Hadar, I.: Cognitive Effectiveness of Conceptual Modeling Languages: Examining Professional Modelers. In *Proceedings of the 5th IEEE International Workshop on Empirical Requirements Engineering (EmpiRE)*, 2015.
- [81] van der Linden, D.J.T et al.: Beyond terminologies: Using psychometrics to validate shared ontologies. *Applied Ontology*, 7, 2012.
- [82] Wand, Y.; Weber, R.: An Ontological Model of an Information System. *IEEE Transactions on Software Engineering*, 16(11):1282–1292, November 1990.
- [83] Wilmont, I. et al.: Abstract Reasoning in Collaborative Modeling. In (Hoppenbrouwers, S.J.B.A.; Rouwette, E.A.J.A.; Rittgen, P. eds.): *Proceedings of the 45th Hawaiian International Conference on the System Sciences, HICSS-45; Collaborative Systems track, Collaborative Modeling minitrack*. IEEE Explore, Los Alamitos, California, 2012.
- [84] van't Wout, J. et al.: *The Integrated Architecture Framework Explained*. Springer, Heidelberg, Germany, 2010.
- [85] Wyssusek, B.: On Ontological Foundations of Conceptual Modelling. *Scandinavian Journal of Information Systems*, 18(1), 2006.
- [86] Wyssusek, B.: Ontological Foundations of Conceptual Modelling Reconsidered: A Response. *Scandinavian Journal of Information Systems*, 18(1): Article 8, 2006.
- [87] Zachman, J.A.: A framework for information systems architecture. *IBM Systems Journal*, 26(3):276–292, 1987.
- [88] Zarwin, Z. et al.: M Natural modelling. *Journal Of Object Technology*, 13(3):4: 1–36, 2014.
- [89] Zarwin, Z.; Sottet, J.S.; Favre J. M.: Natural Modeling - Retrospective and Perspectives - An Anthropological Point of View. *eXtreme Modelling Workshop (XM2012)* organized at the Models 2012 Conference, Innsbruck, Austria, 2012.

Model-driven Runtime State Identification

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Abstract: With new advances such as Cyber-Physical Systems (CPS) and Internet of Things (IoT), more and more discrete software systems interact with continuous physical systems. State machines are a classical approach to specify the intended behavior of discrete systems during development. However, the actual realized behavior may deviate from those specified models due to environmental impacts, or measurement inaccuracies. Accordingly, data gathered at runtime should be validated against the specified model. A first step in this direction is to identify the individual system states of each execution of a system at runtime. This is a particular challenge for continuous systems where system states may be only identified by listening to sensor value streams. A further challenge is to raise these raw value streams on a model level for checking purposes. To tackle these challenges, we introduce a model-driven runtime state identification approach. In particular, we automatically derive corresponding time-series database queries from state machines in order to identify system runtime states based on the sensor value streams of running systems. We demonstrate our approach for a subset of SysML and evaluate it based on a case study of a simulated environment of a five-axes grip-arm robot within a working station.

Keywords: Model-driven Engineering; Time-Series Database; State Identification; Runtime Queries; Process Mining

1 Introduction

Forecasts show that in the upcoming years most of the devices we interact with will be linked to a global computing infrastructure [BS14]. This tendency represents an infrastructure in which the physical environment is populated by interconnected and communicating objects (e.g., sensors, actuators and other smart devices) capable for autonomously interacting with each other and with the environment itself. In order to deal with the increasing complexity of cyber-physical systems (CPS), models are used in many research fields as abstract descriptions of reality. This means that a model serves as an abstraction for a specific purpose, as a kind of “blueprint” of a system, describing the system’s structure as well as desired behavior. However, often we recognize a discrepancy between these models and their real world correspondents [MW16b]. In other words, we experience deviations between design-time models and runtime models discovered from real data.

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This development raises new challenges for *Model-Driven Engineering (MDE)* approaches [MWP18]. While design models help in the engineering process by providing appropriate abstractions, data-driven approaches such as process mining [Aa16] may help to uncover some under-specified or unintended parts of these design models at runtime. For instance, on a high level of abstraction, behavioral modeling languages (e.g., state-machine-based languages) are used to describe the behavior of a physical asset by means of states and transitions. Such models define discrete states, which are represented by defined variable values. A system has to achieve/go through these states during its execution. However in reality, systems do not switch in a time discrete manner between states, but the values of the variables are continuously evolving to the intended values of the next state. This means, each variable undergoes a continuous series of changes that need to be continuously monitored, e.g., to be able to react immediately to a time delay in safety critical systems. The challenge is to continuously listening to value streams in order to determine whether a state has indeed occurred, i.e., if the specific combinations of variable values have occurred over all streams at the same time. In particular, the realization precision of systems as well as measuring inaccuracies complicate this process as false positives and false negatives may occur when matching state templates to data streams.

Based on first ideas presented in [Wo17], we address this challenge by introducing a novel approach where we automatically generate state realization event queries derived from state machines for an appropriate state identification at runtime. This approach enables us to continuously observe multiple data streams of distributed sensor devices for identifying a system's entire state at runtime. By applying the so-called *Model-driven Runtime State Identification (MD-RISE)* approach, we automatically transform behavioral models, i.e., state machines, into time-series queries to be able to match sensor value streams with pre-defined variable values of the design model to report identified states from execution. First evaluation results derived from a case study of a 5-axes grip-arm robot show the potential of the approach in terms of precision and recall of finding system states in sensor value streams. By this, state based monitoring is possible for instance, even if the systems are not able to provide a explicit state-based trace.

The remainder of this paper is structured as follows. In the next section, we present a motivating example for our approach. Section 3 presents the MD-RISE approach by describing the MD-RISE architecture and its prototypical implementation. Section 4 demonstrates the evaluation of MD-RISE based on a case study of a 5-axes grip-arm robot which is interacting with other components within a working station, like a pick-and-place unit. In Section 5, we discuss related work. Finally, we conclude this paper by an outlook on our next steps in Section 6.

2 Motivating Example

As motivating example for this paper, we consider a simple continuous automated system around a 3-axes grip-arm robot (gripper). This gripper is modeled by using by the *Systems*

Modeling Language (SysML) [FMS12], in particular by using the *block definition diagram (BDD)* and the *state machine diagram (SM)*. The BDD is used to define the structure of the gripper with its properties: BasePosition (BP), MainArmPosition (MAP), and GripperPosition (GP) (see Fig. 1(a) Design Models, BDD System). These properties describe the angle positions of the three axes of the gripper. Based on the machine operator's knowledge, these angle positions can be defined for different settings (e.g., drive down, pick-up) with pre-defined tolerance ranges. These ranges fix the accepted margin of deviation (e.g., ± 0.1) for the variable values of each property (BP, MAP, GP). The desired behavior of the gripper is described by various states and state transitions modeled by using the SM (see Fig. 1(a) Design Models, SM Grip-arm robot). These states are DriveDown and PickUp with assigned variable values specifying the respective angle position in these states. During operation (i.e., execution at runtime), the gripper as a continuous system moves in its environment (e.g., pick-and-place unit) on the basis of a workflow described by the SM. These movements are recorded by various axis sensors and returned as continuous sensor value streams on a log recording system. In our motivating example, we record three sensor value streams BP, MAP, GP (see Fig. 1(b) Runtime Data). These records show that the gripper does not “jump” from one discrete state into another as modeled in the SM, but is—of course—continuously moving. Thus, the challenge is to identify possible discrete states by analyzing the sensor value streams. For this purpose we have to raise raw sensor value streams on a higher level of abstraction. This enables, e.g., to better compare an initial model (e.g., SM) with its realization.

The state identification is done by matching the different raw sensor value streams to the pre-defined variable values defined in the SM (see Fig. 1(b) Runtime Data). It should be

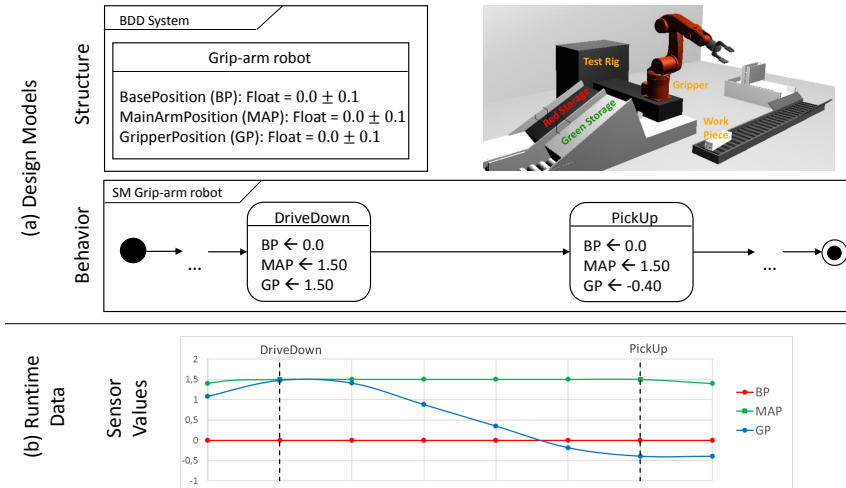


Fig. 1: Design time and runtime perspective of the motivating example

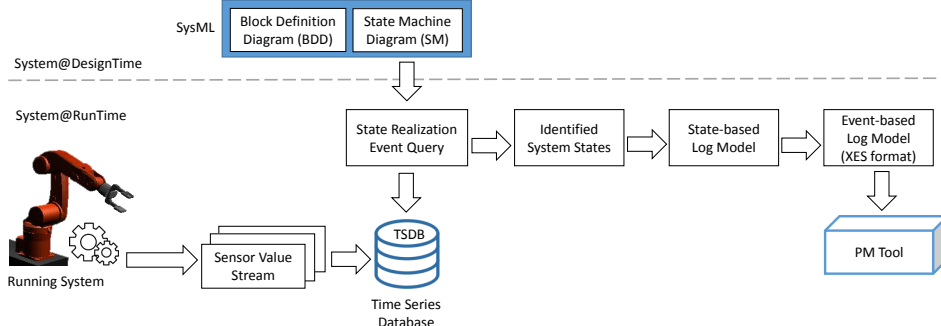


Fig. 2: Architecture for model-driven runtime state identification

considered that the pre-defined absolute variable values in the SM are not necessarily precisely measured in the real world because of, e.g., measuring inaccuracies. Such inaccuracies have to be taken into account by dealing with numerical values of objects of the physical world [MWV16]. Thus, in order to perform the state identification successfully, it is important to define appropriate tolerance ranges (see Section 4). For instance, the sequence of identified states can be used as input for further analysis (see Section 3).

3 Model-driven Runtime State Identification

In this section, we present our *Model-driven Runtime State Identification (MD-RISE)* approach which combines MDE-techniques with a *Time-Series Database (TSDB)* and *Process Mining (PM)*, for states identification, recording, abstraction, and analyses. Fig. 2 shows the architecture of MD-RISE as well as the interplay of design time and runtime artefacts.

3.1 MD-RISE Prerequisites

For prototypically realizing the approach, we have a number of prerequisites that must be met: (i) the system's workflow must be expressible by means of a state machine, (ii) the different states of the system must be unique in order that values describing a state are not identical for two different states, (iii) numeric values must be returned by sensors at runtime and must be storable in a TSDB, and (iv) it must be ensured that the time stamps are accessible.

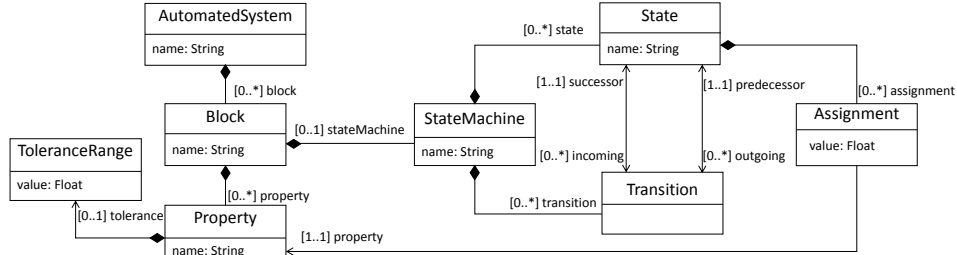


Fig. 3: Metamodel for describing a simple automated system

3.2 MD-RISE Architecture

Based on the motivating example of the gripper (see Section 2) and the mentioned prerequisites, we consider an automated system consisting of a controller, sensors, and actuators. At design time, we model the structure and behavior of this system by using a subset of SysML (see Figure 2: System@DesignTime, BDD and SM). Fig. 3 shows the simplified graphical metamodel used for modeling BDD and SM of the system. Every component of the system (Block) contains properties (Property) and can have a SM (StateMachine), which describes the behavior of this component. Each Property can have a specified tolerance range (ToleranceRange) that defines an acceptable deviation of the assigned property values, e.g., based on measurement inaccuracies. The SM consists of states (State) and transitions (Transition). Generally, a state can have multiple incoming and outgoing transitions. A transition must have a predecessor and successor state (see Fig. 3). Additionally, different values can be assigned to a state (Assignment). In this paper, we just focus on Float property values, since we are interested in value changes during execution (see Section 4).

Based on this metamodel, we automatically derive a query on the basis of the SM, a so-called “state realization event query” (see Fig. 2, System@RunTime). This query helps for identifying states based on the recorded sensor value streams in a TSDB. For this purpose we use a *Model-to-Text (M2T) transformation* to automatically transform model elements to query statements (i.e., text strings) (see Subsection 3.3). During runtime, the sensors of the running system continuously send data over a messaging system middleware. These sensor value streams (e.g., values of the angle positions of the gripper) are recorded in a TSDB (see Figure 2). A single log of the stream contains the following information: *timestamp* (the actual time in the granularity of seconds), *sensor* (the name of the specific sensor), *value* (the measured value). The number of log entries for one component varies depending on the number of sensors. The challenge is to continuously listening to value streams in order to determine whether a state has indeed occurred, i.e., if the specific combinations of variable values have occurred over all streams at the same time (see Fig. 1(b) Runtime Data). For this purpose we apply the aforementioned state realization event query for identifying

states containing the following information: *timestamp* (the actual time in the granularity of seconds), *state* (the recognized state based on measured values).

However, the absolute values assigned in the SM at design time (see Fig. 1(a) Design Models) are necessarily not precisely identified as such during runtime due to measurement inaccuracies. For instance, we define for a certain state (e.g., DriveDown) a value of 1.50 for a certain angle position (e.g., MAP) at design time, but at runtime we measure a value for this position of 1.492. For this purpose we implement a tolerance range, assigned to the initial model (e.g., the SM), to define in which range such inaccuracies are still acceptable (see Figure 3, ToleranceRange). The definition of such a range is crucial. If the range is selected too small, the inaccuracies may result in too few or even no identified states. Otherwise, if the range is too large, too many states are identified. We examine this challenge in our case study presented in Section 4.

In a next step, we generate a state-based log model that consists of the information of all identified states and, in addition, a case ID for identifying the corresponding process instance (see Fig. 2: System@RunTime, State-based Log Model). Such a case ID is required when using PM tools in order to be able to distinguish different executions of the same process. We employ this case ID in our approach to identify single runs of the SM during runtime. In a further step, the state-based log model is transformed to an event-based log model (see Fig. 2, Event-based Log Model) by applying a *Model-to-Model (M2M) transformation*, like presented in previous research work [MW16a]. Since, we use a PM tool for analyzing this model, the structure must be based on *eXtensible Event Stream (XES)* schema. This is a supported input format of ProM Lite⁵ 1.1. For instance, by using this PM tool, the event-based log model can be analyzed, e.g., to uncover some under-specified or unintended events that were not considered in the SM.

In summary, by applying MD-RISE it is now possible to raise raw sensor value streams on a higher level of abstraction, namely the state level. MD-RISE bases on queries, so-called state realization event queries, which are automatically derived from an initial design model for the purpose of state identification at runtime. The identified system states can be automatically transformed into a state-based log model to make the outcome useable, e.g., for PM tools like ProMLite for further analyses.

3.3 MD-RISE Prototypical Realization

For a first prototypical realization, we use the defined metamodel (see Fig. 3) and implement it by using Ecore in the Eclipse Modeling Framework⁶. Based on this metamodel, we develop a M2T transformation by using Xtend⁷ in order to automatically generate state realization event queries out of the SM for different states. The structure of this M2T

⁵ <http://www.promtools.org/doku.php?id=promlite11>

⁶ <https://www.eclipse.org/modeling/emf>

⁷ <http://www.eclipse.org/xtend>

transformation depends on the used TSDB. In our implementation, we use InfluxDB⁸ as TSDB. Therefore, the structure of our state realization event queries are similar to a SQL syntax, as shown in the following pseudo code example based on our metamodel:

```
«FOR s IN Block.stateMachine.state»
SELECT «FOR a IN s.assignment» «a.property.name», «ENDFOR» time
FROM «Block.name»
WHERE «FOR a IN s.assignment»
«a.property.name»>=«a.value-a.property.tolerance.value»
and «a.property.name»<=«a.value-a.property.tolerance.value»«ENDFOR»
«ENDFOR»
```

Based on the raw sensor value streams collected at runtime and stored in the TSDB, the queries are executed and the results are the identified states with their timestamps. In our prototypical implementation, we store the outcome as csv-file, which is then used as input for the state-based log model. This model is a Ecore model representation of the csv-file. In a next step, we use the *Atlas Transformation Language (ATL)*⁹ as transformation tool to transform the state-based log model to an event-based log model for importing it into ProM¹⁰ [MW16a]. The full implementation of MD-RISE can be found at our project website¹¹.

4 Case Study based on a CPPS-Simulation Environment

In this section, we present as well as discuss the accuracy and limitations of MDE-RISE on the basis of a case study of a CPPS-simulation environment around a 5-axes grip-arm. In doing so, we follow the guidelines for conducting empirical explanatory case studies by Roneson and Hörst [RH09]. In particular, we report on applying our approach to detect states at runtime based on stored value streams in a TSDB.

4.1 Research Questions

The study was performed to quantitatively assess the completeness, correctness, and performance of MDE-RISE. More specifically, we aimed to answer the following research questions (RQs):

⁸ <https://www.influxdata.com>

⁹ <https://www.eclipse.org/at1>

¹⁰ <http://promtools.org/doku.php>

¹¹ <https://cdl-mint.big.tuwien.ac.at/case-study-artefacts-for-emisa-2019/>

RQ1—Correctness: Are the identified states at runtime correct in the sense that all identified states are representing real states? If our approach identifies incorrect states, what is the reason for this?

RQ2—Completeness: Are the identified states complete in the sense that all expected states are correctly identified? If the set of identified states is incomplete, what is the reason for missed identifications?

RQ3—Performance: How strongly is the performance of the query execution influenced by the number of sensor value streams or the number of stored values per sensor?

4.2 Case Study Design

Requirements. As an appropriate input for our case study, we require an automated system such as a gripper integrated in a simulated environment where we are able to observe the behavior of the gripper during operation. We require access to multiple sensors of the gripper for log acquisition and a method to automatically identify states based on sensor value streams from simulation runs.

Setup. To fulfill these requirements, we implemented a CPPS-simulation of an autonomous acting production unit executed by using the open source tool Blender¹². The simulation scenario considers a working station, like a pick-and-place unit, where a gripper takes work pieces from a conveyor belt, put them down on a test rig, and finally release them in a red or green storage box based on the information coded on each work piece by a QR-code. Each component communicates via a messaging system middleware with InfluxDB. This TSDB provides us to acquire raw sensor value streams. During simulation, the gripper enters several different states for processing the work pieces. To verify the correctness of our approach, we have chosen two very similar states (differ only in one sensor value stream) to determine if the detection works: DriveDown and PickUp. The assigned values of the axes Base Position (BP), Main Arm Position (MAP), Second Arm Position (SAP), Wrist Position (WP), and Gripper Position (GP) of the two states in the SM are shown in Tab. 1. Furthermore we need to define an acceptable tolerance range to determine when the state identification is as accurate and complete as possible. We use a tolerance range from a deviation of 0 to a deviation of 0.4 (in 0.01 steps). The upper bound is only set for evaluation purposes to show the distribution of precision and recall. In reality, a deviation of 0.4 may be already too large. The deviation values are added or subtracted to the respective SM values (see Tab. 1). We use the same tolerance ranges for all properties and do not vary them.

For our evaluation we use two different database settings in combination with different numbers of sensor value streams that are used for the states identification. We use a dataset

¹² <https://www.blender.org>

Tab. 1: Expected values for the gripper's axes for the states DriveDown and PickUp.

Gripper Axis \ State	DriveDown	PickUp
Base Position (BP)	0.0	0.0
Main Arm Position (MAP)	1.50	1.50
Second Arm Position (SAP)	-0.12	-0.12
Wrist Position (WP)	0.0	0.0
Gripper Position (GP)	1.5	-0.40

with 156 rows and a dataset with 1,560 rows stored in the database. For the state identification we use a single sensor value stream (GP), three sensor value streams (GP, BP, MAP), and all five sensor value streams (GP, BP, MAP, SAP, WP). For the performance check we also extend our dataset up to 15,600, 156,000, and 1,560,000 rows.

For performance purpose of the state realization queries, we calculate the duration between start of the query execution and result return by `System.nanoTime()` in Java. The performance figures have been measured on an Acer Aspire VN7-791 with an Intel(R) Core(TM) i7-4720 HQ CPU @ 2.60 GHz 2.60 GHz, with 16 GB of physical memory, and running the Windows 8.1. 64 bits operating system. Please note that we measured the CPU time by executing each query 40 times for all different settings and calculated the arithmetic mean of these runs in milliseconds (ms).

Measures. In order to assess the accuracy of our approach, we calculate *precision* and *recall* as defined in [MRS08]. In the context of our case study, precision denotes the fraction of *correctly identified* states among the set of *all identified* states. Recall indicates the fraction of *correctly identified* states among the set of *all actually occurring* states. Precision denotes the probability that a identified state is correct and the recall is the probability that an actually occurring state is identified. Both values range from 0 to 1.

Precision is used to answer RQ1 and recall to answer RQ2. Furthermore, we calculate the so-called *f-measure* to avoid having only isolated views on precision and recall [MRS08]. To answer RQ3, we compute the duration of the query execution.

To check if our approach is accurate for a given scenario to identify system states, we have manually obtained the gold standard of state identifications for our given case study (156 rows: 3 expected states for DriveDown and PickUp, 1560 rows: 30 expected states for DriveDown and PickUp). For computing precision and recall, we extract the true-positive values (TPs), false-positive values (FPs) and false-negative values (FNs), with the help of the expected state identifications. From the TP, FP and FN values we then compute *precision*, *recall* and *f-measure* metrics as defined by Olson and Delen [OD08, p. 138].

Tab. 2: Precision, recall and f-measure for a single sensor value stream (GP). Bold line marks the best fit.

	DriveDown			PickUp		
tolerance range	precision	recall	f-measure	precision	recall	f-measure
0	NaN	0	NaN	NaN	0	NaN
0.01	NaN	0	NaN	0.08	1	0.14
0.02	1	1	1	0.08	1	0.14
0.03-0.05	1	1	1	0.07	1	0.14
0.06-0.08	1	1	1	0.07	1	0.13
0.09-0.11	0.75	1	0.86	0.07	1	0.13
0.12-0.19	0.75	1	0.86	0.07	1	0.12
0.20-0.30	0.6	1	0.75	0.05	1	0.10
0.31-0.37	0.5	1	0.67	0.05	1	0.10
0.38-0.39	0.5	1	0.67	0.05	1	0.09

4.3 Results

We now present the results of applying our approach to the different settings of our gripper simulation. Tab. 2–Tab. 4 show the results for precision, recall and f-measure for the two different states in the different value stream settings. The values are valid for both database settings (156 rows, 1560 rows), since there were no differences with regard to precision, recall and f-measure. This can be explained by the fact that the queries are independent of the number of values in the database. As soon as the sensor value streams are in the accepted tolerance range, the state is returned.

Tab. 3: Precision, recall and f-measure for three sensor value streams (GP, BP, MAP). Bold line marks the best fit.

	DriveDown			PickUp		
tolerance range	precision	recall	f-measure	precision	recall	f-measure
0	NaN	0	NaN	NaN	0	NaN
0.01	NaN	0	NaN	1	1	1
0.02-0.08	1	1	1	1	1	1
0.09-0.10	0.75	1	0.86	1	1	1
0.11-0.12	0.75	1	0.86	0.6	1	0.75
0.13-0.16	0.75	1	0.86	0.5	1	0.67
0.17-0.18	0.75	1	0.86	0.43	1	0.6
0.19	0.75	1	0.86	0.25	1	0.4
0.20-0.21	0.6	1	0.75	0.25	1	0.4
0.22-0.30	0.6	1	0.75	0.23	1	0.375
0.31-0.39	0.5	1	0.67	0.23	1	0.375

It is noticeable that the states identification fails and no states are found if the tolerance range is too small. The larger the range, the more false states are detected and the precision decreases as expected. In Tab. 2 for the state `PickUp` it could be recognized that the precision value is really small (highest value 0.08), because of wrong states identification based on a

single sensor value stream. This can be explained by the fact that the gripper moves during the simulation and opens and closes the gripper arm in various locations (e.g., conveyor, test rig). These states do not differ in the value of GP but have a different BP. Thus, this one axis GP is not enough to identify the state PickUp. Furthermore, it is interesting that the use of all gripper's axes for state identification PickUp leads to a lower recall for the tolerance range 0.01 (see Tab. 4).

Tab. 4: Precision, recall and f-measure for five sensor value streams (GP, BP, MAP, SAP, WP). Bold line marks the best fit.

tolerance range	DriveDown			PickUp		
	precision	recall	f-measure	precision	recall	f-measure
0	NaN	0	NaN	NaN	0	NaN
0.01	NaN	0	NaN	1	0.33	0.5
0.02-0.08	1	1	1	1	1	1
0.09-0.10	0.75	1	0.86	1	1	1
0.11-0.12	0.75	1	0.86	0.6	1	0.75
0.13-0.16	0.75	1	0.86	0.5	1	0.67
0.17-0.18	0.75	1	0.86	0.43	1	0.6
0.19	0.75	1	0.86	0.25	1	0.4
0.20-0.21	0.6	1	0.75	0.25	1	0.4
0.22-0.3	0.6	1	0.75	0.23	1	0.375
0.31-0.39	0.5	1	0.67	0.23	1	0.375

Figure 4 shows the results of our performance check. It could be determined that the number of sensor value streams and the number of rows in the database both have an influence on the execution time.

Interpretation of results. *Answering RQ1:* The recognition of correct states depends on the defined tolerance range and the differentiability of states. A precondition for our

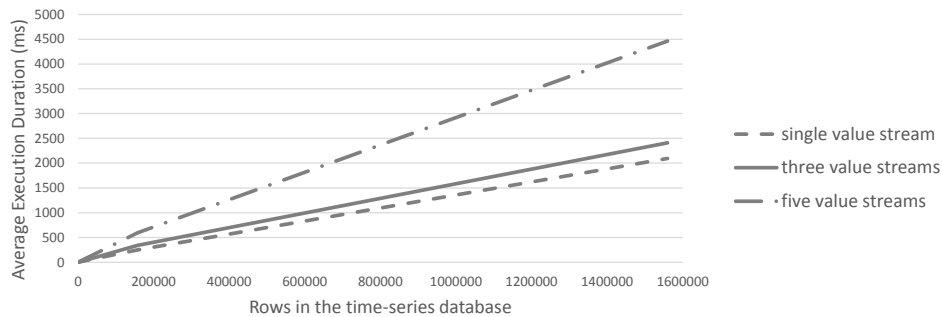


Fig. 4: Performance Results (average execution time in ms) according to sensor value streams and rows in the TSDB.

approach is the uniqueness of states. However, if the various states differ only slightly, the number of sensor value streams used for states identification is relevant for correctness.

Answering RQ2: The selected tolerance range and the number of sensor value streams are also decisive for the completeness of the states identification. The more sensor value streams are used, the more important individual sensor values become for the identification. In addition, the completeness of the identified states is better the larger the selected tolerance range is. In our evaluation we quickly achieve a good completeness. As soon as this is reached, the tolerance range should not be further increased, otherwise the correctness of the identified states suffers.

Answering RQ3: Our investigations of the execution time already show in this simple setting the influence of the number of data records in the database and the used number of different sensor value streams. However, the performance seems still promising for large cases as we experience a linear increase of execution time for all tested settings.

4.4 Threats to Validity

Internal Validity - Are there factors that can influence the results of the case study? At design time, values for our axis positions are assumed on the basis of, e.g., calibration values. At runtime, the same exact values are not always measured, but with a certain fluctuation range. Thus, a certain tolerance range must be defined at design time in which the values are accepted. In our case, we knew exactly which values to expect and were therefore able to keep our tolerance range small. However, this might not work with other settings.

External Validity - Is it possible to generalize the results? Our approach is based on queries automatically created by state machines. We focus on creating queries that are understood by the TSDB InfluxDB. Thus, the queries are currently in SQL syntax. If a different database query language is needed, only the Xtend code has to be adapted regarding syntax without changing the model in the background. At the moment our evaluation is based on a single case of a gripper simulation. For further and more detailed results the study has to be extended to other scenarios. Raw data from sensors are often noisy, incomplete and can contain erroneous records. This is not considered in our case study. In addition, the datasets for performance analysis are relatively small in relation to databases. Larger sets would be needed for further more detailed results.

5 Related Work

Discovering the behavior of running software. In [Li16], the authors utilize process mining (PM) techniques to discover and analyze the real behavior of software. By doing so, they discover behavioral models for each software component by considering hierarchies. In a first step of their approach, they identify component instances and construct event logs

for each component from raw software execution data. In a second step, they recursively transform the logs to a hierarchical event log for each component by considering calling relations among method calls. Based on these hierarchical event logs, the authors discover a hierarchical process model to understand how the software is behaving at runtime. The authors' software component behavior discovery builds on the inter-disciplinary research field of *Software Process Mining (SPM)*, firstly introduced by Rubin et al. [Ru07]. Both approaches base their grounding on the well-established techniques and methods of the research field of PM [Aa16].

Applying reverse engineering for obtaining event logs. In [LA15], the authors present a reverse engineering technique based on PM for obtaining real event logs from distributed systems. Similar to [Li16], the authors present an inter-disciplinary approach based on PM techniques and reverse engineering. The aim of their approach is to analyze the operational processes of software systems when running. The formal definition, implementation, and instrumentation strategy of the approach bases on a joinpoint-pointcut model (JPM) known from the area of aspect-oriented programming [EFB01]. This JPM helps (i) by defining the parts of a system that are to be included, (ii) enables to quickly gain insight into the end-to-end process, and (iii) detects the main bottlenecks. The authors demonstrate the feasibility of their approach by two case studies.

Query-based process analytics. A query approach enabling business intelligence through query-based process analytics is presented by Polyvyanyy et al. [Po17]. In contrast to our approach they are focusing on PM techniques for the automated management of model repositories of designed and executed processes, and on the relationships among these processes. For this purpose the authors introduce a framework for specifying generic functionalities that can be configured and specialized to address process querying problems, such as filtering or manipulation of observed processes.

Finally, we would like to highlight two research works that underline our approach and discuss the differences. Mayr et al. [Ma17] critically note that models are mainly used as prescriptive documents. Therefore, the authors aim for a model-centered architecture paradigm to keep models and developed artefacts synchronized in all phases of software development as well as in the running system. In this context, our approach helps to lift raw sensor data through automated states identification during operation at a model level for enabling a comparison between prescriptive and descriptive models. Senderovich et al. [Se16] apply PM techniques for real-time locating systems. They solve the problem of mapping sensor data to event logs based on process knowledge since location data recordings do not relate to the process directly. Therefore, they provide interactions as an intermediate knowledge layer between the sensor data and the event log [Se16]. Contrary to our approach, their raw sensor log consists already of different business entities and they have to map interactions to activity instances, while the sensor logs in our approach consist only of numerical values which we first have to aggregate to events.

6 Conclusion and Future Work

In this paper, we presented an approach that automatically derives state realization event queries from the design model to identify system states of a continuous system based on sensor value streams at runtime. This enables to raise raw sensor data from the data layer on a higher model layer. At this model level, runtime processes can be analysed more quickly and possible unintended parts within the realized system may be identified more easily and time-saving. Since inaccuracies has to be taken into account by dealing with numerical values of objects of the physical world, additionally we implemented a tolerance range for defining in which range such inaccuracies are still acceptable for an identified state at runtime.

First results of our case study indicate that a high precision and recall of system state identification may be achieved if an appropriate tolerance range for the runtime values was defined. Nevertheless, the uniqueness and distinctiveness of the individual states determine whether the state identification works well or not. If states are very similar, enough different sensor value streams must be used for state identification to obtain a good precision and recall. The approach is a step towards a better integration of model-driven software development to all the operations within a system's life cycle in order to continuously deploy stable versions of application systems.

There are several lines for future work we are going to explore in more detail. First, we plan to apply and validate our approach in a real-world setting, instead of a simulation. Second, we want to extend our approach to monitor different components with a larger set of sensor value streams. Third, we only used identically tolerance ranges for the properties. In a further investigation, we want to find out if there are automated techniques possible to estimate good guesses for the tolerance ranges of different properties. Finally, we want to find out if we could extend our approach for state estimation and detection of possible hidden states.

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References

- [Aa16] van der Aalst, W. M. P.: Process Mining-Data Science in Action. Springer, 2016.
- [BS14] Broy, M.; Schmidt, A.: Challenges in Engineering Cyber-Physical Systems. Computer 47/2, pp. 70–72, 2014.

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- [EFB01] Elrad, T.; Filman, R. E.; Bader, A.: Aspect-oriented Programming: Introduction. *Commun. ACM* 44/10, pp. 29–32, Oct. 2001.
 - [FMS12] Friedenthal, S.; Moore, A.; Steiner, R.: A Practical Guide to SysML. Morgan Kaufmann, 2012, ISBN: 9780123852069.
 - [LA15] Leemans, M.; van der Aalst, W. M. P.: Process mining in software systems: Discovering real-life business transactions and process models from distributed systems. In: *MODELS*. Pp. 44–53, 2015.
 - [Li16] Liu, C.; van Dongen, B.; Assy, N.; van der Aalst, W. M. P.: Component behavior discovery from software execution data. In: *SSCI*. Pp. 1–8, 2016.
 - [Ma17] Mayr, H. C.; Michael, J.; Ranasinghe, S.; Shekhovtsov, V. A.; Steinberger, C.: Model Centered Architecture. In: *Conceptual Modeling Perspectives*. Springer, pp. 85–104, 2017.
 - [MRS08] Manning, C. D.; Raghavan, P.; Schütze, H.: Introduction to information retrieval. Cambridge University Press, 2008.
 - [MW16a] Mazak, A.; Wimmer, M.: On Marrying Model-driven Engineering and Process Mining: A Case Study in Execution-based Model Profiling. In: *SIMPDA*. Pp. 78–88, 2016.
 - [MW16b] Mazak, A.; Wimmer, M.: Towards Liquid Models: An Evolutionary Modeling Approach. In: *CBI*. Pp. 104–112, 2016.
 - [MWP18] Mazak, A.; Wimmer, M.; Patsuk-Bösch, P.: Execution-Based Model Profiling. In: *Data-Driven Process Discovery and Analysis*. Springer, pp. 37–52, 2018.
 - [MWV16] Mayerhofer, T.; Wimmer, M.; Vallecillo, A.: Adding uncertainty and units to quantity types in software models. In: *SLE*. Pp. 118–131, 2016.
 - [OD08] Olson, D. L.; Delen, D.: Advanced Data Mining Techniques. Springer, 2008, ISBN: 978-3-540-76916-3.
 - [Po17] Polyvyanyy, A.; Ouyang, C.; Barros, A.; van der Aalst, W. M.: Process querying: Enabling business intelligence through query-based process analytics. *Decision Support Systems* 100/, pp. 41–56, 2017.
 - [RH09] Runeson, P.; Höst, M.: Guidelines for conducting and reporting case study research in software engineering. *Empirical Software Engineering* 14/2, pp. 131–164, 2009.
 - [Ru07] Rubin, V.; Günther, C. W.; van der Aalst, W. M. P.; Kindler, E.; van Dongen, B. F.; Schäfer, W.: Process Mining Framework for Software Processes. In: *Software Process Dynamics and Agility*. Springer, pp. 169–181, 2007.
 - [Se16] Senderovich, A.; Rogge-Solti, A.; Gal, A.; Mendling, J.; Mandelbaum, A.: The ROAD from Sensor Data to Process Instances via Interaction Mining. In: *CAiSE*. Pp. 257–273, 2016.
 - [Wo17] Wolny, S.; Mazak, A.; Konlechner, R.; Wimmer, M.: Towards Continuous Behavior Mining. In: *SIMPDA*. Pp. 149–150, 2017.

Model-based Testbed Design for Electric Vehicles

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Abstract: Electric cars boom. This puts pressure on providing and improving tools and systems for electric car development. Electric vehicle testbeds (EVTs) are such systems: they serve for testing all high voltage vehicle components like batteries, inverters or complete engines and help to reduce the need of cost intensive road tests. EVT users like manufacturers of automobiles, aircrafts or train engines mostly have individual requirements. EVT users are therefore typically tailor-made solutions. Today's approach to customized testbed (component) design starts with drawing the overall architecture using tools like MS Visio; based here-on, software developers, circuit plan designers, and engineers use their specific low-level design and development environments, obviously with no transformation or generation out of the initial drawing with causes all known challenges of such procedure. This paper presents a novel, innovative and scalable approach to EVT design based on an ontology grounded Domain Specific Modeling Language (DSML). It enables the user to describe the customer requirements in the familiar form. The resulting model can then be used to generate circuit diagrams and software configurations. Such approach not only may reduce development time and cost but may increase the quality of the resulting EVT.

Keywords: Modeling, Meta-Model, Ontology, Circuit plan, Testbed, MDA, DSML, Electric vehicle.

1 Introduction

We present here an innovative, model-based approach to the design of technical systems using Electric Vehicle Testbeds (EVTs) as an example. Most technical disciplines have their specific design methods and languages, for example circuit diagrams in the case of electrical systems. Rarely, these methods are derived from more general conceptualizations like metamodels or ontologies, and just as little are based on universal or standardized conceptual modeling languages like UML, Petrinets or similar. In the case of EVT development projects, which mostly target customized individual solutions, designers typically draw the overall architecture using tools like MS Visio. Based here on, software developers, circuit plan designers, and engineers use their specific low-level design and development environments, obviously with no transformation or generation out of the initial drawing – with all the notorious problems caused by such procedure like inconsistencies, loss of information, manual rework, late design feedback or poor reuse.

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By the example of EVT design, we will show that conceptual modeling may be useful for comparable engineering domains, in particular for mechatronic systems where engineers from different disciplines like electronic, mechatronic, software and management have to collaborate. Our approach is inspired by the state of the art in domain specific modeling methods (DSMMs) [Gh11, MM15, OM14]. In particular, we propose to provide, for a given engineering domain, a tailored domain specific conceptual modeling language (DSML), including tool support and mechanisms for model transformation to the lower domain levels. The work presented here is part of a dissertation project, which currently is implemented in close cooperation with the company AVL List GmbH. We adopt the process model for DSMM development discussed in [MM15] and follow Thalheim's [Th14] definitions regarding conceptual modeling, that presume the background of conceptual models to consist of "a base, a context and a community of practice".

The structure of the paper is as follows: In section 2 we outline the essential aspects of EVTs and their design. Section 3 presents a metamodel and the conceptual DSML we have developed based on the results of an intensive domain analysis including interviews with EVT designers and developers. In addition, we sketch the modeling process using that DSML and the creation of an appropriate modeling tool by deploying the metamodel framework ADOxx [FK13]. Section 4 shortly reviews related work. The paper ends with an outlook on future research in section 5.

2 Electric Vehicle Testbed Design

Electric vehicle testbeds serve for testing all high voltage vehicle components like batteries, inverters or complete engines and help to reduce the need of cost intensive road tests. Users of EVTs are manufacturers of automobiles, aircrafts, train engines and similar. They mostly have individual requirements so that EVTs are typically customized solutions. We concentrate here on the main EVT-components:

- **Unit under Test UUT:** In the case of batteries, the related EVT is called battery testbed (see Fig. 1). If the UUT is an E-Motor together with an inverter (DC to AC), the EVT is called electric powertrain component testbed (see Fig. 2).
- **Battery Management System BMS:** a low voltage component for controlling the battery functions.
- **Engine Control Unit ECU:** a low voltage component for controlling the inverter of the E-Motor.
- **Supply:** A direct current (DC) source that quickly can react on set point changes of voltage, current and power. In an EVT it is used for both, traction battery emulation (Fig. 2), and battery testing (Fig. 1).

- **(Power)Distribution Box PDU:** Connection point for the UUT including safety components (see Fig. 3).
- **Switch Box:** Connects the supply with one or more Distributions Boxes via power cables, or directly with the UUT, if the customized solution does not provide Distribution Boxes.
- **Test Automation System TAS:** Controls the interplay of the EVT components to perform the required test functionality according to a 'Vehicle Model' describing driving patterns, and a 'Battery Model' describing charging and discharging patterns and set points.

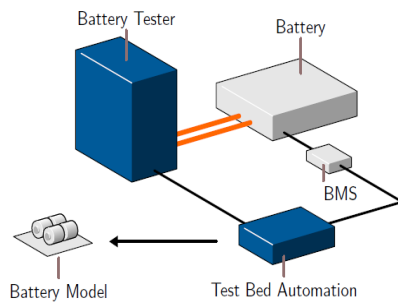


Fig. 1: Battery testbed

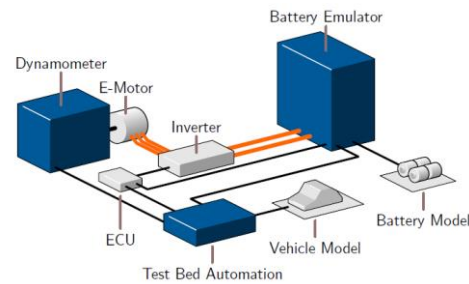


Fig. 2: Electric powertrain component testbed

As mentioned in the Introduction, developing a customized EVT solution starts with drawing an overall structural design using a standard drawing tool. Figure 3 shows a very simple example of such drawing, which even does not contain some of the before mentioned EVT components.

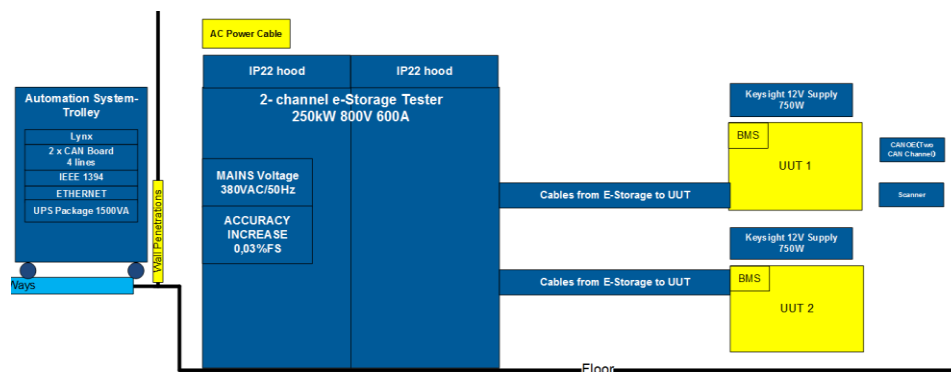


Fig. 3: TTD Example

The elements of such design may be conceptualized, abstracted and composed to a domain specific metamodel (according to level 2 of the OMG Meta Object Facility MOF [OM14]). A related and appropriately instrumented modeling language (a DSML) then serves to create models (on MOF Level 1) of EVT types as extensions of this metamodel. The MOF level 0 elements, being extensions (instances) of such models, are descriptions of concrete customized EVTs.

Clearly, practitioners would not be happy with having to deal with a pure modeling language. Rather they expect appropriate tool support for model creation, combination, reuse and analysis as well as guidance about how to proceed. In addition, circuit plan designers would expect the possibility of automatically generating circuit plans out of such models as this would help to reduce development time and costs, is flexible regarding agile modifications, and could contribute to increase the quality of the EVT development process. Consequently, this leads to the development of a comprehensive domain specific modeling method, i.e. a DSMM. [MM15] present a process model for DSMM development that proposes, on the top level, the following five stages: Preparation, Language, Modelling process, Modelling tool and Evaluation. Following this process model, the first activity in the stage Specification was to elicit the requirements and expectations of the engineers involved in EVT design and development. The results of this endeavor fall into four main categories:

- (1) **Understandability:** The modeling language as well as the models should be intuitively understandable for all stakeholders involved in order act as a "bridge that overcomes the semantic gap" [Gh11] between the various user groups. The language, therefore, must cover all concepts needed for EVT design and only those; the visual notation should be similar to the familiar one (to be effective in the sense of [Mo09]). In addition, the engineers asked for the availability of stakeholder group specific views on models [Br17] increasing understandability for experts from different disciplines collaborating in an EVT project. In the traditional approach, such views would require extra drawing effort and, therefore, are rarely produced.
- (2) **Consistency:** The modeling environment (tool) should provide means for ensuring syntactical correctness, for supporting compliance with semantic construction rules ("EVT Rules"), and for checking specific consistency constraints. Clearly, the traditional approach has to manage without such means and thus is error-prone with all related problems of late error detection.
- (3) **Re-Usability:** Currently, designs are "re-used" by simple copy&paste of diagram parts, again with all related problems. Consequently, the engineers ask for a flexible multi-level [Fr13] modeling environment supporting all kind of model re-use and integration.
- (4) **Cost-Effectiveness:** This relates to all previous requirements, but in addition should be strengthened by the availability of generators for producing lower-level artifacts out of models like circuit plans as well as configuration data for system components. Clearly, in the traditional approach, such means are not available. At least, most of

the common circuit plan tools like EPLAN or WSCAD allow for creating circuit plans by selecting and combining "prefabricated" building blocks [SB07, Wa17, EP18a] but this obviously still is a manual process.

3 EVT-MM: A Modeling Method for EVT Design

This section is structured according to the five DSMM development stages introduced in the previous section.

3.1 Analysis of domain-specific documents

Developing a domain specific modeling method requires a deep analysis of the domain to understand and figure out the important aspects to be conceptualized and included in the metamodel. For that purpose, we analyzed a large number of existing EVT design documents, like the TTD for a battery testbed as shown in figure 3. Such TTD contains information about the main system components, cable lengths, software packages to be installed, information about services. Documents that are more detailed contain information about specific customer requirements regarding controller parameters, customized interface or system limits. Analyzing the product structure of common testbed applications may reveal additional information, as far as EVT standard products with customizable options are already available.

Our analysis came up with a series of aspects to be considered when developing an EVT DSMM: connections, placement of parts, dynamic specifications, timings, the current load of all HV components, the maximum electric strength of components, the cable length influencing the current dynamics, the temperature range and power overload capacity as well as the possible operation modes of the UUTs. In addition, general constraints like Ohm's law, electromagnetic induction, electric capacity and Electric Energy are to be taken into account as well as the relevant Standards: IEC 61439, IEC 13849, IEC 81346, and IEC 60146. As an example think of the length and diameter of a power cable as they these direct impact on the current dynamics that can be achieved by the supply.

3.2 Meta-Model and DSML

Based on these findings we iteratively worked out the necessary conceptualizations and combined these to the metamodel as depicted in Fig. 4 and Fig. 5, the latter refining the concept of "Hardware Component" including the concepts needed for circuit design. The italic-labeled concepts are abstract in the sense that they have no instantiation on the level M1. The semantic foundation of these concepts is done by means of an EVT ontology, which we cannot present here due to lack of space. It will be published elsewhere.

Models, i.e., MOF level M1 extensions (instances) of this metamodel, represent EVT types. M0 level instances of such models then are concrete customized EVT designs corresponding to the traditional TTDs. Table 1 shows some examples of the modeling concepts on the three MOF-layers. The representation concepts for the EVT DSML follow the style of the TTDs. An example is given in figure 8. This conceptual model has been created using a prototype of the modeling tool we are currently developing based on the ADOxx metamodeling framework (see section 3.4).

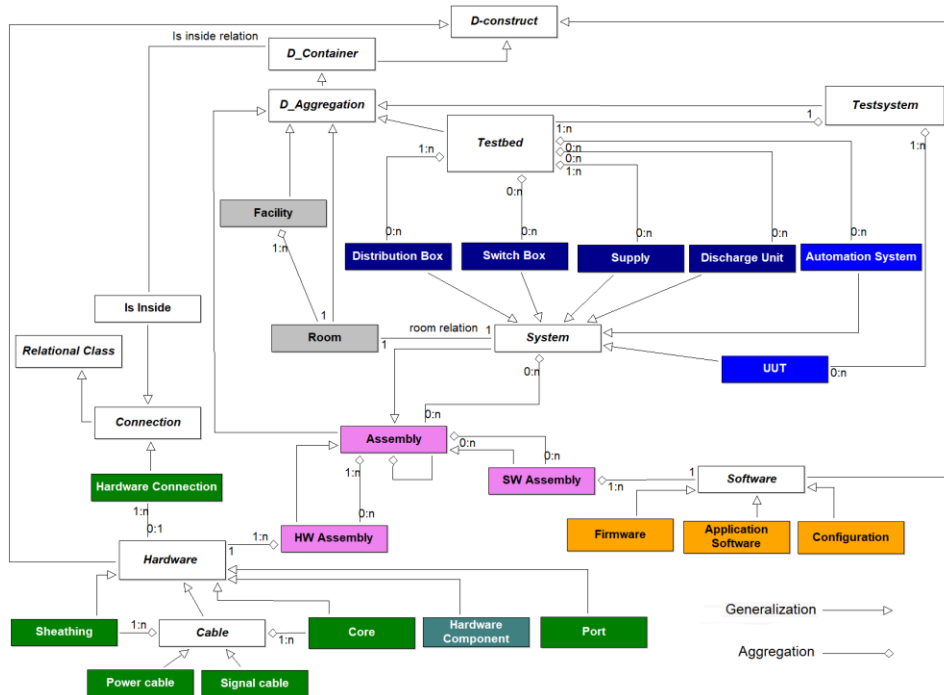


Fig. 4: EVT Metamodel (M2)

M2	M1	M0
Supply	2 channel supply	2 channel supply 800V/600A
Supply	1 channel supply	1 channel supply water cooled
Power cable	Power cable	Power cable 10m, q=150mm ²
Discharge unit	Discharge unit 4x	Discharge unit 4x 1200V
UUT	Battery	Battery Dura Ultra 50kWh
Assembly	Door switch	Door switch DS03
Configuration	Controller parameter	Controller parameter T ₉₀ =0.5ms

Tab. 1: Example of EVT language concepts on MOF: M2, M1 and M0

3.3 Notation

For each element of a MOF hierarchy one (or possibly several) appropriate representation language(s) have to be provided [Ma18]. Usually, for the metamodel itself, a UML class diagram like notation is chosen as we did in section 3.1. For the making the metamodel concepts available on M1 we designed a modeling language EVT-ML by following the principles and guidelines of [Re13, Gu13 and Mo09]. The notations can be divided into the categories *Container Elements* (symbol is an unfilled square), *Software Elements* (yellow rounded rectangle elements), *System Elements* (blue rectangle, based on real system), *Cables* (line) and *Hardware Components* (based on IEC 60417). For reasons of intuitive understandability, aggregations drawn overlapping, for example, System Elements within a Room symbol (see fig. 8) that again might be drawn within a Facility symbol.

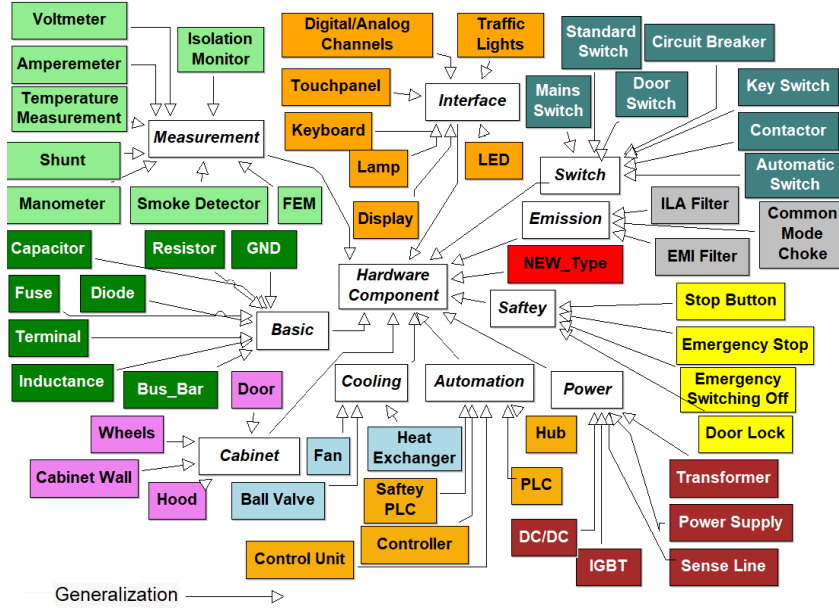
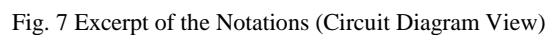
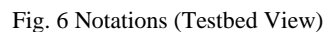


Fig. 5: Hardware Component Metamodel refinement (M2)

Figures 6 and 7 give an overview over the notational elements for testbed and circuit diagram representation. The latter correspond largely to the existing IEC 60417 notations, which are well established in the electrical engineering domain. By using already existing notations, the barrier to learn the new language is reduced [Ka09].

The EVT modeling process is part of the overall EVT development process, which starts with initiating a new project and eliciting the customer requirements. For this purpose, a first rough testbed model is established (possibly building on an appropriate pattern if available in the model base) which then is refined iteratively. It should contain the facility, the rooms, the main parts (systems), the connections (signal cables or power cables) between the systems and the automation system. In addition to that, the properties of the modeling elements must be specified (to allow transformation and model checking techniques). The circuit plan is created using the circuit modeling toolbox (see below) including cables, ports and hardware component elements. A circuit plan example create by use of our modeling prototype is shown in Fig. 9. Each circuit plan belongs to a system (specified by a relation INTERREF).



3.5 Modeling tool

The most efficient way for tool implementation is to use a so-called metamodeling platform like ADOxx [FK13], Eclipse EMF or MetaEdit+ [5,7]. We decided to deploy ADOxx based on the fact that ADOxx has been successfully used and tested since long in a large number of research and industrial projects, in particular also by our department. Moreover, we used it successfully for creating a tool for supporting a DSML for circuit plan design. The Testbed Example Model shown in figure 8 has been created using the current stage of our EVT modeling tool under construction. The colors used correspond to the metamodel concepts from which the particular model element is instantiated. Even this first prototype allows for some basic consistency checks and model analysis (inbuilt in ADOxx) and avoids constructing syntactically incorrect models (correct by construction [Ke14]). This allows for fast feedback during the design phase.

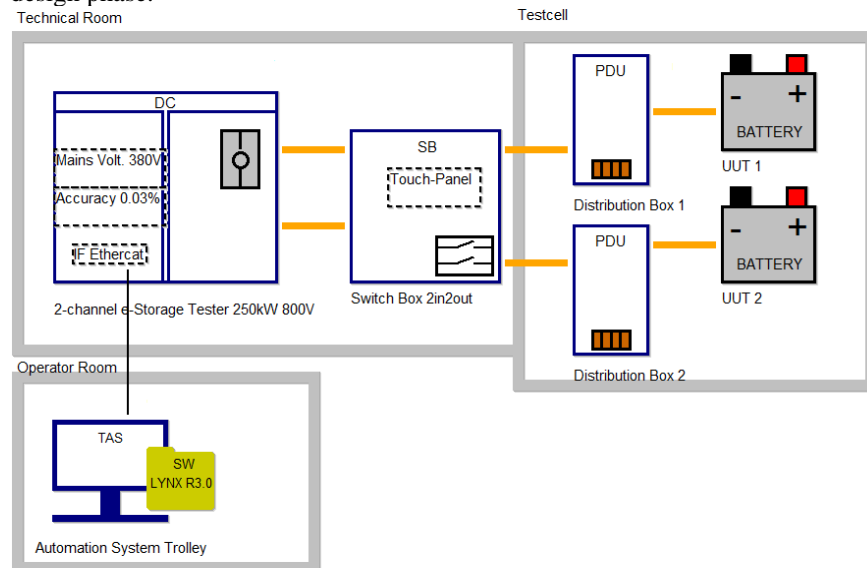


Fig. 8 Simple Testbed Example Model (M1)

Because the EVT modeling tool is to be used by managers and by circuit plan designers who operate at a different level of detail, the EVT modeling tool provides different views on the model. The “Testbed View” which is shown in Fig. 8 is used for modelling the overall testbed and the “Circuit Plan” view is used for modeling the circuit plan of the EVTs (Fig. 9). To reduce complexity the modeling tool provides composition technology. To increase the productivity, template models can be loaded (from a database) which then are further modified.

3.7 Evaluation

Apparently, what we are presenting here is research in progress. However, several evaluations have been done already. At the beginning, an online survey in the EVT manufacturer's development team was performed to figure out the requirements for the DSML and the Modeling tool. The survey included questions, related to the current EVT development process, used tools, important components, customer specific changes, and the application area. To evaluate the understandability of the modelling notation also an online survey has been performed. There the task was to select the correct name for the shown notation element. Based on the results the notation (for the system elements) was reworked. The notation is now based on the real-systems including graphic and text to be understandable intuitively. The modeling prototype has already been rolled out in the development department in order to collect first test results. The developers used it to model the testbed for project documentation, communication across stakeholder and troubleshooting. The main result was, that the models are clearly understandable to the involved persons (project manager, software developer, circuit diagram designer, team

leader, support engineer and product manager). However, they proposed some improvements, e.g., a comment function, and an issue representation for troubleshooting. Moreover, they claimed, that it should be possible for reasons of complexity reduction, to hide elements that are drawn inside others. To evaluate the completeness of the DSML, we modeled twenty already existing EVT's (based on the TTD) using our modeling tool. As a result, all aspects of these EVT's were covered with the exception that there were no concepts for modeling components like a "Climatic Chamber" and similar. We are currently analyzing if it would be advisable to introduce a generic system element for covering such kind of components.

4 Related work

Since the 90s, domain specific modeling, languages and tools as well as ontological grounding are broadly investigated. Metamodelingplatforms like Eclipse EMF, ADOxx and MetaEdit+ provide powerful means for creating modeling and analysis tools for domain specific modeling languages. Tab. 2 shows some existing domain specific methods. [MM15] focus on Model Engineering, i.e. propose a process model for developing domain specific modelling methods. The researchproject IMoMeSA [HRZ15] came up with a development method for mechatronic systems. It enables the development of machines and systems starting from the concept of a virtual prototype. The method integrates already existing tools and enables generation of MCAD, ECAD and IEC 61131-3 code through model transformations. [CSV10] introduces a method to connect domain-specific tools through a higher-level SysML data model. [Ho17] introduces a method to integrate models in the plant engineering domain using the Anlagenreferenzstruktur. Sporer [Sp16] presents an approach to domain specific modeling of embedded automotive mechatronic systems that allows for linking requirements and specifications to the created models. However, so far no references on conceptual modelling method specifically for the domain of EVT design could be found. Clearly, SysML and UML based approaches are basically conceptual, but they are not domain specific in the sense propagated within this paper.

Name	Domain
EPLAN Electric [EP18a]	Mechatronic design
MATLAB [MA18]	Mathematic calculations
FUP [Ha15]	PLC programming
VHDL [IE00]	Electronic design automation
ComVantage [Bu16]	Production Management
	Systems
EMS-DSM [Sp16]	Mechatronic system development

Tab. 2: Modeling methods used in mechatronics

5 Outlook on next steps to do

This paper presents research and work in progress. However, as the idea of deploying a systematic conceptual DSML approach to EVT design is innovative, we decided to present here our first considerations and results. The approach proposed may not only reduce the development time for EVT but also improve the quality of developed customer specific EVTs, in particular when the lower-level design documents are generated by deploying model transformations according to the MDA principles. In addition using a DSMM-tool instead of drawing tools like MS Visio may help to overcome the well known problems caused by purely document based approaches. There is still much open research and work to do: First, more detailed end-user experiments will help evaluating the completeness and appropriateness of the proposed metamodel and DSML. Second, we need turning the prototype into a product including means for handling domain specific consistency constraints as well as continuous adaptations in the EVT domain. Moreover, to provide substantial improvements of effectivity and efficiency in EVT design, we will have to finalize and integrate generators into the EVT tool that produce, for example, circuit plans and configuration data out of a concrete EVT level M0 representations. This will reduce today's need of manual work substantially and thus contribute to the avoidance of related transcription errors.

During creating the metamodel (Fig. 4) it was found that the concepts of the metamodel are not only specific to the electric domain (especially EVT), but also have similarities with the hydraulic domain (e.g. filling plan). Such analogy was already detected in the 19th century by Oliver Lodge (drain-pipe theory) [Na02]. Examples for this are the Supply-pump, cable-pipe, capacitor-tank and resistor-constricted pipe connection. As a consequence we are currently thinking of a generalization of the presented approach.

Bibliography

- [Br17] Bruneliere, H. et al.: A featurebased survey of model view approaches. *Journal Software & Systems Modeling* No. 10270, 2017.
- [Bu16] Buchmann, R. A.: Modeling Product-Service Systems for the Internet of Things: The ComVantage Method. In (Karagiannis, D; Mayr, H; Mylopoulos, J. eds): *Domain-Specific Conceptual Modeling*, pp. 417–437, 2016.
- [CSV10] Chami, M.; Seemullerm H.; Voos, H.: A SysML-based integration framework for the engineering of mechatronic systems. In: *Proc. IEEE/ASME Int. Conf. on Mechatronic and Embedded Systems and Applications MESA 2010, QingDao*, pp. 245–250, 2010.
- [Di12] Dimitrieski, V. et al.: A Comparison of Ecore and GOPRR through an Information System Meta Modeling Approach. In (Störrle et al. eds): *Joint Proceedings of co-located Events at the 8th European Conference on Modelling Foundations and Applications (ECMFA 2012)*, Technical University of Denmark, Copenhagen, Denmark, pp. 217–228, 2012.
- [EP18a] EPLAN Electric P8: Power for electrical planning and engineering,

- <https://www.eplanusa.com/us/solutions/electrical-engineering/eplan-electric-p8/>, accessed: 18/11/2018.
- [EP18b] Eplan Software and Service GmbH. API User Guide, http://www.eplan.help/help/platformapi/2.7/en-us/help/API_UserGuide.html, accessed: 18/11/2018.
- [FK13] Fill, H.; Karagiannis, D.: On the Conceptualisation of Modelling Methods Using the ADOxx Meta Modelling Platform. *Journal Enterprise Modelling and Information Systems Architectures* Issue 1/2013, pp. 4–25, 2013.
- [FKT14] Frakes, W. B.; Kulczynski, G.; Tilley J.: A Comparison of Methods for Automatic Term Extraction for Domain Analysis. In: (Schaefer I., Stamelos I. eds.) *Proc. Software Reuse for Dynamic Systems in the Cloud and Beyond. ICSR 2015. Lecture Notes in Computer Science* Vol. 8919, Springer, Cham, pp. 269–281, 2014.
- [Fr13] Frank, U.: Domain-Specific Modeling Languages: Requirements Analysis and Design Guidelines. In (Reinhartz-Berger, I. et al. eds): *Domain Engineering*, Springer Berlin Heidelberg, pp. 133–157, 2013.
- [Gh11] Ghosh, D.: 2011. DSL for the Uninitiated, *Communications of the ACM* Vol. 54 Issue 7/2011, pp. 44–50, 2011.
- [Gu13] Guizzardi, G.: Ontology-Based Evaluation and Design of Visual Conceptual Modeling Languages. In (Reinhartz-Berger, I. et al. eds): *Domain Engineering*, Springer Berlin Heidelberg, pp. 317–347, 2013.
- [Ha15] Hanssen, D. H.: Function Block Diagram (FBD). In (Hanssen, D. H. ed): *Programmable Logic Controllers: A Practical Approach to IEC 61131-3 using CODESYS*, 2015 John Wiley & Sons, pp. 262–277, 2015.
- [He10] Hepp, M.: Volkswagen Vehicles Ontology, <https://www.volkswagen.co.uk/vocabularies/vvo/ns>, accessed: 18/11/2018, 2010.
- [Ho17] Hooshmand, Y. et al.: An approach for holistic model-based engineering of industrial plants. In (Maier A. eds.): *Proc. 21st Int. Conference on Engineering Design (ICED17)* Vol. 3/2017, Vancouver, 2017.
- [HRZ15] Hackenberg, G.; Richter, C.; Zäh, M.: IMoMeSA Abschlussbericht. Technical Report., <https://mediatum.ub.tum.de/attfile/1253882/incoming/2015-May/570232.pdf>, accessed: 18/11/2018, 2015.
- [IE00] IEEE 2000. IEEE Standard VHDL Language Reference Manual.
- [Je16] Jeusfeld, M. A.: SemCheck: Checking Constraints for Multi-perspective Modeling Languages. In (Karagiannis, D.; Mayr, H.; Mylopoulos, J. eds): *Domain-Specific Conceptual Modeling*, Springer, Cham, pp. 31–53, 2016.
- [Ka09] Karsai, G. et al.: Design Guidelines for Domain Specific Languages. In: *Proc. of the 9th OOPTSLA Workshop on Domain-Specific Modeling*, Helsinki School of Economics, Orlando, USA, 2009.
- [Ka14] Karbe, T. et al.: State of the art for automotive ontology D308.010, crystal, 2014.
- [Ke14] Kezadri-Hamiaz, M. et al.: Correct-by-construction model composition: Application to the Invasive Software Composition method. In (Buhnova, B.; Happe, L.; Kofron, J.

- eds.): Proc. FESCA 2014, Grenoble, France, pp. 108-122, 2014.
- [KKW07] Ahmed-Kristensen, S.; Kim, S.; Wallace, K. M.: A Methodology for Creating Ontologies for Engineering Design (modified version DETC2005-84729). *Journal of Computing and Information Science in Engineering* 2007, pp. 132-140, 2007.
 - [KMP16] Kiritsis, D.; Milicic, A.; Perdikakis, A.: User Story Mapping-Based Method for Domain Semantic Modeling. In (Karagiannis, D.; Mayr, H.; Mylopoulos, J. eds.): *Domain-Specific Conceptual Modeling*, Springer, Cham, 439–454, 2016.
 - [Ma18] Mayr, H.C. et al.: A Model Centered Perspective on Software-Intensive Systems. In (Fellmann, M.; Sandkuhl, K. eds.): *Proc. 9th Int. Workshop on Enterprise Modeling and Information Systems Architectures*. Vol. 2097, CEUR-WS.org, Rostock, Germany, pp 58-64, 2018.
 - [MA18] MathWorks, Math. Graphics. Programming, <https://ch.mathworks.com/products/matlab.html>, accessed: 18/11/2018.
 - [MM15] Michael, J.; Mayr, H. C.: Creating a Domain Specific Modelling Method for Ambient Assistance. In: *Proc. International Conference on Advances in ICT for Emerging Regions (ICTer 2015)*, IEEE, Colombo, Sri Lanka, 2015.
 - [Mo09] Moody, D. L.: The "Physics" of Notations: Toward a Scientific Basis for Constructing Visual Notations in Software Engineering. *IEEE Transactions on Software Engineering*. Vol. 35 Issue 6, pp. 756–779, 2009.
 - [Na02] Nahin, P. J.: *Oliver Heaviside: The Life, Work, and Times of an Electrical Genius of the Victorian Age*, illustrated reprint, John Hopkins University Press, 2002.
 - [OM14] OMG 2014. MDA Guide rev. 2.0., <https://www.omg.org/cgi-bin/doc?ormsc/14-06-01>, accessed: 18/11/2018.
 - [Re13] Reinhartz-Berger, I. et al.: *Domain Engineering: Product Lines, Languages, and Conceptual Model*, Springer Heidelberg New York Dordrecht London, 2013.
 - [SB07] Schaefer, D; Baguley P.: ECAD functionality suitable for webbased optimised automated product variant generation. *International Journal of Internet Manufacturing and Services*. Vol. 1 No. 1, 2007.
 - [Sp16] Sporer, H.: *Mechatronic System Development: an Automotive Industry Approach for Small Teams*, Doctoral Thesis, TUGraz DIGITAL Library, 2016.
 - [Th14] Thalheim, B.: The conceptual model \equiv An adequate and faithful artifact enhanced by concepts. *Frontiers in Artificial Intelligence and Applications* Vol. 260, pp. 241–254, 2014.
 - [Tu06] Tudorache, T.: *Employing Ontologies for an Improved Development Process in Collaborative Engineering*, Doctoral Thesis, 10.14279/depositonce-1477, 2006.
 - [Wa17] Walker, T.: *Elektrokonstruktion im Sondermaschinenbau mit WSCAD hochgradig standardisiert*, Hüthing Verlag, 2017.

Enterprise Information Systems in Academia and Practice: Lessons learned from a MBSE Project

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Abstract: The development of domain-specific information systems, especially web information systems, takes a certain amount of time, needs intensive testing to ensure a certain quality and lacks the consistency of front- and backend. Using model-based strategies for the creation of information systems helps to overcome these problems by fastening the development process, facilitating testing and ensuring consistency-by-construction. In practice, however, they are still rarely used. In this paper, we show that model-based engineering is beneficial for the creation of an enterprise information system and improves the quality of the resulting product. We present the basic functionalities of our Generator for Enterprise Management (MontiGEM) and discuss identified problems and lessons learned in a project in practice. The generator was developed simultaneously with and for an enterprise management system. Our research shows that the use of generative methods and MBSE improves the adaptability and reusability of parts of the application on the one hand but on the other hand, there are still obstacles that slow down its broad application in practice.

Keywords: Agile Development · Data-Intensive Enterprise Information Systems · Domain-Specific Modeling Languages · Generative Software Engineering · Model-Based Software Engineering · MontiGEM · Web Information System Engineering

1 Introduction

Context. To effectively create an enterprise information system (EIS), investigating and modeling the domain in focus is essential to create a usable and reliable system. Using models decreases the gap between software abstractions on the problem level and its implementation. In Model-based Software Engineering (MBSE) models play an important role. It supports strong stakeholder involvement and the *constructive generation* or *manual synthesis of code* from models is among the first steps of model-based development processes. Thus, one or more modeling languages are the central notation and replace the programming language as much as possible. For domain-specific needs, MBSE relies on the use of domain-specific modeling languages (DSML) [Vö13] as a central notation. DSMLs can be developed to be used for several purposes such as designing, programming and testing software systems or for describing the behavior of a system or processes.

Motivation and Relevance. MBSE increases efficiency and effectiveness in software development and its adoption in the software industry is foreseen to grow exponentially in

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the near future [BCW17]. Using MBSE approaches for web applications improves their development as well [MCM14]. In order to impart knowledge about MBSE approaches, more tools and experience with modeling languages as well as more successful examples for practical application in EIS are needed.

Goals. In this paper, we discuss lessons learned and obstacles that slow down the broad application of generative MBSE approaches for EIS in practice in order to identify starting points for future research and improvements.

Approach and Main Results. To be able to discuss the lessons learned in detail, we introduce the practical application of MBSE in an agile EIS development project. As part of a MBSE project, we developed the Generator for Enterprise Management (MontiGEM) based on the language workbench and code generation framework MontiCore [HR17]. The realization was accompanied by strong stakeholder involvement processes: As usual in scrum, we define the use cases together with future users. Interested future users were a part of the engineering process who provided feedback on implemented features. Thus, it was important to consider and react to changes quickly. In [Ad18] we already presented our approach for model-based generation of data-intensive EIS at a glance. This paper (1) presents an improved version of (MontiGEM) and basic functions to handle different DSMLs and (2) shows lessons learned and obstacles for using MBSE for creating EIS. With the help of a generator, some problems, such as data inconsistency on frontend (FE) and backend (BE), can be avoided. Nevertheless, we state additional improvements for the „ease of use“ for engineers.

Outline. The paper is structured as follows: Section 2 presents our approach for MBSE of EIS and the generator MontiGEM. In section 3, we discuss advantages and disadvantages of our approach as well as lessons learned and obstacles in the practical realization in a software engineering (SE) project. Section 4 discusses related work in comparison to our approach and the state-of-the-art of MBSE for web-EIS. The last section reviews the current progress and highlights further goals and next steps for our approach.

2 Model-based Generation of EIS with MontiGEM

With MontiGEM it is possible to generate large parts of data centric business applications: The datastructure and database communication, functions, access control, and the graphical user interfaces (GUIs). The generator MontiGEM uses different kinds of models as input and uses them as the base for code generation of the BE and FE in different target languages. The internal architecture of the generator includes three main processes: read, transformation and generation. A model loader loads all input models and handles their transformation in an internal accessible structure, the abstract syntax tree (AST), by using parsers and a library of data structures and functions. The central part of MontiGEM transforms several input ASTs to output ASTs. The template engine processes each output AST together with standardized as well as project-specific templates, which describe the concrete shape of the

resulting artifacts, and produces as an output the code files for BE and FE. The components model loader and template engine are generated with MontiCore².

CD4A (class diagram for analysis [Ob17]) is used, to describe the basic domain model (data structure). **Purple boxes** represent all the classes generated out of the one given *Classes.cd*, see fig. 1, 2 and 3. Each of these classes are used for a specific task, e.g., the database communication done with hibernate or network transportation with a REST infrastructure. This domain model can be written by domain experts.

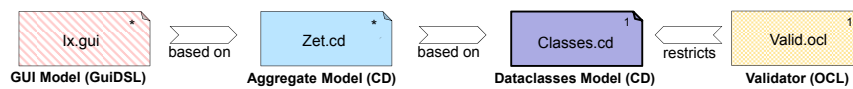


Fig. 1: Model files with their resp. number of occurrences (*: any number, 1: exactly one)

Based on the domain class diagram, an *OCL* [Ma17; Ob14] model is used to restrict the attributes of defined classes to describe valid objects (**yellow boxes**). Resulting validators need different levels of detail, especially FE and BE have distinct demands. Error messages or even specific expressions can be used to adapt objects to the exact behavior required. Through the generation process both, the validators on the FE and BE, are consistent and thus check for the same validity.

Aggregate models (**blue boxes**) summarize attributes of specified domain classes and/or calculated values to limit the view to the data needed in the FE. For each dataclass multiple constellations of aggregates are viable to use. The models and thus the generated code have little information about the logic with which the aggregate object is generated, so a considerable part of it currently has to be written by hand.

Based on the previous described DSMLs, the GuiDSL is used to create views for the FE (GUIs) and fill them with the corresponding data defined by aggregates. For each page there is an affiliated model. This model separation improves the configurability and the separation of concerns. The model describes the usage of the aggregate and generates communication and validity checking. The model is the base for the logic component, which handles the data collection and user interaction, and a HTML view (**red boxes**).

Boxes with a *hwc* addition indicate, that handwritten parts are necessary to work properly. [Gr15] describes the used integration of handwritten and generated object-oriented code. A constant regeneration based on the given models is possible. We expect to be able to (nearly) fully generated these missing parts in the future by improving the DSMLs.

A command infrastructure and generated commands for each domain and aggregate class are used to handle the entire communication between BE and FE. This is based on the command processor pattern [BHS07]. The aggregates selected in the GuiDSL are requested and can be written back by commands on the FE. Through this mechanism data consistency is ensured.

²<http://www.monticore.de/>

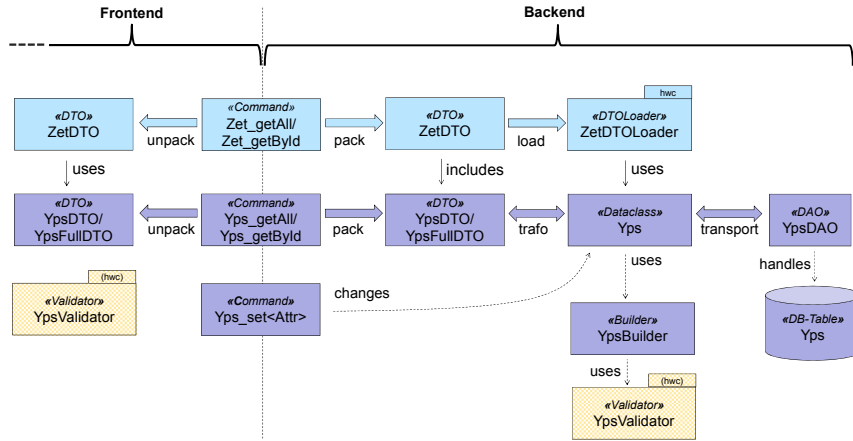


Fig. 2: Generation of BE files for the example class Yps based on the model files from Fig. 1

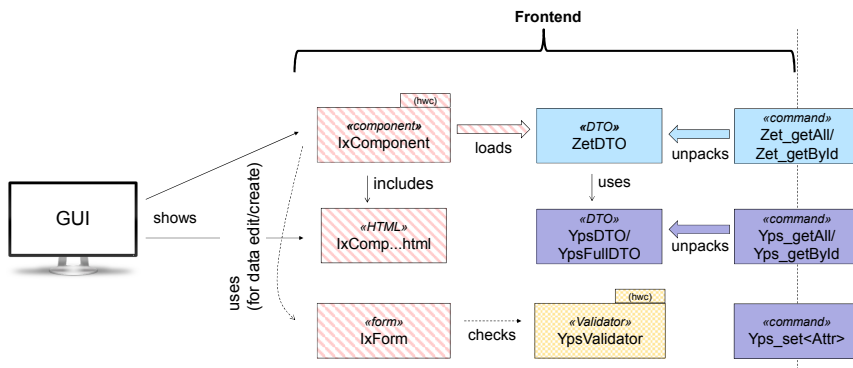


Fig. 3: Generation of FE files for the example class Yps based on the model files from Fig. 1

To sum up, MontiGEM provides us strong support in our practical development project, where we have to consider and react to changes in the requirements quickly. All input models are defined by UML/P [Ru11] inspired DSMLs.

3 Lessons learned in practice

To engineer EIS for research purposes strongly differs from software engineering in industrial-strength projects: in most cases it is enough for academia to have a demonstrator or prototype which is stable for one browser and one screen resolution, there is no need to catch all user errors as oneself and the research team are the only users and performance issues are only important in some cases, e.g. for data-intensive systems.

We developed and evolved MontiGEM in an industrial-strength project for RWTH Aachen university and clearly noticed these differences. The following *lessons we have learned during the MBSE process* lead to research gaps that should be addressed in the future.

The simultaneous development of the application and the generator itself is more time consuming than to do that separately. Clearly, to develop a generator without a specific use case is less effective, but to start a project with a basic generator for similar purposes significantly facilitates the development process. If the development of the generator is completed, the generation of similarly structured applications, e.g. Web-EIS which present data in various ways, in addition with minimal handwritten code is well manageable. Setting up a generator for the first time takes a while. Depending on the complexity of the project, the time taken to configure the generator can consume the time gained from code generation. Reusing a configured generator with prefabricated languages and generator components mitigates this problem.

There are strong dependencies between models of different DSMLs. For example the GUI model requires references to the aggregate model in order to display data. Typical IDEs are not able to check these calls, therefore the developer has to ensure validity. This is highly error prone and is only confirmed after a rebuild. Possible solutions are, e.g., composition on model level based on the symbol table to create a consistent set of models in different DSMLs.

There are strong dependencies of the project on the generator. Changes in the generator may lead to inconsistencies in the GUI. It is possible that validators and handwritten code does not completely fit into the generated files any more. One approach could be to implement generator composition in order to describe more logic in related models and to minimize the need for handwritten code.

Changes in the main data-classes model results in changes of the data-structure and requires migration. As the main data-classes model is generating the database, changes in the model have strong effects on it. If there already exists a running system with real data, this results in regular migrations of the database and change or addition of data, e.g., if required fields are added, existing fields are changed to be required or relations are changed. For a system with only one database this might lead to additional work with manageable time expenditure, but this time expenditure increases for large scale projects with several databases including different data. It even increases more, if several different versions of the EIS exists. In these cases it is important to develop strategies to (semi-)automate the migration process, to ensure that no data is in an inconsistent state or lost (at least they should be recoverable from a backup).

Model changes require manual test changes. Tests need to check the functionality in different browsers and a large variety of screen resolutions. Changes in data-structure or dummy data could lead to failed tests, e.g. check for a certain fixed result. With the goal to support software engineers as much as possible, the generation of the test infrastructure is

an important aspect for time reduction. MBSE should and could improve that by automatic generation of dummy data with all peripheral cases including tests for them.

It is a challenge to identify the generateable parts of a software project. A generator is well suited to apply patterns and rules to a set of models. Thus we can generate many lines of code from a few lines of a model. A more diverse code without common structure requires further adjusted models, which in the worst case match the size of the generated code. It is recommended to model the software project with these similarities in mind, and to adjust with handwritten code. Project with high portions of algorithmic diversity (e.g. SatSolvers) are unlikely to be efficiently generated.

To sum-up: The use of a generator only pays off if (a) a predefined and reusable generator exists (small adaption), (b) the generator is adaptable, (c) language and generator components are modular and (d) you use it for more than only one project (increase reuse).

4 Discussion and Related Work

Model-driven software engineering, model-driven architecture and MBSE are more and more used in practice. There exist several surveys and case studies for its application in industry [HRW11; Li18; MD08; To11] and the generation of specific parts such as for automated test generation [Ar18]. Nevertheless, the maturity of tool environments is criticized and is perceived as unsatisfactory for large-scale industrial adoption [MD08].

There exist several approaches and tools for Model-Driven Web Engineering [MRV08] but the paradigm shift from code-centric to generative approaches that has been expected in industry for years is still to come [MKH18]. There are attempts to explain this phenomenon, such as the impact of personality on the intention to adopt an MBSE method [MKH18]. The findings in this paper in section 3 refer to improvements for „ease of use“ as intention to adopt to MBSE approaches.

In comparison to the seven categories of web-based applications proposed by [GM01] our system generated with MontiGEM is mainly *informational*, *interactive*, and a *basic collaborative work environment*. It is an *informational* EIS, which provides data view-specific based on underlying domain data objects. It is *interactive* as the views and forms provide the possibility to interact with (parts of) the domain data. Our EIS is a *basic collaborative work environment* as several users can work on the data with a defined role and right structure.

Following [Of02] the most important quality criteria for web application success from the point of view of managers and practitioners are reliability, usability, security, availability, scalability, maintainability and time-to- market. MontiGEM generates a reliable system which ensures consistency-by-construction as much as possible, MBSE approaches improve the usability for the developer, the maintainability is improved as well and time-to-market is reduced for generative approaches.

5 Conclusion

Our lessons learned and obstacles show, that there are still several research gaps to work on in future in academia and practice, to provide good tools and facilitate the engineering process of developers in MBSE processes for EIS. Current trends on ICT technologies for EIS face four big challenges [El16] for the next generation of EIS: (1) Data Value Chain Management, (2) Context Awareness, (3) Interaction and Visualization and (4) Human Learning. Using MBSE approaches strongly support (2) and (3).

In future, we will show the practical application of MontiGEM for other domains, e.g. Cyber-Physical-Systems (CPS) with data from sensors, working stations or data from workers in the Internet of Production.

The usage of a generator for complex enterprise applications offers benefits, but also includes custom parts which are only usable in this specific case. A modular and configurable generator is a necessary condition to be able to adapt and reuse the generator to more sophisticated variants such as other coding languages or infrastructures. To further improve the generator and reduce handwritten parts an own aggregate model language with expressions to describe the logic to calculate/ get the values out of domain objects could be added. A *workflow-engine* could be used to completely describe the process within the application (BE/FE), the navigation and simplify the overview for programmers and domain experts.

References

- [Ad18] Adam, K.; Netz, L.; Varga, S.; Michael, J.; Rumpe, B.; Heuser, P.; Letmathe, P.: Model-Based Generation of Enterprise Information Systems. In: EMISA'18. CEUR 2097, pp. 75–79, 2018.
- [Ar18] Arcuri, A.: An experience report on applying software testing academic results in industry: we need usable automated test generation. Empirical Software Engineering 23/4, pp. 1959–1981, 2018.
- [BCW17] Brambilla, M.; Cabot, J.; Wimmer, M.: Model-Driven Software Engineering in Practice. Synthesis Lectures on SE 3/1, pp. 1–207, 2017.
- [BHS07] Buschmann, F.; Henney, K.; Schmidt, D.: Pattern-oriented Software Architecture: on patterns and pattern language. John Wiley & sons, 2007.
- [El16] El Kadiri, S.; Grabot, B.; Thoben, K.-D.; Hribernik, K.; Emmanouilidis, C.; von Cieminski, G.; Kiritsis, D.: Current trends on ICT technologies for enterprise information systems. Computers in Industry 79/, pp. 14–33, 2016.
- [GM01] Ginige, A.; Murugesan, S.: Web engineering: An introduction. IEEE Multimedia 8/1, pp. 14–18, 2001.

- [Gr15] Greifenberg, T.; Hölldobler, K.; Kolassa, C.; Look, M.; Mir Seyed Nazari, P.; Müller, K.; Navarro Perez, A.; Plotnikov, D.; Reiß, D.; Roth, A.; Rumpe, B.; Schindler, M.; Wortmann, A.: Integration of Handwritten and Generated Object-Oriented Code. In: *Model-Driven Engineering and Software Development*. Vol. 580. *Comm. in Comp. and Inf. Science*, Springer, pp. 112–132, 2015.
- [HR17] Hölldobler, K.; Rumpe, B.: *MontiCore 5 Language Workbench Edition 2017*. Shaker Verlag, 2017.
- [HRW11] Hutchinson, J.; Rouncefield, M.; Whittle, J.: Model-driven engineering practices in industry. In: *ICSE 2011*. ACM, New York, N.Y., p. 633, 2011.
- [Li18] Liebel, G.; Marko, N.; Tichy, M.; Leitner, A.; Hansson, J.: Model-based engineering in the embedded systems domain: an industrial survey on the state-of-practice. *Software & Systems Modeling* 17/1, pp. 91–113, 2018.
- [Ma17] Maoz, S.; Mehlan, F.; Ringert, J. O.; Rumpe, B.; von Wenckstern, M.: OCL Framework to Verify Extra-Functional Properties in Component and Connector Models. In: *Proc. of MODELS 2017. Workshop EXE*. CEUR 2019, 2017.
- [MCM14] Martínez, Y.; Cachero, C.; Meliá, S.: Empirical study on the maintainability of Web applications: Model-driven Engineering vs Code-centric. *Empirical Software Engineering* 19/6, pp. 1887–1920, 2014.
- [MD08] Mohagheghi, P.; Dehlen, V.: Where Is the Proof? - A Review of Experiences from Applying MDE in Industry. In: *Model Driven Architecture: Foundations and Applications*. Springer Berlin Heidelberg, pp. 432–443, 2008.
- [MKH18] Mikkonen, T.; Klamma, R.; Hernández, J., eds.: *Web Engineering*. Springer International Publishing, 2018.
- [MRV08] Moreno, N.; Romero, J. R.; Vallecillo, A.: An Overview Of Model-Driven Web Engineering and the Mda. In: *Web Engineering: Modelling and Implementing Web Applications*. Springer London, pp. 353–382, 2008.
- [Ob14] Object Management Group: Object Constraint Language, 2014, URL: <https://www.omg.org/spec/OCL/2.4/PDF>.
- [Ob17] Object Management Group: OMG Unified Modeling Language (OMG UML), 2017, URL: <https://www.omg.org/spec/UML/2.5.1/PDF>.
- [Of02] Offutt, J.: Quality attributes of Web software applications. *IEEE Software* 19/2, pp. 25–32, 2002.
- [Ru11] Rumpe, B.: *Modellierung mit UML*. Springer Berlin, 2011.
- [To11] Torchiano, M.; Tomassetti, F.; Ricca, F.; Tiso, A.; Reggio, G.: Preliminary Findings from a Survey on the MD State of the Practice. In: *Int. Symp. on Empirical Software Engineering and Measurement*. Pp. 372–375, 2011.
- [Vö13] Völter, M.; Benz, S.; Dietrich, C.; Engelmann, B.; Helander, M.; Kats, L. C. L.; Visser, E.; Wachsmuth, G.: *DSL Engineering - Designing, Implementing and Using Domain-Specific Languages*. dslbook.org, 2013.

Business Process Model Patterns: Classification and Repository of Published Work

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Abstract: Patterns have gained widespread interest and acceptance in various domains. Originating from architecture, patterns are nowadays also suggested as solution templates for various problems related to Business Process Management. Due to the abundance of pattern works, getting an overview on available works or searching for specific patterns can be very difficult. What is missing is an instrument for easy exploration and search. To mitigate this problem, we classified published works on pattern and developed a repository for business process model pattern works. The repository is publicly available and enables browsing and filtering of pattern works according to criteria recently developed by analyzing 280 pattern works.

Keywords: Business Process Management, Process Model Patterns, Pattern Repository.

1 Introduction

The idea of patterns can be traced back to the work of Alexander et al. [AlIS77] in the 1970s. This work deals with patterns for town planning and architectural design of buildings. In computer science, the software design patterns introduced by Gamma et al. [GHJV95] paved the way for pattern use. Alexander [Alex79] defines a pattern as a “three part rule, which expresses a relation between a certain context, a problem, and a solution.” Gamma et al. [GHJV95] and many other researchers share this understanding of a pattern as “a solution to a recurring problem in a particular context” [RiZü96]. For the purpose of our survey, we reuse the general idea of the pattern definitions above, but restrict it to the business process model domains as follows, see [FKLS18]:

“A business process model pattern is the description of a proven solution to a recurring problem that is related to the creation or modification of business process models in a specific context. This description is typically organized in a structured document supporting the reader in understanding under which circumstances the proposed solution will be useful.”

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The first patterns in the area of Business Process Management were suggested in [Ould 1995]. Afterwards, the workflow patterns [AaHo12] became a widely known instrument for describing commonly occurring needs in workflow management systems. Though in the field of business process modeling, the term “pattern” is mostly associated with those workflow patterns, much more authors have used patterns for documenting their experiences. While a lot of patterns for business process modeling have been published, we realized that it can be difficult to find relevant works on patterns that can be useful in a given situation. Persons who want to reuse experiences documented by means of patterns and researchers searching for sound literature references are confronted with two problems: *First*, relevant publications can be found in a great variety of proceedings, journals and web sites. We missed a resource that provides an entry point for searching the full spectrum of pattern papers in the field of business process modeling. *Second*, patterns dealing with the same topic are not named in a unified way and persons who want to reuse patterns were confused. For example, patterns dealing with adaption and change between model variants are subsumed by *change patterns* [UrSe15], *adaption patterns* [DöZG10], *variability design patterns* [YSD16] or *high-level change operations* [LRW08].

Compared to related works on classification of business process model patterns works [BeK114, HaMA14], this paper presents a repository of published works on business process model patterns relying on an extensive literature search as presented in [FKLS18]. The pattern repository is available at <http://www.bmpatterns.org>. It aims to establish a starting point for the search for business process model patterns that can be used by practitioners and researchers alike. By providing a taxonomy that categorizes the types of different business process model patterns as well as a research classification to describe various properties of pattern publications, we hope to broaden the knowledge about patterns and their documentation. Published works on patterns addressed in this paper describe suggested solutions that the authors recommend to tackle problems. In addition, anti-patterns, coined in 1995 by Andrew Koenig [Koen95], are solutions that are known to have deficiencies. Anti-patterns are often recognized by the appearance of failures, which are identified during execution or system implementation [Long01]. The classification of related anti-pattern works is accessible in the repository as well.

The next section summarizes our iterative approach to derive the pattern taxonomy and research classification.

2 Business Process Model Pattern Classification and Repository

2.1 Business Process Model Pattern Taxonomy and Research Classification

In order to systematically describe available works in regard to business process model patterns, we developed a business process modeling pattern taxonomy (referred to in the following as “pattern taxonomy”, cf. Tab 1).

- 1. Structure and Behaviour Patterns**
 - 1.1. Instantiation and Termination
 - 1.2. Process Structure and Flow
- 2. Resources Patterns**
 - 2.1. Role and Resource Assignment
 - 2.2. Delegation
- 3. Orchestration and Choreography Patterns**
 - 3.1. Communication
 - 3.2. Negotiation
 - 3.3. Collaboration
- 4. Content Patterns**
 - 4.1. Domain-dependent
 - 4.2. Domain-independent
- 5. Quality, Compliance and Risk Patterns**
 - 5.1. Business Process Compliance
 - 5.2. Risk and Security
 - 5.3. Environmental Impact
- 6. Adaptation and Improvement Patterns**
 - 6.1. Differences and Variability
 - 6.2. Model Improvement
- 7. Integration and Conversion Patterns**
 - 7.1. Model View
 - 7.2. Model Integration
 - 7.3. Model Transformations
- 8. Process Architecture Patterns**

Tab. 1: Business Process Model Pattern Taxonomy

The development was conducted as an iterative process whereby 280 scientific publications have been classified following the method from Nickerson et al. [NVM13]. For detailed information, see [FKLS18]. The taxonomy is organized in eight main categories each with 2–3 subcategories. The categories are ordered from basic aspects of process models such as structure and behavior (category 1) to more advanced aspects such as the composition of process models to process architectures (category 8). Our pattern taxonomy is complemented by a classification scheme (cf. Tab. 2). Within the classification scheme, the pattern taxonomy is used to specify the value of the property *pattern category*.

In general, the classification scheme is used to express additional information about each pattern work in a structured way. It is organized in four sections. In the section **Basic Pattern Information**, the *title* of the publication as well as the *origin* of the paper (e.g. from research or industry) is specified. Additionally, the *method of creation* can be described in terms of the method used to create a pattern (e.g. literature review or automatic mining).

Basic Pattern Information					
Publication Title	<free text>				
Origin	Research			Other (e.g. Industry)	
Method of Creation	Informed Argument	Literature Review	Case Study	Automatic Mining	Manual Mining
Pattern Content					
Pattern Category	<ID from business process model taxonomy>				
View (ISO 19439)	Function		Information	Resource	Organization
Intended User	Business Analyst		IT Specialist		Researcher
Scope	Domain-Specific			Generic	
Pattern Documentation					
Type of Article	Evaluation Research		Proposal of Solution	Personal experience	Survey
Pattern Template	None		Light		Full
Presentation	Textual		Formal		Graphical
Notation	None		Existing, <free text>	Extension, <notation>	New
Language-Dependent	Yes			No	
Extent of Documentation	Partial			Complete	
Pattern Application					
Instructions, Guidelines	Yes			No	
Tool Support	Yes			No	

Tab. 2: Business Process Model Pattern Research Classification

In the section **Pattern Content**, the *category* of a pattern should be specified by referencing a number (ID) from an entry in the pattern taxonomy (cf. Tab. 1). Moreover, the *view* or perspective addressed by the pattern can be classified according to the view concepts of ISO 19439. Moreover, the pattern work can be classified in terms of the *intended user* of the patterns and their *scope*. In the section **Pattern Documentation**, pattern works are classified according to various properties of their description and documentation. For more detailed explanations, see [FKLS18]. Unlike all other properties in this section, the property *notation* contains the values *existing* and *extension* that can be complemented by a string that allows to specify the name of an existing notation or the notation that was extended. Finally in the section **Pattern Application**,

the classification contains properties regarding the application of the respective pattern work such as *guidelines* or *tool support*.

In order to serve the business process community, we decided to create a pattern repository that contains the classification results of 280 pattern works using the pattern taxonomy and research classification introduced above. In this way, modelers and researchers can benefit from our classification effort by using the information to understand existing patterns, to compare patterns, and to have a collection of examples on how to define new patterns. The contents of the repository can also be useful for the design of new business process model patterns and may be helpful to understand differences, commonalities or improvements before publishing new pattern works. In the following, we derive key requirements for the pattern repository. Their implementation is described in Section 3.

2.2 Design of a Pattern Repository

First of all, regarding an easy access to the pattern repository, our development was inspired by other catalogues such as the collection of workflow patterns that are available online (<http://www.workflowpatterns.com>) or the Reference Model Catalog, also available online (<http://rmk.iwi.uni-sb.de/>). Hence we decided that our repository should also be *freely available on the World Wide Web*. Further, the repository should on the one hand provide an *overview on pattern works for browsing*. On the other hand, more advanced *filtering options* should be provided so that properties of our classification can be leveraged to identify pattern works. Moreover, the user should also be able to utilize a keyword search feature. However, since we do not expect the users of the pattern repository to know the terminology or names of patterns in advance, a *semantic search feature* is required so that a search term such as “environment” will retrieve a pattern work on “Green Business Process Patterns”. In summary, the requirements are as follows:

- **R1:** Worldwide easy and free access
- **R2:** Overview on pattern works for browsing
- **R3:** Filtering options using properties of the classification scheme
- **R4:** Semantic search feature

3 Implementation of the Pattern Repository

The Business process model pattern repository has been implemented as a single web page application available at <http://www.bmpatterns.org>. Due to the publication as a web page without access restrictions, **R1** (worldwide easy and free access) is met. After loading the page, a short introduction text is displayed along with the possibility to expand the full pattern classification scheme (button “Show detailed criteria”).

Furthermore, the pattern taxonomy is displayed on the page (cf. Fig. 1, ❶). Next to the ordering number (ID) of each pattern category in the taxonomy there is a small number within a small grey-shaded circle as well as a question mark. The number represents the total amount of pattern works in that category. When hovering with the mouse over the question mark, the description of the pattern category is displayed. By clicking on the link of each category text, the website is dynamically expanded and all pattern works are shown in separate boxes (cf. Fig. 1, ❷). The title of the paper serves as a label for each of the boxes. The boxes are clickable buttons that link to a webpage associated with the paper (e.g. the publisher's webpage or authors page on scientific networks). Due to these features, **R2** (overview on pattern works for browsing) is met.

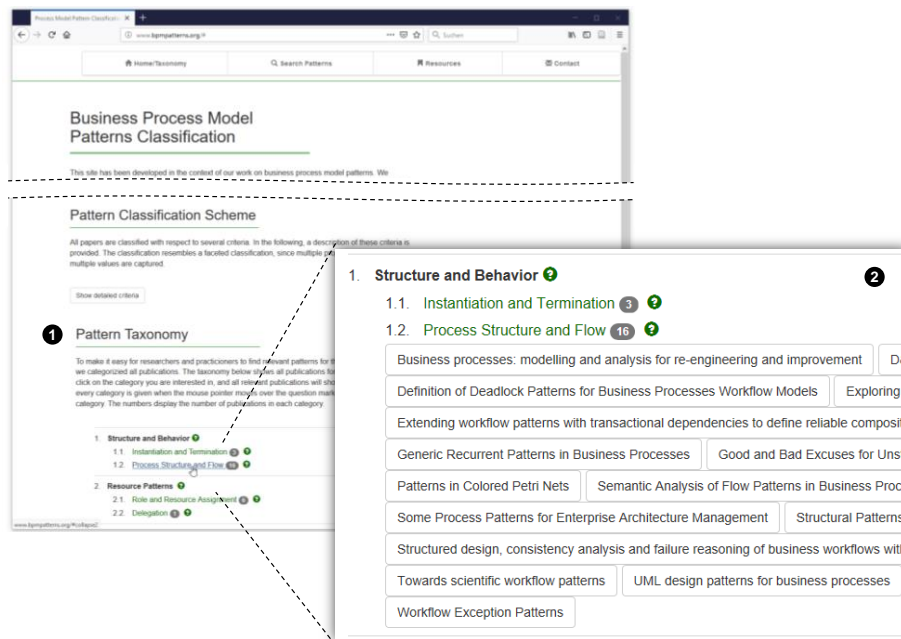


Fig. 1: Start Page of the Repository and Contents of Pattern Category 1.2

In order to utilize advanced filtering options, the user can click on the „Search Patterns“-button on the top of the page. A table of patterns appears whereby each pattern work is contained in a row that is further described in columns by values of a set of pre-selected properties that originate from the pattern classification (cf. Fig. 2, ❶). The user can dynamically add or remove columns to the table by just clicking on „Column visibility“ and then selecting or de-selecting columns in the context menu (cf. Fig. 2, ❷). In this way, the table can be customized and **R3** is met (filtering options using properties of the classification scheme). In order to further refine the contents of the table, the user can leverage the search-box in the upper right corner of the page. Every property of the classification can be used to filter the contents in the table, regardless if the property

values are displayed in a column of the table or not. Moreover, 800 keywords have been added to the table. In this way, the user can retrieve pattern works even if she or he is using a different terminology than the authors of the pattern works. For example, if the user types in “structure 1.” (cf. Fig. 2, ③), then the result table is reduced to three result rows accordingly. Whereas for two of these entries, the word “structure” is contained in the paper title, the third entry does not contain this word in the paper title. This abstraction from the syntactic level thus implements a semantic search feature (R4).

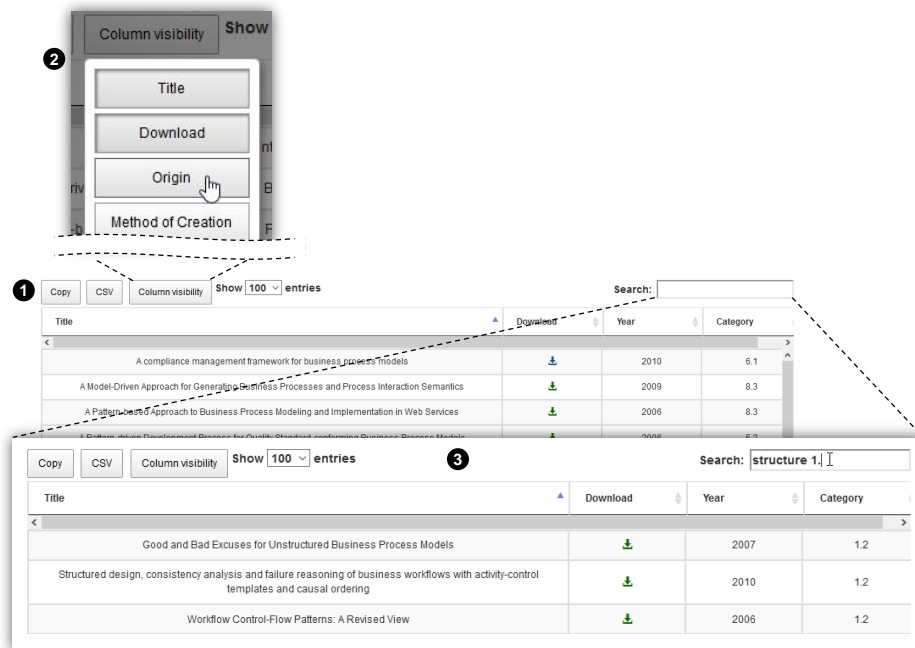


Fig. 2: Search Page of the Repository, Columns and (Semantic) Search

Moreover, the fraction “1.” of the search term entered in the example query acts as a filter for patterns falling into the category “1” of the pattern taxonomy. All of the search and browsing features are implemented in a lightweight way using HTML, CSS and JavaScript in a single webpage programming style. Finally, also export features are provided: The contents of the (filtered) table can either be copied to the clipboard or downloaded as CSV file.

4 Conclusion and Outlook

This paper summarizes our work on business process model patterns. We devised a classification of business process model patterns works and arranged them in a taxonomy. Both the taxonomy and research classification are based on an extensive

literature review. We hope that our online repository is helpful for business process modelers who want to publish BPM related patterns and to understand differences, commonalities or improvements. It is our aim to extend the collection of literature on business process model patterns and anti-patterns on the website that we set up at <http://www.bmpatterns.org/> and we warmly invite other researchers to contribute to this endeavor.

Literature

- [AaHo12] van der Aalst, W.M.P.; ter Hofstede, A.H.M.: Workflow patterns put into context. *Software & Systems Modeling*, Vol. 11(3): 319–323, 2012.
- [AlIS77] Alexander, Ch.; Ishikawa, S.; Silverstein, M.: *A Pattern Language: Towns, Buildings, Construction*. Oxford University Press, 1977
- [Alex79] Alexander, C.: *The timeless way of building*. Oxford University Press, 1979.
- [DöZG10] Döhring, M.; Zimmermann, B.; Godehardt, E.: Extended Workflow Flexibility using Rule-Based Adaptation Patterns with Eventing Semantics. In: *Informatik 2010*. German Informatics Society (GI LNI, Vol. 175), 195–20, 2010.
- [GHJV95] Gamma, E.; Helm, R.; Johnson, R.; Vlissides, J.: *Design Patterns: Abstraction and Reuse of Object-Oriented Design*. In: *7th European Conference on Object-Oriented Programming*, 1993.
- [HaMA14] Haddar, N.Z, Makni, L., Abdalla, H.B.: Literature review of reuse in business process modeling. *Software & Systems Modeling*, (13):975–989, 2014.
- [FKLS18] Fellmann, M.; Koschmider, A.; Laue, R.; Schoknecht, A.; Vetter, A.: Business process model patterns: state-of-the-art, research classification and taxonomy. *Business Process Management Journal*. <https://doi.org/10.1108/BPMJ-01-2018-0021>, 2018.
- [BeKl14] Becker, M., Klingner, S.: A Criteria Catalogue for Evaluating Business Process Pattern Approaches. In: *Enterprise, Business-Process and Information Systems Modeling*, vol. 175 of LNBIP, pp. 257–271, Springer, 2014.
- [Koen95] Koenig, A.: Patterns and Antipatterns. *Journal of Object-Oriented Programming*, vol. 8, no. 1, pp. 46–48, 1995.
- [Long01] Long, J.: Software Reuse Antipatterns. *ACM SIGSOFT Software Engineering Notes*, 26(4): 68, 2001.
- [LRW08] Li, C.; Reichert, M.; Wombacher, A.: On measuring process model similarity based on high-level change operations. In: *27th International Conference on Conceptual Modeling*, Springer (LNCS 5231), pp. 248–264, 2008.
- [NVM13] Nickerson, R.C.; Varshney, U.; Muntermann, J.: A method for taxonomy development and its application in information systems. *European Journal of Information Systems*, Vol. 22(3): 336–359, 2013.
- [RiZü96] Riehle, D.; Züllighoven, H.: Understanding and Using Patterns in Software Development. *Theory and Practice of Object Systems*, 2(1):3–13, 1996.
- [UrSe15] Uronkarn, W.; Senivongse, T.: Change patterns detection and traceability impact analysis of business process models. In: *Transactions on Engineering Technologies*:

International MultiConference of Engineers and Computer Scientists, Springer, pp. 44–455, 2015.

- [YSD16] Yousfi, A.; Saidi, R.; Dey, A.K.: Variability patterns for business processes in BPMN. Information Systems and e-Business Management, Vol. 14 No. 3, pp. 443–467, 2016.

Co-evolution in Business Ecosystems: Findings from Literature

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Abstract: The innovative use of digital technologies has led to a disruption of well-established business models in many industries. To prevent from being disrupted, organizations must transform. However, studies about digital transformation have primarily focused on intra-organizational dynamics, including processes, structures, and business models. Digital transformation, however, substantially changes inter-organizational behavior, sometimes the entire ecosystem. To examine this phenomenon, we draw on co-evolution theory, which states that changes occur among all interacting organizations, permitting transformations to be driven by both direct interactions and ecosystem feedbacks. Thus, goal of this paper is to provide a structured overview of literature about the co-evolution of ecosystems in management, organizational science, and IS literature. Following the six properties of co-evolution, we develop a framework for the co-evolution in ecosystems, comprising 23 configurations, based on the analysis of 44 articles. Ultimately, we suggest avenues for future research.

Keywords: ecosystem, co-evolution, literature review, digital transformation

1 Motivation

Digital platforms having the capacity to combine and deploy innovative technologies create the potential to radically change the way organizations do business in their respective ecosystems. This sometimes leads to a disruption of well-established business models [RT14]. We refer to the organizational transformation to prevent a disruption through the innovative use of digital technologies as digital transformation [WW15, Ri19]. Studies about digital transformation have been primarily concerned with an intra-organizational perspectives, including processes, products, services, organizational structures, and business models [see, e.g., KW15, KHH15]. Digital transformations substantially influence inter-organizational partnerships, particularly in business

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ecosystems, where value is co-created among multiple stakeholders [Sa12, Ce14, Ri18b]. Thus, partnerships are increasingly important, because the market for information technology (IT) is constantly evolving and giving rise to a variety of innovations, e.g., cloud computing, in-memory databases, blockchains, and distributed ledgers [Os18]. These are often provided in platform ecosystems, comprising specific digital platforms and applications and their stakeholders, owners, and complementors [Ti14, Ri18a]. In such ecosystems, we understand that platform owners represent the legal entity owning the platform [Ti14]. Complementors contribute additional value to the platform in the form of applications [Ti14]. Furthermore, platform owners rely on partners to gain access to customers or complementary resources and capabilities [Sa12, LN15]. To study the ongoing digital transformation from an ecosystem perspective, we view the problem through the lens of co-evolutionary theory. This theory assumes that changes can occur at all interacting organizations, permitting transformation to be driven by both direct interactions and positive feedback [LV99, MHG14]. Thus, we analyze the extant literature on co-evolution in IS, management, and organization science literature to build a comprehensive understanding for co-evolution in ecosystems. Second, based on the six propositions of Montealegre et al. [MHG14], we suggest a framework for the co-evolution in ecosystems, including 23 configurations for these propositions. Ultimately, we suggest avenues for future research. This paper is structured as follows. First, we present our conceptual background and research method. Second, we provide an overview of co-evolution theory in literature, particularly in ecosystems. Third, based on the literature review, we propose a framework for co-evolution in ecosystems and suggest avenues for future research. After discussing our results, we conclude with limitations and implications.

2 Digital Transformation in Business Ecosystems

Many digital transformation articles have built upon transformations caused by digital technologies [e.g., Fi14]. Following Yoo, Henfridsson and Lyytinen [YHL10], a new organizational logic is necessary to cope with digital innovations [YHL10]. The case of Kodak shows that new organizational logic is very difficult to achieve, particularly when an organization's business model has been successful for more than a century [LG09]. Using digital technologies, potential co-creation in ecosystems has become easier via the supply of boundary resources [GK12]. As an example, Apple provided a digital platform to distribute iOS applications. Because most of these applications were developed by third parties, developers were forced to learn a specific programming languages and co-evolve their development processes with Apple [Ea15]. Apple supported third-party developers heavily via the supply of boundary resources [Ea15]. Apple relies heavily on co-creation in its ecosystem, which plays a major role in successful digital transformation [Sa12]. However, whereas Apple's partners gained access to a huge customer base, they were critically affected by the digital transformation. Therefore, if digital transformation implies the introduction of a digital platform, the business models of co-creating partners are affected. Riasanow, Galic and Böhm [RGB17] demonstrated that emerging players

who build mobility service platforms induced a substantial transformation of the automotive ecosystem. For ecosystems, three terminologies are commonly used, dividing the field into three broad streams, as found by Jacobides et al. [JCG18]. These terms are business ecosystems, innovation ecosystems, and platform ecosystems. The three streams differ in their foci, but they share the common understanding of ecosystems as a group of interdependent firms. In a hierarchical sense, business ecosystem can be seen as the root, being explored first, with innovation and platform ecosystems derived thereafter. According to Moore [Mo93], business ecosystems comprise entities with co-evolving capabilities around new innovations in a cooperative and competitive way. These entities represent an economic community supported by a foundation of interacting organizations and individuals that produces goods and services of value to customers, who are themselves members of the ecosystem. The member organisms also include suppliers, lead producers, competitors, and other stakeholders [Mo93]. An innovation ecosystem is a business ecosystem that focuses on the solution for the end customer. A concise definition for innovation ecosystems is the “collaborative arrangements through which firms combine their offerings into a coherent customer-facing solution” [Ad06]. In some articles about business ecosystems, the term “platform” is already mentioned, as in the conceptualization of Autio and Thomas [AT14]. Business ecosystems are more generic, of which platforms are the common instantiation. Many business ecosystems, such as Apple iOS ecosystem, have, at their core, a platform that structures and orchestrates complementors and partners [Ea15]. In this work, we use the terms, “business ecosystem” and “platform or innovation ecosystems” as specific instantiations of business ecosystems. Following Jacobides et al. [JCG18], there is broad knowledge on what ecosystems are. However, we still have limited knowledge about their digital transformation. Co-evolution, first recognized in the field of biology, occurs when two or more species reciprocally affect one another's evolution [CHL91, VW13]. When a system evolves to ensure its best fit, its environment also changes, and those changes are likely to result in further system changes, resulting in continuous system change [VW13]. Therefore, we draw on the theoretical lens of co-evolution to examine this phenomenon.

3 Research Approach

Our work follows a four-step research approach. To identify existing literature contributing to the co-evolution in business ecosystems, we conduct a structured literature review following Webster and Watson [WW02]. In the first step, we focus on leading outlets of IS, management, and organization science, (i.e., the AIS Senior Scholars' Basket of Journals and FT50 journals). Using the EBSCOhost and Scopus databases, we apply the following search terms to the titles, abstracts, and keywords: (“co-evolution” OR “co-evolution”) AND (“ecosystem” OR “network”). The search was conducted between May and August 2018. Following Okoli and Schabram [OS10], we reviewed the articles manually and filtered them according to an iterative set of exclusion criteria. Thus, articles not addressing co-evolution in ecosystems, such as Helfat and Raubitschek [HR00], were removed, resulting in 27 selected articles. For the second step, we extended our search to

conferences to include recent contributions since 2000. This yielded another 17 articles, resulting in 44. See Table 1.

Outlet		Hits	Selected articles
IS Journals	Information Systems Research	6	[RT14, GGA11, TRV10, TKB10, VW09, Sa10]
	Journal of the Association for Information Systems	3	[MHG14, VW13, Pu10]
	Journal of Management Information Systems	1	[FN09]
Management and Organization Science Journals	Research Policy	6	[AC01, CV08, HBH04, Ku01, Mu02, Ma13, Mi07]
	Organization Science	6	[An99, DA99, KL99, Mc99, PYH18, SCK10]
	Long Range Planning	3	[Am09, HGB18, Li10]
	Organization Studies	1	[En12]
	Technological Forecasting and Social Change	1	[KTR13]
Top Conferences	International Conference on Information Systems	9	[AC16, AVH17, CA15, HLY17, Hu17, UY16, BPA15a, Ng17, TL17]
	Hawaii International Conference on System Sciences	3	[ST17, SWS18, AZC17]
	European Conference on Information Systems	3	[BAP15b, DC15, WU16]
	Americas Conference on Information Systems	2	[Ja17, HSS16]
Grand Total		44	

Tab. 1: Selected Articles on the Co-evolution in Ecosystems

In the third step, we draw upon the six properties of co-evolution identified by Montealegre et al. [MHG14]. Three experienced raters independently coded the selected articles. Before the raters began coding the articles, they coded several other articles to become familiar with the scheme. Then, they calibrated their procedure. All authors validated the coding of each article and discussed the discrepancies until consensus was reached. This helped eliminate disparities [BT90].

4 Literature on Co-evolution in Business Ecosystems

Montealegre et al. [MHG14] identified six properties of co-evolution theory, which we used to structure our findings.

4.1 Multilevel Effects

Co-evolutionary effects vary across a range of multiple levels of analysis [KL99, LL99]. Each level offers a different perspective on co-evolution. We found nine different levels in the articles. Five were intra-organizational levels, including business process, structure, leadership, culture, and business model. Four were inter-organizational levels, including partners, customers, regulatory environment, and other industries. Vidgen and Wang [VW06] found that co-evolution in agile software development between the business process and structure level can be successful if organizations match the co-evolutionary change rate, maximize self-organization, and balance exploration and exploitation. Lin et al. [Li10] characterized the co-evolution in ecosystems based on exchanges of technology via institutional ties. In a single longitudinal case study of a professional service network in the public accounting industry, a network was intentionally created and formally organized to pursue co-evolving effects for the member organization [KL99]. Co-evolution was also successful at another level, as Höyssä et al. [HBH04] showed in an investigation into the level of interaction between the city and its national and international region, focusing on the city's industrial policy as the mediator industry.

4.2 Multidirectional Causalities

Montealegre et al. [MHG14] understood co-evolutionary effects not as a simple cause–effect logic of linear relations between independent and dependent variables. Instead, they ascertained that co-evolutionary process could have many causes [DV09]. A co-evolutionary effect can, in turn, cause many co-evolutionary effects [Li10]. We refer to multidirectional causality between two configurations (i.e., cooperation and competition). In the studied articles, cooperation was understood as voluntary, for which two or more entities could co-evolve in a mutually beneficial exchange instead of competition. Cooperation in the context of co-evolution can happen where resources adequately exist for both parties or are created by their interaction [RT14, Mu02, JD17]. Based on our findings, competition was observed as a rivalry of competencies, resources, profits, market shares, quality, service, rights, knowledge, partnerships, and IT [KL99, Mc99, AC16, AVH17]. Some scholars argued that co-evolutionary processes could combine the configurations of both competition and cooperation [PYH18, HGB18, Li10].

4.3 Nonlinearity

Cause and effect of change in co-evolutionary relationships often did not follow a simple linear logic. However, dependent variables were often influenced by complex interactions of influencing variables. A small change in the initial variables could lead to very significant changes of outputs and even chaotic consequences [VP95]. We suggest a configurations of “diffusion nonlinearity”, “hierarchical nonlinearity”, and “network nonlinearity” for the co-evolution of business ecosystems and networks in a context characterized by uncertainty following the study of Rogers [Ro95]. Hierarchical

nonlinearity occurs when co-evolutionary dynamics follow a vertical direction through an organization or ecosystem. Volberda and Lewin [VL03] defined “hierarchical renewal” as an engine of co-evolution in multi-unit organizations, where the changes cascade down from the top management. In the opposite direction, McKelvey [Mc99] argued that change could be hierarchically propagated from the bottom as chain of competences toward the top throughout the organization. Lin et al. [Li10] found that bottom-up technologies and top-down institutions drove collaboration between organizations, leading to an inter-network and a co-evolution. The co-evolution of complex adaptive systems occurs via nested hierarchies containing more sub-systems, subject to evolutionary dynamics [An99]. Top-down dynamics are observable in governmental organizations, based on a study of disaster-relief ecosystems [ST17] and another on the sphere of healthcare in the hierarchical structure of hospitals [GGA11].

We refer to network nonlinearity for nonlinear-but-orchestrated developments among ecosystem entities. Co-evolutionary dynamics in inter-organizational networks act in nonlinear ways (e.g., jolts, step functions, and oscillations [MGC05]). However, network structures between organizations can emerge in the absence of an authoritative entity. Their creation and development are generally influenced by the actions of an orchestrating entity [PH13]. In the context of a professional services organization network, co-evolution is orchestrated from a headquarters entity that coordinates and facilitates the network exchange [KL99]. It can also be led from the context of innovation policy making the orchestration role less required [Ku01]. From the context of ecosystems, nonlinear diffusion is observed in the form of the diffusion process of technology standards among network members [En12]. Similarly, innovations are diffused in ecosystems among suppliers, end users, and new entrants [HGB18], and they are sparked by spillover effects [Mu02]. Similarly, Bhattacharya et al. [BPA15] analyzed diffusion processes of content postings in social-media networks, where diffusion was mentioned in a different sense, as a formalized process for technology transfer out of the organization [AC01] or as an institution for that specific purpose [CV08]. Some argued nonlinear dynamics went beyond the three identified configurations. A spiral process of co-evolution was detected by van den Ende et al. [VP95]. Kuhlmann [Ku01] uncovered a revolution of innovation. Further, nonlinearity was also used to explain why organizations were unable to renew their offerings in a radical, big-bang approach, in the context of a digital ecosystems of small and medium enterprises (SME) [CA15].

4.4 Mechanisms for Positive Feedback

Positive feedback was described by Lewin and Volberda [VL03] as actions and interactions between entities undergoing recursive co-evolution, leading to recursive interdependencies [Mo93]. A rich variety of positive feedback mechanisms was identified in the selected articles, which we organized into three configurations: “capabilities”, “architectural decisions”, and “managerial actions”. Organizational capabilities can enable co-evolution, including capabilities for customization and standardization of IT to create and appropriate value in co-evolutionary processes [AC16]. In the context of cross-border

organizational integration, mechanisms for the co-evolution of capabilities with the organizational structure were depicted by Ambos et al. [Am09], including an integration action plan, an introduction of routines for alignment and standardization, and the development of a knowledge broker for bidirectional knowledge transfer. Positive feedback was also operationalized via architectural decisions of the platforms in ecosystems [KL99]. For software platforms, the decisions on platform openness, architectural decomposition, and modularity were the central levers alongside governance and decision rights mechanisms shaping their co-evolutionary growth dynamics [TKB10]. For the co-evolution of SMEs and their respective ecosystems and environments, Dehbokry and Chew [DC15] suggested a reference architecture that incorporated different views covering strategy, capabilities, and knowledge alongside contingencies with other institutions and the macro environment. Another mechanism used to strengthen the co-evolution was managerial actions, including exclusive agreements for ecosystem members, who legally govern the collaboration and co-evolution of the organizations [AVH17]. Holgersson et al. [HGB18] found that, in the context of an intellectual property strategy, mechanisms for supporting co-evolution included the coordination of working-group networks, cross-licensing agreements for technology accessibility across organizational boundaries, and technical standardization as a governance tool [VW09].

4.5 Path and History Dependencies

The circumstances and conditions in which co-evolutionary processes occur are determined by unexpected events with uncertain outcomes [En12]. Addressing these conditions in a co-evolutionary environment requires following a path having a history of dependencies [MHG14]. Circumstances causing or helping co-evolutionary conditions can be both exogenous and endogenous to the industry, individual organizations, and the ecosystem [KL99]. Therefore, decisions regarding a path-dependent course will influence future actions, strategies, and objectives [Am09] to offer compliance with changes in the ecosystem [Gr12]. The changes in circumstances over time create a history of dependency, shaped by the changing conditions of the evolutionary path and the legacy actions and decisions used to address them [VW13], i.e., ‘legacy’. Because of the individual history and path dependencies among the co-evolving organizations, they develop their own individual capabilities to differentiate their historical evolution paths [TRV10]. Lin et al. [Li10] postulated that the co-evolution between two networks included general environmental shifts and endogenous communications needed to build inter-dependencies and mutual transformations. These dependencies could also be influenced by an extant community with inter-organization collaborations influenced by their prior capabilities [RT14] or networks shaping choices and paths [Mu02]. Specific path dependencies, over time, can develop a beneficial outcome for an organization and ecosystem [Am09], supplemented by organizational socio-technical capabilities [DC15, LL99]. However, organizations with no legacy start-ups may conduct co-evolution as a “greenfield” approach.

4.6 Technology

Montealegre et al. [MHG14] described technology as both an external and internal force, influencing decision making within a business ecosystem or environment. Extending this notion, we found three configurations of technology in co-evolution: disregarded, supported, and enabled. In some articles, technology was not detectable as a driver for co-evolution and was disregarded [e.g., DA99]. As a supportive technology role, Hukal [Hu17] argued that the introduction of new technologies acted as a proxy for co-evolution. Technology can also help to mobilize the transformation of customers in the ecosystem [HLY17]. Digital platform technologies can also support the transformation of end-users to value-co-creators [SWS18]. Um and Yoo [UY16] introduced the most recent property of technology as an "enabler", leveraging characteristics to be changed without restraining the use of existing technologies. Instead, it could enhance the use of different fields by promoting the construction of novel growth patterns in a focal platform system. This was also shown by Janze [Ja17], where blockchain technology enabled the co-evolution of darknet platforms through the usage of cryptocurrencies.

Property	Configuration				
Multilevel effects	Intra-organizational levels				
	Business processes	Structures	Leaderships	Cultures	Business models
	Inter-organizational levels				
	Partners	Customers	Regulatory environment	other industries	
Multi-directional causality	Cooperation		Competition		
Nonlinearity	Diffusion	Hierarchical	Network	Big bang	
Mechanism for positive feedback	Capabilities		Architectural decisions		Managerial activities
Path and history dependency	Greenfield		Legacy		
Technology	Disregarded		Support		Enabler

Tab. 2: Properties and Configurations of Co-evolution in Business Ecosystems

5 Discussion and Future Research

Through our review of IS, management, and organization science literature on co-evolution processes in ecosystems, our work provided a structured overview of the field

from a transdisciplinary perspective. Second, we developed a framework for co-evolution in business ecosystems based on the six properties offered by Montealegre et al. [MHG14], comprising multilevel effects, multidirectional causalities, nonlinearities, mechanisms of positive feedback, paths, and historical dependencies. Furthermore, we extended Montealegre et al. [MHG14] using the property technology, identifying 23 configurations. Second, based on our discussion of the properties and configurations of co-evolution, we provided avenues for future research.

This study has limitations. First, the identified articles are limited to our search terms and the selected articles. Second, this work is limited by the coding of the articles to their respective co-evolution properties and configurations. To mitigate these limitations, three experienced raters coded the articles independently. We ensured that a broad amount of co-evolution articles was included by opening the search to conference articles.

Based on this study, four theoretical contributions came to light. First, the findings of our structured literature review about the identified configurations showed that co-evolution materialized in different ways in different business ecosystems. Therefore, the study enlarged the literature of Lewin and Volberda [LV99] and Montealegre [MHG14]. Second, we fused insights from IS, management, and organizational science and built upon the proposition of Jacobides [JCG18] to contribute a theory about ecosystem transformation by suggesting the notion of co-evolution. Third, our findings showed that co-evolution in business ecosystems was dependent of new properties, which are particularly evident because of the emerging role of technology. Fourth, we showed that co-evolution was a suitable lens for examining digital transformation from an inter-organizational perspective.

This study provided two practical contributions. First, we invited practitioners and scholars to apply the identified configurations to the properties of co-evolution when discussing digital transformation in business ecosystems. Moreover, we provided 23 configurations for the six properties. Second, managers obtained insights about co-evolution novelties in business ecosystems with respect to digital transformations. For example, co-evolution in business ecosystems can be driven by enabling digital technologies, which are the core of digital platforms.

Based on our discussions of the findings, we suggest five avenues for future research. First, as we annotated for the existing literature on co-evolution processes, we were surprised by the limited occurrence of platforms, particularly digital platforms lying at the center of value creation. Thus, we suggest the use of co-evolution theory to examine platform ecosystems. Second, regarding technologies enabling co-evolution, we suggest the analysis of boundary resources, such as application programming interfaces (API) [Ea15, UY16]. Um and Yoo [UY16] understood APIs as the key role of managing the tension between control and generativity of a platform. We suggest that we should also study the effect of changing APIs over time on the business model of complementors or service offerings in platform ecosystems. Co-evolution may be also helpful for determining the effect of API changes on value capturing or value co-creation. Third,

regarding multi-directional causality in platform ecosystems, there is a gap in how cooperation or competition can be leveraged. Thus, competition via different platform ecosystems (e.g., Android or iOS) should be examined. Fourth, the nonlinearity configurations of diffusion, hierarchy, network, or big bang could be used to design longitudinal studies for examining co-evolution. Further, we suggest that researchers seek to detect managerial co-evolution mechanisms driving positive feedback in platform ecosystems. Thus, scholars could shed light on co-evolutionary mechanisms for platform owners to enable the co-evolution of complementary partners. Mechanisms used to manage the evolution of platforms should also be evaluated.

References

- [AC01] Amesse, F., Cohendet, P.: Technology Transfer Revisited from the Perspective of the Knowledge-based Economy. *Research Policy* 30/9, pp. 1459-1478, 2001.
- [AC16] Ahuja, S., Chan, Y.E.: Digital Innovation: A Frugal Ecosystem. In: 37th International Conference on Information Systems (ICIS), Dublin, 2016.
- [Ad06] Adner, R.: Match Your Innovation Strategy to Your Innovation Ecosystem. *Harvard Business Review* 84/4, pp. 98-109, 2006.
- [Am09] Ambos, T.C., Schlegelmilch, B.B., Ambos, B., Brenner, B.: Evolution of Organisational Structure and Capabilities in Internationalising Banks. *Long Range Planning* 42/5, pp. 633-653, 2009.
- [An99] Anderson, P.: Perspective: Complexity Theory and Organization Science. *Organization Science* 10/3, pp. 216-232, 1999.
- [AT14] Autio, E., Thomas, L.D.W.: Innovation Ecosystems: Implications for Innovation Management. In: Dogson, M., Philips, N., Gann, D.M. (eds.) *Oxford Handbook of Innovation Management*, pp. 204-228. Oxford University Press, 2014.
- [AVH17] Amarilli, F., van Vliet, M., van den Hooff, B.: An Explanatory Study of the Co-evolutionary Mechanisms of Business IT Alignment. In: 38th International Conference on Information Systems (ICIS), Seoul, 2017.
- [AZC17] Anderson, C.L., Zéphy, L., Cardell, J.B.: A Vision for Co-optimized T&D System Interaction with Renewables and Demand Response. In: 50th Hawaii International Conference on System Sciences (HICSS), 2017.
- [BPA15a] Bhattacharya, P., Phan, T.Q., Airoidi, E.: Investigating the Impact of Network Effects on Content Generation: Evidence from a Large Online Student Network. In: 36th International Conference on Information Systems (ICIS), Fort Worth, 2015.
- [BPA15b] Bhattacharya, P., Phan, T., Airoidi, E.: Analyzing the Co-evolution of Network Structure and Content Generation in Online Social Networks. In: 23rd European Conference on Information Systems (ECIS), Münster, 2015.
- [BT90] Bullock, R., Tubbs, M.E.: A Case Meta-analysis of Gainsharing Plans as Organization Development Interventions. *The Journal of Applied Behavioral Science* 26/3, pp. 383-404, 1990.
- [CA15] Chan, Y., Ahuja, S.: Digital Ecodynamics in Small Firms: Using Information Technology to Compete. In: 35th International Conference on Information Systems (ICIS), Fort Worth, 2015.
- [Ce14] Ceccagnoli, M., Forman, C., Huang, P., Wu, D.J.: Digital platforms. *Communications of the ACM* 57/2, pp. 38-39, 2014.

-
- [CHL91] Chaloner, W.G., Harper, J.L., Lawton, J.: The Evolutionary Interactions of Animals and Plants. *Philosophical Transactions of the Royal Society of London B* 333/1, pp. 177-186, 1991.
 - [CV08] Chaminade, C., Vang, J.: Globalisation of Knowledge Production and Regional Innovation Policy: Supporting Specialized Hubs in the Bangalore Software Industry. *Research Policy* 37/10, pp. 1684-1696, 2008.
 - [DA99] Djelic, M.-L., Ainamo, A.: The Coevolution of New Organizational Forms in the Fashion Industry: A Historical and Comparative Study of France, Italy, and the United States. *Organization Science* 10/5, pp. 622-637, 1999.
 - [DC15] Dehbokry, S., Chew, E.K.: Toward a Multi-Disciplinary Business Architecture Reference Model for SMEs. In: 23rd European Conference on Information Systems (ECIS), Münster, 2015.
 - [DV09] Durand, R., Vaara, E.: Causation, Counterfactuals and Competitive Advantage. *Strategic Management Journal* 30/12, pp. 1245-1264, 2009.
 - [Ea15] Eaton, B., Elaluf-Calderwood, S., Sørensen, C., Yoo, Y.: Distributed Tuning of Boundary Resources: The Case of Apple's iOS Service System. *MIS Quarterly* 39/1, pp. 217-243, 2015.
 - [En12] van den Ende, J., van de Kaa, G., den Uijl, S., de Vries, H.: The Paradox of Standard Flexibility: The Effects of Co-evolution between Standard and Interorganizational Network. *Organization Studies* 33/5, pp. 705-736, 2012.
 - [FN09] Fang, Y., Neufeld, D.: Understanding Sustained Participation in Open Source Software Projects. *Journal of Management Information Systems* 25/4, pp. 9-50, 2009.
 - [Fi14] Fichman, R.G.: Digital Innovation as a Fundamental and Powerful Concept in the Information Systems Curriculum. *MIS Quarterly* 38/2, pp. 329-353, 2014.
 - [GGA11] Goh, J., Gao, G., Agarwal, R.: Evolving Work Routines: Adaptive Routinization of Information Technology in Healthcare. *Information Systems Research* 22/3, pp. 565-585, 2011.
 - [GK12] Grover, V., Kohli, R.: Co-creating IT Value: New Capabilities and Metrics for Multiform Environments. *MIS Quarterly* 36/1, pp. 225-232, 2012.
 - [Gr12] Grant, A.M.: Leading with Meaning: Beneficiary Contact, Personal Impact, and the Performance Effects of Transformational Leadership. *Academy of Management Journal* 55/2, pp. 458-476, 2012.
 - [HBH04] Höyssä, M., Bruun, H., Hukkinen, J.: The Co-evolution of Social and Physical Infrastructure for Biotechnology Innovation in Turku, Finland. *Research Policy* 33/5, pp. 769-785, 2004.
 - [HGB18] Holgersson, M., Granstrand, O., Bogers, M.: The Evolution of Intellectual Property Strategy in Innovation Ecosystems: Uncovering Complementary and Substitute Appropriability Regimes. *Long Range Planning* 51/12, pp. 303-319, 2018.
 - [HLY17] Hua, W., Leong, C., Yu, J.: Exploring User-Created Digital Content Ecosystem: A Study of China's Digital Celebrity Industry. In: 38th International Conference on Information Systems (ICIS), Seoul, 2017.
 - [HR00] Helfat, C.E., Raubitschek, R.S.: Product Sequencing: Co-evolution of Knowledge, Capabilities and Products. *Strategic Management Journal* 21/10, pp. 961-979, 2000.
 - [HSS16] Han, E., Suh, B., Shin, S.K.: Developing a Reference Model for Analyzing Mobile Platform Business: From an Ecosystem View. In: 22nd Americas Conference on Information Systems (AMCIS), San Diego, 2016.
 - [Hu17] Hukal, P.: On the Role of Module Interdependencies in Platform Evolution. In: 38th International Conference on Information Systems (ICIS), Seoul, 2017.
 - [Ja17] Janze, C.: Are Cryptocurrencies Criminals Best Friends? Examining the Co-evolution

- of Bitcoin and Darknet Markets. In: 23rd Americas Conference on Information Systems (AMCIS), Boston, 2017.
- [JCG18] Jacobides, M.G., Cennamo, C., Gawer, A.: Towards a Theory of Ecosystems. *Strategic Management Journal* 39/8, pp. 2255-2276, 2018.
- [JD17] Jacob, J., Duysters, G.: Alliance Network Configurations and the Co-evolution of Firms' Technology Profiles: An Analysis of the Biopharmaceutical Industry. *Technological Forecasting and Social Change* 120/7, pp. 90-102, 2017.
- [KHH15] Kaltenecker, N., Hess, T., Huesig, S.: Managing Potentially Disruptive Innovations in Software Companies: Transforming from On-premises to the On-demand. *Journal of Strategic Information Systems* 24/4, pp. 234-250, 2015.
- [KL99] Koza, M., Lewin, A.: The Coevolution of Network Alliances: A Longitudinal Analysis of an International Professional Service Network. *Organization Science* 10/5, pp. 638-653, 1999.
- [KTR13] Kraemer-Mbula, E., Tang, P., Rush, H.: The Cybercrime Ecosystem: Online Innovation in the Shadows? *Technological Forecasting and Social Change* 80/3, pp. 541-555, 2013.
- [Ku01] Kuhlmann, S.: Future Governance of Innovation Policy in Europe - Three Scenarios. *Research Policy* 30/6, pp. 953-976, 2001.
- [KW15] Karimi, J., Walter, Z.: The Role of Dynamic Capabilities in Responding to Digital Disruption: A Factor-Based Study of the Newspaper Industry. *Journal of Management Information Systems* 32/1, 39-81, 2015.
- [LG09] Lucas, H.C., Goh, J.M.: Disruptive Technology: How Kodak Missed the Digital Photography Revolution. *Journal of Strategic Information Systems* 18/1, pp. 46-55, 2009.
- [Li10] Lin, H., Chen, H., Sher, P., Mei, H.: Inter-Network Co-evolution: Reversing the Fortunes of Declining Industrial Networks. *Long Range Planning* 43/5, pp. 611-638, 2010.
- [LL99] Lewin, A.Y., Long, C.P.: The Coevolution of New Organizational Forms. *Organization Science* 10/5, pp. 535-550, 1999.
- [LN15] Lusch, R.F., Nambisan, S.: Service Innovation: A Service-Dominant Logic Perspective. *MIS Quarterly* 39/1, pp. 155-175, 2015.
- [LV99] Lewin, A.Y., Volberda, H.W.: Prolegomena on Coevolution: A Framework for Research on Strategy and New Organizational Forms. *Organization Science* 10/5, pp. 519-534, 1999.
- [Ma13] Manning, S.: New Silicon Valleys or a New Species? Commoditization of Knowledge Work and the Rise of Knowledge Service Clusters. *Research Policy* 42/2, pp. 379-390, 2013.
- [Mc99] McKelvey, B.: Avoiding Complexity Catastrophe in Coevolutionary Pockets: Strategies for Rugged Landscapes. *Organization Science* 10/3, pp. 294-321, 1999.
- [MGC05] Meyer, A., Gaba, V., Colwell, K.: Organizing Far from Equilibrium: Nonlinear Change in Organizational Fields. *Organization Science* 16/5, pp. 456-473, 2005.
- [MHG14] Montealegre, R., Hovorka, D., Germonprez, M.: A Coevolutionary View on Information Services Development: Lessons from the U.S. National Oceanic and Atmospheric Administration. *Journal of the Association for Information Systems* 15/4, pp. 577-613, 2014.
- [Mi07] Mina, A., Ramlogan, R., Tampubolon, G., Metcalfe, J.S.: Mapping Evolutionary Trajectories: Application to the Growth and Transformation of Medical Knowledge. *Research Policy* 36/5, pp. 789-806, 2007.
- [Mo93] Moore, J.: Predators and Prey: A New Ecology of Competition. *Harvard Business Review* 71/3, pp. 75-86, 1993.

-
- [Mu02] Murray, F.: Innovation as Co-evolution of Scientific and Technological Networks: Exploring Tissue Engineering. *Research Policy* 31/8, pp. 1389-1403, 2002.
 - [Ng17] Ng, E., Muthukannan, P., Tan, B., Leong, C.: Fintech Platform Development: A Revelatory Case Study of a Chinese Microloan Startup. In: 38th International Conference on Information Systems (ICIS), Seoul, 2017.
 - [OS10] Okoli, C., Schabram, K.: A Guide to Conducting a Systematic Literature Review of Information Systems Research. *Working Papers on Information Systems* 10, pp. 1-26, 2010.
 - [Os18] Oswald, G.; Soto Setzke, D.; Riasanow, T.; Krcmar, H.: Technologietrends in der digitalen Transformation. In (Oswald, G.; Krcmar, H., eds.) *Digitale Transformation*. Springer Fachmedien, Wiesbaden, pp. 11-34, 2018.
 - [PH13] Paquin, R., Howard-Grenville, J.: Blind Dates and Arranged Marriages: Longitudinal Processes of Network Orchestration. *Organization Studies* 34/11, pp. 1623-1653, 2013.
 - [Pu10] Putzke, J., Fischbach, K., Schoder, D., Gloor, P.A.: The Evolution of Interaction Networks in Massively Multiplayer Online Games. *Journal of the Association for Information Systems* 11/2, pp. 69-94, 2010.
 - [PYH18] Pacheco, D.F., York, J.G., Hargrave, T.J.: The Coevolution of Industries, Social Movements, and Institutions: Wind Power in the United States. *Organization Science* 25/6, pp. 1609-1632, 2018.
 - [RGB17] Riasanow, T., Galic, G., Böhm, M.: Digital Transformation in the Automotive Industry: Towards a Generic Value Network. In: 25th European Conference on Information Systems (ECIS), Portsmouth, 2017.
 - [Ri18a] Riasanow, T., Flötgen, R.J., Soto Setzke, D., Böhm, M., Krcmar, H.: The Generic Ecosystem and Innovation Patterns of the Digital Transformation in the Financial Industry. In: 22nd Pacific Asian Conference on Information Systems (PACIS), Yokohama, 2018.
 - [Ri18b] Riasanow, T., Burckhardt, F., Soto Setzke, D., Böhm, M., Krcmar, H.: The Generic Blockchain Ecosystem and its Strategic Implications. In: 24th Americas Conference on Information Systems (AMCIS), New Orleans, 2018.
 - [Ri19] Riasanow, T., Soto Setzke, D., Böhm, M., Krcmar, H.: Clarifying the Notion of Digital Transformation: A Transdisciplinary Review of Literature. *Journal of Competences, Strategy and Management* 10, pp. 5-36, 2019.
 - [Ro95] Rogers, E.M.: *The Diffusion of Innovations*. Free Press, New York, NY, 1995.
 - [RT14] Rai, A., Tang, X.: Information Technology-Enabled Business Models: A Conceptual Framework and a Coevolution Perspective for Future Research. *Information Systems Research* 25/1, pp. 1-14, 2014.
 - [Sa10] El Sawy, O.A., Malhotra, A., Park, Y., Pavlou, P.A.: Seeking the Configurations of Digital Ecodynamics: It Takes Three to Tango. *Information Systems Research* 21/4, pp. 835-848, 2010.
 - [Sa12] Sarker, S., Sarker, S., Sahaym, A., Bjorn-Andersen, N.: Exploring Value Cocreation in Relationships Between an ERP Vendor and Its Partners: A Revelatory Case Study. *MIS Quarterly* 36/1, pp. 317-338, 2012.
 - [SCK10] Schulte, M., Cohen, N.A., Klein, K.J.: The Coevolution of Network Ties and Perceptions of Team Psychological Safety. *Organization Science* 23/2, pp. 564-581, 2010.
 - [ST17] Sakurai, M., Thapa, D.: Exploring Effective Ecosystems in Disaster Management: Case Studies of Japan and Nepal. In: 50th Hawaii International Conference on System Sciences (HICSS), 2017.
 - [SWS18] Skog, D.A., Wimelius, H., Sandberg, J.: Digital Service Platform Evolution: How

- Spotify Leveraged Boundary Resources to Become a Global Leader in Music Streaming. In: 51st Hawaii International Conference on System Sciences (HICSS), 2018.
- [Ti14] Tiwana, A.: Platform Ecosystems: Aligning Architecture, Governance, and Strategy. Morgan Kaufmann, Burlington, MA, 2014.
- [TKB10] Tiwana, A., Konsynski, B., Bush, A.A.: Platform evolution: Coevolution of Platform Architecture, Governance, and Environmental Dynamics. *Information Systems Research* 21/4, pp. 675-687, 2010.
- [TL17] Tanriverdi, H., Lim, S.-Y.: How to Survive and Thrive in Complex, Hypercompetitive, and Disruptive Ecosystems? The Roles of IS-enabled Capabilities. In: 38th International Conference on Information Systems (ICIS), Seoul, 2017.
- [TRV10] Tanriverdi, H., Rai, A., Venkatraman, N.: Reframing the Dominant Quests of Information Systems Strategy Research for Complex Adaptive Business Systems. *Information Systems Research* 21/4, pp. 822-834, 2010.
- [UY16] Um, S., Yoo, Y.: The Co-evolution of Digital Ecosystems. In: 37th International Conference on Information Systems (ICIS), Dublin, 2016.
- [VL03] Volberda, H., Lewin, A.: Co-evolutionary Dynamics Within and Between Firms: From Evolution to Co-evolution. *Journal of Management Studies* 40/8, pp. 2111-2136, 2003.
- [VP95] Van De Ven, A., Poole, M.: Explaining Development and Change in Organizations. *Academy of Management Review* 20/3, pp. 510-540, 1995.
- [VW06] Vidgen, R., Wang, X.: From Business Process Management to Business Process Ecosystem. *Journal of Information Technology* 21/4, pp. 262-271, 2006.
- [VW09] Vidgen, R., Wang, X.: Coevolving Systems and the Organization of Agile Software Development. *Information Systems Research* 20/3, pp. 355-376, 2009.
- [VW13] Vessey, I., Ward, K.W.: The Dynamics of Sustainable IS Alignment: The Case for IS Adaptability. *Journal of the Association for Information Systems* 14/6, pp. 283-311, 2013.
- [WU16] Weeger, A., Ulrich, H.: How Contradictions Facilitate Evolutionary Transformation: An Exploration into the Dynamics of Business-IT Alignment from the Perspective of Activity Theory. In: 24th European Conference on Information Systems (ECIS), Istanbul, 2016.
- [WW02] Webster, J., Watson, R.T.: Analyzing the Past to Prepare for the Future: Writing a Literature Review. *MIS Quarterly* 26/2, xiii-xxiii, 2002.
- [WW15] Weill, P., Woerner, S.L.: Thriving in an Increasingly Digital Ecosystem. *MIT Sloan Management Review* 56/4, pp. 27-34, 2015.
- [YHL10] Yoo, Y., Henfridsson, O., Lyytinen, K.: Research Commentary: The New Organizing Logic of Digital Innovation: An Agenda for Information Systems Research. *Information Systems Research* 21/4, pp. 724-735, 2010.

Towards a Virtual Reality-based Process Elicitation System

Jannis Vogel¹ and Oliver Thomas¹

Abstract: Today's worldwide operating companies must design their processes globally. Stakeholders within a global process cannot know each circumstance that is spread over several areas. However, digitalization and globalization lead to process redesigns that have to be discussed and reflected in process modelling workshops with various stakeholders that are more likely non-modelling experts. Hence, traditional process elicitation techniques such as interviews or modelling workshops meet new challenges in a globalized and digitalized world. A promising approach to encounter them is the use of virtual reality as a technology-based process elicitation technique. We have performed a systematic literature review and identified 32 articles to existing technology-based process elicitation techniques. Based on the identified literature a taxonomy and specific requirements for the virtual reality-based process elicitation system were derived. Additionally, the paper proposes an architecture for a virtual reality-based process elicitation system that includes today's virtual reality 360-degree recording- and hardware standards.

Keywords: Process Elicitation, Virtual Reality, Domain-specific Modelling Language, Process Modelling, Process Modelling Workshop.

1 Introduction and Motivation

Novices without any process modelling expertise face problems to model actively and correctly during process modelling workshops [RSR10]. However, the digitization calls for process modelling workshops with collective participation from all business stakeholders, especially the collection of tacit and explicit knowledge is crucial for businesses [Sm01]. Furthermore, due to global processes the circumstances from globally distributed business locations have to be reflected in process redesigns. This increases process elicitation difficulties and adds potential language barriers. A virtual reality-based process elicitation system (cf. section 4) should encounter these issues. Virtual Reality (VR) can be "defined as a real or simulated environment in which a perceiver experiences telepresence" [St92]. A comprehensive conducted research project for the use of VR in business process modelling was made by Leinenbach in 2000 [Le00]. He evolved a VR-based system to document business process knowledge with a desktop-based VR simulation of business environments that will be automatically transformed into a semi-formal event-driven process chain. Forty-five consultants were questioned regarding improvement potentials through the system and 73% of them estimate that process documentation and workshops can be enhanced. Additionally, the visualization of the process elicitation environment can increase the recall ability of information [HBJ17]. A study with 40 participants showed that they had an 8% better recall ability due to the usage

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of VR headsets and their associated improved immersion compared to monitors [KPV18]. Further, another study revealed that practitioners prefer storyboard design instead of semiformal modelling languages [WGK13]. Consequently, VR could be in favor to elicit processes for process modelling novices than standard process elicitation techniques due to a high degree of immersion into the real world. Moreover, VR environments can be used de facto unlimited for process elicitation [Ha15] that allows a multiple process elicitation simultaneously.

Although different process elicitation techniques exist (cf. section 3), interviews are still amongst the most effective elicitation approach [Da06]. Studies revealed that a higher theoretical modelling competency supports the reading of business process models [TVC17]. A process facilitator can partly support both tasks during a process modelling workshop. Nonetheless, carrying out a participative modelling workshop is a non-trivial task, requiring cognitive efforts and a trained modelling facilitator [SPS07]. Objectives of the research project are to support the workshop facilitator and participating domain experts in terms of a simplified domain-specific modelling language (DSML) in VR and a precise recall ability of information due to the VR-based process elicitation system. Hence, we developed the following research question:

RQ: How can a virtual reality-based process elicitation system be designed to facilitate process elicitation in particular for non-modelling experts?

The remainder of this paper is structured as follows: In section 2, the research method to execute the research project is presented. In section 3, related work regarding technology-based process elicitation techniques is represented by means of a systematic literature review. The conceptual idea behind the VR-based process elicitation system is explained in section 4. Thereby objectives and an architecture for a VR-based process elicitation system are outlined. Finally, the last section mentions limitations, discusses and sums up the paper.

2 Research Method

The research project follows the problem-oriented Design Science Research Method (DSRM) by Peffers et al. [Pe08] to address the before mentioned real-world problem. Figure 1 shows the DSRM steps and associated research activities. We identified the problem and motivated for a VR-based process elicitation system in section 1. Furthermore, we concluded a systematic literature review that results are presented in section 3 to figure out existing and related technology-based process elicitation techniques. In doing so, we found out that to the best of our knowledge no previous direct work exists that uses VR in combination with 360-degree recordings to elicit processes. Based on the identified literature, a taxonomy for technology-based process elicitation systems is developed that allows the classification of the VR-based process elicitation system. In addition, based on insights from previous related work such as virtual worlds,

requirements and objectives are derived. For the identification of additional requirements, we will carry out a mixed-method approach and add behavioral research methods, i.e. quantitative studies by online surveys and qualitative studies by semi-structured interviews in the design and evaluation phase [HD13]. The presented architecture for the system (cf. section 4) constitutes an important groundwork to derive further requirements and do not purport to be complete. Lastly, to evaluate the system after a demonstration by a VR-based process elicitation workshop, a modelling session with practitioners and novice modelling users will be carried out to elicit the applicability and usability of the system.

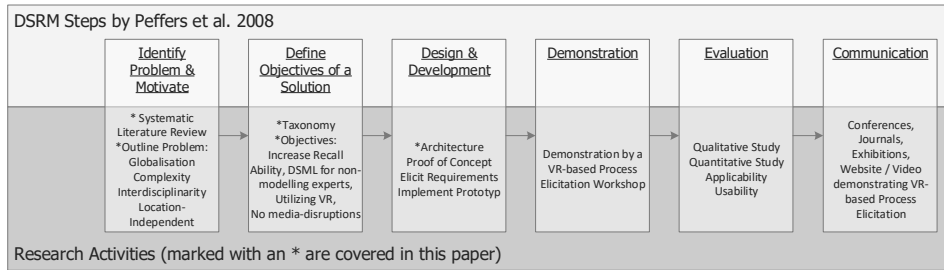


Fig. 1: Research Activities to streamline the Research Project in accordance with the DSRM by Peffers et al. [Pe08]

3 Technology-based Process Elicitation Techniques

3.1 Research Results and Classification of identified Literature

The aim of this research is the development of a new technology-based elicitation method that is not fully covered, but based on standard elicitation methods such as interviews, observations, document analysis, work diaries or modelling workshops [Sa14]. Therefore, we conducted a systematic literature review according to vom Brocke et al. [Vo09] in December 2018. The literature review process is structured by Dybå and Dingsøyr [DD08] and is depicted in Figure 2. We used the search term “process elicitation” with quotation marks and searched in the title, abstract, and full-text. We identified literature with the following databases in the field of information systems: Springer Link, Google Scholar, ScienceDirect, ISI Web of Knowledge, IEEE Xplore and AISel. Then, we exported the articles meta-data of each query, if a query reaches results over 1000, we only imported the first 1000 based on relevance. In total meta-data of 1667 articles were collected. After that, we deleted 178 duplicates identified by the title. Based on the unique titles, we identified in a first step relevant literature and excluded 1381 articles. The including criteria was if the observed title indicates a technology-based process elicitation or modelling approach. Afterwards we used the abstract as second criteria and excluded additional 63 articles that did not fit. Lastly, we excluded 26 articles based on their full-text. Thus, we identified 17 suitable articles that include technology-based process

elicitation techniques. Further overall 15 articles were identified with a forward and backward search applying the same inclusion and exclusion criteria. Thereby, we identified 8 articles with the application of a forward search. Therefore, we used the database Google Scholar and the cited by functionality. Finally, additional 7 articles are included based on the references used in the primarily 17 articles. This lead to 32 identified paper in the final set, which is mentioned in the concept matrix according to Webster and Watson [WW02] (cf. Table 1).

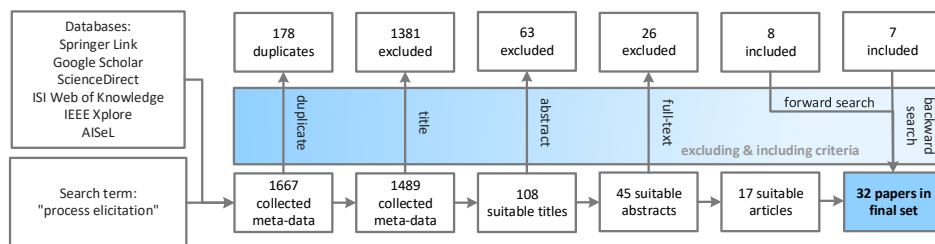


Fig. 2: Literature Search Process for Technology-based Process Elicitation Techniques (according to Dybå and Dingsøyr [DD08])

During the literature analysis, we classified the identified literature into four concepts. The first concept (I) represents if the process elicitation technique uses some kind of process modelling tool. The second concept (II) is fulfilled if the process elicitation technique is based on technology. If the paper contains a study about a process elicitation approach, the third concept (III) is satisfied. The fourth concept (IV) reflects if the elicitation approach can be applied in a workshop format. Following the main insights regarding each concept are summarized:

(I) Process modelling tools: The literature review reveals a close relationship between process elicitation techniques and the capturing of the elicited knowledge with process modelling tools. 24 articles out of 32 (~75%) use in some kind of way a process modelling tool. Notable was the extensive usage of non-standardized process modelling languages. For instance, the applied Subject-oriented BPM in the concept “model as you do” is used in virtual worlds [Ha15].

(II) Technology-based elicitation techniques: The broadness of different technologies for process elicitation is wide. Dominant technologies are virtual worlds (5), text mining or natural language processing for stories (5) and different software-based applications for smartphones or tablets (7) or even smart glasses (2).

(III) Process elicitation studies: One important study is the investigation by Leyh et al. [LBS17]. They investigated if elicitation techniques for business process management (BPM) changed during digitization. They discovered that elicitation approaches did not change, and interviews or workshops are applied with pleasure as elicitation techniques, although digitization facilitates more complex organizations and processes. However,

Leyh et al. espouse the combination of classical elicitation approaches with upcoming tools through digitization e.g. automated process elicitation [SAC18].

#	Topic	Src	I	II	III	IV
General elicitation studies:						
1	Investigation if elicitation techniques changed during digitization	[LBS17]			•	
2	Aggregated view onto elicitation techniques	[Da06]			•	
3	State-of-the-Art of process mining approaches for natural language text	[RTT16]			•	
Virtual Worlds to enhance process elicitation:						
4	Modelling BPMN Processes in Virtual Reality	[OPM18]	•	•		
5	3D Virtual Worlds for process training	[Ay16]	(•)	•		
6	Augmenting in 3D Virtual World to elicit tacit knowledge	[Br14]		•		
7	Study about the recall of information with a virtual reality headset compared to a monitor	[HBJ17]		•	•	
8	Concept “model as you do”, virtual reality tasks are directly saved into a process model	[Ha15]	•	•		
9	Modelling through a role-playing approach in a virtual airport	[Ha16]	•	•	•	
(Story)telling and text interpretation as a process elicitation technique:						
10	Process elicitation through storytelling technique, a story can be created with the definition of different scenes	[An13]	(•)	•		•
11	Comparison of storytelling modelling with traditional modelling	[SAC18]	(•)	•	•	•
12	Teams recall their daily work with stories, based on the stories a text mining approach identifies process elements	[DSB09]f	•	•		•
13	The interpretation of natural language leads to formal process models	[Ca16]	•	•		
14	The interpretation of the text in semantic wikis leads to process models	[DV11]	•	•		
15	Web tool to collect process stories and create process models	[SBP08]	•	•		•
Game-based process elicitation:						
16	Process elicitation while playing a game with BPMN-like notation elements	[HS09]	•	•		•
Digital tools that enable process elicitation:						
17	Mobile web-based modelling tool to model petri nets	[AH16]	•	•		
18	Gesture-based process modelling on mobile touch devices	[KRR12]	•	•		
19	Netsketcher a mobile tool that allows the drawing of BPMN shapes with handwritten text on tablets	[Ba11]	•	•		•
20	MOBIZ allows the collaborative creation of BPMN process models on smartphone or tablets with well-known process elements	[Ba13]	•	•		•
21	CEPE tool a Cooperative Editor for Process Elicitation: Workshop participants can draw the process through CEPE elements in a desktop-based drawing surface and share them among the workshop participants	[De03]	•	•		•
22	Study about the usage of multi-touch tables in modelling sessions	[Wi12]	•	•	•	•
23	Concept “model while you work” provides a software tool for the modelling on a tablet with easy recognizable modelling elements	[LS16]	•	•		
24	Process analyst can save contextual information during a process interview in the form of sketches	[Si12]	(•)	•		•
25	Process elicitation with Smart Glasses	[Me18]	(•)	•		
26	Comparison of tangible process modeling methods with a tabletop interface	[FSS14]	•	•		•
27	A table touch process modelling approach with tangible modelling blocks	[OS14]	•	•		•
28		[KO15]	•	•		•
Event logs/activity recognition based on cameras, sensors and wearables:						
29	Technology-based process elicitation approach realized through the use of different cameras that detect activities during process execution	[Kn18]		•		
30	Elicit processes through wearable sensors	[Ra18]		•		
31	Real-time modelling tool with the usage of Smart Glasses, a first-person view video recorded by the Smart Glasses is used as an input to create augmented reality-based manuals	[PPS13]	(•)	•		
32	Event-based data from software is analyzed and interpreted into process models	[CW98]	•	•		
Legend: • concept is directly fulfilled (•) concept is indirectly fulfilled						

Tab. 1: Concept Matrix of Technology-based Process Elicitation Techniques in accordance with Webster and Watson [WW02]

(IV) Process elicitation techniques in Workshops: Process elicitation has a strong relationship with workshop sessions, 12 out of 32 papers link process elicitation with workshops. Especially the following process elicitation approaches are mainly represented: (Story)telling and digital tools. For instance, Simões et al. [SAC18] revealed that storytelling has a positive effect on process elicitation.

3.2 Taxonomy for Technology-based Process Elicitation Techniques

We followed the method for taxonomy development by Nickerson et al. [NVM13] (cf. Figure 3) to create the taxonomy for technology-based process elicitation techniques. First, the implied meta-characteristic defines the objects that are interested in the developed taxonomy. These are solely technology-based process elicitation techniques such as referred in the concept matrix (cf. Table 1). The ending condition contains the basic definition of a taxonomy, i.e. dimensions with mutually exclusive and comprehensive characteristics [NVM13].

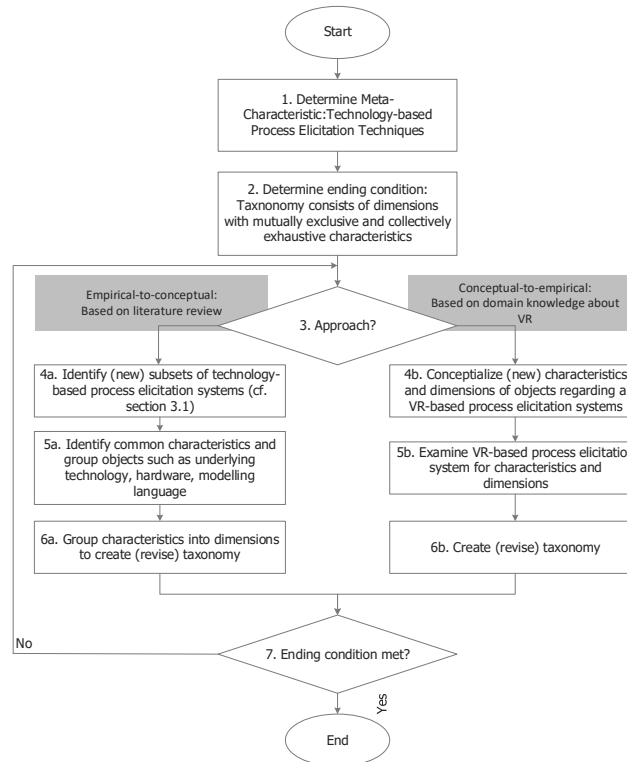


Fig. 3: Applied taxonomy development method in accordance with Nickerson et al. [NVM13]

We first undertake the empirical-to-conceptual approach based on the findings of the literature review and performed steps 4a, 5a and 6a with several iterations till the ending condition was met. Afterwards, we supplemented dimensions and characteristics by carrying out the conceptual-to-empirical approach with the steps 4b, 5b and 6b. In these steps, we integrated technology knowledge about today's VR hardware that is hitherto not reflected by technology-based process elicitation techniques in the literature. This procedure leads to the following taxonomy depicted in Table 2.

Dimension Class	Dimension	Characteristic			
Human	Communication	Workshop		Digital Collaborative	
		Face to Face		Alone	
Computer	Technology-based elicitation technique	Story(telling)		Interview	
		Sketch		Event Log	
		Camera		(Modelling) Tool	
		360-degree Recording		Text Mining	
				Virtual World / Reality	
	Device	Desktop		Smartphone	
		Tablet		Multi-touch Table	
		Smart Glasses		VR Headset	
		Wearable		Sensor	
				Workshop	
Interaction	Modelling elements	Standardized modelling elements		Domain-specific modelling elements	
	Transformation of elicitation knowledge into a process model			No modelling elements	
		Direct	Text-mining	Activity Recognition	Workshop Facilitator

Tab. 2: Taxonomy for Technology-based Process Elicitation Techniques

We defined three dimension classes that are oriented on human-computer-interaction systems due to technology-based process elicitation systems can be sorted into them as subsystems. The first dimension classifies what kind of communications are involved during the process elicitation phase. The next dimension consists of technology-based elicitation techniques that are identified in the literature review and are supplemented with characteristics from the VR domain. The third dimension classifies the device to elicit the processes. The fourth dimension includes if a modelling language is applied during the elicitation. As already mentioned in 75 % of the identified literature a process modelling environment is integrated to elicit processes. Finally, the last dimension classifies how the transformation of the elicited knowledge into a process model will be achieved. The in grey highlighted values are covered by the VR-based process elicitation system. Although the marked characteristics are not exclusive, they represent different statuses within the VR-based process elicitation system (cf. section 4).

4 Designing a VR-based Process Elicitation System

4.1 Objectives of a VR-based Process Elicitation System

Based on insights of VR and the affiliated problem, we state objectives of the VR-based process elicitation system. The recall ability of information by process modelling users should be increased due to the direct visualization of the elicited process environment.

Furthermore, modelling activities should be simplified. This is achieved by a reduction of process notation elements for tasks, events and organizational units and an easy selection within VR. Moreover, novice process modelling users should learn a process modelling language faster due to the direct visual connection between the real world and the process notation elements. Lastly, discussions within a process modelling workshop can be enhanced. This is realized due to a minimized language barrier explained by visualization. Also, discussions about global processes could be more efficient due to the reflection of globally distributed business locations by using 360-degree recordings.

4.2 Requirements and Architecture

We identified important concepts based on the literature review that is in our point of view applicable for a VR-based process elicitation system. The proposed architecture is shown in Figure 4. We suggest the usage of a domain-specific modelling language (DSML) to annotate tacit knowledge in 360-degree panorama recordings [SC15] with the VR system. The DSML should represent different tasks, information or events. A similar approach is done in [Br14] by augmenting knowledge in 3D virtual worlds. Here virtual worlds facing the problem that they have to be modelled and programmed. In our point of view, the associated costs are not justified and are not in proportion to the generated benefit. Hence, we propose the usage of 360-degree panorama recordings that can be generated easier and are related to fewer staff costs. A 360-degree panorama recording is taken by a 360-degree camera that is able to shot the whole surrounding with one shot. In combination with this concept is the use of computer vision to recognize specific objects and to receive automatically generated modelling recommendations. A further developed gesture recognition system enables the functionality to draw specific signs into the 360-degree recording. Therefore, additional input sensors such as the Leap Motion Controller can be used to identify detailed hand gestures [BWR18]. For instance, a drawn triangle creates a warning sign. Besides the controller input, the domain expert can use voice to assign longer process knowledge in the VR environment. A voice recognition subsystem transfers the speech into text and a text mining approach such as in [DSB09] could identify process elements. A basic user authorization leads to a proper assignment of released 360-degree recordings. Finally, a transformation system interprets the created annotations (drawings, voice annotations, logs) in the 360-degree recordings and generates semi-formal process models that is similar to the realized IMPROVE process modeler by Leinenbach [Le00].

The main components such as 360-degree recordings, VR hardware system, and the previously described VR-based process elicitation system are mandatory. The system can be optionally extended by a live view, a desktop-based process modelling environment, and a smartphone application to retrieve recommendations (covered in blue) to include a modelling component. By the extension, the system can be integrated into modelling workshops and interlinks the modelling facilitator who can design the semi-formal models

with the desktop-based modelling system. Workshop participants can see the actual VR environment by the live view. Furthermore, they can send recommendations via smartphone to the domain expert who is situated in the VR environment. Moreover, we want to consider the seven design principles for tools that facilitate participatory modelling sessions [Lü11] for the development of the VR-based system. The proposed architecture has strengths and weaknesses. On the one hand, many integrated subsystems make the system applicable for different use cases. On the other hand, increased implementation efforts are related to them. The usage of 360-degree recordings and a user authorizations system allows the system to become a scalable public available web-based system assuming that it is hosted in the cloud. Users solely have to upload their 360-degree recordings and can use the system. By this approach, the development costs can be shared with the entire users and as a result the system will be more cost-efficient.

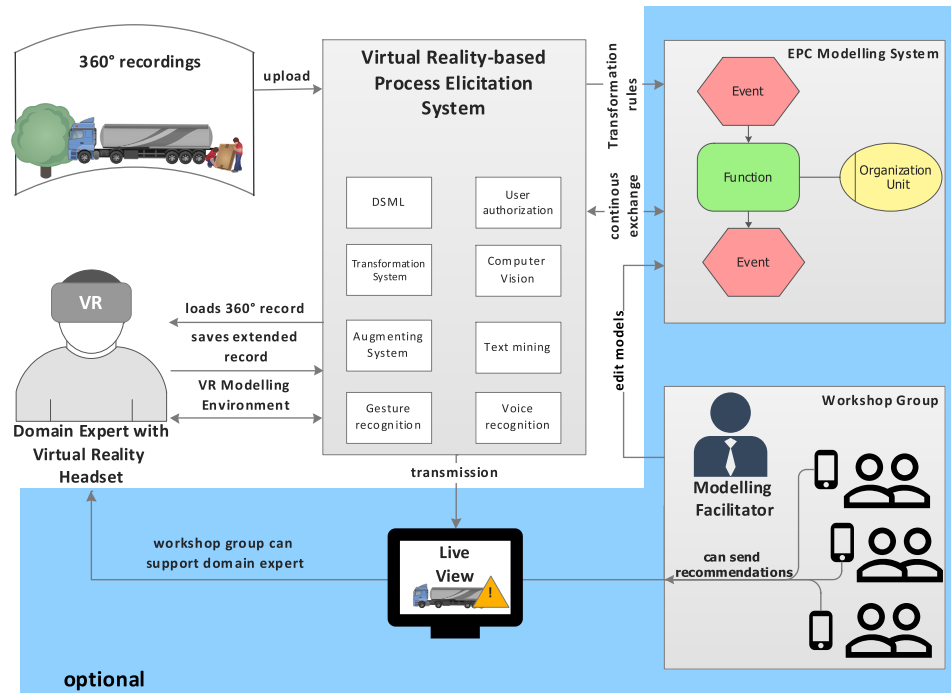


Fig. 4: Architecture for the Virtual Reality-based Process Elicitation System

5 Discussion, Limitations, and Conclusion

5.1 Discussion and Limitations

The design science-oriented research project is subjected to certain limitations. Firstly, an overall check if VR is suitable to elicit processes was not done. Predominantly VR is mainly used in domains such as the gaming industry or for planning and design e.g. architecture. Although associated co-existing work with virtual worlds exists and usage is therefore not new, it has to be discovered if a process elicitation with VR is appropriate in terms of usability. Factors that could negatively affect the usability are the added complexity and the high-tech feel due to VR headset and controllers that hinder or distract users. Further investigations have to be taken regarding what kind of processes are suited to be represented in VR.

The evolved architecture was developed based on empirical insights from the literature review. However, it remains in a subjective point of view by the authors. Therefore, the architecture has to be discussed and validated during the requirements elicitation phase in the future. Moreover, the presented architecture represents only a rough representation. Additionally, proposed subsystems and concepts have to be designed in detail in future studies. The same applies to the derived taxonomy for technology-based process elicitation systems. Moreover, extensive insights will be achieved during the design and development phase with a first implemented proof of concept and demonstration in a process modelling workshop. At this time the suspected advantages of the proposed solution in particular for novice modelling users can be validated, i.e. better recall ability, easier process elicitation, elicitation of globally distributed processes, minimizing language barriers and faster learning of process modelling notations.

5.2 Conclusion

This paper presents a new research direction that is based on previous work in the domain of technological-based process elicitation techniques. The groundwork delivering 32 identified papers by means of a conducted systematic literature review. A VR-based process elicitation system with the integration of today's VR hardware in combination with 360-degree recordings should improve the elicitation of processes, especially for non-modelling experts. The presented elicitation approach can be used in a single, collaborative and workshop environment. Thereby, it is broadly applicable and provides to the best of our knowledge the first time a proposal, by means of architecture, to integrate today's VR 360-degree hardware standards into an elicitation system. In doing so, the system should be in favor to elicit processes that are globally distributed and simplify the process elicitation for novice modelling users due to visualization and immersion. Further research steps are the elicitation of additional requirements with quantitative and qualitative studies. Based on the requirements a runnable prototype has to be developed

that delivers the first proof of concept. Then, supplementary evaluation studies reveal improvement possibilities.

6 Acknowledgements

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References

- [AH16] Alpers, S., Hellfeld, S.: Werkzeug zur mobilen Modellierung von Geschäftsprozessen mittels Petri-Netzen. In (Betz, S. and Reimer, U.): Modellierung 2016 - Workshopband. Gesellschaft für Informatik e.V., Bonn, pp. 147–152, 2016.
- [An13] Antunes, P. et al.: An end-user approach to business process modeling. *J. Netw. Comput. Appl.* 36, 1466–1479, 2013.
- [Ay16] Aysolmaz, B., Brown, R., Bruza, P., Reijers, H.A.: A 3D Visualization Approach for Process Training in Office Environments. In (Debruyne, C., Panetto, H., Meersman, R., Dillon, T., Kühn, E., O’Sullivan, D., and Ardagna, C.A.): On the Move to Meaningful Internet Systems: OTM 2016 Conferences: Confederated International Conferences. Springer International Publishing, Cham, pp. 418–436, 2016.
- [Ba11] Baloian, N. et al.: A collaborative mobile approach for business process elicitation. In: Proceedings of the 2011 15th International Conference on Computer Supported Cooperative Work in Design (CSCWD). pp. 473–480, 2011.
- [Ba13] Baloian, N. et al.: Mobile Collaboration for Business Process Elicitation from an Agile Development Methodology Viewpoint. In: 2013 IEEE 10th International Conference on e-Business Engineering. pp. 306–311, 2013.
- [Br14] Brown, R. et al.: Augmenting and Assisting Model Elicitation Tasks with 3D Virtual World Context Metadata. In (Meersman, R., Panetto, H., Dillon, T., Missikoff, M., Liu, L., Pastor, O., Cuzzocrea, A., and Sellis, T.): On the Move to Meaningful Internet Systems: OTM 2014 Conferences. Springer, Berlin Heidelberg, pp. 39–56, 2014.
- [BWR18] Bachmann, D., Weichert, F., Rinkenauer, G.: Review of Three-Dimensional Human-Computer Interaction with Focus on the Leap Motion Controller. *MDPI Sensors*. 18, 1–39, 2018.
- [Ca16] Caporale, T.: Geschäftsprozessmodellierung mit kontrollierter natürlicher Sprache Motivation und Problemstellung. In (Mayr, H.C. and Pinzger, M.): Informatik 2016, Lecture Notes in Informatics (LNI). pp. 1957–1962, 2016.
- [CW98] Cook, J.E., Wolf, A.L.: Discovering Models of Software Processes from Event-Based Data. *ACM Trans. Softw. Eng. Methodol.* 7, 215–249, 1998.

- [Da06] Davis, A. et al.: Effectiveness of Requirements Elicitation Techniques: Empirical Results Derived from a Systematic Review. In: 14th IEEE International Requirements Engineering Conference (RE'06). pp. 179–188, 2006.
- [De03] de Freitas, R.M. et al.: Groupware support for Cooperative Process Elicitation. In (Favela, J and Decouchant, D.): CRIWG 2003, LNCS. pp. 232–246, 2003.
- [DD08] Dybå, T., Dingsøyr, T.: Empirical studies of agile software development: A systematic review. *Inf. Softw. Technol.* 50, 833–859, 2008.
- [DSB09] de A. R. Goncalves, J.C., Santoro, F.M., Baiao, F.A.: Business process mining from group stories. In: 13th International Conference on Computer Supported Cooperative Work in Design. pp. 161–166, 2009.
- [DV11] Dengler, F., Vrandečić, D.: Wiki-Based Maturing of Process Descriptions. In (Rinderle-Ma, S., Toumani, F., and Wolf, K.): *Business Process Management*. Springer, Berlin Heidelberg, pp. 313–328, 2011.
- [FSS14] Fleischmann, A., Schmidt, W., Stary, C.: Tangible or Not Tangible – A Comparative Study of Interaction Types for Process Modeling Support. In (Kurosu, M.): *Human-Computer Interaction. Advanced Interaction Modalities and Techniques*. Springer International Publishing, Cham, pp. 544–555, 2014.
- [Ha15] Harman, J. et al.: Model as you do: engaging an S-BPM vendor on process modelling in 3D virtual worlds. *S-BPM Wild*. 2015.
- [Ha16] Harman, J. et al.: Augmenting process elicitation with visual priming: An empirical exploration of user behaviour and modelling outcomes. *Inf. Syst.* 62, 242–255, 2016.
- [HBJ17] Harman, J., Brown, R., Johnson, D.: Improved memory elicitation in virtual reality: new experimental results and insights. *IFIP Conf. Human-Computer*. 2017.
- [HD13] Huysmans, P., De Bruyn, P.: A Mixed Methods Approach To Combining Behavioral And Design Research Methods In Information Systems Research. In: *Proceedings of the 21st European Conference on Information Systems*. pp. 1–12, 2013.
- [HS09] Hoppenbrouwers, S., Schotten, B.: A Game Prototype for Basic Process Model Elicitation. In (Persson, A. and Stirna, J.) *The Practice of Enterprise Modeling*. Springer, Berlin Heidelberg, pp. 222–236, 2009.
- [Kn18] Knoch, S. et al.: Technology-Enhanced Process Elicitation of Worker Activities in Manufacturing. In (Teniente, E. and Weidlich, M.): *Business Process Management Workshops*. Springer International Publishing, Cham, pp. 273–284, 2018.
- [KO15] Kannengiesser, U., Oppl, S.: Business Processes to Touch: Engaging Domain Experts in Process Modelling. *BPM*. 2015.
- [KPV18] Krokos, E., Plaisant, C., Varshney, A.: Virtual memory palaces: immersion aids recall. *Virtual Real*. 2018.
- [KRR12] Kolb, J., Rudner, B., Reichert, M.: Towards Gesture-Based Process Modeling on Multi-touch Devices. In (Bajec, M. and Eder, J.): *Advanced Information Systems Engineering Workshops*. Springer, Berlin Heidelberg, pp. 280–293, 2012.

- [LBS17] Leyh, C., Bley, K., Seek, S.: Elicitation of Processes in Business Process Management in the Era of Digitization – The Same Techniques as Decades Ago? In (Piazolo, F., Geist, V., Brehm, L., and Schmidt, R.): *Innovations in Enterprise Information Systems Management and Engineering*. Springer International Publishing, Cham, pp. 42–56, 2017.
- [Le00] Leinenbach, S.: *Interaktive Geschäftsprozessmodellierung: Dokumentation von Prozesswissen in einer Virtual Reality-gestützten Unternehmungsvisualisierung*. Deutscher Universitäts-Verlag, 2000.
- [LS16] Lerchner, H., Stary, C.: Model While You Work: Towards Effective and Playful Acquisition of Stakeholder Processes. In: *Proceedings of the 8th International Conference on Subject-oriented Business Process Management*. p. 1:1–1:10. ACM, New York, 2016.
- [Lü11] Lübke, A.: PRINCIPLES FOR BUSINESS MODELING WITH NOVICE USERS. In: *Participatory Innovation Conference 2011*. Sønderborg, Denmark, pp. 1–5, 2011.
- [LW12] Luebbe, A., Weske, M.: Investigating Process Elicitation Workshops Using Action Research. In (Daniel, F., Barkaoui, K., and Dustdar, S.) *Business Process Management Workshops*. Springer, Berlin Heidelberg, pp. 345–356, 2012.
- [Me18] Metzger, D. et al.: The Next Generation – Design and Implementation of a Smart Glasses-based Modelling System. *Enterp. Model. Inf. Syst. Archit. Int. J. Concept. Model.* 13, 1–25, 2018.
- [NVM13] Nickerson, R.C., Varshney, U., Muntermann, J.: A method for taxonomy development and its application in information systems. *Eur. J. Inf. Syst.* 22, 336–359, 2013.
- [OPM18] Oberhauser, R., Pogolski, C., Matic, A.: VR-BPMN: Visualizing BPMN Models in Virtual Reality. In (Shishkov, B.): *Business Modeling and Software Design*. Springer International Publishing, Cham, pp. 83–97, 2018.
- [OS14] Oppl, S., Rothschild, T.: Separation of concerns in model elicitation–role-based actor-driven business process modeling. *Conf. Subj. Bus. Process*, 2014.
- [Pe08] Peffers, K., Tuunanen, T., Rothenberger, M.A., Chatterjee, S.: A Design Science Research Methodology for Information Systems Research. *J. Manag. Inf. Syst.* 24, 45–77, 2008.
- [PPS13] Petersen, N., Pagani, A., Stricker, D.: Real-time modeling and tracking manual workflows from first-person vision. In: *2013 IEEE International Symposium on Mixed and Augmented Reality (ISMAR)*. pp. 117–124, 2013.
- [Ra18] Raso, R. et al.: Activity Monitoring Using Wearable Sensors in Manual Production Processes – An Application of CPS for Automated Ergonomic Assessments. In: *Multikonferenz Wirtschaftsinformatik 2018*. pp. 231–242, 2018.
- [RSR10] Recker, J., Safrudin, N., Rosemann, M.: How Novices Model Business Processes. In (Hull, R., Mendling, J., and Tai, S.): *Business Process Management*. Springer, Berlin Heidelberg, pp. 29–44, 2010.
- [RTT16] Riefer, M., Ternis, S.F., Thaler, T.: Mining Process Models from Natural Language Text: A State-of-the-Art Analysis. *Tagungsband der Multikonferenz*

- Wirtschaftsinformatik. Multikonferenz Wirtschaftsinformatik (MKWI-16), Illmenau, pp. 1–12, 2016.
- [Sa14] Sandkuhl, K. et al.: Elicitation Approaches in Enterprise Modeling. In: *Enterprise Modeling: Tackling Business Challenges with the 4EM Method*. Springer, Berlin Heidelberg, pp. 39–51, 2014.
- [SAC18] Simões, D., Antunes, P., Carriço, L.: Eliciting and Modeling Business Process Stories. *Bus. Inf. Syst. Eng.* 60, 115–132, 2018.
- [SBP08] Santoro, F.M., Borges, M.R.S., Pino, J.A.: Tell us your process: A group storytelling approach to cooperative process modeling. In: *12th International Conference on Computer Supported Cooperative Work in Design*. pp. 29–34, 2008.
- [SC15] See, Z.S., Cheok, A.D.: Virtual reality 360 interactive panorama reproduction obstacles and issues. *Virtual Real.* 19, 71–81, 2015.
- [Si12] Silva, D.M. et al.: Defining context in a business process collaborative elicitation approach. In: *Proceedings of the 2012 IEEE 16th International Conference on Computer Supported Cooperative Work in Design (CSCWD)*. pp. 861–868, 2012.
- [Sm01] Smith, E.A.: The role of tacit and explicit knowledge in the workplace. *J. Knowl. Manag.* 5, 311–321, 2001.
- [SPS07] Stirna, J., Persson, A., Sandkuhl, K.: Participative Enterprise Modeling: Experiences and Recommendations. In (Krogstie, J., Opdahl, A., and Sindre, G.): *Advanced Information Systems Engineering*. Springer, Berlin Heidelberg, pp. 546–560, 2007.
- [St92] Steuer, J.: Defining Virtual Reality: Dimensions Determining Telepresence. *J. Commun.* 42, 73–93, 1992.
- [TVC17] Turetken, O., Vanderfeesten, I., Claes, J.: Cognitive Style and Business Process Model Understanding. In (Metzger, A. and Persson, A.): *Advanced Information Systems Engineering Workshops*. Springer International Publishing, Cham, pp. 72–84, 2017.
- [Vo09] vom Brocke, J. et al.: Reconstructing the Giant: On the Importance of Rigour in Documenting the Literature Search Process. In: *ECIS 2009 Proceedings*. AIS Electronic Library, pp. 2206–2217, 2009.
- [WGK13] Weitlaner, D., Guettinger, A., Kohlbacher, M.: Intuitive Comprehensibility of Process Models. In (Fischer, H. and Schneeberger, J.): *S-BPM ONE – Running Processes*. Springer, Berlin Heidelberg, pp. 52–71, 2013.
- [Wi12] Wittern, H.: Empirical study evaluating business process modeling on multi-touch devices. In: *IEEE 12th International Conference on Software Science*. pp. 20–29, 2012.
- [WW02] Webster, J., Watson, R.T.: Analyzing the past to prepare for the future writing a literature review. *MIS Q.* 26, 2002.

Qualitative Comparison of Enterprise Architecture Model Maintenance Processes

Simon Hacks and Horst Lichter¹

Abstract: Enterprise Architecture (EA) is no end in itself but has to provide central, important, and up-to-date information of the organization to its clients. So far, different researchers have elaborated on processes to ensure a (semi-)automated EA model maintenance. For practitioners this raises the question how the processes can be compared to each other. To answer this question, we identified a set of five quality criteria and asked EA researcher and practitioners to rate those for three processes.

Keywords: EA Model Maintenance; Comparative Study; Quality Assessment; Quantitative Study

1 Introduction

Information technology (IT) pervades organizations more and more and becomes further important for the business [VSM10]. Furthermore, the integration of business requirements with implemented IT functionality becomes more important. Consequently, the business-IT alignment has been most important for CIOs of different industries and different organization sizes for a long time [Lu05, LBZ10]. To promote the business-IT alignment, more and more information system (IS) change and development projects focus on the realization of technical solutions for local business needs. Enterprise Architecture (EA) is a widely accepted discipline to guide local IS endeavours through a holistic view on the fundamental structures, design, and evolution principles of the overall organization [BY06]. EA eases the alignment of IS projects with enterprise-wide objectives, which leads to reduced complexities as well as integration efforts in the overall corporate IS landscape [AW09, PI07].

Since its beginnings in the 1980's [Ko16], EA has developed to an established discipline in industry and research. A widely accepted definition of the term architecture is given in the ISO 42010:2011, which defines architecture as the “fundamental concepts or properties of a system in its environment embodied in its elements, relationships, and in the principles of its design and evolution” [III11]. As this definition implies, the EA model, comprised by the elements and relationships of the organization, is one central artifact of EA. The model provides a holistic view on the organization and, therefore, eases the value creation for EA's stakeholder [NP13].

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EA is no end in itself but has to provide central, important, and up-to-date information of the organization (e.g., business processes, application and data architectures, or infrastructure components) to its clients, for instance, to all projects of an organization. There are a lot of different drivers for changes of the EA model [Fa12], which contribute to a continuous evolution of the EA. However, the input can be contradictory, for example, because the interaction between data providers and the EA is not coordinated systematically, leading to a state where EA model and the information offered by different data providers are not in sync, but inconsistent.

So far, different researchers have elaborated on processes to ensure a (semi-)automated EA model maintenance (see [FAW07, Mo09, HL18]). For practitioners this raises the question how the processes can be compared to each other. We focus on quality aspects and, accordingly, we wonder first:

What are important quality criteria of EA model maintenance processes?

After answering this question, we can move forward to our research question:

How differ certain EA model maintenance processes with respect to these quality criteria?

To answer this question, we identified five quality criteria and asked EA practitioners and EA researcher to rate three different EA model maintenance processes [FAW07, Mo09, HL18] based on this quality criteria.

The rest of this work is structured as follows: First, we present in Section 2 which quality criteria we like to test and their interrelation, as well as how the questionnaire is designed, and the way we collected the data. Section 3 presents the three processes, which should be assessed as well as how we prepared them for evaluation. The results are outlined and discussed in Section 4. Before we come to the conclusion, we present some related work.

2 Methodology

2.1 Tested Quality Criteria

Assessing the quality of a process is quite challenging. Especially, if the process cannot be applied in reality but has to be assessed based on its description only, as in our case. Therefore, we wanted to create a set of quality criteria, which captures a broad range of process facets. Additionally, the set should not be too big so that the participant can keep the different criteria in mind. First, we evaluated our own quality framework to rate EA models [Ti17]. Unfortunately, our framework assesses only the model quality and no deeper aspects of the process.

Next, we searched for a small set of quality criteria and ended up with the well-known eight dimensions of quality [Ga87]. However, those quality criteria are related to products

and, therefore, some criteria are hardly applicable to our issue. For example, aesthetics is a criterion, which does not really matter for processes.

Last, we evaluated quality criteria arising from the domain of software engineering [LL13, p. 66]. We reduced the extensive set of quality criteria by removing those, which does not suit the issue of rating process quality. For example, we neglect modularity, as we do not want to assess the reusability of the processes. Following, we present the five quality criteria, we use to compare the three processes to each other:

- **Comprehensibility** describes how easy the process model can be understood.
- **Effectiveness** relates to the capability of the process under inspection to keep an enterprise architecture model up-to-date. When something is deemed effective, it means it has an intended outcome.
- **Completeness** assesses if the process contains all the necessary process steps to maintain an enterprise architecture model.
- **Minimality** reflects if the process contains only those process steps that are necessary to maintain an enterprise architecture model.
- **Efficiency** presents to which degree the process is perceived –in terms of time– to maintain changes into an enterprise architecture model.

We expect that the beforehand introduced quality criteria are not completely independent from each other. First, we anticipate a strong mutual correlation between completeness and effectiveness. This is grounded in the fact that a process, which is not complete, can be hardly effective as if something is missing effectiveness cannot be guaranteed. Same holds vice versa, because if a process is not effective, it is likely that something is missing within the process. Nonetheless, –up to our mind– effectiveness and completeness are not the same. We argue that, for example, just small parts of the process could be missing which have a strong influence on the perceived effectiveness.

Second, we expect a mutual correlation between minimality and efficiency. If a process is minimal, there are no additional parts, which could slow down the process and, therefore, decrease its efficiency. Same holds vice versa, as the most efficient process does not contain unnecessary process steps. However, we do not expect the correlation between efficiency and minimality as strong as between completeness and effectiveness, because efficiency of the whole process is strongly related to the efficiency of each process step, which is not the case for minimality. Last, we expect a positive correlation between minimality and comprehensibility, as we think that it is easier to understand a process which is minimal than a process which is not.

We will check our beforehand stated assumptions in Section 4.1 and if necessary, we will discard a criterion.

2.2 Questionnaire Design

To collect the necessary data, we created a seven-page questionnaire in German and English language. The first page introduces the research topic, and defines the targeted group of participants.

The second page explains the expectations towards the participant and introduces the five quality criteria to be assessed (cf. Section 2.1). Both pages have in common that they contain a not negligible amount of text to create a *high hurdle* [Re02]. Doing so, we want to sort out participants, which are not motivated to answer our questionnaire and reward the other participants as it is easier to capture the whole content on the following pages.

The next three pages present in each case one of the processes in a unified representation (see Figure 1, 2, and 3). Therefore, we sketched the processes in a “box-and-lines” notation, because we want the participant to focus on the process itself and not on notations. Additionally, we give a short description of the process’ aim, followed by a characterization of all included roles. We unified also the role names and their description to ease the understanding of the different processes. Additionally, we provide an abstract of the process itself.

As the participant got all information she needs to assess process’ quality, we ask her to rate every quality criterion on a five-point Likert-scale [Da08] to which degree the process suits the criterion from 1 (not) to 5 (perfect). If she is not able to assess a certain criterion, she can also indicate this. After rating the criteria, we offer the participant to give qualitative feedback on each process, too.

The sixth page is facilitated to collect demographic information on the EA experience of the participant and her organization. Further, she can also provide feedback on the questionnaire or give other comments.

On the last page, we ask the participant on her seriousness and consent to use her data. This is a common technique to exclude questionnaires which were not seriously filled [TW12, p. 114f].

To ensure usability of our questionnaire, we conducted a three-stage development. In the first step the first author created the questionnaire and the second author checked it for any flaws. In the second stage, the questionnaire was distributed within the research group of the authors to check for flaws and to determine the necessary time to answer it. In the last stage, the questionnaire was distributed throughout several EA practitioners for a last check.

2.3 Data Collection

We distributed the questionnaire among different channels to reach as many EA practitioners and researcher as possible. Therefore, we asked our industrial cooperation partners to answer

the questionnaire and to distribute it also to other EA practitioners. Additionally, we asked the participants of three regional EA related meetings to answer the questionnaire. To get responses of the scientific EA community, we send the questionnaire to our research network and distributed it through several EA related e-mail-lists.

In total, we received 123 questionnaires, which finished at least the questions related to the processes. First, we removed all questionnaires where the participant stated that she did not answered the questionnaire seriously ending up with 100 questionnaires. Second, we checked the demographic answers of the questionnaires where the participant did not answer the question regarding conscientiousness. As those answers seemed to be very randomly (e.g., 999 years of experience in EA or 1000 architects employed in a medium sized organization), we removed further 20 questionnaires.

The most of the left 80 participants are employed within the IT sector (27.5%), followed by the insurance sector (16.3%). 18.8% are working in an organization with more than 10,000 employees, followed by 15% working in an organization with 1,000 to 2,500 employees. However, the participants are likely distributed along all organization sizes and gained an experience of 3.8 years in average. The predominant part of the participants works as an employee without personnel responsibility (60%), followed by 16.7% working in the operational management (e.g., team or group leader). In average, the companies employed around 18 enterprise architects and the median is at 5. The companies have in average an EA initiative since 6.6 years in place.

3 EA Model Maintenance Processes

Following, we present the three processes we evaluate. We restrict us to three processes to stick in a period of maximum 15 minutes to answer the questionnaire. The first process [FAW07] focuses on the integration of information distributed in different systems and is highly cited. The second process [Mo09] focuses on the integration of information from different sources and is highly cited. The third process [HL18] is designed by the authors and focuses on integrating information generated by projects.

3.1 Process 1: A Federated Approach to EA Model Maintenance

The process presented at [FAW07] focuses on the integration of information distributed in different systems. Essentially, four different roles are assigned to the process:

- **EA Coordinator:** EA coordinator is part of the EA team and reports to the Chief Architect. Her main tasks include improving the EA meta-model, maintaining the EA model, and designing EA reports.

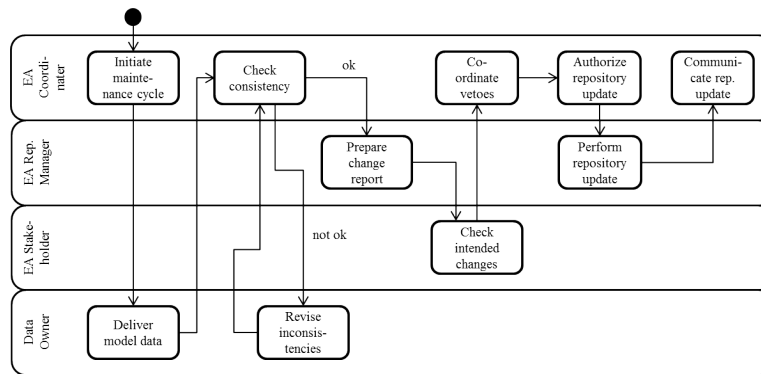


Fig. 1: A Federated Approach to EA Model Maintenance [FAW07].

- **EA Repository Manager:** The focus of the EA repository manager is more technical. She is responsible for user administration, software updates, and the repository update.
- **EA Stakeholders:** EA stakeholders are business and IT departments that use EA information, e.g., to implement the strategy or security management.
- **Data Owner:** A data owner is responsible for a system whose data is to be transferred to the central EA model.

The process (see Figure 1) starts with the EA coordinators wanting to update the EA model and, for that reason, requesting up-to-date information from the appropriate data owner. Once she has delivered the information, the EA coordinators check the information for consistency. If inconsistencies persist, the data owner is notified and revises the information accordingly.

If the consistency check was successful, all changes to the EA model are identified and made available to all affected stakeholders. They review the changes and, if vetoed by a stakeholder, the EA coordinators coordinate a discussion to resolve the differences between stakeholders and data owners. After everyone agrees to the changes, the EA model can be updated and the changes communicated.

3.2 Process 2: Process Patterns for EA Management

The process of Moser et al. [Mo09] focuses on the integration of information from different sources. Essentially, three different roles are assigned to the process:

- **Domain Expert:** Domain experts are a subset of EA's stakeholders. They formulate information requirements to the EA and are recipients of the information.

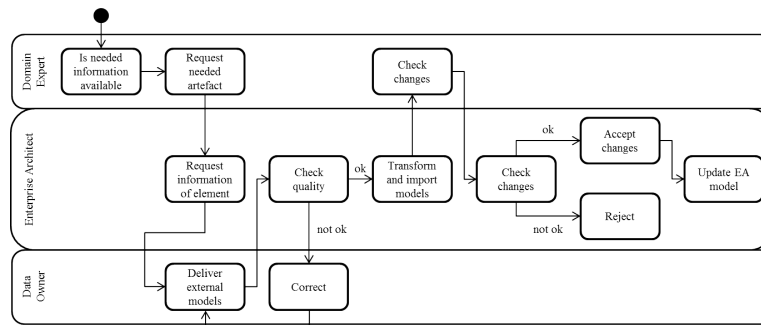


Fig. 2: Process Patterns for EA Management [Mo09].

- **Enterprise Architect:** Enterprise architects are responsible for maintaining and keeping the EA model up-to-date.
- **Data Owner:** A data owner is responsible for a system whose data is to be transferred to the central EA model.

The process (see Figure 2) starts when a domain expert notices that she does not have all the information she needs for a particular task. Therefore, she asks the enterprise architects for this information. These check the request and contact the data owner who holds the corresponding information. She provides the information to the enterprise architects, whereupon they check its quality. If the result of the check is negative, the data owner improves the information.

Once the quality check has been successfully completed, the information is transformed and prepared for import. Before that, the changes will be checked by domain experts and enterprise architects. If there is no objection from any side, the information is imported and the updated EA model is made available.

3.3 Process 3: A Roundtrip Based EA Model Evolution

The process presented in [HL18] focuses on integrating information generated by projects. However, the projects can also be replaced by any other source of information. Essentially, two different roles are assigned to the process:

- **Enterprise Architect:** Enterprise architects are responsible for maintaining and keeping the EA model up to date.
- **Solution Architect:** The solution architects develop a solution for the project that evolves the EA and, thus, the EA model. Therefore, these changes have to be included in the central model.

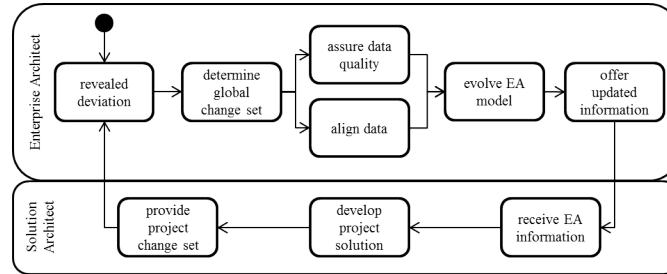


Fig. 3: An EA Model Evolution [HL18].

The process (see Figure 3) starts when enterprise architects identify changes in the EA and want to incorporate these changes into their core EA model. First, all changes that should be included in the next evolution of the EA model are captured. Subsequently, the data is quality-assured and aggregated to the necessary abstraction level of the EA model. Afterwards, the changes can be incorporated into the central EA model and the updated model distributed to the EA stakeholders.

For example, new projects receive this information and model the changes they make. These changes are then made available to enterprise architects and are the starting point for the next evolutionary step.

3.4 Preliminary Assumptions

Bringing the quality criteria and the processes together, we can formulate some assumptions how the processes are related to each other. First, we expect that process one and two are less comprehensible than process three as they include more process steps and roles. The plenty of process steps and roles in process one and two causes also our expectation that the third process gets the best rating for minimality.

As the third process includes no explicit negotiation between the different roles, we expect that the participants perceive this one as the most incomplete. Towards effectiveness and efficiency, we have no concrete expectations.

4 Results and Discussion

Following, we will present the results of our survey. As the participants could choose not to rate a certain criterion, we like to mention that only the comprehensibility was always rated. The efficiency of the processes was answered scarcest with a ratio of 93% (see Table 1).

Tab. 1: Descriptive Analysis of the Given Ratings.

	Comprehensibility			Effectiveness			Completeness			Minimality			Efficiency		
Answering Ratio	1.00			0.98			0.95			0.98			0.93		
Process	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
Median	4	4	4	3	4	3	4	4	3	3	3	4	3	3	3
Mean	3.65	3.84	3.80	3.33	3.44	3.34	3.68	3.49	3.33	2.94	3.32	3.58	3.16	3.24	3.35
SD	0.85	0.74	0.71	0.77	0.76	0.75	0.70	0.83	0.85	0.74	0.71	0.79	0.89	0.79	0.70

4.1 Dependencies Between Quality Criteria

To test if our questionnaire might contain criteria, which are coupled too close to each other, we calculated ρ_T according to [Ch16]. Commonly, $\rho_T > 0.7$ means that the conducted items are in an acceptable matter linked to each other. As we calculate a value of 0.697, we can assume that we measure different concepts in our questionnaire. However, the value is close to 0.7 and, therefore, we calculate for each pair of our criteria ρ_T . As a result, we recognize for effectiveness and efficiency a value of 0.76. All other values are lower than 0.6.

To test the expected dependencies between our criteria, we calculated the Pearson correlation [Pe95] for each pair of criteria. We assume that an absolute value greater than 0.66 means a strong correlation and an absolute value between 0.66 and 0.33 a weak correlation. First, we can confirm a correlation between completeness and effectiveness. However, the correlation is not as strong as expected with a value of 0.42. Second, we found also a correlation between efficiency and minimality (0.39). Third, we could not uncover a correlation between minimality and comprehensibility (0.27).

Apart from the expected correlations, we notice a strong correlation between effectiveness and efficiency (0.62) and weak correlations between comprehensibility and effectiveness (0.34) as well as between completeness and efficiency (0.34). We assume that the correlation between effectiveness and efficiency can be explained by the fact that people often struggle to differentiate between both terms. This could also explain the unexpected correlations between completeness and efficiency as we expected a correlation between completeness and effectiveness. The correlation between comprehensibility and effectiveness can also be explained by the confusion of efficiency and effectiveness and a transitive relation along minimality.

4.2 Process Comparison

We show the results of the descriptive analysis of all responses in Table 1. Every quality criterion contains three values per measurement where the first value represents the first process, the second value represents the second process, and the third value represents the third process.

Following, we will discuss the insights we gathered from the survey:

- **Comprehensibility:** The comprehensibility is very likely perceived among all process models very likely. However, the first process achieved a smaller mean as the other processes as well as the standard deviation (SD) is higher, indicating a bigger uncertainty. On the one hand, this is surprising as the second process contains more process steps and more decisions. On the other hand, process one comprises the biggest set of roles. Therefore, we conclude that the amount of roles is more important for the perceived comprehensibility of a process model than the number of elements and decisions within a process. Additionally, we expected the third process to be most comprehensible as it is the simplest model. But, this is not the case. Consequently, a too abstract description – resulting in fewer process steps – does not necessarily lead to a better comprehensibility.
- **Effectiveness:** The participants perceived the effectiveness of the processes similarly according to the mean and SD. Only process two seems to be a little bit more effective as the median is higher than for the other processes. This may stem from the fact that process two lasts of the most process steps and, therefore, the participants assume that it is most effective.
- **Completeness:** In accordance to our expectations, the third process got the lowest scores for completeness, because it is the simplest process and the participants are missing certain steps (e.g., “The process is missing certain information”, “There are no binding criteria for reporting deviations or need for action.”, or “Does the enterprise architect get all needed information”). Additionally, the participants are very discordant about the completeness as the SD is 0.85, which is the second highest score in general.
- **Minimality:** The minimality scores are as expected. In accordance to our observations at comprehensibility, we can recognize that the plenty of roles in process one have a bigger effect on the minimality than the plenty of process steps and decisions in process two. Furthermore, we can appreciate a higher influence of this fact. The participants also stress this as they state that “the plenty of roles lead to a communicative overhead” and the necessity to coordinate vetoes every time is questioned.
- **Efficiency:** All processes have in common that they are not perceived as very efficient. Again, process one gains a lower score and the participants are very uncertain. The communication between the different roles seems to be the main driver for this low score. This is in line with the feedback of the participants as they think that “reconciliation with so many parties may lead to efficiency losses” and that “there are too many communication channels”.

Apart from the feedback directly related to the quality criteria, we can differentiate two divergent groups related to the complexity of the processes. The first group advocates for a “lean” maintenance process and claim a reduction of process steps and roles in processes one and two. The second group demands not only more roles and steps in process three but also further reconciliations in process two.

A further point, which should be considered, concerns all processes: Several participants remark a neglect of business stakeholder in the processes (e.g., “The maintenance of EA artifacts must also be handled by the business side”). They should not be “demoted to be only the auditor”, but “actively involved into the [EA model] maintenance”.

To summarize, if the organization tends to be more “agile” or “lean” the third process would be the best guess. If the organization tends to be more “classical” with strict hierarchies and lots of different stakeholders the second process suits best. The first process was never able to outperform the other processes in a significant manner.

5 Related Work

To the best of our knowledge, there was so far no study conducted to compare different EA model maintenance processes to each other. Therefore, we rely for related work on the assessment of business process quality and the comparison of business processes.

Different works have been published aiming the assessment of business process’ quality. For instance, Heravizadeh et al. [HMR09] assess the dimensions of business process quality by focusing on the gap between as-is and to-be process modeling. Heinrich and Paech [HP10] facilitate the body of knowledge in software engineering and develop a set of criteria to assess business process’ quality. Lohrmann and Reichert [LR13] build on the aforementioned results, take a management perspective, and propose a framework for business process quality. Additionally, they demonstrate their means with an illustrative case.

Apart from the quality of the business process itself, there have been also research conducted on the quality of business process models. For example, van der Aalst [va98] introduce the soundness of workflow nets, Rinderle et al. [Ri05] elaborate on quality issues with respect to a case-based capturing of knowledge, and Ly et al. [Ly11] propose a means to ensure compliance of business processes to global rules and regulations.

Research on the comparison of concrete business processes appears seldom. Mostly, comparative research in the domain of business processes is related to business process modeling techniques. However, there is some research around. Dijkman et al. [Di11] propose three metrics to compare the similarity of processes. Kunze et al. [KWW11] suggest a further metric relying on the behavioral similarity of processes. In contrast, Venkatraman and Ramanujam [VR86] focus on a classification scheme, which permits the classification of an exhaustive coverage of measurement approaches and provides a framework to discuss merits and demerits of processes.

6 Conclusion & Threats to Validity

Within this work, we wanted to compare different EA model maintenance processes based on their quality. To answer this question, we identified a set of five quality criteria and asked EA researchers and practitioners to rate those for each process. Facilitating the outcome of this questionnaire, we cannot answer the question which process is qualitatively best in general. In point of fact, the answer is related to the setting the process should be deployed: Process three suits best in an “agile” environment while process two suits better in a “classical” environment.

Our work offers insights for future EA model maintenance designs: All processes lacked the integration of the business side. The participants stressed that it is necessary to involve the business stakeholder actively into the maintenance. This would result in a shift from a central maintained EA model to a local maintained model.

Last, our survey incorporates some limitations. First, the 80 answered questionnaires are not representative for the complete population of all EA experts. Additionally, there is a selection bias as we asked mainly EA experts from Europe in general and German speaking countries in special. However, we believe that our questionnaire gives a good insight into the perception of maintenance process’ quality. Second, we focused on a set of five quality criteria to keep the questionnaire lean. Obviously, there are other quality criteria, which could be assessed, too. Nonetheless, none of the participants remarked that an important criterion is missing.

Third, we neglected nearly one third of the questionnaires, because the questionnaires were either not answered seriously or we thought that the answers were filled randomly. This might be grounded in the fact that we distributed our questionnaire through several channels. Thus, a lot of people might want to have a look. This could also explain the relatively high standard deviations. Fourth, the participants seemed to be confused by the terms of efficiency and effectiveness. Hence, the results on these both criteria should be considered with caution.

References

- [AW09] Aier, Stephan; Winter, Robert: Virtual Decoupling for IT/Business Alignment – Conceptual Foundations, Architecture Design and Implementation Example. *Business & Information Systems Engineering*, 1(2):150–163, 2009.
- [BY06] Boh, Wai Fang; Yellin, Daniel: Using Enterprise Architecture Standards in Managing Information Technology. *Journal of Management Information Systems*, 23(3):163–207, 2006.
- [Ch16] Cho, Eunseong: Making Reliability Reliable. *Organizational Research Methods*, 19(4):651–682, 2016.

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- [Da08] Dawes, John: Do data characteristics change according to the number of scale points used? An experiment using 5-point, 7-point and 10-point scales. *International journal of market research*, 50(1):61–104, 2008.
 - [Di11] Dijkman, Remco; Dumas, Marlon; van Dongen, Boudewijn; Käärik, Reina; Mendling, Jan: Similarity of business process models: Metrics and evaluation. *Information Systems*, 36(2):498–516, 2011.
 - [Fa12] Farwick, Matthias; Schweda, Christian M.; Breu, Ruth; Voges, Karsten; Hanschke, Inge: On Enterprise Architecture Change Events. In (Aier, Stephan; Ekstedt, Mathias; Matthes, Florian; Proper, Erik; Sanz, Jorge L., eds): *Trends in Enterprise Architecture Research and Practice*. Springer, Berlin, Heidelberg, pp. 129–145, 2012.
 - [FAW07] Fischer, Ronny; Aier, Stephan; Winter, Robert: A Federated Approach to Enterprise Architecture Model Maintenance. In: EMISA. 2007.
 - [Ga87] Garvin, David: Competing on the eight dimensions of quality. *Harv. Bus. Rev.*, pp. 101–109, 1987.
 - [HL18] Hacks, Simon; Lichter, Horst: Towards an Enterprise Architecture Model Evolution. In (Czarnecki, Christian; Sultanow, Eldar; Brockmann, Carsten, eds): *Workshops der Informatik 2018. Lecture Notes in Informatics*, Gesellschaft für Informatik e.V, Bonn, 2018.
 - [HMR09] Heravizadeh, Mitra; Mendling, Jan; Rosemann, Michael: Dimensions of Business Processes Quality (QoBP). In (Ardagna, Danilo; Mecella, Massimo; Yang, Jian, eds): *Business Process Management Workshops*. Springer Berlin Heidelberg, Berlin, Heidelberg, pp. 80–91, 2009.
 - [HP10] Heinrich, Robert; Paech, Barbara: Defining the Quality of Business Processes. In: *Modellierung*. volume 161, pp. 133–148, 2010.
 - [III11] ISO; IEC; IEEE: , Systems and software engineering – Architecture description, 01.12.2011.
 - [Ko16] Kotusev, Svyatoslav: The History of Enterprise Architecture: An Evidence-Based Review. *Journal of Enterprise Architecture*, 12(1):31–37, 2016.
 - [KWW11] Kunze, Matthias; Weidlich, Matthias; Weske, Mathias: Behavioral Similarity – A Proper Metric. In (Rinderle-Ma, Stefanie; Toumani, Farouk; Wolf, Karsten, eds): *Business Process Management*. Springer Berlin Heidelberg, Berlin, Heidelberg, pp. 166–181, 2011.
 - [LBZ10] Luftman, Jerry N.; Ben-Zvi, Tal: Key Issues for IT Executives 2010: Judicious IT Investments Continue Post-Recession. *MIS Quarterly Executive*, 9, 2010.
 - [LL13] Ludewig, Jochen; Lichter, Horst: *Software Engineering: Grundlagen, Menschen, Prozesse, Techniken*. dpunkt. verlag, 2013.
 - [LR13] Lohrmann, Matthias; Reichert, Manfred: Understanding Business Process Quality. In (Glykas, Michael, ed.): *Business Process Management: Theory and Applications*, pp. 41–73. Springer Berlin Heidelberg, Berlin, Heidelberg, 2013.
 - [Lu05] Luftman, Jerry N.: Key Issues for IT Executives 2004. *MIS Quarterly Executive*, 7, 2005.

- [Ly11] Ly, Linh Thao; Knuplesch, David; Rinderle-Ma, Stefanie; Göser, Kevin; Pfeifer, Holger; Reichert, Manfred; Dadam, Peter: SeaFlows Toolset – Compliance Verification Made Easy for Process-Aware Information Systems. In (Soffer, Pnina; Proper, Erik, eds): *Information Systems Evolution*. Springer Berlin Heidelberg, Berlin, Heidelberg, pp. 76–91, 2011.
- [Mo09] Moser, Christoph; Junginger, Stefan; Brückmann, Matthias; Schöne, Klaus-Manfred: Some Process Patterns for Enterprise Architecture Management. In (Münch, Jürgen; Liggesmeyer, Peter, eds): *Software Engineering 2009 - Workshopband*. Gesellschaft für Informatik e.V., Bonn, pp. 19–30, 2009.
- [NP13] Niemi, Eetu; Pekkola, Samuli: Enterprise Architecture Quality Attributes: A Case Study. In: 2013 46th Hawaii International Conference on System Sciences. IEEE, pp. 3878–3887, 2013.
- [Pe95] Pearson, Karl: Notes on regression and inheritance in the case of two parents. *Proceedings of the Royal Society of London*, 58:240–242, 1895.
- [PI07] Plazaola, Leonel; Flores, Johnny; Silva, Enrique; Vargas, Norman; Ekstedt, Mathias: An approach to associate strategic business-IT alignment assessment to enterprise architecture. In: *Fifth Conference on Systems Engineering*. 2007.
- [Re02] Reips, Ulf-Dietrich: Standards for Internet-based experimenting. *Experimental psychology*, 49(4):243–256, 2002.
- [Ri05] Rinderle, Stefanie; Weber, Barbara; Reichert, Manfred; Wild, Werner: Integrating Process Learning and Process Evolution – A Semantics Based Approach. In (van der Aalst, Wil M. P.; Benatallah, Boualem; Casati, Fabio; Curbera, Francisco, eds): *Business Process Management*. Springer Berlin Heidelberg, Berlin, Heidelberg, pp. 252–267, 2005.
- [Ti17] Timm, Felix; Hacks, Simon; Thiede, Felix; Hintzpeter, Daniel: Towards a Quality Framework for Enterprise Architecture Models. In (Lichter, Horst; Anwar, Toni; Sunetnanta, Thanwadee, eds): *Proceedings of the 5th International Workshop on Quantitative Approaches to Software Quality (QuASoQ 2017) co-located with APSEC 2017*. CEUR-WS.org, pp. 10–17, 2017.
- [TW12] Thielsch, Meinold T.; Weltzin, Simone: Online-Umfragen und Online-Mitarbeiterbefragungen. *Praxis der Wirtschaftspsychologie II*, pp. 109–127, 2012.
- [va98] van der Aalst, Wil M. P.: The application of Petri nets to workflow management. *Journal of Circuits, Systems and Computers*, 08(01):21–66, 1998.
- [VR86] Venkatraman, N.; Ramanujam, Vasudevan: Measurement of Business Performance in Strategy Research: A Comparison of Approaches. *Academy of management Review*, 11(4):801–814, 1986.
- [VSM10] Vodanovich, Shahper; Sundaram, David; Myers, Michael: Research Commentary—Digital Natives and Ubiquitous Information Systems. *Information Systems Research*, 21(4):711–723, 2010.

The Generic InsurTech Ecosystem and its Strategic Implications for the Digital Transformation of the Insurance Industry

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Abstract: The emergence of insurance technology companies (InsurTechs) through the easy access of digital technologies is transforming the entire insurance industry and heralding a new era of business models. With digital technologies such as big data analytics, robo advisors, and mobile distribution models or blockchain, InsurTechs are challenging the prevailing position of traditional insurance institutions. However, the literature does not provide a structured overview of digital transformation (DT) in the insurance industry, including strategic implications and inter-organizational innovation patterns. By analyzing 956 InsurTechs, this paper visualizes the 34 generic roles and value streams within the insurance ecosystem using the e3-value method. Moreover, through semi-structured interviews with industry experts, we identify and discuss five strategic implications following seven inter-organizational innovation patterns of DT in the insurance industry. We contribute to the literature by examining DT in the insurance industry from an inter-organizational perspective. Practitioners may apply the model to position themselves in a digital insurance ecosystem and to identify disruptive actors or potential business opportunities.

Keywords: Ecosystem, Insurance Industry, InsurTech, Digital Transformation, Innovation Pattern, e3-value model

1 Motivation

Disruptive technologies are the engine of digital transformation (DT). They transform industries, society, and governments by introducing the digital lifestyle and eliminating well-established business models [Bh13, Ri19]. Recent developments and adaptations, such as mobile payments, robo advisors, peer-to-peer, and blockchain [Os18], are some of the most promising drivers in the insurance industry.

The combination of new and innovative technologies and the development of new digital platforms fundamentally change the value creation of existing companies and how business is executed [LG09, Ti15]. The transformative impact on pre-digital products, especially in the insurance industry, has remained unnoticed in the information systems

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(IS) literature for years [YHL10]. However, companies are forced to overthink and redefine their business models to stay competitive against recently founded startups that are more agile given their IT-enabled digital business models [Lu13, Ve94]. In this context, the term InsurTech is often used for startup companies that deliver innovative or disruptive solutions to the market [Pu17, BC95]. Established insurance companies and insurance brokers are forced to compete with a rising number of new market entrants that provide customer-centric solutions for their customers and substantially engage in the current ecosystem [MHB15]. The industry is facing new trends, such as pay on demand insurance, data science for preventive health care, and insurance compare platforms, and new market entrants in this changing environment are shaping DT in the industry [Lu13, Ri19].

However, the existing literature does not provide an inter-organizational and strategic overview of the current and ongoing industry transformation, particularly through InsurTechs [Pu17]. Further, strategic implications for the industry through InsurTechs are particularly missing [Pu17]. Therefore, this paper aims to answer the following overall research question: What is the generic ecosystem of the DT in the insurance industry and which strategic implications can be observed?

We follow the research approach of Riasanow et al. [Ri18a] to identify 34 generic roles derived from analyzing 956 companies. We extracted company data from the Crunchbase database and used the e3-value method to develop a generic ecosystem of the DT in the insurance industry, including InsurTechs based on these 34 roles. Following Riasanow [Ri18a], we discuss five strategic implications following seven inter-organizational innovation patterns of the DT in the insurance industry, such as the aggregation of intermediaries.

The paper is organized as follows. First, based on the literature on DT, we analyze the related background on the DT in the insurance industry through InsurTechs. Second, we describe our methodology. Third, the 34 generic roles and the generic ecosystem are presented. Further, we provide a framework for five strategic implications following seven innovation patterns of DT in the insurance industry. Next, we discuss the results, implications, and future research. The final section presents the conclusion.

2 Digital Transformation in the Insurance Industry and the Role of InsurTechs

DT is currently one of those topics that practitioners and researchers can hardly avoid when talking about IS or developing business strategies. DT is an industry level phenomenon (see, for example, da Silva Freitas et al. [Si16], Downes and Nunes [DN13]) that changes the way organizations compete within and across industries. Therefore, DT “affect large parts of companies and even go beyond their borders, by impacting products, business processes, sales channels, and supply chains” [MHB15].

Following Horlacher et al. [Ho16], inherent to DT is the development of technology-enabled business models that are new to the organization that has initiated the transformation. This development is particularly relevant for the insurance industry as a number of emerging technology-enabled players penetrate the market [Pu17]. These organizations, the so-called InsurTechs, use innovative digital technology to create novel insurance services or products that either improve existing processes or create new business models, such as robo advisors [ZDS16]. According to Zeier et al. [Ze18], the central advantages of InsurTechs are cost efficiency, flexibility, speed, and scalability. Changes in the role of IT, customer behavior, ecosystems, and regulations are the main drivers for the success of InsurTechs [Pu17, ZDS16]. Moreover, DT means changing the manner in which value is delivered to customers, which is also observable in the insurance industry. Hence, InsurTechs revolutionize the insurance industry in several ways. They may improve established processes, products, or services, create competition through innovative products or services, or eventually disrupt established business models [Pu17, ZDS16]. To be successful, the evolution of a company's business model needs to be complemented by a co-evolution on the customer side [Ri19]. In particular, Haffke et al. [HKB16] emphasized the effects on "sales and communication channels, which provide novel ways to interact and engage with customers" and a "firm's offerings (products and services)" that replace or augment physical offerings. Recognizing this interdependence, researchers have analyzed DT through an intra-organizational perspective (see, for example, Bley et al. [BLS16]; Haffke et al. [HKB16]; Matt et al. [MHB15]; Piccinini et al.). However, research is missing the strategic implications for the industry and a detailed inter-organizational, macroeconomic analysis of the current and ongoing DT in the insurance industry [Pu17] given existing studies' sole focus on organizations' business models. Thus, we analyze the DT in the insurance industry from the perspective of its ecosystem.

3 Research Approach

We conducted a five-step research approach based on Riasanow et al. [Ri18a]. To develop the insurance industry's generic ecosystem, we first decided to use data from Crunchbase, a comprehensive database of existing companies and startups, to derive the roles in the ecosystem [Ma15]. To collect all organizations of the insurance industry and the related technologies, we filtered the Crunchbase category list by the search terms "InsurTechs" and "FinTechs and Insurance," resulting in a sample size of 1,424 worldwide funded companies. Screening the data, we found companies with no relationship to the insurance industry. Hence, we shortened the data set by a further 454 companies. Second, we presented the generic ecosystem based on the previously identified 34 roles and value streams. Third, we validated the model through seven semi-structured expert interviews. Subsequently, we identified strategic implications and followed and modified the discovered innovation pattern of Riasanow et al. [Ri18a] of the DT in the financial industry using qualitative content analysis.

4 Generic Ecosystem of the Insurance Industry including InsurTechs

Given the emergence of innovative digital technologies, the insurance industry is transforming, particularly as a result of new market entrants such as InsurTechs.

We first derive the roles of the actors in the ecosystem by drawing on data from 956 companies derived from the Crunchbase database. Actors, which offer similar services and products to the customer, are abstracted to one role based on a structured content analysis following Mayring [Ma10]. Because our roles are on a more abstract level than business models, one role can refer to different types of business models. Further, one company can act in different roles by offering different services to other players. In Table 1, we present the generic roles of the traditional actors in the insurance industry.

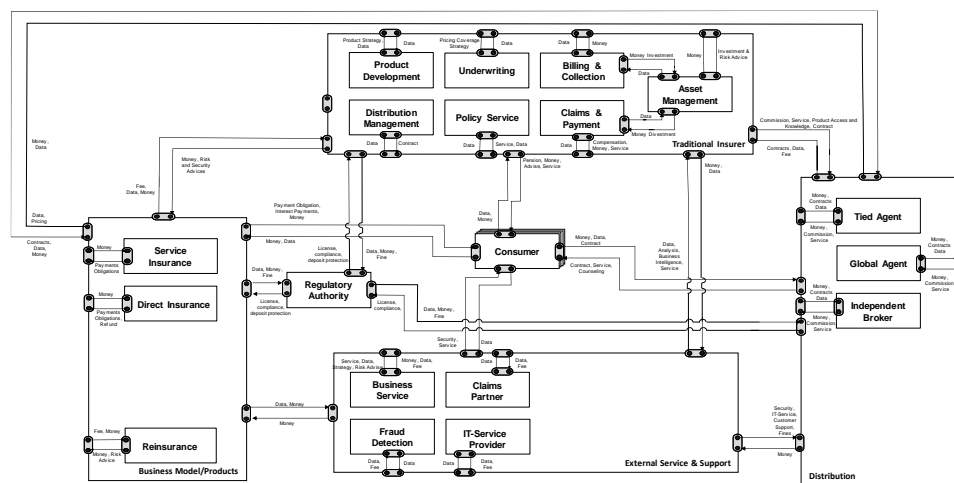
Role	Description	Example(s)
Consumer	Consumers request, among other applications, insurance services for business or private use. In some cases, the consumer is a prosumer by simultaneously using and creating a service.	Private, business client
Product Development	Develops and modifies products for new or changing customer needs and aims to create new products for an optimal customer journey with short development cycles [Go15].	Allianz, AIG, AXA
Underwriting	A primary insurer's or reinsurer's process to check applications, assess risks, and finalize them. Underwriting assumes real significance for businesses with industrial or general risks and for reinsurance [Go15, Fa06].	Allianz, AIG, AXA
Distribution Management	Translates an insurance company's strategic goals into sales targets that can be implemented operationally [Go15].	Allianz, AIG, AXA
Policy Service	The basic function of insurance administration that only indirectly serves the actual purpose of the operation and ensures that operations run smoothly by looking after client-related requests and issues [Go15].	Allianz, AIG, AXA
Billing & Collection	Because insurance companies handle large money streams, a large aspect of administration is billing and collecting insurance premiums [Go15, Fa06].	Allianz, AIG, AXA
Claims & Payment	Administration, assessment, and settlement of insurance claims and life insurance refunds are handled by a specified division in every insurance line [Go15, Fa06].	Allianz, AIG, AXA
Asset	Assesses and predicts future cash flows and adjusts	Allianz Global

Management	investment strategy accordingly to provide enough cash flow for claims payments and life insurance refunds [Go15, RM08].	Investor, AIG-Global Capital, AXA Assets
Global Agent	Coordinates the distribution of multinational clients and provides them with needed insurance coverage. In the respective markets, these agents have exclusive partnerships with insurance companies, which may differ between the insurance lines and countries [Go15].	Aeon, Willis Tower Watson
Independent Broker	Anyone who commercially handles the brokerage or conclusion of insurance contracts for the principal without being entrusted by an insurer or insurance agent.	FondsFinanz, Euroassekuranz
Fraud Detection	Aims to protect customer and enterprise information, assets, accounts, and transactions by analyzing activities. Fraud detection is not intrusive to a user unless the user's activity is suspect [Gr12, Ph10].	Trulioo, Fraugster
Business Service	Services handled by an external service provider in all aspects of the insurance industry, including Consulting, Human Resource Management, and Debt Collection services.	Aeon, Price Waterhouse Cooper, InkassoDirect
Claims Partner	Policyholders and insurers turn to claims partners as professionals with claims-relevant expertise and onsite capacity to handle claims. Claims partners support the parties in the event of a claim, especially during the claims settlement process [Go15].	Cognotekt, MotionsCloud, McLaren
IT-Service Provider	Related to the use of information technology and supports the insurance industry partner's business processes and digital identity management [Pu17].	Capgemini, Yoti, AimBrain, OneVisage
Service Insurance	Uses personal contacts with customers and a wide branch agent and broker network.	Allianz, AXA, Zurich
Direct Insurance	Offers comparison and purchase possibilities without meeting with agents or brokers. The customer receives advice only via Internet chat, e-mail, or a telephone hotline.	DirectCar, HUK 24, AllSecur
Reinsurance	Insurance for insurance corporations that transfers part of the risks assumed by a direct insurer to policyholders under insurance contracts or via statutory provisions, or transfers risk to a second insurer—the reinsurer—that is not directly related to the customer [Go15].	Munich RE, Swiss RE
Regulatory	Supervises the solvency of insurers and other	SEC, EIOPA,

Authority	financial service providers. Its market supervision facilitates fair and transparent market conditions and protects consumers.	BaFin
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Table 1: Generic roles in the traditional insurance industry

Second, in Figure 1, we propose a generic ecosystem of the traditional insurance industry. Drawing on the e3-value method, the ecosystem depicts the identified roles and the value streams among them.

**Figure 1:** Generic ecosystem of the traditional insurance industry

Third, in Table 2, we show the generic roles of the emerging actors that are exclusively based on InsurTechs. Further, following the generic ecosystem for cloud computing, we included the four roles of cloud infrastructure provider, cloud platform provider, cloud application provider, and cloud market platform, as extracted from Böhm et al [Bö10].

Role	Description	Example(s)
Comparison Platform	Comparison platforms enable customers to form adequate decisions regarding different products and providers.	getinsured, impacthealth, comfortplan.de
Digital Broker/Robo Adviser	Digital brokers are intermediaries that offer insurance brokerage services by incorporating digital technologies, such as artificial intelligence, web-based platforms, and mobile applications.	Knip, Clark
Cross-Seller	Cross-sellers target the potential of insurance in a digital environment by focusing on e-commerce solutions for online shops that combine the traditional	Simplesurance, Check24

	insurance business with new digital online shopping through a one-click solution.	
Big Data Analytics/Predictives	Big data analytics and predictives provide services and solutions for risk takers to manage data and take advantage of large data collections for extensive analytics, such as analyses of target customers, calculations of quotes, decreases in claims-related expenses, fraud detection, frequent risk assessments, and stress-test simulations.	Laptetus, Fraugster, Cognotect
Smart Contract/Blockchain	Blockchain technology is a secure technology incorporated by InsurTechs to automate processes in claims regulation, payment management, and data and platform handling.	Black, safeshare
Instant Insurance	Instant insurance is a product for a selected period, in contrast to conventional insurance products that provide coverage at any time.	Trōv
Peer-to-Peer Insurance	Peer-to-peer insurance supplies competitively priced insurance products financed by eliminating moral hazard and profit margins through reinsurance contracts.	Friendsurance, Lemonade
E-Payment Provider	The term “e-payment” generally encompasses various functionalities that are handled via mobile phones [Ma07]. Provision of payments includes the use of mobile devices, such as smartphones.	PayPal, ApplePay, AliPay

Table 2: Generic roles of InsurTechs

Third, we used the e3-value method to develop a generic ecosystem of DT in the insurance industry, including InsurTechs. This method extends the ecosystem of InsurTechs in Figure 1 that we determined by drawing on the identified generic roles for InsurTechs; see Figure 2.

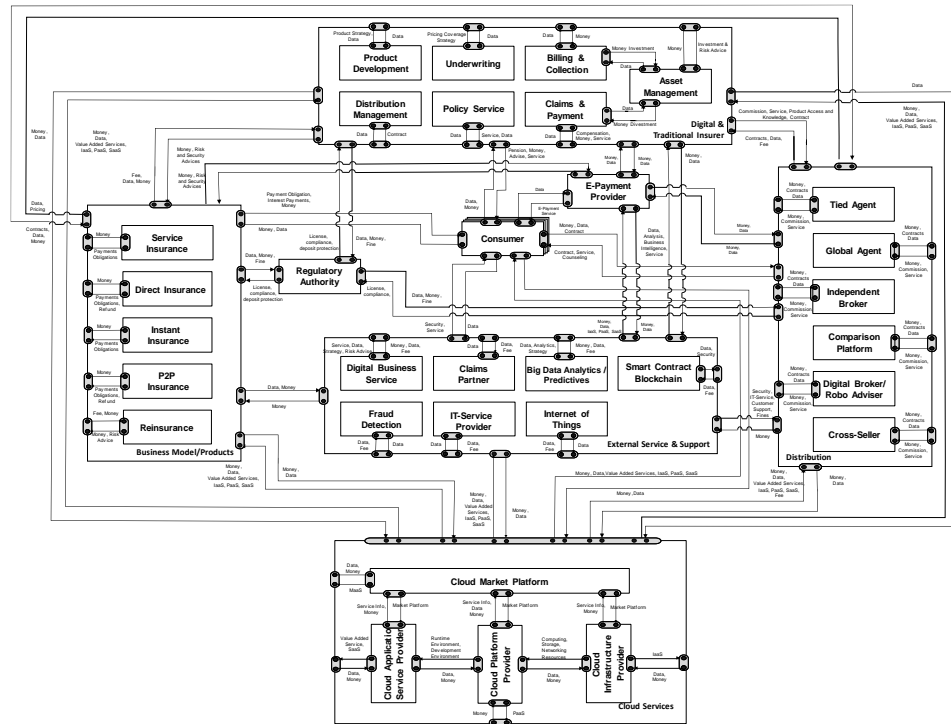


Figure 2: Generic ecosystem of the insurance industry including InsurTechs

5 Strategic Implications and Innovation Patterns in Insurance Industry

Based on the analysis of the DT in the generic ecosystem, such as comparing Figure 1 with Figure 2 and the interviews with seven industry experts, we extend and modify the research of Riasanow et al. [Ri18a] through strategic implications and inter-organizational innovation patterns.

Strategic Implication	Innovation Pattern
Customer centricity	Aggregation of Intermediaries
Create coverage for customer ecosystem	Enhanced Transparency
	Service Aggregation
Restructuring the organization to enable DT	Prosumption

	Cloud-based Services
Leverage in-house collaboration	
Integrate partners with complementary services in the ecosystem	Service Integration
	Parallel Universe

Table 3: Strategic implications and innovation patterns

The first strategic implication is to provide *customer centricity*, which is independent of location and time, and is a key enabler of DT [HKB16, LV16]. Given accelerating media and channel fragmentation and evolving new customer expectations, omni-channel management has become more complicated for the insurer. Moreover, customer-to-customer interactions through simultaneously using and creating a service are creating significant challenges and opportunities for the insurer. Customer experiences are more social in nature, and peer customers also influence experiences. Overall, insurers also have much less control over the customer experience and the customer journey [LV16]. In reaction, insurers need to develop a new base of “digital only” clients and launch and support a new direct-to-customer channel, which is also shown in the *aggregation of intermediaries* by InsurTechs’ roles as comparison platforms or robo advisers. They provide appropriate expertise such as personalized and digital app-based interactions with the customer by also integrating new customer services, such as robo advisors or smart contract interactions.

Creating coverage for customer ecosystems is the second strategic implication and is also related to transparency. *Enhancing transparency* refers primarily to the generic roles in the areas of distribution, coverage reliability, and product design, and is the second innovation pattern in the industry. There, the generic roles in distribution channels, fraud detection, asset management, and product development are intended to generate transparency in claims management, fund management, and the overall understanding of insurance products. This development provides a more customer-focused systems view in the industry, in contrast to the traditional focus on insurance services that only included a single insurance provider and a customer. We define the digital ecosystem as a conglomerate of all interactions that an insurer has with its customers within all of the ranges of products and services that the insurer provides to them. The need to identify customers’ hidden interest in insurance coverage without an insurance stimulus on the customer side is critical for the insurer in this context. Therefore, *service aggregation* is the third innovation pattern in the insurance industry. There, the service provider aggregates a plethora of services and makes them accessible through a single solution, such as in the dimensions of customer-ecosystems in Smart Home, Connected Health, Life, and Mobility. These dimensions also introduce our fourth innovation pattern *prosumption*, enabled through cloud-based services [Bö10] and the integration of advanced big data analytics in which the customer simultaneously uses and creates a service (e.g., such as when a user shares personal data with Google Maps when navigating with the aggregated real-time traffic information of other users) [RGB17, Ri18a].

This innovation pattern needs to be integrated within the organizational processes and

structure that set the third strategic implications of *restructuring the organization to enable DT*. Because of the mentioned change in customer demands, new competitors such as InsurTechs, and increasing pressure from digitalization, insurers need to reorganize and close the “digital gap.” Providing a flexible and comprehensive IT infrastructure enables new ways to enhance efficiency. Handling business tasks without human interaction is critical in the insurance industry to increase efficiency and profitability. The field of application ranges from manually setting up workarounds to complex software on a virtual machine. Providing IT services in an appropriate environment of *cloud-based services* is the fifth innovation pattern [Bö10]. These services are built on a modular cloud infrastructure that enables quick scalability and, therefore, eliminates the boundaries of traditional insurance administration, products, or services that are bound to the capacities of the insurance institution. Here, the scalability is bound to the computing power of the cloud infrastructure provider [YBS08]. In an environment of constantly increasing demands coupled with enormous cost pressure, cloud-based services, big data analytics, and process automation can deliver high-quality work results on a flexible schedule and offer new business opportunities, thus strengthening the position in the ecosystem.

Fourth, insurers should *leverage in-house collaboration* and human resources. Most insurers are functionally and regionally organized with standardized processes. For a company in a changing and agile market environment and given new digital technologies, company employees must be able to position themselves differently and adopt a stronger entrepreneurial focus. New types of collaboration empowered through cloud-based services and the use of new forms of organization and working methods encounter different cultures, visions, goals, and strategies. In particular, cross-company collaboration and design are needed, as are cultivating an entrepreneurial attitude and promoting it among all managers and employees. This collaboration and design also include modern ways of working and other ways to consciously take risks and establish the associated culture of error, which also contributes to positive cultural development. Within the organization, specific individuals can be engaged with this role to evaluate action-oriented future opportunities and, as a consultant in a structured approach, make these opportunities transparent and conduct business development. Insurance companies should establish Smart Circles across functionalities, regions, and silos to support a culture of continuous collaboration between different roles such as underwriting, product development, asset management, claims, and distribution. The purpose of these circles is to develop a joint understanding of current business performance and to identify areas of opportunity and action that are both aligned and understood by all different roles.

The insurance industry belongs to the network economy and is shaped by complementary network effects. Thus, the industry behaves like a massively interconnected network of organizations, technologies, consumers, and products. Hence, our final strategic implication is to *integrate partners with complementary services in the ecosystem*. The insurance industry and its value proposition for customers was the result of independent developments of standardized products driven by a regulatory background. The execution focus was on developing customer insights, building core competencies, and beating the competition in price and efficiency. Thus, companies devoted less attention to external

companies that were neither competitors nor customers. However, in the insurance industry, this centralized and vertical perspective has changed significantly. The management of dependencies on a multitude of external complementary companies is relevant to success in strengthening the position in the ecosystem. For the right position in the ecosystem, suitable partners are an important factor [Ri18a, Ba04], such that an insurer and its partners create value for the customer through additional services, which is the seventh innovation pattern of *service integration*. Therefore, the success of an insurance company depends not only on its own quality but also on its ability to manage a landscape of multiple partners to meet the customer's desire for a comprehensive product and service offer. Furthermore, the integration of partnerships for data generation and analysis is critical for business success. Additionally, the emergence and creation of a *parallel universe*—the sixth innovation pattern—is particular to the case for blockchain technology [Ri18b] and peer-to-peer insurance. The case of Trov shows that insurance products or services can be substituted by connecting customers to new platform setups and incentives.

6 Discussion

Based on this work, five theoretical contributions arise. First, based on our analysis of 956 companies, we contribute to the literature on InsurTechs given that existing studies solely focus on the business model of InsurTechs or the transformation of the business model of established financial institutions [Pu17]. Second, by developing the generic, inter-organizational e3-value model of the insurance industry, including InsurTechs, we provide a macroeconomic overview of the current and ongoing transformation of the insurance industry. We identified 34 generic roles for traditional and emerging players in the insurance industry. Third, this study shows that DT is more than an intra-organizational phenomenon because it affects the entire ecosystem. Thus, we extend Fitzgerald et al. [Fi13], who understands DT primarily as an intra-organizational phenomenon. Fourth, based on the comparison of the traditional actors and the emerging InsurTechs and industry insights derived from interviews, we identified five strategic implications following seven inter-organizational innovation patterns. In particular, these patterns that drive the DT in the insurance industry through InsurTechs were missing [Pu17]. Fifth, we confirm the generic cloud computing ecosystem of Böhm et al. [Bö10] by showing that most of the innovation in the insurance industry is driven by cloud-based services.

Six practical contributions arise. First, decision makers, such as from traditional insurance institutions, can apply the model to identify potential threats to their current market positions, potential opportunities to adapt to trends, or shifts in customer needs. Second, we show that the different layers of innovation patterns influence and drive strategic implications for the DT of insurance companies. Third, we prove that the innovation pattern of the financial industry discovered by Riasanow et al. [Ri18a] is also valid in the insurance industry, such as the recombination of insurance services in the service integrator role or the intelligent combination of existing services to generate a new service in the service aggregator role. As is typical for DT, the roles show that the way that value

is delivered to the customer is changing [Pi15]. Fourth, the inter-organizational innovation patterns differ in magnitude and effect. The innovation prosumption pattern shows that this is also true for the insurance industry because consumers are co-creating value with insurance service providers. Fifth, blockchain as a disruptive technology may be understood as the most promising digital technology for traditional insurance institutions. In all categories of insurance products and services and payment, asset management, and financing, we found insurance-related or process-optimizing InsurTechs using blockchain technology. Sixth, from an ecosystem perspective, InsurTechs do not possess a significant market share, and a crowding out effect or disruption is not visible. However, a number of traditional insurance institutions and regulatory authorities are increasingly experimenting with new and innovative technology. Seventh, we see that new business models as peer-to-peer insurance do not necessarily represent a parallel universe in this context. Nevertheless, many products and services are under strict regulations from governmental authorities. Therefore, the extent of the impact of new technologies, such as blockchain or new business models, on traditional insurance institutions is unknown.

7 Limitations and Future Research

Our study is subject to limitations. First, the model is limited by the information provided by the Crunchbase database and our coding of the generic roles. Second, drawing on the value streams between the roles, we relied on publicly available information, such as company websites, reports, press articles, and annual reports. However, we established intercoder reliability among two independent coders with an alpha of 0.87. Third, we conducted seven semi-structured interviews with experts from the insurance industry or InsurTech founders to validate the proposed generic ecosystem and the presented strategic implications and innovation patterns [Ri18a]. Following Puschmann [Pu17], we suggest that future research detect intra-organizational, microeconomic innovation patterns. Second, we are curious to further investigate the developed strategic implications. Third, many InsurTechs offer their services on digital platforms [ZDS16]; however, we invite scholars to investigate the success factors for the digital platforms in the DT process of the industry that remain uncovered.

8 Conclusion

This paper presents the generic ecosystem for the insurance industry based on 34 generic roles of traditional financial institutions and InsurTechs identified by a structured content analysis of the Crunchbase data of 956 financial organizations. DT creates new roles for value creation in the insurance industry and, thus, affects the entire ecosystem. The ecosystem shows that robo advisors, big data, or short-term insurance providers penetrate the market and, thus, threaten the value creation of traditional insurance institutions. To discuss this phenomenon, we developed five strategic implications following seven inter-organizational patterns of the DT [Ri18a] in the insurance industry, such as the

development of a customer-centric voice through the aggregation of intermediaries or the integration of new services in the creation of customer ecosystems. Our work contributes to the literature on InsurTech and to the growing body of knowledge on DT. We encourage traditional insurance institutions to actively experiment with innovative technologies or to collaborate with emerging new players in the market.

References

- [Ba04] Barua, A., Konana, P., Whinston, A.B., Yin, F.: An Empirical Investigation of Net-Enabled Business Value. *MIS Quarterly* 28/4, pp. 585-620, 2004.
- [BC95] Bower, J.L., Christensen, C.M.: Disruptive technologies: Catching the Wave. *Harvard Business Review* 73/1, pp. 43-53, 1995.
- [Bh13] Bharadwaj, A., El Sawy, O.A., Pavlou, P.A., Venkatraman, N.V.: Digital Business Strategy: Toward a Next Generation of Insights. *MIS Quarterly* 37/2, pp. 471-482, 2013.
- [BLS16] Bley, K., Leyh, C., Schäffer, T.: Digitization of German Enterprises in the Production Sector - Do they know how "digitized" they are? In: 22nd Americas Conference on Information Systems (AMCIS), San Diego, 2016.
- [Bö10] Böhm, M., Koleva, G., Leimeister, S., Riedl, C., Krcmar, H.: Towards a Generic Value Network for Cloud Computing. In: International Workshop on Grid Economics and Business Models, Ischia, 2010.
- [DN13] Downes, L., Nunes, P.: Big-bang Disruption. *Harvard Business Review* 91/3, pp. 44-56, 2013.
- [Fa06] Farny, D.: *Versicherungsbetriebslehre*. Verlag Versicherungswirtschaft, Karlsruhe, 2006.
- [Fi13] Fitzgerald, M., Kruschwitz, N., Bonnet, D., Welch, M.: Embracing Digital Technology: A New Strategic Imperative. *Sloan Management Review* 55/2, pp. 1-13, 2013.
- [Go15] Gondring, H.: *Versicherungswirtschaft: Handbuch für Studium und Praxis*. Franz Vahlen, München 2015.
- [Gr12] Griffin, R.: Using Big Data to Combat Enterprise Fraud. *Financial Executive International* 28/10, pp. 44-47, 2012.
- [HKB16] Haffke, I., Kalgovas, B., Benlian, A.: The Role of the CIO and CDO in an Organization's Digital Transformation. In: 37th International Conference on Information Systems (ICIS), Dublin, 2016.
- [Ho16] Horlacher, A.: Co-Creating Value - The dyadic CDO-CIO Relationship during the Digital Transformation. In: 24th Americas Conference on Information Systems (AMCIS), San Diego, 2016.
- [LG09] Lucas, H.C., Goh, J.M.: Disruptive Technology: How Kodak Missed the Digital Photography Revolution. *Journal of Strategic Information Systems* 18/1, pp. 46-55, 2009.
- [Lu13] Lucas, H.C., Agarwal, R., Clemons, E.K., El Sawy, O.A., Weber, B.W.: Impactful Research on Transformational Information Technology: An Opportunity to Inform New Audiences. *MIS Quarterly* 37/2, pp. 371-382, 2013.
- [LV16] Lemon, K.N., Verhoef, P.C.: Understanding Customer Experience throughout the Customer Journey. *Journal of Marketing* 80/9, pp. 69-96, 2016.
- [Ma07] Mallat, N.: Exploring Consumer Adoption of Mobile Payments - A qualitative Study. *Journal of Strategic Information Systems* 16/4, pp. 413-432, 2007.
- [Ma10] Mayring, P.: *Qualitative Inhaltsanalyse*. VS Verlag für Sozialwissenschaften,

- Wiesbaden, 2010.
- [Ma15] Marra, A., Antonelli, P., Dell’Anna, L., Pozzi, C.: A Network Analysis using Metadata to Investigate Innovation in Clean-tech—Implications for Energy Policy. *Energy Policy* 86, pp. 17-26, 2015.
 - [MHB15] Matt, C., Hess, T., Benlian, A.: Digital Transformation Strategies. *Business & Information Systems Engineering* 57/5, pp. 339-343, 2015.
 - [Os18] Oswald, G.; Soto Setzke, D.; Riasanow, T.; Krcmar, H.: Technologietrends in der digitalen Transformation. In (Oswald, G.; Krcmar, H., eds.) *Digitale Transformation*. Springer Fachmedien, Wiesbaden, pp. 11-34, 2018.
 - [Ph10] Phua, C., Lee, V., Smith, K., Gayer, R.: A Comprehensive Survey of Data Mining-based Fraud Detection Research. In: *Intelligent Computation Technology and Automation (ICICTA)*, Changsha, 2010.
 - [Pi15] Piccinini, E., Hanelt, A., Gregory, R., Kolbe, L.: Transforming Industrial Business: The Impact of Digital Transformation on Automotive Organizations. In: *36th International Conference on Information Systems (ICIS)*, Fort Worth, 2015.
 - [Pu17] Puschmann, T.: Fintech. *Business Information Systems Engineering (BISE)* 59/1, pp. 69-76, 2017.
 - [RGB17] Riasanow, T., Galic, G., Böhm, M.: Digital Transformation in the Automotive Industry: Towards a Generic Value Network. In: *25th European Conference on Information Systems (ECIS)*, Portsmouth, 2017.
 - [Ri18a] Riasanow, T., Flötgen, R.J., Soto Setzke, D., Böhm, M., Krcmar, H.: The Generic Ecosystem and Innovation Patterns of the Digital Transformation in the Financial Industry. In: *22nd Pacific Asian Conference on Information Systems (PACIS)*, Yokohama, 2018.
 - [Ri18b] Riasanow, T., Burckhardt, F., Soto Setzke, D., Böhm, M., Krcmar, H.: The Generic Blockchain Ecosystem and its Strategic Implications. In: *24th Americas Conference on Information Systems (AMCIS)*, New Orleans, 2018.
 - [Ri19] Riasanow, T., Soto Setzke, D., Böhm, M., Krcmar, H.: Clarifying the Notion of Digital Transformation: A Transdisciplinary Review of Literature. *Journal of Competences, Strategy and Management* 10, pp. 5-36, 2019.
 - [RM08] Romeike, F., Müller-Reichert, M.: *Risikomanagement in Versicherungsunternehmen*. Wiley, 2008.
 - [Si16] da Silva Freitas, J.C., Macada, A.C.G., Brinkhues, R.A., Zimmermann Montesdioca, G.: Digital Capabilities as Driver to Digital Business Performance. In: *22 Americas Conference on Information Systems (AMCIS)*, San Diego, 2016.
 - [Ti15] Tiwana, A.: Evolutionary Competition in Platform Ecosystems. *Information Systems Research* 26/2, pp. 266-281, 2015.
 - [Ve94] Venkatraman, N.: IT-Enabled Business Transformation: From Automation to Business Scope Redefinition. *Sloan Management Review* 35/2, pp. 73-87, 1994.
 - [YBS08] Youseff, L., Butrico, M., Da Silva, D.: Toward a Unified Ontology of Cloud Computing. In: *2008 Grid Computing Environments Workshop*, Austin, 2008.
 - [YHL10] Yoo, Y., Henfridsson, O., Lyytinen, K.: The New Organizing Logic of Digital Innovation: An Agenda for Information Systems Research. *Information Systems Research* 21/4, pp. 724-735, 2010.
 - [ZDS16] Zavolokina, L., Dolata, M., Schwabe, G.: FinTech – What’s in a Name? In: *37th International Conference on Information Systems (ICIS)*, Dublin, 2016.
 - [Ze18] Zeier Röschmann, A.: Digital insurance brokers—old wine in new bottles? How digital brokers create value. *Zeitschrift für die gesamte Versicherungswissenschaft* 107, pp. 273-291, 2018.

Towards an Internet of Production

A Model-Assisted and Data-Driven Ecosystem Based on Digital Shadows

Matthias Jarke¹

Abstract: Data-driven machine learning methods are typically most successful when they can rely on very large and in some sense homogeneous training sets in areas where little prior scientific knowledge exists. Production engineering, management, and usage satisfy few of these criteria and therefore do not show very many success stories, beyond narrowly defined specific issues in specific contexts. While, in contrast, the last years have seen impressive successes in model-driven materials and production engineering methods, these methods lack context and real-time adaptivity. Our vision of an Internet of Production, pursued in an interdisciplinary DFG Excellence Cluster at RWTH Aachen University, addresses these shortcomings: Through sophisticated heterogeneous data integration and controlled data sharing approaches, it broadens the experience base of cross-organizational product and process data. At the method level, it interleaves fast “reduced models” from different engineering fields, with enhanced explainable machine learning techniques and model-driven re-engineering during operations. As a common conceptual modeling abstraction, we investigate Digital Shadows, a strongly empowered variant of the well-known view concept from data management. Several initial experiments indicate the power of this approach but also highlight many further research challenges.

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Knowledge Graph Processing Made (more) Simple

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Abstract: Knowledge graphs based on RDF and SPARQL are gaining popularity for integrated semantic representation of structured and unstructured data. As knowledge graphs in practical applications tend to become huge, distributed processing using Apache Spark SQL and Hadoop on top of a compute cluster is attractive. For the corresponding relational representation of a knowledge graph a simple relational design using only one single table is proposed. As a consequence no time consuming relational design considerations are required and newly discovered RDF data can be integrated with nearly no extra additional relational design effort.

Keywords: Knowledge Graph, RDF, SPARQL, Apache Spark SQL, Parquet, Hadoop

1 Introduction

Knowledge graphs [DG14, IBM] are gaining popularity for integrated semantic representation of structured and unstructured data. For example, a knowledge graph may result from enriching local structured corporate data by various unstructured data from the Linked Open Data Cloud. The Resource Description Framework (RDF) and its associated processing language SPARQL are widely used in this context. As knowledge graphs in practical applications tend to become huge, processing becomes challenging which has triggered the development of a large number of different approaches [WH18].

In this extended abstract we elaborate on SQL-based SPARQL processing using Apache Spark SQL and Hadoop as distributed processing platform. While our earlier work using Hadoop as platform suffered from the inflexibility of the rigid implementation of the MapReduce paradigm [SP13], Spark SQL allows mapping SPARQL queries into SQL directly and processing them akin to a distributed main-memory database system [SP16,CF18]. Based on the obtained experiences we now give arguments supporting the claim that a mostly simple underlying relational design using only one single wide table is competitive to other designs typically based on several tables. This approach allows efficient query processing and does not require additional relational design considerations. Moreover it is able to account to any kind of newly discovered RDF data with nearly no extra design effort [AK19].

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2 Single Wide Property Table Approach

Using RDF, a knowledge graph is represented by a set R of (s, p, o) -triples, where s denotes a subject, p a property (predicate) and o an object. In the literature various approaches have been discussed for representation of such sets [WH18]: a single triple table, a set of tables resulting from partitioning the triples by properties, a single wide table covering all properties, and a set of tables akin to tables defined by an emergent schema, are the considered designs. For the wide property table approach WPT, each subject s identifies a single row in the table and each property p is assigned to a column. Objects o are the values inside the table, where each such value may be either a constant or an IRI identifying the subject s' being in a relationship with s as stated by property p . The resulting WPT table in general is very sparse and in addition must be able to handle properties which assign multiple values to the respective subject. These crucial aspects can be solved by using Hive, Spark and Parquet for data representation. These technologies offer an efficient representation of sparse tables, and are also able to store multiple values in columns by their support for complex data types, such as arrays or maps.

For example, consider a knowledge graph which represents a `friendOf`-relationship between persons and may represent the age for persons. The following SPARQL query determines those persons which are stated to be a friend of a 65 year old person:

```
SELECT DISTINCT ?usr, ?fr WHERE { ?usr friendOf ?fr . ?fr age "65" }
```

Let KG be the wide property table representing the knowledge graph. The schema of KG can be stated by $KG(s, \dots, age, \dots, friendOf, \dots)$ as we are only interested in the columns s for the subjects, `friendOf` and `age`. As `friendOf` in general is multivalued, the respective Spark SQL expression being equivalent to the above SPARQL query has the following structure:

```
SELECT usr, fr FROM
  ( SELECT s as usr, xfo as fr FROM KG lateral view explode (friendOf) fo as xfo ) F
JOIN
  ( SELECT s as usr FROM KG WHERE age IS NOT NULL AND age='65') A
ON F.fr = A.usr
```

Note that by an `explode` operation the potential multivalued property `friendOf` is replaced by a table such that an implicit lateral join can be applied.

For a more realistic context, we investigated the Yago (version 2s 2.5.3) knowledge graph, which is derived from Wikipedia, WordNet and GeoNames with approximately 220 Million triples and 104 properties. The resulting WPT is of storage size 3.61GB and extremely sparse: the ratio between number of null values and number of elements in the table is 0.975.

3 Distributed Implementation

We use Apache Hadoop as distributed processing platform. Our cluster runs Cloudera CDH 5.10.0 with Spark 2.2 on Ubuntu 14 and consists of one master and nine workers giving in total 198GB to be used and 108 virtual cores. To validate our expectations about WPT we analyzed the performance of Yago queries executed on top of the different table designs, i.e. single triple table, partitioning by properties, WPT, and a set of tables stemming from an emergent schema. As we detail in [AK19] the single wide property table approach has competitive efficiency. As reasons for this surprising behavior we see: (1) star joins can be solved by selections, as all properties for a certain subject reside in the same row; (2) the number of joins required is minimal with respect to the other approaches; (3) and, because of its size, a single wide property table implies a physical partitioning which provides work for as many nodes in the cluster as possible. Moreover, WPT does not require any additional design overhead and is able to account to any kind of newly discovered RDF data with nearly no extra design effort.

Literature

- [AK19] Victor Anthony Arrascue Ayala, Polina Koleva, Anas Alzogbi, Matteo Cossu, Michael Färber, Patrick Philipp, Guilherme Schievelbein, Io Taxisdou, Georg Lausen. Relational Schemata for Distributed SPARQL Query Processing. CoRR, 2019
- [AL18] Victor Anthony Arrascue Ayala, Georg Lausen. A Flexible N-Triples Loader for Hadoop. ISCW (Posters & Demos), 2018
- [CF18] Matteo Cossu, Michael Färber, Georg Lausen. PRoST: Distributed Execution of SPARQL Queries Using Mixed Partitioning Strategies. EDBT 2018
- [DG14] Xin Luna Dong, Evgeniy Gabrilovich, Jeremy Heitz, Wilko Horn, Ni Lao, Kevin Murphy, Thomas Strohmman, Shaohua Sun, Wei Zhang. Knowledge Vault: A Web-Scale Approach to Probabilistic Knowledge Fusion. KDD 2014
- [IBM] <https://console.bluemix.net/docs/services/discovery/building-kg.html#watson-discovery-knowledge-graph> (March 2019)
- [SP13] Alexander Schätzle, Martin Przyjaciół-Zablocki, Thomas Hornung, Georg Lausen. PigSPARQL: A SPARQL Query Processing Baseline for Big Data. ISCW (Posters & Demos) 2013
- [SP16] Alexander Schätzle, Martin Przyjaciół-Zablocki, Simon Skilevic, Georg Lausen. S2RDF: RDF Querying with SPARQL on Spark. PVLDB 9(10), 2016
- [WH18] Marcin Wylot, Manfred Hauswirth, Philippe Cudré-Mauroux, Sherif Sakr. RDF Data Storage and Query Processing Schemes: A Survey, ACM Comput. Surveys. 2018

Disruption – Informatik wider den Schwarzen Schwan?

Peter C. Lockemann¹

Abstract

Als *Innovation* gilt die Umsetzung von neuen Ideen oder Erfindungen in neue Produkte, Dienstleistungen, Verfahren, die erfolgreich den Markt durchdringen. Schon die *normale Innovation* – das ist die Erneuerung eines Marktes ohne ihn grundlegend zu verändern – gilt als herausfordernd. Bedrohlich wird aber die *disruptive Innovation*: Sie zerschlägt oder verdrängt einen gesamten Markt (Geschäftsmodelle, Produkte, Technologien, Dienstleistungen). Die Ursachen einer Disruption werden gerne mit dem Begriff des *Schwarzen Schwans* umschrieben: Dies ist ein extrem unwahrscheinliches Ereignis mit immensen und oft falsch eingeschätzten Auswirkungen [Ta07].

Bei aller Geschwindigkeit kann man von der Entwicklung einer Technologie kaum sagen, dass sie urplötzlich eintritt. Unerwartet ist sie nur dann, wenn man die Entwicklung übersehen hat und von ihr überrascht wird. Ob es sich dabei auch um einen Schwarzen Schwan handelt, lässt sich letztlich nur aus dem Blickwinke des einzelnen Unternehmens beurteilen.

Zu den aktuellen Innovationen zählt man gerne die *Digitalisierung*. Verschläft man sie, kann dies die eigene Existenz kosten. Größe ist kein ausreichender Schutz. Warnende Beispiels sind etwa Kodak oder Nokia. Ein kluger Wechsel des Geschäftsmodells kann jedoch das Überleben sichern – siehe IBM. Emporkömmlinge ohne den Ballast einer Vergangenheit sind aber im Vorteil: Sie helfen eher dem Schwarzen Schwan dabei, flügge zu werden – siehe etwas Uber oder Airbnb.

Etablierte kleinere Unternehmen (KMU) mit einem noch gut funktionierenden Portfolio gelten als besonders bedroht, ihnen gilt daher in Deutschland auch die Aufmerksamkeit der Politik. Doch die läuft häufig ins Leere: Für KMU ist der Zugang zu Technologie- und Marktanalysen beschwerlich, auch fehlen wegen der gut gefüllten Auftragsbücher die personellen Ressourcen, um die Analysen auszuwerten oder gar selbst welche anzustellen, knapp sind zudem Zeit und Geld für Beratungsleistungen durch Externe, und meist fehlt überhaupt das geeignete Fachpersonal.

Und damit wären wir beim Kernproblem: Den Unternehmen wäre schon geholfen, wenn ihnen bei Analysen und Reaktionen ein Gutteil der Arbeit durch Werkzeuge der Informatik abgenommen würde. Unterstützung sollte bei drei Fragestellungen geboten werden:

1. Welche technologischen und wirtschaftlichen Trends soll ich laufend verfolgen, um ihr Innovationspotenziale für mich frühzeitig zu erkennen?

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2. Wie kann ich es einer Innovation ansehen, ob sie für mich einen disruptiven Charakter besitzt? Worin besteht die Disruption?
3. Wie antworte ich konstruktiv auf die Disruption? Wie muss ich mein Unternehmen zukünftig aufstellen?

Doch wie könnten die Werkzeuge aussehen? Lassen Sie uns ein wenig spekulieren.

Die erste Frage führt auf den gängigen Begriff des Technologie Scouting. Unterstellt man, dass sich Innovationen erst in der Öffentlichkeit bemerkbar machen, nachdem sie einen gewissen Reifegrad erreicht haben, und dass man dann Hinweise in Messekatalogen, Veröffentlichungen, Vortragsankündigungen, Veranstaltungsprogrammen findet, so bietet sich hierfür Text Mining an. Damit lassen sich etwa Themen gewichten, deren Häufigkeit des Auftretens bestimmen und Hypothesen generieren. Doch dann müssen die wesentlichen Themen auch bewertet werden: Welche sind Schlüsseltechnologien oder gar Schrittmachertechnologien? Dazu bräuchte man einen Leistungskatalog, anhand dessen man Technologien aus Anwendungssicht charakterisieren kann, z.B. Ubiquität, Personalisierbarkeit, Speicherkapazität, Verarbeitungsgeschwindigkeit, Datenerfassung, Sicherheit. Mit ihm ließen sich die neuen mit den derzeit eingesetzten Technologien vergleichen.

Kritisch wird es, wenn neue Technologien nicht nur die Merkmale der bisher eingesetzten Technologien quantitativ verbessern, sondern gänzlich neue Merkmale bieten. Der Vergleich muss also je nach Überdeckungsgrad oder Grad an Ausreißern zwischen Optimierungs- und Disruptionspotenzial der Technologien unterscheiden. Gerade im letzteren Fall muss eine Bedrohungsanalyse folgen. Welche Unternehmensprozesse und in Folge welche Geschäftsmodelle können nicht so bleiben wie bisher oder müssen sogar neu hinzukommen?

Die dritte Frage lässt sich nur durch kreative Ideen beantworten. Den Umgang mit Chancen und Bedrohungen kann man aber zumindest trainieren: Dazu eignen sich Planspiele, die aber aufwändig zu erstellen sind, oder Ansätze des Serious Gaming, mit denen zumindest Strategieüberlegungen gefördert werden. Hat man Ansatzpunkte gefunden, so steht man vor einer Aufgabe des Change Management, und dort wäre es hilfreich, wenn man Modelle der bestehenden Unternehmensstruktur und -prozesse („as-is“) in Modelle der Zukunft („to-be“) transformieren könnte.

Natürlich müsste man alle diese Fragen präzisieren, bevor man nach Antworten sucht. Der Nutzen wäre aber für beide Seiten erheblich: Für die Wissenschaft, denn die spannendsten Forschungsfragen stellen sich oft im Umgang mit der realen Welt, und für die KMU, denn sie könnten sich trotz ihrer begrenzten Ressourcen der Zukunft erfolgreich stellen.

[Ta07] Taleb, N.N.: Der Schwarze Schwan – Die Macht höchst unwahrscheinlicher Ereignisse. Hanser Verlag, 2007. Originalausgabe: The Black Swan – The Impact of the Highly Improbable. Random House, 2007

Universität 4.0: Herausforderungen, Konzepte und erste (ERCIS) Erfahrungen

Gottfried Vossen¹

Universität 4.0 ist eines von vielen heutigen Buzzwords, welches (in gewisser Analogie zu Industrie 4.0) auszudrücken versucht, dass Universitäten bemüht sind um Anpassung an die Anforderungen des aktuellen Berufslebens und an die Bedürfnisse heutiger Studierender. Ein zentraler Treiber ist auch hier die Digitalisierung sowie die digitale Transformation, welche durch den immer schneller werdenden technischen Fortschritt ermöglicht werden und welche sich auch in Universitäten und ihrem Lehransatz disruptiv bemerkbar machen. Dieser Vortrag geht zunächst auf Ursachen und deren Konsequenzen ein, aus denen sich zahlreiche Herausforderungen ergeben, mit denen Universitäten heute konfrontiert sind. Sodann stehen die Eigenschaften der Universität 4.0 im Vordergrund, und es werden Konzepte wie Flipped Classroom, Just-in-Time-Teaching oder Gamification sowie damit in Münster gemachte Erfahrungen beleuchtet. Der Vortrag endet mit Empfehlungen zur weiteren Ausbildung im Bereich Informationssysteme.

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Können Gemeinschaften autonomer Einheiten beim Modellieren digitaler Ökosysteme helfen?

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Abstract: In dieser kurzen Abhandlung wird das Konzept der Gemeinschaften autonomer Einheiten informell skizziert, das für die formale Modellierung logistischer Systeme interaktiver autonomer Prozesse eingeführt wurde. Ein erster versuchsweiser Vergleich mit digitalen Ökosystemen weist gewisse Ähnlichkeiten auf, so dass es sich lohnen kann, das näher zu untersuchen.

Keywords: Gemeinschaften autonomer Einheiten, digitale Ökosysteme, autonome Prozesse, Selbststeuerung, Modellierung

1 Einleitung

Der Sonderforschungsbereich 637 *Selbststeuernde logistische Prozesse – ein Paradigmenwechsel und seine Grenzen* lief von 2004 bis 2012 an der Universität Bremen anfangs unter der Leitung von Otthein Herzog und später von Bernd Scholz-Reiter als eine interdisziplinäre Kooperation von Forschungsgruppen aus der Elektrotechnik, Informatik, Mathematik, Produktionstechnik und aus der Wirtschaftswissenschaft. Zielsetzung war die systematische und breit angelegte Erforschung und Nutzbarmachung der Selbststeuerung als ein neues Paradigma für logistische Prozesse (siehe z.B. [HW07, HSW11] für einen Überblick). In diesem Rahmen ist das Konzept der Gemeinschaften autonomer Einheiten vorgeschlagen und intensiv untersucht worden, um logistische Systeme von interaktiven autonomen Prozessen mit rigoroser Syntax und Semantik zu modellieren und einen Ansatz bereitzustellen, der semantische Analysen einschließlich Korrektheitsbeweise erlaubt (siehe z.B. [HKK06, KK07, HKK09, KK10, KKT11]).

In dieser kurzen Abhandlung wird das Konzept der Gemeinschaften autonomer Einheiten informell vorgestellt und auf gewisse Ähnlichkeiten zu digitalen Ökosystemen hingewiesen. Deshalb mag die Frage erlaubt sein, ob Gemeinschaften autonomer Einheiten helfen können, digitale Ökosysteme formal zu modellieren und auf der semantischen Ebene zu analysieren. Allerdings ist für eine systematische Klärung dieser Frage eine sorgfältigere und tiefergehende Studie erforderlich, als diese erste noch sehr oberflächliche Betrachtung zu leisten vermag.

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Im folgenden Abschnitt werden die syntaktischen und semantischen Hauptmerkmale von Gemeinschaften autonomer Einheiten skizziert, um dann im dritten Abschnitt einen Bezug zu digitalen Ökosystemen herzustellen.

2 Gemeinschaften autonomer Einheiten

Eine *Gemeinschaft autonomer Einheiten* stellt eine *Umgebung* zur Verfügung, in der alle ihre Einheiten unabhängig voneinander agieren und miteinander interagieren. Spezielle Umgebungen können als Start gewählt werden. Jede *autonome Einheit* einer solchen Gemeinschaft kann in spezifischer Weise seine Umgebung lokal erfassen und verändern. Für jede Einheit und für die ganze Gemeinschaft können *Ziele* formuliert werden. Das Zusammenwirken der Einheiten (zwischen intensiver Zusammenarbeit und starker Konkurrenz) kann durch *Kooperationsbedingungen* reguliert werden. Formal werden Umgebungen als *Graphen* modelliert, und die Einheiten verfügen über *Regeln*, mit denen sie lokal auf die jeweils aktuelle Umgebung zugreifen und dort Teile löschen und zufügen können. Um die Anwendung von Regeln zu steuern, bekommt jede Einheit *Kontrollbedingungen*, die zum Beispiel die Reihenfolge der Regelanwendungen festlegen oder Prioritäten setzen. Ziele werden durch logische Formeln oder durch spezielle Eigenschaften der zu erreichenden Umgebungen spezifiziert. Kooperationsbedingungen dienen vor allem dazu, das Maß der Nebenläufigkeit, Parallelität oder Sequenzialität der interagierenden Einheiten festzulegen. Beispielsweise kann gefordert werden, dass immer alle Einheiten gleichzeitig agieren, dass die Aktionen bestimmter Einheiten die gleichzeitige Aktion anderer Einheiten ausschließt oder dass konkurrierende Einheiten immer abwechselnd aktiv werden.

Semantisch beschreibt eine Gemeinschaft autonomer Einheiten Folgen von Regelanwendungen, die bei einer Startumgebung beginnen und beliebig lange laufen, wenn keine Gesamtziele formuliert sind, und die bei einer Zielumgebung enden, soweit allgemeine Ziele definiert sind. Bei geeigneter Wahl von Regeltypen lassen sich aus den Einzelregeln Parallelregeln bilden, so dass nicht nur sequentielle, sondern auch parallele Abläufe in der *Ablaufsemantik* berücksichtigt werden können. Darüber hinaus ist es ebenfalls möglich, Regeln und Regelanwendung so zu wählen, dass Regeln nur dann sequentiell ausgeführt werden müssen, wenn sie kausal abhängig sind. Das erlaubt eine nebenläufige Semantik, bei der eine zeitliche Reihenfolge nur im Falle der kausalen Abhängigkeit besteht. Bei allen anderen Aktionen ist nicht zu ermitteln, ob sie in beliebiger Reihenfolge nacheinander oder zeitgleich stattfinden, also echt nebenläufig sind. Die Folgen müssen sowohl den Kontrollbedingungen aller einzelnen Einheiten wie auch den Kooperationsbedingungen der Gemeinschaft genügen. In dem Falle, dass globale Ziele definiert sind, induziert die Ablaufsemantik auch eine *Ein-/Ausgabe-Relation* zwischen Startumgebungen und Zielumgebungen, die durch Abläufe ineinander überführt werden. Die in dem Ansatz verwendeten Konzepte der *Graphtransformation* sind z.B. [Ro97] ausführlich behandelt.

Die auf Regelanwendung basierende Ablaufsemantik bildet auch die Grundlage für semantische Analysen. Da eine Regelanwendung einen gegebenen Umgebungsgraphen in präzis definierter Weise in einen neuen Umgebungsgraphen transformiert, lassen sich alle

Einzelschritte genau untersuchen. Darüber hinaus – und für den Nachweis globaler Eigenschaften interessanter – lassen sich über die Längen der Regelanwendungsfolgen Induktionsbeweise führen. In [Da10] beispielsweise wird gezeigt, dass sich auf dieser Basis die Stabilität von Produktionsnetzen untersuchen lässt. Oder in [KK08] wird die Routenplanung für Abhol- und Zustell-Fahrzeuge so modelliert, dass sich Aussagen über Pünktlichkeit, Auslastung und Ähnliches beweisen lassen. Die Ein-/Ausgabe-Semantik bildet außerdem die Grundlage, auch Fragen der Berechenbarkeit, der Komplexität und der Erzeugungsmächtigkeit zu untersuchen und korrekt zu beantworten.

3 Vergleich mit digitalen Ökosystemen

Ein erster vorläufiger und noch recht kursorischer Blick in die Literatur zu digitalen Ökosystemen (siehe z.B. [BC07, BSD11, DIM11, LBB12]) weist auf einige Ähnlichkeiten zu Gemeinschaften autonomer Einheiten hin. Ein digitales Ökosystem umfasst diverse Entitäten, die vielfach als Agenten bezeichnet oder modelliert werden und die autonomen Einheiten gleichen, da sie ebenfalls konkurrierend oder kooperierend lose gekoppelt und unabhängig voneinander agieren. Das Environment, in dem dieses Zusammenwirken geschieht, oder zumindest Teile davon werden gern durch graphische, diagrammatische Strukturen dargestellt. Das Kernprinzip der Selbstorganisation entspricht der Autonomie aller Einheiten, die zwar durch Kooperationsbedingungen eingeschränkt werden kann, aber nicht muss. Ansonsten ist jede Einheit frei, das zu tun, was ihre eigenen Fähigkeiten in der Wechselwirkung mit dem aktuellen Zustand der Umgebung erlaubt. zusammengekommen organisiert sich das Gesamtsystem selbst, weil es keine übergeordnete Steuerungsinstanz gibt.

Aus diesen Beobachtungen ergibt sich die Frage, ob der Modellierungsansatz der Gemeinschaften autonomer Einheiten auch zur formalen, syntaktisch und semantisch präzisen Modellierung digitaler Ökosysteme taugt. Lässt sich das bejahen, ergäbe sich die Chance, gewünschte Eigenschaften von digitalen Ökosystemen wie Nachhaltigkeit, Stabilität, Anpassungsfähigkeit und Fairness beweisen.

Literaturverzeichnis

- [BC07] Boley, H.; Chang, E.: Digital ecosystems: principles and semantics. In Damiani, E. (Ed), Inaugural IEEE International Digital Ecosystems and Technologies Conference (DEST). Cairns, Australia: IEEE, S. 398-403. 2007.
- [BSD11] Briscoe, G., Sadedin, S. & De Wilde, P.: Digital Ecosystems: Ecosystem-Oriented Architectures. *Natural Computing* 10:1143, 2011. doi.org/10.1007/s11047-011-9254-0
- [Da10] Dashkovskiy, S. et al.: Production Networks as Communities of Autonomous Units and Their Stability. *International Electronic Journal of Pure and Applied Mathematics* 2, S. 17-42, 2010.

-
- [DIM11] Dini, P.; Iqani, M.; Mansell, R.: The (im)possibility of interdisciplinarity: lessons from constructing a theoretical framework for digital ecosystems. *Culture, Theory and Critique*, 52 (1). S. 3-27, 2011.
 - [HKK06] Hölscher, K.; Kreowski, H.-J.; Kuske, S.: Autonomous Units and their Semantics – The Sequential Case. In Corradini, A. et al. (Editors): *Proc. 3rd Intl. Conference on Graph Transformations (ICGT 2006)*, *Lecture Notes in Computer Science*, Band 4178, S. 245-259, 2006.
 - [HKK09] Hölscher, K.; Kreowski, H.-J.; Kuske, S.: Autonomous Units to Model Interacting Sequential and Parallel Processes. *Fundamenta Informaticae* 92, S. 233-257, 2009.
 - [HSW11] Hülsmann, M.; Scholz-Reiter, B.; Windt, K. (Editors): *Autonomous Cooperation and Control in Logistics*. Springer-Verlag, Heidelberg-Berlin, 2011.
 - [HW07] Hülsmann, M.; Windt, K. (Editors): *Understanding Autonomous Cooperation and Control in Logistics*. Springer-Verlag, Heidelberg-Berlin, 2007.
 - [KK07] Kreowski, H.-J.; Kuske, S.: Autonomous Units and Their Semantics – The Parallel Case. In Fiadeiro, J.L.; Schobbens, P.Y. (Editor): *Recent Trends in Algebraic Development Techniques*, 18th International Workshop, WADT 2006, *Lecture Notes in Computer Science*, Band 4409, S. 56-73, 2007.
 - [KK08] Kreowski, H.-J.; Kuske, S.: Communities of Autonomous Units for Pickup and Delivery Vehicle Routing. In Schürr, A. et al. (Editors): *Proc. 3rd Intl. Workshop on Applications of Graph Transformation with Industrial Relevance (AGTIVE '07)*, *Lecture Notes in Computer Science*, Band 5088, S. 281-296, 2008.
 - [KK10] Kreowski, H.-J.; Kuske, S.: Autonomous Units and Their Semantics – The Concurrent Case. In Gregor Engels, G. et al. (Editors): *Graph Transformations and Model Driven Engineering – Essays Dedicated to Manfred Nagl on the Occasion of his 65th Birthday*, *Lecture Notes in Computer Science*, Band 5765, S. 102-120. 2010.
 - [KKT11] Kreowski, H.-J.; Kuske, S.; von Totth, C.: Modeling Production Networks with Discrete Processes by Means of Communities of Autonomous Units. *Logistics Research* 3, S. 159-175, 2011.
 - [LBB12] Li, W.; Badr, Y.; Biennier, F.: Digital ecosystems: challenges and prospects. *Proceedings of the International Conference on Management of Emergent Digital EcoSystems*, S. 117-122, 2012.
 - [Ro97] Rozenberg, G. (Ed.): *Handbook of graph grammars and computing by graph transformation: volume I. Foundations*. World Scientific Publishing Co., Inc. River Edge, NJ, USA, 1997.

Carinthia University of Applied Sciences – AAL Research

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Abstract: Anchored to the Carinthia University of Applied Science, (computer) engineering researchers incorporate to improve daily living for elderly people. This paper gives an overview of the Active and Assisted Living research emphases. Embedded in an engineering and IT department (area of studies medical engineering / research unit Active & Assisted Living) one part is implementing and evaluating technology and, furthermore, in an interdisciplinary infrastructure (Institute of Applied Research on Ageing) technological, economic and social aspects of aging are focused. The portfolio has different evaluation and requirement analysis methods as well as software conceptualization and development - always with a strong focus on user involvement.

Keywords: Active and Assisted Living, AAL, User Experience, Smart Home, User Interaction, Smart Living, Smart Health, Telemonitoring

1 Introduction

To advance research, development and innovation processes at Carinthia University of Applied Sciences (CUAS) different research units and research institutes with special research focus were established. Scientists, consolidated from different technical and non-technical professions, work together on the topic of research, development and anchoring of new processes, concepts, technical solutions and integrated services for ageing well. This research is performed in the “Research Unit Active & Assisted Living (RUAAL)”. In the “Institute for Applied Research on Ageing (IARA)”, which is a consolidation of the technique department “Health and Assistive Technologies (HAT)”, the social department “Intergenerational Solidarity, Activity and Civil Society (ISAC)” and the economy department “Demographic Change and Regional Development (DCRD)” interdisciplinary research is realized. In this paper, the focus is set on the research topics in RUAAL and the HAT department of IARA.

research group is involved in different national and international research projects as lead or project partner with a focus on technique conceptualization and development, technology-related evaluation such as technology acceptance, user experience or usage analysis as well as projects with a strong focus on strategic network-building and transnational knowledge exchange.

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2 Research fields of RUAAL

The research unit AAL, established in 2018 [KRA17] aims to develop concepts, products and services to connect technologies and the social environment with one another and thereby make a positive contribution to increasing the quality of life in old age as well as all phases of life. Basis for applied research is a Living Lab R&D&I approach that includes methods, processes, infrastructure and partnerships for the realization of cooperative, applied research (ideation, conception, validation and testing, evaluation) of technical products, services, concepts in the context of AAL.

2.1 Smart Home / Smart Living Applications (- Environments)

Technical innovations with an emphasis on Smart Home / Smart Living focus on intelligent living with interconnected sensors, actuators, and IoT technologies. The main emphasis is the situation-adaptive, modular and interoperable implementation, integration and evaluation of smart sensors as well as the development of interoperable interfaces and AAL-IoT layers. A further content-related emphasis of the RUAAL is the development of algorithms for the recognition of activities of daily living (ADLs) describing parameters (sensor based) as an indicator for changes in the daily living routines; e.g. monitored changes of health conditions over a longer period.

2.2 Smart Health and Telemonitoring Applications

Health care, monitoring of health conditions as well as teleinterventions (medical support, rehabilitation) are especially in rural areas of major importance and are a core theme in the AAL Vision Austria 2025 [BLG18]. Applications with a (semi-) automatic acquisition, visualization, and transmission of vital parameter data are implemented. Furthermore, data from medical/therapeutic assessments are processed for experts to give skilled feedback to their clients. Every development is realized with a strong focus on privacy, security and safety issues and with respect on the Austrian DSGVO 2018 [EU18] as well as on the GTelG [OEB13] legislation.

2.3 Smart Interaction – User groups – and contextual universal User Interfaces

Besides the technology development in the other two emphases, it is important to conceptualize and evaluate an appropriate interface for the interaction of the users with technological solutions. The third emphasis is on the development, conceptualization, and evaluation of human-system interaction interfaces for AAL solutions and the evaluation of (new) interaction strategies to increase accessibility (universal design), to decrease usage barriers and to improve the user experience. To fulfill these tasks it is important to work together with the user groups in an iterative co-creation approach.

3 Living Lab Approach

Since 2013, the research group is working with the Living Lab approach. In the Living Lab PROLIDA (Professional Living, Innovation and Development Lab for an Ageing Society) supporting infrastructure and methodical approaches for accompanying research in projects as well as for commissioned research from business partners are provided.

3.1 Infrastructure

As part of the CUAS, PROLIDA includes the laboratory infrastructure provided and implemented over the years. Two laboratories are of special interest for the AAL research: the iADLlab and the UX lab. The iADL lab (instrumental activities of daily living lab) is a lab that contains a demo-apartment including kitchen, living room, bedroom, dining room, and bathroom. In that flat, it is possible to test different smart home sensor settings as well as it can be used as a networking place for different stakeholder groups. The UX lab (user experience lab) extends the possibilities of the iADL lab in a way that observations and different soft- and hardware tests according to UX concerns can be realized.

3.2 Methods

To support different project partners during technology development/evaluation, a set of different methodologies was implemented into the PROLIDA catalog of benefits. These methods cover the support from a project idea to the implementation of functional prototypes and the implementation of sustainability strategies. For a successful project start, it is possible to do a requirement analysis with user involvement to gather the needs of the addressed user groups. Another service is the software development from the conceptualization (functionality, design, interaction strategy) to a functional prototype. The provided UX methods are technology acceptance, usability evaluations, development of (online) surveys in a quantitative, qualitative and mixed characteristic; or in the form of standard surveys like TE-AG³, TUI⁴, AttrakDiff⁵, meCUE⁶, UEQ⁷, or SUMI⁸. Moreover, supporting methods like observations, interviews, workshops/focus groups and evaluation of software related to barrier-free design for different user groups are included in the set. The researchers are also constantly working on customized tools to improve the user involvement; e.g. an own interaction design diagram was developed

³ TA-EG survey: https://www.mms.tu-berlin.de/fileadmin/fg268/Forschung/TA-EG_Fragebogen_Technikaffinitaet.pdf

⁴ TUI survey: https://www.ffg.at/sites/default/files/allgemeine_downloads/thematische%20programme/programmdokumente/tui_manual.pdf

⁵ AttrakDiff survey: <http://attrakdiff.de/>

⁶ meCUE survey: <http://www.mecue.de/>

⁷ UEQ survey: <https://www.ueq-online.org/>

⁸ SUMI survey: <http://sumi.uxp.ie/>

that helps to get information from non-technical users about the understanding of navigation strategies of software [SKO18].

4 Best practice: Smart VitAALity

The AAL pilot region Smart VitAALity⁹ considers the aim of an adequate and technology-driven technology development, multi-dimensional evaluation (technology acceptance, usage analysis, user experience evaluation, socio-economical potential analysis, effectiveness analysis) as well as a derived sustainability strategy. In the project, an integrated AAL system in a smart-city-setting “health, inclusion and assisted living” will be evaluated with 230 elderly people (intervention and control group) in the province of Carinthia in the urban triangle Klagenfurt – Villach – Ferlach. The Smart VitAALity system combines different technology components to support elderly people during their daily living. The major goal is to increase the specific domains of quality of life of the target group. The technology package includes different (state of the art) communication- and information technology components e.g. a smartwatch and a tablet, smart home sensors as well as devices for vital parameter measuring. These technologies are provided in combination with accompanying services like a care center service to support the personal health monitoring process and to give the users feedback on their general health condition, or a call center to realize a 24/7 emergency call system to increase safety.

Bibliography

- [BLG18] Bertel D.; Leitner, P.; Geser, G.; Hornung-Prähauser, V.; Psihoda, S.; Zgud, J.: AAL Vision 2025 – für Österreich unter Einbeziehung relevanter Stakeholder und internationaler Trends. Wien, 2018.
- [EU18] Europäische Union: EU-Datenschutzgrundverordnung, 2018
- [OEB13] Österreichisches Bundesrecht: Gesamte Rechtsvorschrift für Gesundheitstelematikverordnung, 2013
- [SKO18] Ströckl, D. E.; Krainer, D.; Oberrauner, E.: Improving Interdisciplinary Communication – Use Case Focused User Interaction Diagram 2.0. IARIA – Ambient 2018 Conference Proceedings, Athen, Greece, 2018
- [KRA17] Krainer, D.: Design and Concept of Research Unit Active and Assisted Living in respect of Zentrale Forschungsförderung 1+ der Fachhochschule Kärnten, Full application, 2017, confidential.

⁹ Smart VitAALity Webseite: www.smart-vitaality.at

The Application Engineering Research Group at Alpen-Adria-Universität Klagenfurt

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Abstract: We sketch here the general orientation (“Mission”) and the recent research projects of our research group which is part of the Institute of Applied Informatics in the Faculty of Technical Sciences.

Keywords: Application Engineering, Model Engineering, Model Centered Architecture, Domain Specific Modeling Languages, User Centered Computing, Digital Ecosystems

1 Mission

The Application Engineering Research Group was founded in 1990 and has been active until now. Although the group head is a professor emeritus since October 2016, the group is still working together based on common interests: all members now have different affiliations but communicate regularly on common research and are publishing together. In addition, there is a number of master and PhD students working at subjects of the group’s research fields.

Since its beginnings, the group focuses on human-centered informatics; our research and teaching activities address topical issues in this area. We continuously take part in the international scientific discussion and assessment, and we cooperate with research institutions all over the world. At the same time, by regional activities (e.g. consulting- and development projects with local enterprises) we contribute to empowering our region.

2 Research Topics and Projects

In research and teaching we focus on human centered research in

1. model engineering: user centered (requirements) modeling languages that are intuitively to understand, apply and validate,
2. design and realization of user-oriented application architectures with a strong focus on the integration of user needs into the development process,

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3. customer centered, accessible, effective and sustainable software and services.

We conduct both fundamental research as well as experimental and applied research in close cooperation with industry following the principle: “There is nothing more practical than a good theory”

2.1 Model Centered Architecture

The Model Centered Architecture paradigm sees an information system to be a compound of various models, each of which is formed with the means of a Domain Specific Modeling Language (DSML). Figure 1 shows the template structure of a digital ecosystem component.

From a MOF perspective, MCA focuses on the MOF levels M2 (definitions of the DSMLs to be used for the specification of the system, its interfaces and its contexts), M1 (specification of all system and data components using the DSMLs) and M0 (the instances, i.e. models of concrete objects, functions and processes).

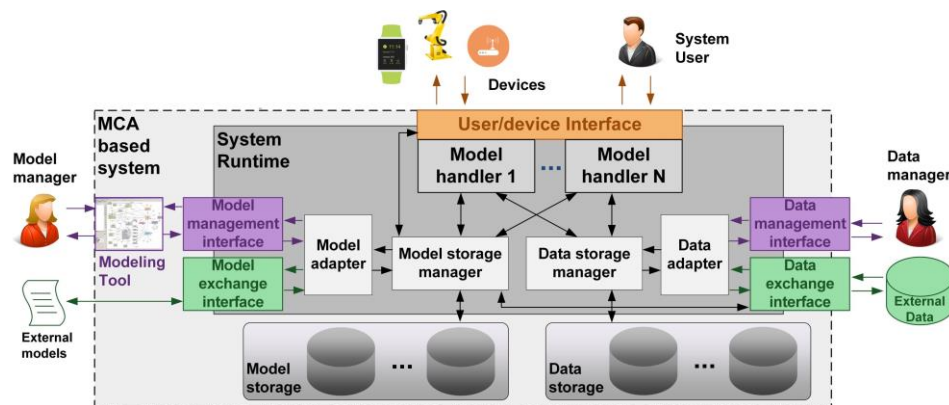


Figure 1: MCA based system template

2.2 HBMS

The vision of Human Behavior Monitoring and Support (HBMS) is to develop an Ambient Assistive Living System, which is able to

1. monitor an individual carrying out activities (e.g. of daily life),
2. to abstract, aggregate and integrate the observed behavior into an individual human cognitive model (HCM) and
3. to assist the individual in cases of need retrieving knowledge from the HCM and reasoning about the most appropriate advice to give.

Thus, HBMS facilitates elderly people with memory weaknesses to live longer autonomously in their familiar environment.

The practical result of this project is the HBMS system prototype (see figure 2), which we implemented following the MCA paradigm. The prototype realizes the aforementioned vision by components that allow

- to obtain the data corresponding to the observed user behavior from external Human Activity Recognition (HAR) systems through a flexible HAR interface controlled by models expressed in the DSML AREM-L;
- to match the obtained observation data against the predefined HCM which is expressed in the DSML HCM-L to determine the current status of the user action in the specific behavioral scenario;
- to form the support propositions based on the result of the match and present them to the user via multimodal support interface (e.g. as audio suggestions or via the tablet UI) which again is defined using a DSML.

In forming support propositions, the system relies on predictive models based on probabilistic ontologies, which allow anticipating next steps in the scenario.

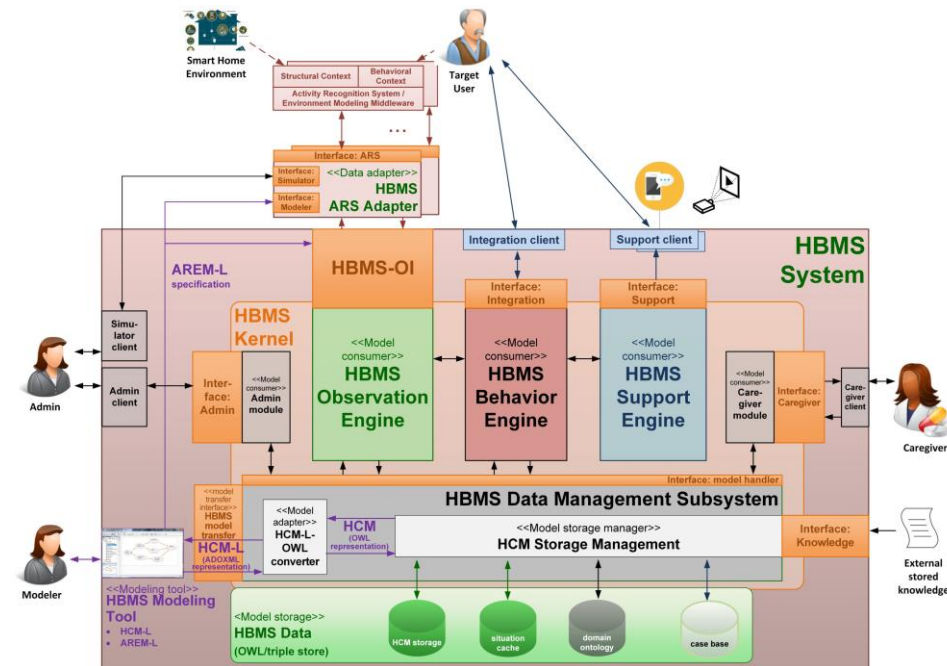


Figure 2: Architecture of the HBMS prototype system

We plan to continue the research in the area of cognitive modeling of human behavior, concentrating mainly on collecting the observations from IoT devices and covering Industry 4.0 scenarios (e.g. in production environment with potentially dangerous steps).

2.3 QuASE

The Quality Aware Software Engineering project focuses on organizing and supporting an efficient quality-related communication between all parties in the development process (such as software developers and business stakeholders). The different backgrounds and contexts of stakeholders are considered by an ontology-backed harmonization (mutual mapping) of views and concepts learned from various data and knowledge bases (e.g. those empowering ticketing systems).

The practical result of this project is the QuASE system (see figure 3), which again was implemented following the MCA paradigm. The system allows

1. to specify terminological glossaries based on common ontological core;
2. to connect these glossaries to understandability contexts (e.g. user categories, project categories, or specific projects and users);
3. to define understandability content units as containers of information which can be misunderstood and has to be harmonized. Such units can be arbitrary documents or fragments of problem descriptions managed by ticketing systems such as JIRA.
4. To harmonize the information shaped by content units by translating the terminology therein between understandability contexts.

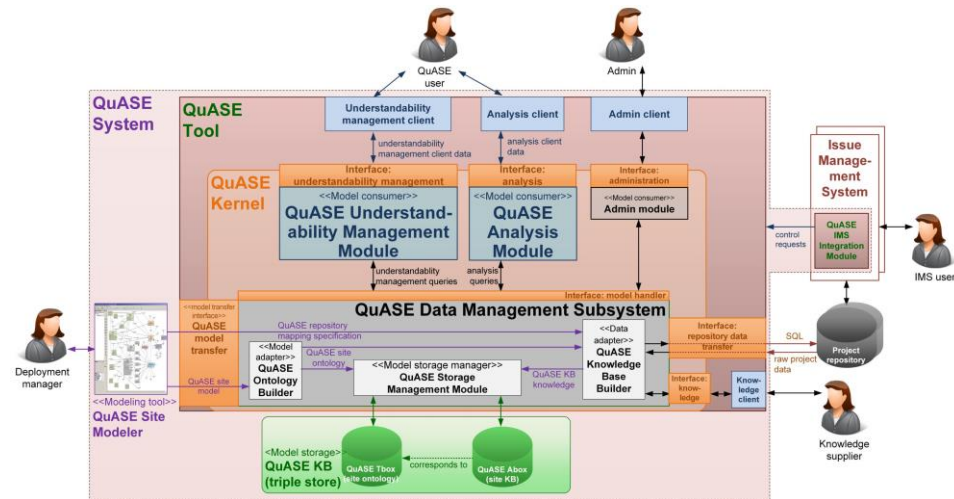


Figure 3: Architecture of the QuASE system

3 Relevance for the EMISA Special Interest Group

The head of the AE Group, Heinrich C. Mayr, founded the EMISA special interest group together with Bernd Meyer in 1979. Since then he has been a member of the steering committee. The members of the AE Group have organised several EMISA events. We are also involved in related international activities, such as the International Conference on Conceptual Modeling, which took place in Klagenfurt in 2005. Since then, Heinrich C. Mayr has been a member of the ER Steering Committee. During the term of office 2016-2018 he was its chairman.

In the field of teaching, we deal with topics that are very similar to those of the EMISA. The focus is on modeling with its formal foundations and its applications in business practice, the development of modeling methods, model-based application architectures and application engineering.

4 Recent Related Publications

- [PM 19] Paczona, M.; Mayr, H.C.: Model-Driven Mechatronic System Development. In: Proc. 15th IEEE International Conference on Automation Science and Engineering, CASE 2019, Vancouver, BC, Canada, ISBN 978-1-7281-0356-3
- [PMP 19] Paczona, M.; Mayr, H.C., Prochart, G.: Model-based Testbed Design for Electric Vehicles: In: Proc. 40 Years EMISA, LNI Vol. P-304, 2019.
- [SM 19] Ströckl, D.E.; Mayr, H.C.: Multi-Modal Human-System Interaction based on MCA. In: Proc. 2nd Int. Conference on Intelligent Human Systems Integration: Integrating People and Intelligent Systems, Feb. 2019, San Diego, California.
- [SM 18] Ströckl, D.E.; Mayr, H.C.: MCA Driven Interaction Interfacing. In (W. Karwowski and T. Ahram eds.): IHSI 2019, pp. 1-7, SpringerNatureSwitzerlandAG2019; https://doi.org/10.1007/978-3-030-11051-2_80 2018.
- [ML18] Machado Lunardi, G. et al.: IoT-based Human Action Prediction and Support. Internet of Things, Vol 3-4, 2018, Elsevier B.V., pp 52-68.
- [Sh 18] Shekhovtsov, V. et al.: Domain Specific Models as System Links. In (Woo, C. et al. Eds.) Advances in Conceptual Modeling, LNCS 11158, Springer, 2018.
- [Mi 18] Michael, J. et al.: The HBMS Story - Past and Future of an Active Assistance Approach. In Enterprise Modelling and Information Systems Architectures – International Journal of Conceptual Modeling, Vol. 13 (2018), pp. 345-370.
- [Ma 18] Mayr, H.C. et al.: A Model Centered Perspective on Software-Intensive Systems. Proc. 9th Int. Workshop on Enterprise Modeling and Information Systems Architectures, Rostock Germany, CEUR-WS.org Vol 2097, pp 58-64.

- [Ma 17]: Mayr, H.C. et al.: Model Centered Architecture. In Cabot, J. et al. (eds.): Conceptual Modeling Perspectives. Springer Nature, 2017.
- [MM 17] Michael, J.; Mayr, H.C.: Intuitive understanding of a modeling language. In: Proc. 13th Asia-Pacific Conference on Conceptual Modeling ACSW '17, January 2017, Geelong, Australia; ACM, New York, NY, USA, DOI: <https://doi.org/10.1145/3014812.3014849>.
- [MM 16] Michael, J.; Mayr, H.C.: Creating a Domain Specific Modeling Method for Ambient Assistance (Extended Abstract). EMISA Forum 26, Heft 2, 2016, pp. 25-28. ISSN 1610-3351
- [SM 16] Shekhovtsov, V.A.; Mayr, H.C.: View Harmonization in Software Processes: from the Idea to QuASE. In: Informatik: von Menschen für Menschen. Lecture Notes in Informatics, Volume P-259, Köllen-Verlag, 2016.
- [AMR 16] Al Machot, F.; Mayr, H.C., Ranasinghe, S.: A Windowing Approach for Activity Recognition in Sensor Data Streams. In: Proc. 8th IEEE Int. Conf. On Ubiquitous and Future Networks, Vienna July 2016.
- [AM 16] Al Machot, A.; Mayr, H.C.: Improving Human Activity Recognition by Smart Windowing and Spatio-Temporal Feature Analysis. In: Proc. 9th Int. Conf. on Pervasive Technologies Related to Assistive Environments PETRA 2016, ACM Digital Library Proceedings, 2016.
- [KM 16] Karagiannis, D.; Mayr, H.C.; Mylopoulos, J. (eds.): Domain-Specific Conceptual Modeling - Concepts, Methods and Tools. Springer, 2016.
- [MM 15] Michael, J.; Mayr, H.C.: Creating a Domain Specific Modelling Method for Ambient Assistance. In: Proc. Int. Conf. on Advances in ICT for Emerging Regions ICTer2015, Colombo, August 2015.
- [MAM 15] Michael, J.; Al Machot, F.; Mayr, H.C.: ADOxx based Tool Support for a Behavior Centered Modeling Approach. In: Proc. 8th Int. Conf. on Pervasive Technologies Related to Assistive Environments PETRA 2015, ACM Digital Library Proceedings, 2015.
- [SML 15] Shekhovtsov, V.; Mayr, H.C.; Lubenskyi, V.: QuASE: A Tool Supported Approach to Facilitating Quality-Related Communication in Software Development. In: da Silva, A.R. et al. (eds.): QUATIC'2014, IEEE Press, 2014, pp. 162-165.
- [SMK 15] Shekhovtsov, V.A.; Mayr, H.C., Kop, Ch.: Facilitating Effective Stakeholder Communication in Software Development Processes. In: Information Systems Engineering in Complex Environments. Springer Int. Publishing 2015, LNBIP, Vol. 204, pp. 116-132.

The Business Process Technology Research Group

Luise Pufahl and Mathias Weske¹

Abstract: In this paper the Business Process Technology research group at the Hasso Plattner Institut, University of Potsdam and its relevance for the EMISA special interest group is presented. The paper starts by reviewing the main research areas and contributions to the research community the group has provided, before sketching some of the current research topics the group is working on. In addition to the conceptual research results, the prototypes developed by BPT in the context of the BPT architecture are introduced, which relate to process modeling, event processing, and process execution.

Keywords: Business Process Modeling; Event Processing; Decision Management; Case Management; Blockchains

1 General Orientation

The Business Process Technology research group ("BPT") was founded in 2001. The mission of BPT is addressing real-world problems in business process management with formal approaches and engineering useful prototypes.

In capturing real-world problems and in devising formal approaches, modeling plays a key role. While process modeling is essential, it is by far not the only aspect that needs representation in models. Research results include modeling of events, cases, decisions, and resources. Models are not a research result *per se*, but models are used for particular purposes. These range from a better, a precise understanding of the problem domain to models that are blueprints of information systems to be engineered for illustrating the feasibility of the conceptual solution.

The group has a record of research prototypes that are provided to the international research community. The tools that BPT has developed over the years range from programming libraries for process-related data, like the jBPT library [PW13], to process engines for flexible workflow management and, later, case management [HW16]. The group is probably best known for the development of Oryx [DOW08], an extensible web-based process modeling and analysis framework that has led to the foundation of Signavio, which is today a well-established company in the area of business process modeling and analysis.

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With the general approach of BPT to address real-world problems, to use models to devise conceptual solutions and to engineer systems to show the feasibility of the solutions, in its research, BPT uses methods and techniques that also play an important role in the EMISA special interest group.

2 Research Topics

2.1 Batch Activities in Business Processes

Business process management (BPM) supports organization in process improvement and automation by capturing business processes in process models. These serve as blueprints for a number of process instances. However, process instances are typically considered running independently of each other. *Batch processing* – the collectively execution of several instances at specific process activities – is a common phenomenon in operational processes to reduce cost or time. In our group, we have developed a concept for *batch activities* that allows stakeholders to explicitly configure their batch activities in process models, which can be then automatically executed [PMW14]. This was also implemented in an existing, open-source BPM system, Camunda [PW16b]. We extended this approach to batch activities over multiple business processes [PW16a].

2.2 Decision Management

A company's value chain is directly affected by how well it designs and coordinates enterprise decision making. Therefore, decision modeling is applied complementary to business process modeling. Coupling the two disciplines comes with various challenges. Thus, a criteria for the sound integration of process and decision models was defined [BW17] by our research group. Variations of those criteria lead to different degrees of decision soundness, described in [BHW17]. All decision soundness notions require knowledge about the possible outputs of the decision model. In [BW18], an approach is reported that efficiently determines the possible outputs of decision tables. Additionally, decision-aware compliance checking verifies semantic properties of business processes while considering complementary decision logic [HBW18].

2.3 Case Management

Case Management (CM) is a paradigm to support the design, execution, monitoring, and evaluation of knowledge-intensive processes. These types of processes are often found in domains where highly trained workers (i.e., *knowledge workers*) deal with very diverse units of work (i.e., *cases*). In our group, we have developed the *fragment-based Case*

Management approach [HW16, He18] that reuses BPMN (Business Process Model and Notation) concepts – the industry-standard for process modeling. A fragment-based case model consists of structured parts – i.e. *process fragments* – that are flexibly combined at run-time based on data conditions. The approach is supported by the Chimera engine [Ha15], which is an on-going implementation project² in our group. Currently we use the Chimera engine to realize the SMile project³, a national funded project to innovate the last mile logistics of parcels.

2.4 Event Handling

Business processes today are often run in a distributed environment with several participants. Events are a form of message/signal exchanges between the partners. Also, processes can receive events from external sources like a sensor or a traffic API. The information carried by the events are then used to improve the flexibility or decision making of the business processes [Ja17]. An event processing platform connects to different event sources, operates on event streams, and notifies the event consumers about specific event occurrences. In our research group, our research group was the first one integrating a BPM system with an event processing platform [Be16] to support different IoT scenarios. Further, we research on various aspects that need to be considered while using events in business processes as discussed by Janiesch et al. [Ja17], for example, event binding, event subscription, event buffering [MHW17, MWW17].

2.5 Choreographies and Blockchains

Businesses are interacting with each other. Choreography diagrams were introduced to represent interactions between business processes, run by different partners. While there is considerable work on using process models during process implementation, there is little work on using choreography models to implement interactions. We developed a novel approach to enhance choreography diagrams with execution information. The approach is based on the REST architecture style [Ni15, NWM18], which is an important technology for communication between interacting systems.

To address the security and transparency needs of interacting business processes, recently blockchain technology was proposed as an enactment platform for interacting business processes [Me18]. We argue that decisions are an essential aspect of interacting business processes, and, therefore, benefit from being executed on a blockchain. The immutable representation of decision logic can be used by the interacting processes, so that decision taking will be more secure, more transparent, and better auditable. The approach is based on a mapping of the DMN language S-FEEL to Solidity code to be run on the Ethereum blockchain [Ha18].

² <https://github.com/bptlab/chimera>

³ <http://smile-project.de/>

3 BPT System Architecture

In this section, the BPT system architecture is presented whereby the different BPT prototypes and their interrelation are introduced. In the center of the BPT architecture is *Chimera*⁴, the flexible process engine, and its process modeler *Gryphon*⁵.

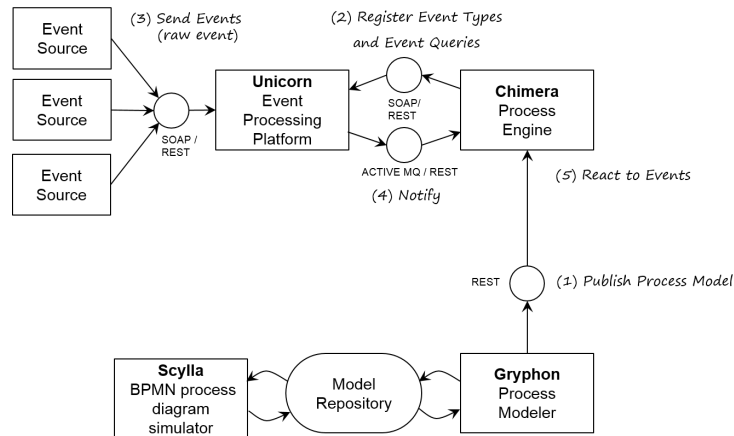


Fig. 1: BPT System Architecture: Prototypes developed at BPT and their interrelation.

Gryphon is based on *bpmn.io* (a BPMN 2.0 rendering toolkit and web modeler) and allows, additionally to traditional process modeling, the design of fragment-based case models as described by [HW16]. The defined process/case models can be stored in a model repository. For a pre-evaluation of the process models, *Scylla*⁶ [PW17] – an extensible simulator for BPMN process diagrams – can be used. This java-based BPMN simulator is open-source and can be extended by well-defined entry points based on a plug-in structure. As input, the simulator needs a BPMN process diagram. In its interface, then the simulation and the resources needs to be configured. As soon as a simulation is finished, the simulator provides as output an XES event log and a log with the basic statistics, such as flow time, process costs, and resource utilization.

The designed case models in *Gryphon* can be also published via a REST interface in *Chimera*. There, the case model can be started and executed for different cases by case managers. The case execution can be enriched by receiving also external events via *Unicorn* to trigger process fragments or continue the execution of process fragments as described in [Be16]. *Unicorn*⁷ is an event processing platform developed in our group. In general, event processing platforms are responsible to observe, filter, compose, and process events from different sources and provide them to event consumer based on their defined event

⁴ <https://bptlab.github.io/chimera/>

⁵ <https://github.com/bptlab/gryphon>

⁶ <https://github.com/bptlab/scylla>

⁷ <https://github.com/bptlab/Unicorn>

queries. Unicorn builds on top of Esper⁸ and can be connected to several event sources, such as small sensors, weather or flight tracker APIs etc. We provide a full integration of the three systems *Gryphon*, *Chimera*, and *Unicorn* to allow the integration of external events in the execution of cases, for instance, for the implementation of IoT use cases as presented in [FVH18]. In *Gryphon*, the process designer can define event queries in BPMN message events. When the case model is deployed to *Chimera*, the event types and queries given in the message event of the case model are registered in *Unicorn*. As soon as the event is received in Unicorn, it notifies the Chimera engine where it triggers or continues the respective process fragments.

The combination of *Gryphon*, *Chimera*, and *Unicorn* is currently applied in the SMile research project⁹ to realize the process of the “wish-time” delivery of parcels. In SMile, the goal is to deliver a parcel at the first try in a so-called *micro-depot*, which is in the close neighbourhood of the recipient. From there the parcel can be delivered by small, local delivery service to the recipient at a desired time frame.

References

- [Be16] Beyer, Jonas; Kuhn, Patrick; Hewelt, Marcin; Mandal, Sankalita; Weske, Mathias: Unicorn meets Chimera: Integrating External Events into Case Management. In (Azevedo, Leonardo; Cabanillas, Cristina, eds): Proceedings of the BPM Demo Track 2016 Co-located with the 14th International Conference on Business Process Management (BPM 2016), Rio de Janeiro, Brazil, September 21, 2016. pp. 67–72, 2016.
- [BHW17] Batoulis, Kimon; Haarmann, Stephan; Weske, Mathias: Various notions of soundness for decision-aware business processes. In: International Conference on Conceptual Modeling. Springer, pp. 403–418, 2017.
- [BW17] Batoulis, Kimon; Weske, Mathias: Soundness of decision-aware business processes. In: International Conference on Business Process Management. Springer, pp. 106–124, 2017.
- [BW18] Batoulis, Kimon; Weske, Mathias: Disambiguation of DMN decision tables. In: International Conference on Business Information Systems. Springer, pp. 236–249, 2018.
- [DOW08] Decker, Gero; Overdick, Hagen; Weske, Mathias: Oryx - An Open Modeling Platform for the BPM Community. pp. 382–385, 2008.
- [FVH18] Friedow, Christian; Völker, Maximilian; Hewelt, Marcin: Integrating IoT Devices into Business Processes. In (Matulevicius, Raimundas; Dijkman, Remco M., eds): Advanced Information Systems Engineering Workshops - CAiSE 2018 International Workshops, Tallinn, Estonia, June 11-15, 2018, Proceedings. Springer, pp. 265–277, 2018.
- [Ha15] Haarmann, Stephan; Podlesny, Nicolai; Hewelt, Marcin; Meyer, Andreas; Weske, Mathias: Production Case Management: A Prototypical Process Engine to Execute Flexible Business Processes. In (Daniel, Florian; Zugal, Stefan, eds): Proceedings of the BPM

⁸ <http://www.esper.tech.com/esper/>

⁹ <https://github.com/bptlab/smile>

- Demo Session 2015 Co-located with the 13th International Conference on Business Process Management (BPM 2015), Innsbruck, Austria, September 2, 2015. pp. 110–114, 2015.
- [Ha18] Haarmann, Stephan; Batoulis, Kimon; Nikaj, Adriatik; Weske, Mathias: DMN Decision Execution on the Ethereum Blockchain. In: International Conference on Advanced Information Systems Engineering. Springer, pp. 327–341, 2018.
- [HBW18] Haarmann, Stephan; Batoulis, Kimon; Weske, Mathias: Compliance Checking for Decision-Aware Process Models. In (Daniel, Florian; Sheng, Quan Z.; Motahari, Hamid, eds): Business Process Management Workshops - BPM 2018 International Workshops, Sydney, NSW, Australia, September 9-14, 2018, Revised Papers. Springer, pp. 494–506, 2018.
- [He18] Hewelt, M.; Wolff, F.; Mandal, S.; Pufahl, L.; Weske, M.: Towards a Methodology for Case Model Elicitation. In: Enterprise, Business-Process and Information Systems Modeling. BPMDS 2018, EMMSAD 2018. volume 318. Springer, 2018.
- [HW16] Hewelt, Marcin; Weske, Mathias: A Hybrid Approach for Flexible Case Modeling and Execution. In (Rosa, Marcello La; Loos, Peter; Pastor, Oscar, eds): Business Process Management Forum - BPM Forum 2016, Rio de Janeiro, Brazil, September 18-22, 2016, Proceedings. volume 260. Springer, 2016.
- [Ja17] Janiesch, Christian; Koschmider, Agnes; Mecella, Massimo; Weber, Barbara; Burattin, Andrea; Ciccio, Claudio Di; Gal, Avigdor; Kannengiesser, Udo; Mannhardt, Felix; Mendling, Jan; Oberweis, Andreas; Reichert, Manfred; Rinderle-Ma, Stefanie; Song, WenZhan; Su, Jianwen; Torres, Victoria; Weidlich, Matthias; Weske, Mathias; Zhang, Liang: The Internet-of-Things Meets Business Process Management: Mutual Benefits and Challenges. CoRR, abs/1709.03628, 2017.
- [Me18] Mendling, Jan; Weber, Ingo; Aalst, Wil Van Der; Brocke, Jan Vom; Cabanillas, Cristina; Daniel, Florian; Debois, Søren; Ciccio, Claudio Di; Dumas, Marlon; Dustdar, Schahram et al.: Blockchains for business process management-challenges and opportunities. ACM Transactions on Management Information Systems (TMIS), 9(1):4, 2018.
- [MHW17] Mandal, Sankalita; Hewelt, Marcin; Weske, Mathias: A framework for integrating real-world events and business processes in an IoT environment. In: OTM Confederated International Conferences On the Move to Meaningful Internet Systems". Springer, pp. 194–212, 2017.
- [MWW17] Mandal, Sankalita; Weidlich, Matthias; Weske, Mathias: Events in business process implementation: Early subscription and event buffering. In (Carmona, Josep; Engels, Gregor; Kumar, Akhil, eds): Business Process Management Forum - BPM Forum 2017, Barcelona, Spain, September 10-15, 2017, Proceedings. Springer, pp. 141–159, 2017.
- [Ni15] Nikaj, Adriatik; Mandal, Sankalita; Pautasso, Cesare; Weske, Mathias: From choreography diagrams to RESTful interactions. In: International Conference on Service-Oriented Computing. Springer, pp. 3–14, 2015.
- [NWM18] Nikaj, Adriatik; Weske, Mathias; Mendling, Jan: Semi-automatic derivation of restful choreographies from business process choreographies. Software & Systems Modeling, pp. 1–14, 2018.

-
- [PMW14] Pufahl, Luise; Meyer, Andreas; Weske, Mathias: Batch Regions: Process Instance Synchronization based on Data. In: Enterprise Distributed Object Computing (EDOC). IEEE, pp. 150–159, 2014.
- [PW13] Polyvyanyy, Artem; Weidlich, Matthias: Towards a compendium of process technologies: The jBPT library for process model analysis. In: Proceedings of the CAiSE'13 Forum at the 25th International Conference on Advanced Information Systems Engineering (CAiSE). Sun SITE Central Europe, pp. 106–113, 2013.
- [PW16a] Pufahl, Luise; Weske, Mathias: Batch Processing Across Multiple Business Processes Based on Object Life Cycles. In (Abramowicz, Witold; Alt, Rainer; Franczyk, Bogdan, eds): Business Information Systems - 19th International Conference, BIS 2016, Leipzig, Germany, July, 6-8, 2016, Proceedings. Springer, pp. 195–208, 2016.
- [PW16b] Pufahl, Luise; Weske, Mathias: Enabling Batch Processing in BPMN Processes. In (Azevedo, Leonardo; Cabanillas, Cristina, eds): Proceedings of the BPM Demo Track 2016 Co-located with the 14th International Conference on Business Process Management (BPM 2016), Rio de Janeiro, Brazil, September 21, 2016. volume 1789 of CEUR Workshop Proceedings, pp. 28–33, 2016.
- [PW17] Pufahl, Luise; Weske, Mathias: Extensible BPMN Process Simulator. In (Clariso, Robert; Leopold, Henrik; Mendling, Jan; van der Aalst, Wil; Kumar, Akhil; Pentland, Brian; Weske, Mathias, eds): BPM Demo Track and BPM Dissertation Award, BPM 2017. volume 1920 of CEUR Workshop Proceedings, 2017.

The Research Group Digitalization and Information Systems

Hans-Georg Fill¹

Abstract: In this paper the Research Group Digitalization and Information Systems at the University of Fribourg and its research topics are presented. This is followed by a discussion on the relevance for the EMISA special interest group.

Keywords: Digitalization; Information Systems; Research

1 General Orientation

The Research Group Digitalization and Information Systems at the University of Fribourg, Switzerland is part of the interfaculty Department of Informatics. The research activities of the group are positioned with the field of design-oriented business informatics and in particular within information systems engineering and development [Ö11]. Based on the principle of research-guided teaching, courses are offered for the business informatics bachelor and master curricula as well as for the curricula in business and economics of the University of Fribourg and the Swiss Joint Master of Science in Computer Science by the Universities of Bern, Neuchâtel, and Fribourg.

2 Research Topics

Within the field of business informatics we follow an engineering-oriented, explorative and experimental research approach that ultimately leads to the design of new types of modeling languages, the realization of innovative software prototypes and the application of these artifacts in industrial use cases and practical scenarios. The research topics are currently grouped by the following focus areas: Digitalization, Metamodeling, Blockchain, and Visualization. Research on these topics and across the topics is conducted in internally and externally funded research projects as well as theses and seminal work.

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2.1 Digitalization

Digitalization encompasses the technology-based transformation of organizations including their business models, products and services, business processes, and IT architectures. The support of organizations who aim for digitalization is one of the core competencies of business informatics. Through our research we contribute to this field by designing, implementing and applying various kinds of enterprise modeling methods, c.f. [Sa18]. These permit to represent domain requirements in a visual and intuitive way and enable at the same time a transition to technology-oriented views for designing, analyzing, optimizing and implementing information systems.

We are particularly interested in new and innovative technologies that have the potential of radically changing existing business models, processes, and IT architectures. Current technologies under investigation in our group comprise blockchains, virtual and augmented reality, novel forms of device-less interaction, and semantic technologies. Thereby we follow a human-centric approach with the goal of integrating technologies and the society.

2.2 Metamodeling

Metamodeling takes up a fundamental approach of science in the sense that it aims for discovering concepts on a metalevel that are applicable in multiple scenarios. In particular, metamodeling as we use it in our research and teaching activities stands for the design, formalization, and development of domain-specific conceptual modeling methods. It is thus concerned with the discovery of concepts for modeling languages, model algorithms, and modeling procedures and their technical realization in the form of modeling tools and services [FK13]. The application domains of metamodeling are manifold and constantly expanding. Domains that have been investigated in the past include: Strategic Management [Fi11b], Business Process Management [Fi12, Fi11a], Quality Management [JF17], Software Engineering [Fi04], Data Management and Databases [GI17, FKL15], Smart Cities [Bo16], Product Service Systems [BMF16], Ontologies and Rule Languages [Fi17, Fi18, PF19], Legal Informatics [NF17, FH16].

2.3 Blockchain

Blockchains constitute a new way of combining well-known and experienced technologies for realizing innovative IT-based applications. Their core elements comprise the decentralized storage of information, distributed consensus mechanisms, smart contracts, and digital signatures. From a business and economic perspective, blockchains have the potential to replace intermediaries through an automated and trustworthy consensus mechanism, which does not require physical persons for deciding about the validity of transactions.

In our research group we approach blockchains from three perspectives: i. the *business perspective* for designing and evaluating new types of business models; ii. the *technical perspective* for further developing enterprise information systems; and iii. the *societal perspective* for designing IT-based solutions that are accessible by non-technical users. Recent research results of the group include the approach of Knowledge Blockchains [FH18] and an approach for the decentralized modeling and tracking of processes [Hä18].

2.4 Visualization

In the context of digitalization and information systems, visualization plays a major role for communicating and analyzing complex types of information between different stakeholders [Fi09]. In this context, new forms of visualizations such as used in Virtual Reality and Augmented Reality applications also require new forms of interaction. In this research topic we thus not only investigate new types of visualizations for information systems but also emerging interaction paradigms such as device-less interaction where humans communicate with information systems in new ways.

3 Relevance for the EMISA Special Interest Group

The described research topics all contribute to development methods for information systems and their application. Thereby, the topic of digitalization stands for the alignment of information systems with current challenges for businesses, organizations, and individuals. Metamodeling is an established method for the creation of domain-specific conceptual modeling methods as used in many areas of information systems' development. The topics of blockchains and visualization stand for innovative contributions to information systems and their application in new and existing business scenarios.

References

- [BMF16] Boucher, X.; Medini, K.; Fill, H.-G.: Product-Service-System Modelling Method. In (Karagiannis, D.; Mayr, H.C.; Mylopoulos, J., eds): Domain-Specific Conceptual Modelling: Concepts, Methods and Tools. Springer, pp. 455–484, 2016.
- [Bo16] Bork, D.; Fill, H.-G.; Karagiannis, D.; Miron, E.-T.; Tantouris, N.; Walch, M.: Conceptual Modelling for Smart Cities: A Teaching Case. Interaction Design and Architecture(s) Journal - IxD&A, 27:10–27, 2016.
- [FH16] Fill, H.-G.; Haiden, K.: Visuelle Modellierung für rechtsberatende Berufe am Beispiel der gesetzlichen Erbfolge. Jusletter IT, (25. Februar 2016), 2016.
- [FH18] Fill, H.-G.; Härer, F.: Knowledge Blockchains: Applying Blockchain Technologies to Enterprise Modeling. In: HICSS'51. AIS, pp. 4045–4054, 2018.

- [Fi04] Fill, H.-G.: UML Statechart Diagrams on the ADONIS Metamodeling Platform. *Electronic Notes in Theoretical Computer Science*, 127(1):27–36, 2004.
- [Fi09] Fill, H.-G.: *Visualisation for Semantic Information Systems*. Springer/Gabler, 2009.
- [Fi11a] Fill, H.-G.: Using Semantically Annotated Models for Supporting Business Process Benchmarking. In: *BIR'2011*. Springer, pp. 29–43, 2011.
- [Fi11b] Fill, H.-G.; Eberhart, A.; Laslop, A.; Reischl, I.; Lang, T.: An Approach to Support the Performance Management of Public Health Authorities using an IT based Modeling Method. In: *International Conference on Wirtschaftsinformatik WI 2.011*. pp. 38–47, 2011.
- [Fi12] Fill, H.-G.: An Approach for Analyzing the Effects of Risks on Business Processes Using Semantic Annotations. In: *European Conference on Information Systems 2012*. AIS, 2012.
- [Fi17] Fill, H.-G.: SeMFIS: A Flexible Engineering Platform for Semantic Annotations of Conceptual Models. *Semantic Web (SWJ)*, 8(5):747–763, 2017.
- [Fi18] Fill, H.-G.: Semantic Annotations of Enterprise Models for Supporting the Evolution of Model-Driven Organizations. *Enterprise Modelling and Information Systems Architectures - International Journal of Conceptual Modelling*, 12, 2018. DOI: <https://doi.org/10.18417/emisa.13.5>.
- [FK13] Fill, H.-G.; Karagiannis, D.: On the Conceptualisation of Modelling Methods Using the ADOxx Meta Modelling Platform. *Enterprise Modelling and Information Systems Architecture*, 8(1):4–25, 2013.
- [FKL15] Fill, H.-G.; Karagiannis, D.; Lichka, C.: Integration of Conceptual Models and Data Services Using Metamodeling. In: *IEEE SoEA4EE'2015*. IEEE, 2015.
- [GI17] Glässner, T.; Heumann, F.; Keßler, L.; Härer, F.; Steffan, A.; Fill, H.-G.: Experiences from the Implementation of a Structured-Entity-Relationship Modeling Method in a Student Project. In: *International Workshop on Practicing Open Enterprise Modeling within OMiLAB*. CEUR, 2017.
- [Hä18] Härer, F.: Decentralized Process Modeling and Instance Tracking Secured by a Blockchain. In: *European Conference on Information Systems*. AIS, 2018.
- [JF17] Johannsen, F.; Fill, H.-G.: Meta Modeling for Business Process Improvement. *Business & Information Systems Engineering*, 59(4):251–275, 2017.
- [NF17] Nabizai, Arzo; Fill, Hans-Georg: Eine Modellierungsmethode zur Visualisierung und Analyse von Gesetzestexten. *Jusletter IT*, (23. Februar 2017), 2017.
- [PF19] Pittl, B.; Fill, H.-G.: A Visual Modeling Approach for the Semantic Web Rule Language. *Semantic Web (SWJ)*, Pre-Press, 2019. DOI: 10.3233/SW-180340.
- [Sa18] Sandkuhl, K.; Fill, H.-G.; Hoppenbrouwers, S.; Krogstie, J.; Matthes, F.; Opdahl, A.; Schwabe, G.; Uludag, Ö.; Winter, R.: From Expert Discipline to Common Practice: A Vision and Research Agenda for Extending the Reach of Enterprise Modeling. *Business & Information Systems Engineering*, 60(1):69–80, 2018.
- [Ö11] Österle, H.; Becker, J.; Frank, U.; Hess, H.; Karagiannis, D.; Kremer, H.; Loos, P.; Mertens, P.; Oberweis, A.; Sinz, E.: Memorandum on design-oriented information systems research. *European Journal of Information Systems*, 20:7–10, 2011.

OMiLAB-Node Vienna at the Research Group Knowledge Engineering, University of Vienna

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Abstract: This paper presents the OMiLAB-Node Vienna, which supports the educational and research activities undertaken by the Research Group Knowledge Engineering at the University of Vienna, the Node's host. The OMiLAB Vienna Node is part of a larger community which is presented subsequently. Last but not least the OMiLAB community's relevance for the EMISA Special Interest Group is discussed.

Keywords: OMiLAB, open models, domain-specific conceptual modeling, Agile Modeling Method Engineering, digital product design

1 General Orientation

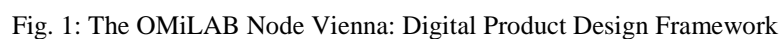
The advent of the Digital Age, wherein the physical and digital converge visibly requires concepts, methods and tools where advanced information systems support emerging and evolving ecosystems. The Research Group Knowledge Engineering focuses on establishing appropriate research approaches as well as enabling the creation of the corresponding artefacts within design-oriented information systems engineering [Ös01]. As such the Agile Modelling Method Engineering (AMME) Framework [Ka15] prescribes an iterative conceptualization lifecycle, which can be applied to create modelling methods [KK02] and tools. AMME considers, amongst others, the requirement of agility, i.e. the idea that nowadays modelling methods might be required to be responsive to emergent or evolving needs for extension, adaptation, hybridization or generally customization [Bo19]. One example domain with such requirements is described in [Hi16]. These circumstances require not only suitable scientific concepts but also appropriate advanced laboratories with experimental spaces, which allow the iterative design, development and deployment of modelling languages.

2 OMiLAB-Node Vienna

The OMiLAB Node Vienna is such an advanced laboratory. Similarly to the other Nodes of the OMiLAB community, it is equipped both with the physical and virtual lab facilities for the conceptualization, development and deployment of modelling methods, tools and the models designed with them.

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Each experimentation space is designed in a three-layered architecture. On the top level use cases from the Application Domain (represented through the Business Layer) provide requirements for modelling methods and models to be refined and then modelled on the middle level, i.e. the Conceptual Modelling Layer. On the technology deployment level, i.e. the Proof-of-Concept Layer, technology-specific constructs must be mapped to modelling concepts, possibly imposing constraints and the need for interoperability between the modelling and the run-time environment [Bo19].



The Evaluation Space is used both during the research and educational process of the Research Group. For instance students at graduate level, work within the evaluation space, to define their own modelling methods for domains as different as Smart Cities [Bo16], Cyber-Physical Systems [WK19], and Enterprise Modelling [Sa18] and execute

corresponding experiments. Research projects like DIGITRANS² use the OMiLAB-Node Vienna to implement a modelling tool prototype and disseminate the results for exploitation to the community.

The virtual lab facilities replicate the functionalities of the physical lab and add services to them. As such a virtual space can be set-up to execute, document and share experiments, a project space for individual or (student) group-based projects can be created, and access to tools and development services as well as remote access to the CPS-environment in the physical lab is possible.

The virtual lab is also one of the interaction points for the physical lab with the OMiLAB community. Others include activities like publications, events, and common projects.

3 OMiLAB

The concept of OMiLAB was inspired by the open source movement and motivated by the belief that the conceptual modelling community has yet to harness its collaborative innovation potential. Hence, OMiLAB functions as an open community and resource repository, by orchestrating various enablers that deploy together a conceptualization and operationalization process for modelling methods [Bo19]. The community follows a user-driven approach in its understanding of the term “model”; it recognizes that there are useful models in widely different domains and functional areas of enterprises. As such the concept of an OMiLAB-Node can be applied to any domain and application that derives value from conceptual models as OMiLAB is open to all applications and domains.

Organisationally OMiLAB is composed of a network of individual OMiLAB-Nodes – similar to the one presented in Chapter 2. A non-profit organisation, located in Berlin (Germany), provides administrative and organisational support to the community.

OMiLAB’s audience is a multi-disciplinary community comprising multiple roles, each bringing its requirements or expertise for common benefits, e.g.:

- experts from different domains, who want to be supported by conceptual modelling methods and tools
- modelling method engineers who need to consult domain expertise in order to understand the requirements and semantics of a specific domain
- modellers seeking agile modelling tools whose degree of domain-specificity may be customized for different goals
- scientists who need an experimentation setup that involves models, either as a means to an end or as an artefact under study [GMS16]

² DIGITRANS Project, <http://www.interreg-danube.eu/approved-projects/digitrans>

Collaboration between the different user roles and OMiLAB-Nodes is enacted in different activities, which are either (1) educational, (2) research- or innovation-oriented, or (3) community-oriented in nature. Some sample activities are presented hereinafter.

a) Modelling tools for education: Bee-Up³

Bee-Up is an implementation of a hybrid modelling method which incorporates and extends the following modelling languages: Business Process Modelling Notation (BPMN), Event-driven Process Chains (EPC), Entity-Relationship Diagrams (ER), the Unified Modelling Language (UML) and Petri-Nets [Ka16].

Bee-Up is a ready-to use open educational tool, implemented on the ADOxx[®] meta-modelling platform. It enables model design, processing (e.g. simulation, semantic transformation and SQL-code generation) and settings for the application of models together with Cyber-Physical Systems.

b) Collaboration Project: The DigiFoF Example

The Erasmus+ Knowledge Alliance project “DigiFoF: Digital Design Skills for Factories of the Future” applies concepts and methods from different disciplines to provide a holistic education on Factory of the Future (FoF) design for students and professionals. 5 OMiLAB-Nodes, customized for FoF needs, will be created in Romania, France, Italy, Poland and Finland. These quasi-industrial spaces will aid trainees to develop creativity and knowledge suitable for digital workplace requirements by giving them access to state-of-the-art design tools as well as open-source platforms and communities.

c) The NEMO Summer School⁴

NEMO stands for “Next-Generation Enterprise Modelling”. It is an intensive short programme which takes place yearly since 2014 and which has established an international academic collaboration forum. Students have the unique opportunity to interact with a large number of professors addressing different foci of enterprise modelling, while the community has a meeting place to share experiences and discuss future collaboration opportunities.

4 Relevance for the EMISA Special Interest Group

Both the activities as well as the OMiLAB-Node infrastructures contribute to the development of modelling methods and models for enterprises. They enable academics

³ Bee-Up Tool: <http://austria.omilab.org/psm/content/bee-up/info?view=home>

⁴ NEMO Summer School: <http://nemo.omilab.org/nemo/>

and researchers to address the societal challenge of Digital Transformation with regard to conceptual models and their use in and for information systems.

References

- [Bo16] Bork, D.; Fill, H.-G.; Karagiannis, D.; Miron, E.-T.; Tantouris, N.; Walch, M.: Conceptual Modelling for Smart Cities: A Teaching Case. *Interaction Design and Architectures (IXD&A)* 27/15, pp. 10-28, 2015.
- [Bo19] Bork D.; Buchmann R.A.; Karagiannis D.; Lee M.; Miron E.-T.: An Open Platform for Modelling Method Conceptualization: The OMiLAB Digital Ecosystem. *Communications of the Association for Information Systems* to appear in 2019.
- [GMS16] Götzinger D.; Miron E.-T.; Staffel F.: OMiLAB: An Open Collaborative Environment for Modelling Method Engineering. In (Karagiannis D.; Mayr H.C.; Mylopoulos J. eds.): *Domain-specific Conceptual Modelling: Concepts, Methods and Tools*, Springer, pp. 55-76, 2016.
- [Hi16] Hinkelmann, K.; Gerber, A.; Karagiannis, D.; Thoenssen, B.; van der Merwe, A.; Woitsch, R.: A new paradigm for the continuous alignment of business and IT: Combining enterprise architecture modelling and enterprise ontology. *Computers in Industry, Special Issue on Future Perspectives On Next Generation Enterprise Information Systems/16*, pp. 77 – 86, 2016.
- [Ka15] Karagiannis D.: Agile Modelling Method Engineering. In (Karanikolas, N. N.; Akoumianakis, D.; Nikolaidou, M.; Vergados, D. D.; Xenos, M.; Giaglis, G. M.; Gritzalis, S.; Merakos, Lazaros F.; Tsanakis, P.; Sgouropoulou, C. eds.): *Proceedings of the 19th Panhellenic Conference on Informatics (PCI2015)*, pp. 5-10, 2015.
- [Ka16] Karagiannis, D.; Buchmann, R. A.; Burzynski, P.; Reimer, U.; Walch, M.: Fundamental Conceptual Modeling Languages in OMiLAB. In (Karagiannis D.; Mayr H.C.; Mylopoulos J. eds.): *Domain-specific Conceptual Modelling: Concepts, Methods and Tools*. Springer, pp. 3-30, 2016.
- [KK02] Karagiannis D.; Kühn H.: Metamodeling Platforms. In (Bauknecht K.; Tjoa A.; Quirchmayr G. eds.): *Proceedings of the Third International Conference EC-Web 2002*, Springer, pp. (p. 182), 2002.
- [Ös01] Österle, H.; Becker, J.; Frank, U.; Hess, H.; Karagiannis, D.; Krcmar, H.; Loos, P.; Mertens, P.; Oberweis, A.; Sinz, E.: Memorandum on design-oriented information systems research. *European Journal of Information Systems* 1/11, p. 7-10, 2011
- [Sa18] Sandkuhl, K.; Fill, H.-G.; Hoppenbrouwers, S.; Krogstie, J.; Matthes, F.; Opdahl, A.; Schwabe, G.; Uludag, Ö.; Winter, R.: From Expert Discipline to Common Practice: A Vision and Research Agenda for Extending the Reach of Enterprise Modelling. *Business & Information Systems Engineering* 15/18, pp.69-80, 2018.
- [WK19] Walch, M.; Karagiannis, D.: How to connect design thinking and cyber-physical systems: the s*IoT conceptual modelling approach. In (Bui, T.X.; Sprague, R.H. eds.), *Proceedings of the 49th Hawaii International Conference on System Sciences*, S. 7242-7251, 2019

Business Process Modeling Approaches and Tools at the Institute for Project Management and Information Modeling (IPIM)

Christian Seel^{1†}, Julian Dörndorfer¹, Daniel Hilpoltsteiner¹ and Holger Timinger¹

Abstract: Information Modeling has been a core research area in the IS discipline. Furthermore, the design and implementation of information modeling tools is an established and frequently used method to examine artifacts and phenomena. Especially in design-science-research (DSR) the implementation of prototypic modeling tools is often a key success factor for the proof-of-concept and evaluation of artefacts. The Institute for Project Management and Information Modeling (IPIM) focuses on DSR and implementation of modeling prototypes, e.g. the SenSoMod-Modeler or an adaptive BPMN modeling tool. SenSoMod is a domain-aware modeling language, which enables to model the data origin and aggregation of context as input for mobile context-sensitive business processes. The BPMN modeling tool enables the modeling of adaptive process models including all variants of a process. The tool also enables the extraction of a concrete variant from the adaptive model using parameters. At the exhibition both concepts and tools will be presented.

Keywords: Business Process Modeling, Modeling Adaption, Domain-Specific Modeling

1 Introduction and Motivation

Information Modeling has been a core research area in the IS discipline. Furthermore, the design and implementation of information modeling tools is an established and frequently used method to examine artifacts and phenomena. Especially in design-science-research (DSR) the implementation of prototypic modeling tools is often a key success factor for the proof-of-concept and evaluation of artefacts. The Institute for Project Management and Information Modeling (IPIM) focuses on DSR and implementation of modeling prototypes. The Institute was founded in 2014 as a central, cross-faculty institute and defines its areas of activity on the basis of three pillars. The first pillar addresses current issues of efficient project management. It focuses in particular on topics such as hybrid and agile project management in small and medium-sized enterprises (SMEs) [TS16]. The second pillar is information modelling. Topics such as modeling of business processes [DS17], data and operational software systems [PSM15], Business Process as a Service (BPaaS) [BS14] or the development of domain-specific modeling languages [DSH18] are on focus. The intersection of these two topics results in the third pillar of the institute, which deals with reference and process models for project management. Within the framework of this third pillar, work is currently being carried out on an adaptive reference

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model for hybrid project management [Ch18]. In particular, this improves cooperation between SMEs and large companies in projects that combine agile and classical project management methods. Furthermore, the institute addresses questions concerning the application of artificial intelligence in all three pillars. All three subject areas are represented at the IPM in research, teaching and further education. Several research projects, funded by the Free State of Bavaria², the Federal Ministry of Education and Research³ (BMBF) and the EU⁴, are currently conducted. The IPIM is an active member in a number of renowned professional associations and standardization organizations, such as the Object Management Group (OMG), the Gesellschaft für Projektmanagement (GPM) or the Gesellschaft für Informatik (GI). Besides of the undergraduate courses in project management and information modelling in several bachelor and master programs, the institute offers further education in the form of its own MBA program Systems and Project Management as well as several certificate courses.

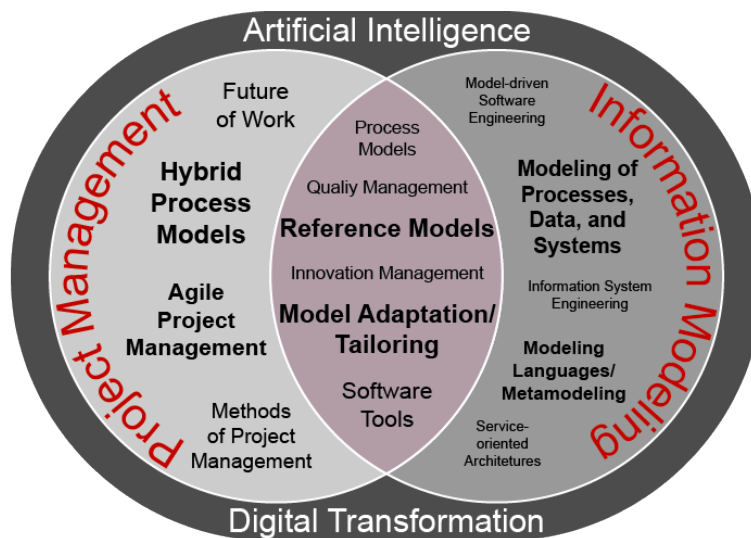


Fig. 1: Topics of the IPIM

² Internet Kompetenzzentrum Ostbayern – Kompetenzzentrum Mobile Business und Social Media <http://www-mbsm.uni-regensburg.de/index.php>

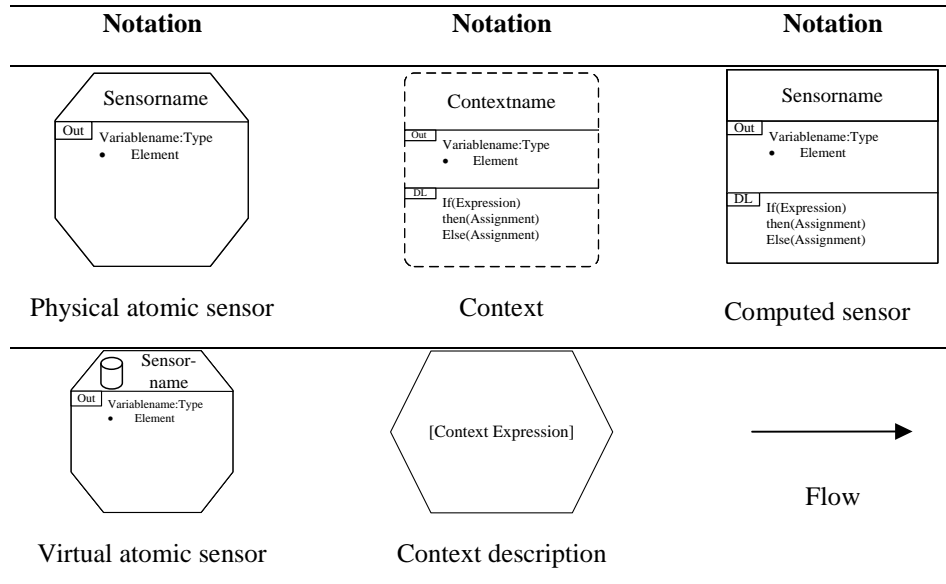
³ Self Service Konfiguration von Projektmanagementmethode und -werkzeug (PRAGUE) Funding Number: 01IS17093C

⁴ European Regional Development Fund (ERDF) – „Investition in Wachstum und Beschäftigung“ Bavaria 2014 – 2020. Funding Number: EU-1703-0001

2 Modeling Approaches and Tools

2.1 SenSoMod

SenSoMod is a domain-specific modeling language (DSML) for modeling the data collection and aggregation for context. The reason to develop a new DSML instead of extending an existing modeling language (e.g. BPMN) was that this would be an extensive enlargement which would lead to large and overloaded models. It was developed after the visualization principles by DEELMAN and LOSS [DL04], which includes guidelines for using similar shapes, line types and thickness, among others. The notation of SenSoMod can be seen in Tab. 1. A sensor can be any source of data, e.g. usual physical sensors which measure physical quantities, or a database or an application. Therefore, physical and virtual atomic sensors have to be distinguished to indicate the origin of the data. Furthermore, an atomic sensor indicates that the data cannot be aggregated from other sensors. When data can be derived or aggregated from different sources, the element *computed sensor* should be used. All sensors have an *Out* field to state and describe their outgoing objects and data types for example a float type for the humidity. In addition, the computed sensor has an *DL* field to describe the decision logic for outgoing elements. This is necessary to express when a certain state from the *Out* field of a sensor will be returned. The context element is based on at least one sensor and has to match with the name of the mentioned context in the context description.



Tab. 1: Notation of SenSoMod

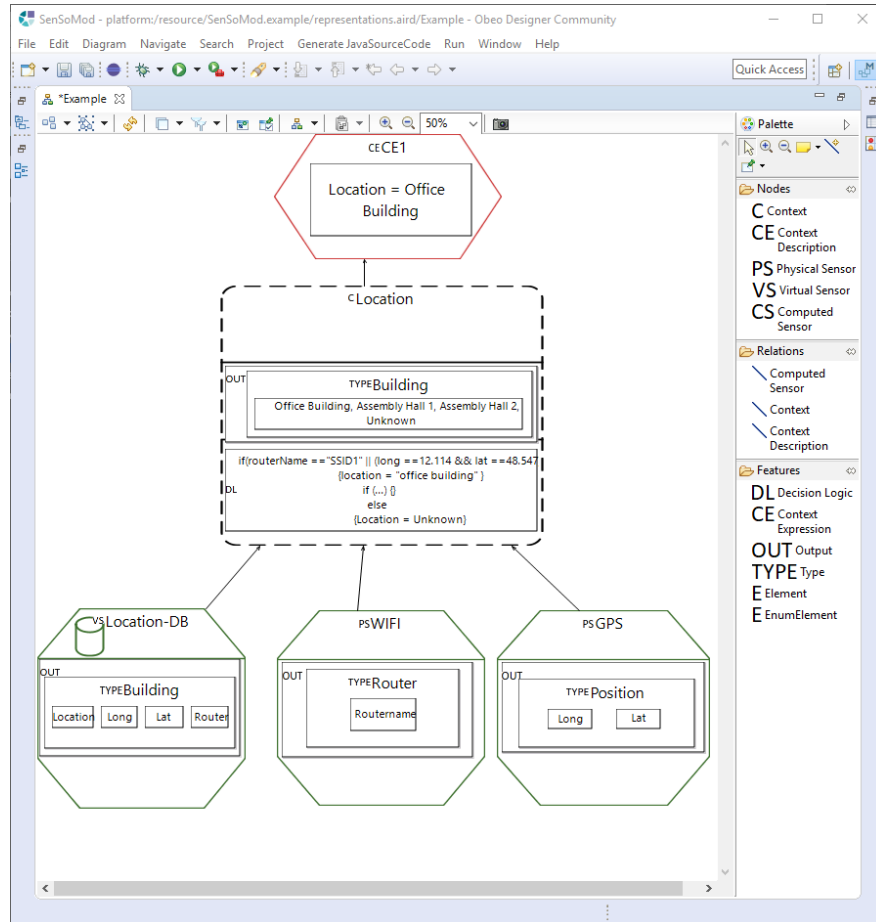


Fig. 2: SenSoMod-Modeler

The context description element is dedicated to describe a context term in a business process and is also part of the BPMN extension Context4BPMN. A more elaborated explanation of SenSoMod can be found in [DSH18]. The Language Workbench Obeo Designer [Ob18] was used to create a comprehensive modelling tool for SenSoMod, which can be seen in Fig. 2. This Tool is called the SenSoMod-Modeler. It enables to model with the SenSoMod notations according to the rules of the language. Fig. 2 also shows a small example of how SenSoMod can be used to model the context 'location' from the sensors 'WIFI', 'GPS' and 'Location-DB'. The latter can be seen as green atomic sensors at the bottom of the screenshot. The *Out*-area shows that for example the GPS sensor returns an object 'Position' with the values Long and Lat. In the middle of the screenshot the context 'location' can be seen. It also returns an object 'Building'. Depending on the decision logic in the DL-area it returns the relevant building. The SenSoMod-Modeler can also generate

java code from the model which includes the defined types of the *Out* as well as the logic of the *DL* areas.

2.2 BPMN-Modeler

Information modeling has been established as a standard description tool in business informatics and is frequently used to model processes and company data [Se10]. In practice, concrete problems arise in the management of model variants. These problems can be found in many industries and application areas, such as logistics, project management [TS16] and vehicle leasing for the bank of an automobile manufacturer [Se17]. A concrete example would be related to maintaining consistency across different process variants, which only differ in small details. LA ROSA et al. provide an overview of various existing approaches to model process variants through adaptive, configurable models [La17]. In general, configurable models can be adapted by adding or removing submodels. However, the existing approaches of the construction of adaptive information model are only practicable if they are supported by software tools, which is why software support is indispensable [Th06]. In a study, SEEL et al. examined various open source modeling tools for their suitability as research prototypes for the construction of adaptive information models [Se16]. The study find that previous modeling tools are only of limited use for this purpose since they do not contain all necessary functionalities. The Camunda Modeler was identified as a solid basis for a more comprehensive modeling tool to construct adaptive information models. HILPOLTSTEINER et al. presented the conception and development of a research prototype based on the Camunda modeler. The tool supports users maintaining the single adaptive model with all different variants and let them extract a concrete process variant in a situation based on variables. Using a single model can reduce the administration amount and reduces the risk of inconsistencies across multiple files. As an example, for the complexity of variant management, the situation of a larger car leasing bank, which maintains process variants for different countries of the world was chosen. In this example process variants for different countries only differ in small details, because of regional characteristics of the market or applicable law [HSD18]. In concrete terms, an adaptive information model was created from various individual process variants. This was extended with the help of configuration terms to identify the variants later. A configuration term represents decision rules and consists of a combination of variables and logical operators, which together lead to a true or false statement. This procedure is called element selection by terms [Be02]. Furthermore, the modeling tool was used by HILPOLTSTEINER et al. to identify and document process variants in the field of goods picking [HBS18]. Several Variants of picking processes were identified in different companies and combined in an adaptive model (cf. Fig. 3). Some of the companies used different of these picking process variants for special product categories. With the help of the Technology Centre at the University of Applied Sciences Landshut and cooperation partners in the technology transfer project, work is continuing on constructing adaptive information models for further improvements and evaluation.

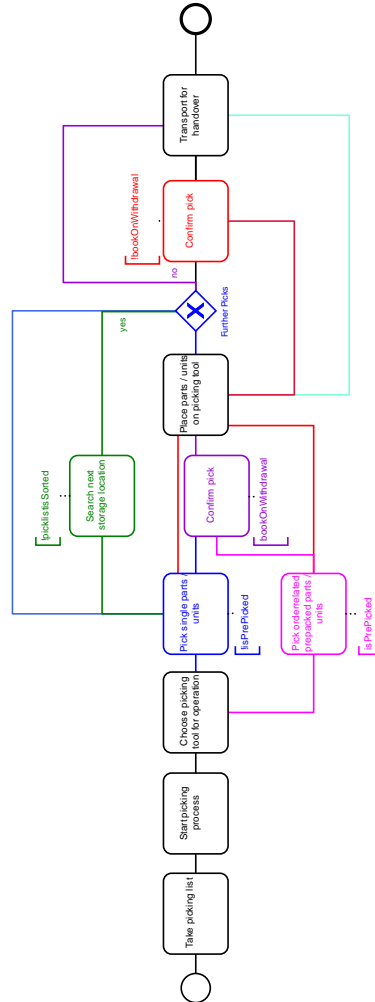


Fig. 3: Adaptive Information model for the picking process found in small and medium sized enterprises. Source: Hilpoltsteiner et al. [HBS18]

3 Further Research

In general, business process modeling is the basis for a variety of applications in different areas. Thus, business process modeling itself is subject to ongoing research in order to adapt to changing requirements and new applications. The Institute for Project Management and Information Modeling (IPIM) addresses this by developing – where necessary – new modeling languages, appropriate tools in order to conduct the modeling

process, new applications which are enabled by new models, new modeling techniques or new modeling tools. With SenSoMod, IPIM developed a new domain-specific modeling language (DSML) which serve as a context modeling language. It enables to model contextual influences on business process and (mobile) applications. Good software design and user-friendly mobile applications require well-designed business processes. These in turn can be created and optimized using thorough models. While static models serve as basis for the creation and optimization of business processes, more sophisticated applications require the use of (self-)adaptive business process models. Adaptive models offer the opportunity, to optimize a generic process model in dependence of a set of parameters. To demonstrate the feasibility and the opportunity of such adaptive business process models, IPIM developed a research prototype which is based on the Camunda modeler tool. In order to determine further research needs in the combined area of process and project management, IPIM developed a maturity model for digitalization in project management [TS18]. According to this, adaptive process models are required for various applications, like self-learning and knowledge management using artificial intelligence. The unique nature of project requires a sound knowledge base, which is represented by process models. For this, the BPMN modeler can be used and serve as development platform for future prototypes and applications.

Literaturverzeichnis

- [Be02] Becker, J. Hrsg.: Wissensmanagement mit Referenzmodellen. Konzepte für die Anwendungssystem- und Organisationsgestaltung ; mit 13 Tab. Physica-Verl., Heidelberg, 2002.
- [BS14] Barton, T.; Seel, C.: Business Process as a Service – Status and Architecture. In (Mutschler, B.; Otjacques, B.; Feltz, F. Hrsg.): Enterprise Moelling and Information Systems Architectures (EMISA), 2014; S. 145–158.
- [Ch18] Christian Seel, Holger Timinger, Martina Blust, Christian Neu, Dirk Werth: Hybrides Projektmanagement. Modellbasiert zum individuellen Vorgehen in Projekten. In IM+io, 2018, 2018.
- [DL04] Deelmann, T.; Loos, P.: Grundsätze ordnungsmäßiger Modellvisualisierung. In (Rumpe, B. Hrsg.): Modellierung 2004. Proceedings. Ges. für Informatik, Bonn, 2004; S. 289–290.
- [DS17] Dörndorfer, J.; Seel, C.: A Meta Model Based Extension of BPMN 2.0 for Mobile Context Sensitive Business Processes and Applications. In (Leimeister, J. M.; Brenner, W. Hrsg.): Proceedings der 13. Internationalen Tagung Wirtschaftsinformatik (WI), St. Gallen, 2017; S. 301–315.
- [DSH18] Dörndorfer, J.; Seel, C.; Hilpoltsteiner, D.: SenSoMod – A modeling language for context-aware mobile applications. In (Paul, D. et al. Hrsg.): Multikonferenz Wirtschaftsinformatik (MKWI). Data Driven X - Turning Data into Value, 2018; S. 1435–1446.
- [Fo05] Fowler, M.: Language Workbenches: The Killer-App for Domain Specific

- Languages? <https://www.martinfowler.com/articles/languageWorkbench.html>, 22.11.2018.
- [HBS18] Hilpoltsteiner, D.; Bäuml, S.; Seel, C.: Picking Process Variability in Small and Medium-Sized Enterprises. State of the Art and Knowledge Modeling: Proceedings of the 10th International Joint Conference on Knowledge Discovery, Knowledge Engineering and Knowledge Management. SCITEPRESS - Science and Technology Publications, 2018; S. 120–127.
- [HSD18] Hilpoltsteiner, D.; Seel, C.; Dörndorfer, J.: Konzeption und Implementierung eines Softwarewerkzeuges zum Management von BPMN-Prozessvarianten. In (Hofmann, R.; Alm, W. Hrsg.): Wissenstransfer in der Wirtschaftsinformatik. Fachgespräch im Rahmen der MKWI 2018. Hochschule Aschaffenburg, Information Management Institut, Aschaffenburg, 2018; S. 15–24.
- [La17] La Rosa, M. et al.: Business Process Variability Modeling. In ACM Computing Surveys, 2017, 50; S. 1–45.
- [Ob18] Obeo: The Professional Solution to Deploy Sirius - Obeo Designer. <https://www.obeodesigner.com/en/>, 22.11.2018.
- [PSM15] Panfilenko, D. V.; Seel, C.; Martin, A.: The VCLL: A Multi-view Computation Independent Modelling Language for MDA-Based Software Development. In (Sedera, D.; Gronau, N.; Sumner, M. Hrsg.): Enterprise Systems. Strategic, Organizational, and Technological Dimensions. Springer International Publishing, Cham, 2015; S. 138–153.
- [Se10] Seel, C.: Reverse Method Engineering. Methode und Softwareunterstützung zur Konstruktion und Adaption semiformaler Informationsmodellierungstechniken. Logos, Berlin, 2010.
- [Se16] Seel, C. et al.: Vergleichende Analyse von Open-Source-Modellierungswerkzeugen als Basis für Forschungsprototypen. In Landshuter Arbeitsberichte zur Wirtschaftsinformatik (Lab WI), 2016; S. 1–43.
- [Se17] Seel, C.: Metamodellbasierte Erweiterung der BPMN zur Modellierung und Generierung von Prozessvarianten. In (Barton, T. et al. Hrsg.): Prozesse, Technologie, Anwendungen, Systeme und Management 2017. Angewandte Forschung in der Wirtschaftsinformatik Tagungsband zur 30. AKWI-Jahrestagung vom 17.09.2017 bis 20.09.2017 an der Hochschule Aschaffenburg. Hochschule Aschaffenburg; mana-Buch, Aschaffenburg, Heide, 2017; S. 41–50.
- [Th06] Thomas, O.: Das Referenzmodellverständnis in der Wirtschaftsinformatik. Historie, Literaturanalyse und Begriffsexplikation. In Institut für Wirtschaftsinformatik (IWi), 2006.
- [TS16] Timinger, H.; Seel, C.: Ein Ordnungsrahmen für adaptives hybrides Projektmanagement. In GPM-Magazin PMaktuell, 2016, 2016; S. 55–61.
- [TS18] Timinger, H.; Seel, C.: Vision und Reifegradmodell für digitalisiertes Projektmanagement. In (Barton, T.; Müller, C.; Seel, C. Hrsg.): Digitalisierung in Unternehmen. Von den theoretischen Ansätzen zur praktischen Umsetzung. Springer Fachmedien Wiesbaden, Wiesbaden, 2018; S. 159–175.

Model-Based Software Engineering at RWTH Aachen University

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Abstract: In this article, the Software Engineering Research Group of RWTH Aachen University presents its research aim, research topics and some research highlights that have been researched over the last ten years. Furthermore, the relevance of agile, generative and model-based software engineering methods for the special interest group Enterprise Modelling and Information Systems Architectures (SIG-EMISA) is discussed.

Keywords: Agile Development Methods · Domain-Specific (Modeling) Languages · Generation of Enterprise Information Systems · Generative Methods · Model-Based Software Engineering · Research

1 The Research Group

The chair of Software Engineering (SE) is one out of 30 research areas of the Department of Computer Science in the Faculty for Mathematics, Computer Science and Natural Sciences of RWTH Aachen University, the largest university for technical studies in Germany. The research focus of SE is the definition and improvement of languages, methods, concepts, tools and infrastructures for the efficient development of software. The chair is currently organized in four working groups: Automotive and Cyber-Physical Systems (ASE), Model-Based Assistance and Information Services (MBAIS), Model-Driven System Engineering (MDSE) and Modeling Language Engineering (MLE). SE is a partner in the Cluster of Excellence *Internet of Production* and co-initiator of the *Center for Systems Engineering* at RWTH Aachen University.

Our teaching activities include courses in Software Engineering, Model-Based Software Engineering, Software Language Engineering and Software Architectures for the informatics bachelor and master curricula as well as for other curricula such as software and systems engineering, data science or mathematics. Following a research driven teaching approach, our exercises and seminar topics are strongly related to current topics such as autonomous driving, digital transformations, model-based assistance and e-health and model-driven systems engineering for cyber-physical systems.

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2 Research Aim and Topics

The history of software development is marked by a series of software projects that have been unsuccessful or have failed altogether: They ran out of time, were more expensive than expected or used the wrong technology. Even if they were regarded as successful from the developer's point of view, they could fail due to the acceptance of the future users. We believe and have successfully demonstrated in various industrial projects that the use of agile, model-based and generative methods could help to overcome such problems.

The aim of the SE group is to improve software and systems development by identifying languages, methods, concepts, tools and infrastructures for developing software systems better and faster in order to achieve a high quality product in less time while incorporating constantly changing requirements in an agile way.

Current fields of research include model-based development of software and systems in an agile manner using generative methods. The input for generators are models created using domain-specific modeling languages. Other topics, which are strongly related to the research focus of the special interest group EMISA, is the modeling of software architectures, enterprise information systems as well as assistive systems. The broad knowledge of the research group is documented in over 200 publications and a series of successful research projects.

Agile, Model-Based Software Engineering (MBSE). Software engineers typically use *models* to be able to understand complex software systems. In model-based development processes, one or more modeling languages are the central notation and replace the programming language as much as possible. To use an executable, abstract and multi-view modeling language for modeling, designing and programming allows to use an agile development process [Ru12; Ru17]. Thus, the SE group has successfully evaluated agile, model-based software engineering in various industrial projects in the areas of embedded systems, autonomous vehicles, IoT, smart buildings, IoP, robotics and cloud systems within the last decade.

Generative Software Engineering. The use of generative methods and MBSE improves the adaptability and reusability of applications, increases the quality of the software and supports iterative development through constant regeneration based on the given models. For product and test code generation, we use the UML/P language family [Ru12; Ru16] as a simplified and semantically sound derivate of the UML. With *MontiCore* [HR17; KRV10], the framework for the creation and processing of domain-specific languages, the SE group has successfully demonstrated the practical application of generative and model-based methods. Projects included requirements analysis, functional, version and variant modelling as well as the development of software and hardware architectures.

Domain Specific (Modeling) Languages (DSLs). For domain-specific needs, MBSE relies on the use of DSLs as a central notation. DSLs can be developed to be used for several purposes such as designing, programming and testing software systems or for describing

the behavior of a system or process. The SE group has already developed a collection of UML/P [Ru11] inspired DSLs such as Class Diagrams for Analysis or the GUI DSL [Ad19]. Moreover, the chair has a sound theoretical knowledge of modelling languages and their semantics [KR18]. Other work in this area focusses, e.g., on guidelines to define DSLs [Ka09].

Modeling Software Architecture. Distributed interactive system architectures rely on the communication paradigm of asynchronous message passing between actors. We built a concrete tooling infrastructure called MontiArc [HRR12] for modeling such distributed interactive systems and their architecture design as well as extensions for states [RRW13]. Current work focusses e.g., on the architecture of cloud services for the digital me in privacy-aware environments [Ei17], or on tool integration via component connector architectures [Da19].

Models in Enterprise Information System Development. Using our experiences in the model-based generation of code with MontiCore, we developed several generators for data-centric applications. The most recent one, MontiGEM [Ad19], was successfully applied in an application project for the financial controlling of the chairs of RWTH Aachen University. [Ad18] presents our approach for the model-based generation of data-intensive EIS in the MaCoCo project. Current research adapts and extends MontiGEM for mobile applications, further graphical representation components as well as the development of information portals.

Model-Based Assistance. Assistive systems support people in carrying out their activities by providing them a just-in-time activity support. Continuing work started at the Universität Klagenfurt [MM13], model-based approaches for assistive systems and their context models [MS17] are under investigation. The mark-up of online manuals for non-smart devices [SM18] as well as websites [SM19] is one further step to provide human-centered assistance. Other aspects are data-structures and architectural decisions for user-centered privacy-driven system design [Mi19].

Besides these research topics, the SE group works on (1) methodologies for software language engineering (SLE), (2) the analysis of the semantics of modeling languages, (3) evolution, transformation, compositionality and modularity of models, (4) variability and Software Product Lines (SPL), (5) the interplay of software and hardware in cyber-physical systems (CPS), (6) the area model-driven systems engineering in which software for modern systems of systems is investigated and developed, (7) the application of state-based modeling (automata) on systems and (8) the application of MBSE in particular domains such as robotics, automotive energy management, cloud computing, Internet of Things(IoT) or industry 4.0. Our domain specific language framework *MontiCore*² features the agile and compositional development of DSLs and forms a basis for further developments and solutions.

²<http://www.monticore.de/>

3 Relevance for the SIG-EMISA

The research topics of the SE group that we have explained in more detail in this paper, contribute especially to the engineering of information systems, services and their architectures, which are as well some main aspects of the SIG-EMISA.³ Our research considers the software development process from a scientific perspective, from the model to the delivered software. The model-based development of software and systems in an agile way with generative methods and domain-specific modelling languages offers a good foundation for the development of information and assistance services and systems based on a stable system architecture.

References

- [Ad18] Adam, K.; Netz, L.; Varga, S.; Michael, J.; Rumpe, B.; Heuser, P.; Letmathe, P.: Model-Based Generation of Enterprise Information Systems. In: EMISA'18. CEUR 2017, pp. 75–79, 2018.
- [Ad19] Adam, K.; Michael, J.; Netz, L.; Rumpe, B.; Varga, S.: Enterprise Information Systems in Academia and Practice: Lessons learned from a MBSE Project. To appear in: In: EMISA'19. Pp. 1–8, 2019.
- [Da19] Dalibor, M.; Jansen, N.; Michael, J.; Rumpe, B.; Wortmann, A.: Towards Sustainable Systems Engineering-Integrating Tools via Component and Connector Architectures. In: Antriebstechnisches Kolloquium 2019: Tagungsband zur Konferenz. Pp. 121–133, 2019.
- [Ei17] Eikermann, R.; Look, M.; Roth, A.; Rumpe, B.; Wortmann, A.: Architecting Cloud Services for the Digital me in a Privacy-Aware Environment. In: Software Architecture for Big Data and the Cloud. Elsevier Science & Technology, chap. 12, pp. 207–226, June 2017.
- [HR17] Hölldobler, K.; Rumpe, B.: MontiCore 5 Language Workbench Edition 2017. Shaker Verlag, 2017.
- [HRR12] Haber, A.; Ringert, J. O.; Rumpe, B.: MontiArc - Architectural Modeling of Interactive Distributed and Cyber-Physical Systems, Technical Report AIB-2012-03, RWTH Aachen University, Feb. 2012.
- [Ka09] Karsai, G.; Krahn, H.; Pinkernell, C.; Rumpe, B.; Schindler, M.; Völkel, S.: Design Guidelines for Domain Specific Languages. In: Domain-Specific Modeling Workshop (DSM'09). Techreport B-108, Helsinki School of Economics, pp. 7–13, Oct. 2009, ISBN: 978-952-488-371-9.

³Clearly, members of the SE group are not only involved in the SIG-EMISA: They are also actively involved in the SIG Software Engineering, as well as the cross-sectional committee for modelling (Querschnittsfachausschuss Modellierung) of the german informatics society (GI).

- [KR18] Kautz, O.; Rumpe, B.: Semantic Differencing of Activity Diagrams by a Translation into Finite Automata. In: Proceedings of MODELS 2018. Workshop ME. Copenhagen, Oct. 2018.
- [KRV10] Krahn, H.; Rumpe, B.; Völkel, S.: MontiCore: a Framework for Compositional Development of Domain Specific Languages. *International Journal on Software Tools for Technology Transfer (STTT)* 12/5, pp. 353–372, Sept. 2010, ISSN: 1433-2779.
- [Mi19] Michael, J.; Koschmider, A.; Mannhardt, F.; Baracaldo, N.; Rumpe, B.: User-Centered and Privacy-Driven Process Mining System Design for IoT. In: Proceedings of the CAiSE'19 Forum. LNBIP, Springer, pp. 1–12, 2019.
- [MM13] Michael, J.; Mayr, H. C.: Conceptual Modeling for Ambient Assistance. In (Ng, W.; Storey, V. C.; Trujillo, J., eds.): *Conceptual Modeling - ER 2013*. Vol. 8217. LNCS, Springer, pp. 403–413, 2013.
- [MS17] Michael, J.; Steinberger, C.: Context Modeling for Active Assistance. In (Cabanillas, C.; España, S.; Farshidi, S., eds.): *Proc. of the ER Forum 2017 and the ER 2017 Demo Track co-located with the 36th International Conference on Conceptual Modelling (ER 2017)*. Pp. 221–234, 2017.
- [RRW13] Ringert, J. O.; Rumpe, B.; Wortmann, A.: MontiArcAutomaton: Modeling Architecture and Behavior of Robotic Systems. In: *Conference on Robotics and Automation (ICRA'13)*. IEEE, pp. 10–12, 2013.
- [Ru11] Rumpe, B.: *Modellierung mit UML*. Springer Berlin, 2011.
- [Ru12] Rumpe, B.: *Agile Modellierung mit UML: Codegenerierung, Testfälle, Refactoring*. Springer Berlin, 2012.
- [Ru16] Rumpe, B.: *Modeling with UML: Language, Concepts, Methods*. Springer International, 2016.
- [Ru17] Rumpe, B.: *Agile Modeling with UML: Code Generation, Testing, Refactoring*. Springer International, 2017.
- [SM18] Steinberger, C.; Michael, J.: Towards Cognitive Assisted Living 3.0. In: *Advanced Technologies for Smarter Assisted Living solutions: Towards an open Smart Home infrastructure (SmarterAAL workshop) at Percom'18*. IEEE, pp. 1–6, 2018.
- [SM19] Steinberger, C.; Michael, J.: Using Semantic Markup to Boost Context Awareness for Assistive Systems. In: *Smart Assisted Living - towards an open smart home infrastructure*. Springer, 2019.

The Research Group Business Information Systems at the University of Rostock

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Abstract: The paper presents the general orientation, research topics and contribution to the EMISA special interest group of Rostock University's research group on Business Information Systems, which is part of the Institute of Computer Science in the Faculty of Computer Science and Electrical Engineering.

Keywords: Enterprise Modelling, Capability Management, Enterprise Architecture Management, Digital Business, Knowledge Management, Smart Process Management, Mobile Computing, Wearable Computing, Reference Modelling.

1 General Orientation

For many years the modelling of processes, enterprises and knowledge forms the frame of business information systems (IS) research in Rostock. In general, this research field is concerned with the systematic process of capturing, representation, analysis and evolution of domain knowledge aligned towards pre-defined enterprise goals. Therefore, it combines traditional topics of IS research (e.g. IS modelling) with work from computer science (e.g. knowledge representation) and approaches from the field of industrial organization (e.g. enterprise engineering). In the following, more detailed information is given about our research topics.

2 Research Topics

2.1 Capability Management

Nowadays, enterprises and organizations are confronted with rapidly changing situations in their environment when it comes to changing regulations, globalization of market structures, time-to-market pressures and advances in technology. In many industrial sectors, efficient and effective value creation and service delivery processes are considered as the key factors to competitiveness in a globalized market environment. In this context, the systematic management of capabilities of an enterprise is considered an important activity

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in organizations. The capabilities of an enterprise often are reflected in the business services offered to customers and the technical services associated to them. The notion of capability has received a lot of attention as the enabler of business/IT alignment in changing environments. The term is used in various industrial and academic contexts with often different meanings. Most conceptualizations of the term agree that capability includes the ability to do something (know-how, organizational preparedness, appropriate competences) and the capacity for actual delivery in an application context. Our work in the area of capability management currently focuses on capabilities in enterprise architecture management and capabilities in service-oriented organizations [SS18].

2.2 Reference and Enterprise Architectures

Enterprise Architecture Management (EAM) is an established function in many enterprises responsible for a systematic and coordinated development of business, information systems and IT technology. Many enterprises frequently are forced to modify their business models or their established business architectures because of new market demands, changes in regulations or new technologies. IT often is not only a key resource to facilitate these changes but also essential for daily operations. Enterprise Architectures help to visualise the dependencies within and between the different architectures, develop and analyse alternative options for change, supervise the current status of the architecture or plan changes and roadmaps.

In the field of business information systems, the research group conducts a number of research activities related to EAM methods and to Reference-Enterprise Architectures (R-EA). Methods concern the management of capabilities in EAM, the integration of EAM and Enterprise Modelling, policies and notations in EAM, and EAM use in small and medium-sized enterprises. Reference architectures aim at identifying and capturing typical and recurring architecture elements, their structures and relationships in a defined application domain, e.g., an industry sector. The research group has been working on a R-EA for IT-based compliance for financial industries (project COFIN [TS18]) and medium-sized utility companies (project ECLORA [WTS15]). In the context of these R-EA development projects not only the actual R-EA were constructed but also the methodology for developing R-EA has been subject of research [TS18].

2.3 Digital Business Models

The business model of an enterprise defines, in a nutshell, what products and services are offered by an enterprise for what customer groups to achieve defined business goals and a viable economic situation. In a digital business model, the products and/or services of an enterprise and the way they are provided and delivered are largely digital, i.e. based on IT, often involving mobile devices, collecting data using sensors, and new services and user experience. Analysis and development of business models are a core competence of the research group and require a much more detailed and differentiated understanding of

business models than indicated by the above simplified description [WS17]. Typical perspectives to be taken into account in business models are what value creation happens in an enterprise, what services and products are offered based on this value creation, what suppliers are required, how the market situation looks like (demand structure and competitive situation), how revenues are generated and what the distribution model for the products and services is. In addition to business model analysis and development, implementation of business models is another important aspect of our research. This includes the effects and changes in enterprise architectures and technology building blocks for new business models and digital transformation, such as interactivity, availability, contextualization, mobility, networking, user experience or scalability.

2.4 Knowledge and Context-based Systems

Knowledge-based systems (KBS) are used in various applications areas for, e.g., providing decision support, supporting organizational knowledge management, capturing and implementing business rules, etc. From a technical perspective, KBS require capturing the relevant knowledge in a knowledge base (knowledge engineering). The research group has experiences from a number of projects in both, knowledge engineering and knowledge-based systems [SS19]. From research perspective currently our research topics are ontology design patterns, ontology quality metric (e.g. [LS15]), semantic technologies and their application in small and medium-sized enterprises. Context-based systems use all relevant information from the environment of a user or an application system for adapting functionality, behaviour or user interface to the actual context. Examples for context-based systems are, e.g., e-learning systems adapting to the learner, digital services adapting to their deployment environment or business models adapting to changes in the technical/organizational infrastructure (e.g. [Sa12]). Context-based systems often used a knowledge base to store and evaluate context information. From a research perspective, the research group investigates methods for context modelling, situation-based information supply based on context and context as part of digitization solutions.

2.5 Smart Process Management

Process models play a vital role for the design and implementation of enterprise information systems. In the research field "smart process management", we develop methods and intelligent assistance systems that are tailored to the respective application context and also regularly organize workshops in this context (e.g. [Fe18b]). With this, a more adequate support of the model-based design and the management of process-oriented systems is envisioned. In more detail, in the subject area of business process modelling we explore how recommender systems can be applied to simplify and accelerate the design of models while maintaining a high model quality [Fe17]. Further, we analyse the contribution of patterns and templates to facilitate modelling [Fe18a]. In the subject area of modelling and execution of processes, we investigate to what extent new approaches and tools for case management can contribute to the provision of personal services (e.g. [La18]). In addition,

approaches for individual process management are being developed to better reflect the characteristics of the employees executing a process. Furthermore, the challenges of mining personal service process data for process analysis are in focus. Characterized by unstructured, often incomplete data traces, ad-hoc workflows, human interaction, and soft goals, these processes demand for new process analysis approaches.

2.6 Mobile & Wearable Information Systems

Mobile and wearable information systems are omnipresent. Smartphones are an indispensable part of everyday life and smartwatches and fitness trackers enjoy an increasing popularity. In the research field "Mobile & Wearable Information Systems", we investigate how sensor data, analytics and feedback that build on such devices can be integrated into personal and organizational ways of working [LFS18]. The aim of this integration is to help individuals and organizations to do more productive work – and at the same time increase the well-being of the actors. A particular focus of our research is personal time and task management. In general, when designing such methods and corresponding assistance systems, care must be taken to ensure that a balance is found between the protection of personal data and the functionality of the system. Furthermore, control over the disclosure of personal data should always remain with the user.

3 Relevance for the EMISA Special Interest Group

Our work in the research topics described in section 2 is based on a number of core competencies contributing to the area of enterprise modelling and information systems architecture. Our core competences include the development of modelling methods, tools that support the modelling process, user participation during the model development, modelling practices and the value of modelling. Furthermore, we aim at contributing to the overall development of the topic by investigating future topics and potential roadmaps for addressing them. [Sa18]

Bibliography

- [Fe17] Fellmann, M.; Metzger, D.; Jannaber, S.; Zarvic, N.; Thomas, O.: Process Modelling Recommender Systems – A Generic Data Model and its Application to a Smart Glasses-based Modelling Environment. In: Business & Information Systems Engineering (BISE), 2018, 60; pp. 21–38.
- [Fe18a] Fellmann, M.; Koschmider, A.; Laue, R. Schoknecht, A.; Vetter, A.: Business Process Model Patterns: State-of-the-Art, Research Classification and Taxonomy. Business Process Management Journal. <https://doi.org/10.1108/BPMJ-01-2018-0021>

- [Fe18b] Fellmann, M.; Laue, R.; Koschmider, A.; Schoknecht A. (Eds.): Proc. of the 4th Workshop „Workshop zum Stand, den Herausforderungen und Impulsen des Geschäftsprozessmanagements“ (ZuGPM 2018). In: Czarnecki et al. (Eds.) Workshops der INFORMATIK 2018; pp. 223–300.
- [La18] Lantow, B.: Adaptive Case Management-A Review of Method Support. In IFIP Working Conference on The Practice of Enterprise ..., 2018.
- [LFS18] Lambusch, F.; Fellmann, M.; Sauer, V.: The Data Perspective of Sensor-enabled Personal Work Support Systems. In: Proc. of the Workshop MCI-WS18 – Smart Factories: Mitarbeiterzentrierte Informationssysteme für die Zusammenarbeit der Zukunft, held at Mensch und Computer, 2018; 7 pages
- [LS15] Lantow, B.; Sandkuhl, K.: An analysis of applicability using quality metrics for ontologies on ontology design patterns. In Intelligent Systems in Accounting ..., 2015.
- [Sa12] Sandkuhl, K. et al.: Towards adaptive business models for intelligent information logistics in transportation. In Satellite Workshops & ..., 2012.
- [Sa18] Sandkuhl, K. et al.: From Expert Discipline to Common Practice: A Vision and Research Agenda for Extending the Reach of Enterprise Modeling. In Business & Information Systems Engineering, 2018, 60; p. 69–80.
- [SS18] Sandkuhl, K.; Stirna, J.: Capability Thinking. In (Sandkuhl, K.; Stirna, J., Eds.): Capability Management in Digital Enterprises. Springer, 2018; p. 1–24.
- [SS19] Sandkuhl, K.; Smirnov, A. Sandkuhl, K.; Smirnov, A.: Context-oriented Knowledge Management in Production Networks, 2019.
- [TS18] Timm, F.; Sandkuhl, K.: Towards a Reference Compliance Organization in the Financial Sector. In (Xie, L. et al., Eds.): Tagungsband Multikonferenz Wirtschaftsinformatik (MKWI) 2018, p. 1209–1220.
- [TS18] Timm, F.; Sandkuhl, K.: A Reference Enterprise Architecture for Holistic Compliance Management in the Financial Sector. In (Heje, J.-P.; Ram, S.; Rosemann, M., Eds.): Proceedings of the International Conference on Information Systems ICIS 2018, San Francisco, CA, USA. AIS, 2018.
- [WS17] Wißotzki, M.; Sandkuhl, K.: The Digital Business Architect - Towards Method Support for Digital Innovation and Transformation Conference, PoEM 2017, Leuven, Belgium, Proceedings; p. 352–362.
- [WTS15] Wißotzki, M.; Timm, F.; Sonnenberger, A.: A Survey on Enterprise Architecture Management in Small and Medium Enterprises Enterprise Information Systems, Volume 3, Barcelona, Spain 2015. In (Hammoudi, S.; Maciaszek, L. A.; Teniente, E., Eds.): ICEIS 2015 - Proceedings of the ICEIS 2015, Volume 3, Barcelona, Spain. SciTePress, 2015; p. 213–220.

Enterprise Modelling Research Group at University of Hagen

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Abstract: On behalf of the entire team, I present the research programme and research themes pursued by the Enterprise Modelling Research Group at the University of Hagen, Germany.

Keywords: Enterprise Modelling; Conceptual Modeling; Modeling Tool Research; Individual Modeling Processes; Modeling Difficulties; Learning Conceptual Modeling;

1 General orientation

Enterprise models empower us to shape the digital transformation of organisations—of small and medium businesses, large corporations, public administration, unions, clubs and associations of all kinds. Without conceptual models of such enterprises, their social action systems in coaction with their computer information systems, we cannot understand the complex human-computer-interactions that concern us and cannot seize the opportunities of their applications to problems of modern society. At the Enterprise Modelling Research Group, we construct enterprise models, design modeling languages, develop modeling methods and corresponding modeling software tools, study their use in application contexts and evaluate their application to digital transformation challenges including managerial decision-making in business domains such as Strategic Management [BS18], Auditing [HSF14], and Performance Management [St12].

The Enterprise Modelling Research Group at the University of Hagen was founded in 2015 at the Chair for Information Systems Development after a three-year initiation period subsequent to the author receiving the honour to head the Chair for Information Systems Development at the School of Management and Economics, University of Hagen (FernUniversitaet in Hagen) in November 2011. A small research group, the Enterprise Modelling Research Group hosts four full-time researchers at the doctoral and postdoctoral levels as well as several additional staff including undergraduate and graduate research assistants. Thanks to the commitment, ambition and dedication of its group members, an array of research initiatives has been launched since then including the modeling tool and observatory TOOL [Te20, Te19, Te17] and a corresponding series of mixed-methods research studies on individual modeling processes using TOOL for data and business process modeling [RTS20b, RTS20a, RS19, RTS19].

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2 Research Topics

2.1 Foundations

Our research programme operates on the basic assumption that conceptual modeling involves an intricate array of cognitive processes and performed actions including abstracting, conceptualizing, contextualizing, associating, visualizing, interpreting & sense-making, judging & evaluating, and, in group settings, communicating, discussing and agreeing [RS19]. Hence, learning as well as performing conceptual modeling is construed as a complex task based on codified and tacit knowledge that involves mastering theoretical foundations, modeling languages and methods, applying them to practical problems as well as critically thinking and reflecting upon technical terminology and technical language of the targeted application domain. Despite its relevance and complexity, surprisingly little is known about how conceptual modeling is performed by modelers, how the learning of conceptual modeling proceeds, which modeling difficulties modelers experience and why, and how to overcome these difficulties by targeted modeling (tool) support [RTS20b]. We have, therefore, set out to better understand individual modeling processes and the learning of conceptual modeling—pursuing the overarching research objective of designing and implementing targeted tool support for modelers at different stages of their learning and mastering of conceptual modeling. In our pursuit of this research objective, we are convinced that individual modeling processes demand and deserve study from several complementary perspectives including verbalization of modelers’ modeling decisions and related thought processes—to account for the richness of conceptual modeling as a learning and performing task.

2.2 Modeling tool research

From the outset, we have been researching, designing and implementing TOOL, a modeling tool and observatory for studying modeling processes [Te17]. In a nutshell, TOOL is a web application with a JavaScript-driven user interface (Web-browser-based frontend) and a Java EE (Enterprise Edition)-based server backend. Presently, TOOL implements two graphical modeling editors: (1) An editor for a variant of the Entity-Relationship Model (ERM) for data modeling and (2) an editor for a subset of the Business Process Model and Notation (BPMN) for business process modeling [Te20]. For supporting modelers in general as well as learners of conceptual modeling in particular, the TOOL prototype implements an ad-hoc syntax validation to point to modeling errors as well as a feedback component to guide the modeling process by making recommendations for sensible and adequate labels based on Natural Language Processing (NLP) techniques [TRS20].

TOOL is not only a graphical modeling tool designed to make modeling processes more productive. For studying individual modeling processes both under laboratory conditions as well as in online settings, TOOL implements multi-modal observation and data generation

techniques complementing different modes of observation of individual modeling processes. Currently, TOOL allows for (1) tracking modeler-tool interactions as timed-discrete events for visualizing modeling processes as heatmaps, dot diagrams, and to allow for stepwise replays of those interactions individually and in comparison with other modelers' tracked interactions, (2) recording verbal data protocols of modeler's thinking out loud following the tenets of think aloud research methods (including remotely in online studies), and (3) pre- and post-modeling surveying of studied subjects, e. g. about their prior modeling experience [Te19].

TOOL has been applied to an initial test series, to pilot studies as well as in a series of research studies on individual modeling processes at the University of Hagen, the Universitat Politècnica de València, Spain and the Katholieke Universiteit Leuven, Belgium (see next section). Moreover, TOOL has supplemented our teaching of a 300+ students course on Modeling Business Information Systems in the undergraduate programmes where students have been using it for the past semester to create data models for their assignments.

2.3 Individual modeling processes and modeling difficulties

Using TOOL in a series of observation studies, we have been studying individual modeling processes of experienced and non-experienced modelers through complementary modes of observation to identify modeling difficulties these modelers face while performing a conceptual modeling task, e. g. a data modeling task [RTS20b]. Observing individual modeling process poses interesting methodological challenges which has led us to run mixed-methods research designs in which we combine data from subject surveys, modeler-tool interaction tracking, verbal data protocols, and video recordings of the modeling subjects while working on the modeling task to arrive at a more complete observation of the phenomenon under investigation. Initial, preliminary findings of these studies indicate regularities among the observed modeling difficulties which leads us to expect to identify regular patterns of types of such difficulties in further, extended studies, and to develop a taxonomic theory of modeling difficulties intended to inform design science research on tool support for experienced and non-experienced models [RS19].

2.4 Learning conceptual modeling

Building upon both our modeling tool research on TOOL and on our research on individual modeling processes, we have been taking a closer look at how conceptual modeling is learned and how software tool support may assist learners in their learning processes. Learning conceptual modeling has for long been a focus in Conceptual Modeling research but has recently received renewed attention as we show in a comprehensive literature study covering contributions from 1986 to 2017 [RTS19, RTS20a]. Our current main research theme is to design and develop a feedback component for TOOL to provide process-oriented

learner feedback by processing the natural language description of a modeling task using NLP techniques to assist learners in identifying candidates for data modeling concepts, e. g. for entity and relationship types as well as attributes, and for formulating labels for these model elements. On a different research path, we have started to think and reflect upon conceptual modeling didactics and have initiated a research project to develop a technical methodology (in German: “Fachdidaktik”) for conceptual modeling for use in (high-)school education and higher education and corresponding curriculum development.

3 Relevance for the EMISA Special Interest Group

Conceptual modeling is at the core of our research programme and, likewise, at the core of development methods for information systems and their application. Our group’s research efforts are aimed at contributing to SIG EMISA’s foci in two interlinked respects: We aim to contribute to a more differentiated understanding of how conceptual modeling is performed and learned which, in turn, is aimed at adding to the foundational knowledge on which we all build development methods and corresponding software tools for information systems development.

Acknowledgement

I would like to express my gratitude to my team who actually *is* the Enterprise Modelling Research Group, and would like to thank Kristina Rosenthal, Benjamin Ternes, Markus Fischer, Elisabeth Böhmer, Arne Bergmann and Hagen Barth for their dedication and commitment. It has been a joy to work with you on so many interesting research challenges for the past five years.

Bibliography

- [BS18] Bergmann, Arne; Strecker, Stefan: A Modeling Method in Support of Strategic Planning: Language Design and Application (Short Paper). In (Pries-Heje, Jan; Ram, Sudha; Rosemann, Michael, eds): Proceedings of the International Conference on Information Systems - Bridging the Internet of People, Data, and Things, ICIS 2018, San Francisco, CA, USA, December 13-16, 2018. Association for Information Systems, 2018.
- [HSF14] Heise, David; Strecker, Stefan; Frank, Ulrich: ControlML: A domain-specific modeling language in support of assessing internal controls and the internal control system. *Int. J. Account. Inf. Syst.*, 15(3):224–245, 2014.
- [RS19] Rosenthal, Kristina; Strecker, Stefan: Toward a Taxonomy of Modeling Difficulties: A Multi-Modal Study on Individual Modeling Processes. In (Krcmar, Helmut; Fedorowicz, Jane; Boh, Wai Fong; Leimeister, Jan Marco; Wattal, Sunil, eds): Proceedings of the 40th International Conference on Information Systems, ICIS 2019, Munich, Germany, December 15-18, 2019. Association for Information Systems, 2019.

- [RTS19] Rosenthal, Kristina; Ternes, Benjamin; Strecker, Stefan: Learning Conceptual Modeling: Structuring Overview, Research Themes and Paths for Future Research. In (vom Brocke, Jan; Gregor, Shirley; Müller, Oliver, eds): 27th European Conference on Information Systems - Information Systems for a Sharing Society, ECIS 2019, Stockholm and Uppsala, Sweden, June 8-14, 2019. 2019.
- [RTS20a] Rosenthal, Kristina; Ternes, Benjamin; Strecker, Stefan: Learning Conceptual Modeling: Structuring Overview, Research Themes and Paths for Future Research (Extended Abstract). In (Michael, Judith; Bork, Dominik; Fill, Hans-Georg; Fettke, Peter; Karagiannis, Dimitris; Köpke, Julius; Koschmider, Agnes; Mayr, Heinrich C.; Rehse, Jana-Rebecca; Reimer, Ulrich; Striwe, Michael; Tropmann-Frick, Marina; Ullrich, Meike, eds): Companion Proceedings of Modellierung 2020 Short, Workshop and Tools & Demo Papers co-located with Modellierung 2020, Vienna, Austria, February 19-21, 2020. volume 2542 of CEUR Workshop Proceedings. CEUR-WS.org, pp. 63–64, 2020.
- [RTS20b] Rosenthal, Kristina; Ternes, Benjamin; Strecker, Stefan: Understanding individual processes of conceptual modeling: A multi-modal observation and data generation approach. In (Bork, Dominik; Karagiannis, Dimitris; Mayr, Heinrich C., eds): Modellierung 2020, 19.-21. Februar 2020, Wien, Österreich. volume P-302 of LNI. Gesellschaft für Informatik e.V., pp. 77–92, 2020.
- [St12] Strecker, Stefan; Frank, Ulrich; Heise, David; Kattenstroth, Heiko: MetricM: A modeling method in support of the reflective design and use of performance measurement systems. *Inf. Syst. E-Business Management*, 10(2):241–276, 2012.
- [Te17] Ternes, Benjamin: Design and Evaluation of a Web-based Modeling Platform to Support the Learning of Conceptual Modeling and of Studying the Corresponding Learning Processes. In (Gulden, Jens; Nurcan, Selmin; Reinhartz-Berger, Iris; Guédria, Wided; Bera, Palash; Guerreiro, Sérgio; Fellmann, Michael; Weidlich, Matthias, eds): Joint Proceedings of the Radar tracks at the 18th BPMDS, and the 22nd EMMSAD, and the 8th International Workshop on Enterprise Modeling and Information Systems Architectures (EMISA) co-located with the 29th International Conference on Advanced Information Systems Engineering 2017 (CAiSE 2017), Essen, Germany, June 12-13, 2017. volume 1859 of CEUR Workshop Proceedings. CEUR-WS.org, pp. 138–142, 2017.
- [Te19] Ternes, Benjamin; Strecker, Stefan; Rosenthal, Kristina; Barth, Hagen: A browser-based modeling tool for studying the learning of conceptual modeling based on a multi-modal data collection approach. In (Ludwig, Thomas; Pipek, Volkmar, eds): Human Practice. Digital Ecologies. Our Future. 14. Internationale Tagung Wirtschaftsinformatik (WI 2019), February 24-27, 2019, Siegen, Germany. University of Siegen, Germany / AISeL, pp. 1984–1988, 2019.
- [Te20] Ternes, Benjamin; Rosenthal, Kristina; Barth, Hagen; Strecker, Stefan: TOOL - Modeling Observatory & Tool: An Update. In (Michael, Judith; Bork, Dominik; Fill, Hans-Georg; Fettke, Peter; Karagiannis, Dimitris; Köpke, Julius; Koschmider, Agnes; Mayr, Heinrich C.; Rehse, Jana-Rebecca; Reimer, Ulrich; Striwe, Michael; Tropmann-Frick, Marina; Ullrich, Meike, eds): Companion Proceedings of Modellierung 2020 Short, Workshop and Tools & Demo Papers co-located with Modellierung 2020, Vienna, Austria, February 19-21, 2020. volume 2542 of CEUR Workshop Proceedings. CEUR-WS.org, pp. 198–202, 2020.
- [TRS20] Ternes, Benjamin; Rosenthal, Kristina; Strecker, Stefan: Supporting Learners of Data Modeling: A Natural Language Processing Approach. Manuscript currently under review, 2020.



40 Years EMISA

Programm

**Digital Ecosystems of the Future:
Methods, Techniques and Applications**

GI Fachgruppe Entwicklungsmethoden für
Informationssysteme und deren Anwendung

Tutzing am Starnberger See, 15.-17. Mai 2019



Mittwoch, 15. Mai 2019	
13:30h	Begrüßung und Eröffnung
14:00-15:30h	Sitzung 1 Chair: Jan Mendling, EMISA-Sprecher seit 2016, WU Wien
14:00h	Towards an Internet of Production – A Model-Assisted and Data-Driven Ecosystem Based on Digital Shadows Matthias Jarke, RTWH Aachen und Fraunhofer FIT
14:30h	Knowledge Graph Processing Made (more) Simple Georg Lausen, EMISA-Sprecher 1987-1990, Universität Freiburg
15:00h	EMISA 40 Jahre Helmut Thoma, EMISA-Sprecher 1991-1994
	15:30h Kaffeepause bei der Rotunde
16:00-17:30h	Sitzung 2 Chair: Ulrich Reimer, FHS St. Gallen
16:00h	Fundamental Challenges in Systems Modelling Henderik Proper, Marija Bjeković, Luxembourg Institute of Science and Technology
16:30h	Model-driven Runtime State Identification Sabine Wolny, CDL-MINT, TU Wien, Alexandra Mazak, Institute of Telecooperation, CIS, JKU Linz, Manuel Wimmer, CDL-MINT, TU Wien Christian Huemer, Business Informatics Group, TU Wien
17:00h	Model-based Testbed Design for Electric Vehicles Martin Paczona, AVL List GmbH, Graz Heinrich C. Mayr, Alpen-Adria-Universität Klagenfurt Guenter Prochart, AVL List GmbH, Graz
17:30-18:30h	Sitzung 3 EMISA 2019 Madness Show Moderation: Agnes Koschmider, Karlsruher Institut für Technologie KIT Matthias Weidlich, Humboldt-Universität zu Berlin
	19:00h Abendessen
20:00h	Empfang und gemütliches Beisammensein Grußwort der GI-Geschäftsführung Cornelia Winter
21:00h	Sitzung des EMISA-Leitungsgremiums; Raum tbd

Donnerstag, 16. Mai 2019	
8:30-10:00h	Sitzung 4 Chair: Heinrich C. Mayr, EMISA Sprecher 1979-1982, AAU Klagenfurt
8:30h	Grußwort des Präsidenten der Gesellschaft für Informatik Hannes Federrath, Universität Hamburg
9:00h	Disruption – Informatik wider den Schwarzen Schwan? Peter Lockemann, Karlsruher Institut für Technologie KIT
9:30h	EMISA agil Ernst Denert, Technische Universität München
	10:00h Kaffeepause im Musiksaal
10:30-12:00h	Sitzung 5 Chair: Andreas Oberweis, Karlsruher Institut für Technologie KIT
10:30h	Enterprise Information Systems in Academia and Practice: Lessons learned from a MBDE project Kai Adam, Lukas Netz, Simon Varga, Judith Michael, Bernhard Rumpe, RWTH Aachen
11:00h	Business Process Model Patterns: Classification and Repository Ralf Laue, Westsächsische Hochschule Zwickau, Agnes Koschmider, KIT; Michael Fellmann, Universität Rostock; Andreas Schoknecht, Arthur Vetter, KIT
11:30h	Co-evolution in Business Ecosystems: Findings from Literature Tobias Riasanow, TU München; Rob Jago Flötgen, IfM Univ. of Cambridge; Michael Greineder, Dominik Möslin, Markus Böhm, Helmut Krcmar, TUM
	12:00h Mittagessen
14:00-15:30h	Sitzung 6 Chair: Stefan Strecker, FernUniversität Hagen
14:00h	Reminiszenzen über 40 Wolffried Stucky, Karlsruher Institut für Technologie KIT
14:30h	Komposition von Komponenten: der Schlüssel zur Konstruktion großer Systeme Wolfgang Reisig, Humboldt-Universität zu Berlin
15:00h	Wie autonom sind autonome Systeme? Andreas Reuter, EML European Media Laboratory GmbH
	15:30h Kaffeepause im Musiksaal
16:00-17:00h	Sitzung 7 Chair: Manfred Reichert, Universität Ulm
16:00h	Universität 4.0: Herausforderungen, Konzepte und erste (ERCIS) Erfahrungen Gottfried Vossen, Universität Münster
16:30h	Die Botschaft der Modellierung Bernhard Thalheim, Christian-Albrechts-Universität zu Kiel
17:00-18:30h	Sitzung 8 Podiumsdiskussion Entwicklungsmethoden für Informationssysteme in Zeiten von Big Data und KI Moderation: Jan Mendling und Gottfried Vossen
19:00h	Festbankett im Musiksaal Grußwort des Sprechers des GI-Fachbereichs Datenbanken und Informationssysteme Erhard Rahm, Universität Leipzig After Dinner Speech Frank Schönthaler, PROMATIS software GmbH

Freitag, 17. Mai 2019	
8:30-10:00h	Sitzung 9 Chair: Wolffried Stucky, Karlsruher Institut für Technologie KIT
8:30h	Können Gemeinschaften autonomer Einheiten bei der Modellierung digitaler Ökosysteme helfen? Hans-Jörg Kreowski, Universität Bremen
9:00h	“Integration” als zentrale Herausforderung der Entwicklung betrieblicher Informationssysteme Andreas Oberweis, EMISA-Sprecher 2000-2006, Karlsruher Institut für Technologie KIT
9:30h	BPM: Wofür steht das M? Mathias Weske, EMISA-Sprecher 2006-2012, Hasso Plattner Institut Potsdam
	10:00h Kaffeepause im Musiksaal
10:30-12:00h	Sitzung 10 Chair: Bernhard Thalheim, Christian-Albrechts-Universität zu Kiel
10:30h	Towards a Virtual Reality-based Process Elicitation System Jannis Vogel und Oliver Thomas, Universität Osnabrück
11:00h	Qualitative Comparison of Enterprise Architecture Model Maintenance Processes Simon Hacks und Horst Lichter, RWTH Aachen
11:30h	The Generic InsurTech Ecosystem and its Strategic Implications for the Digital Transformation of the Insurance Industry Michael Greineder, Tobias Riasanow, Markus Böhm, Helmut Krcmar, TU München
	12:00h Mittagessen
13:00-14:30h	Sitzung 11 Chair: Mathias Weske, EMISA-Sprecher 2006-2012, HPI Potsdam
13:00h	Digital Process Management: Challenges, Technologies, Applications Manfred Reichert, EMISA-Sprecher 2012-2015, Universität Ulm
13:30h	Understanding and Problem Solving with Diagrams in Information Systems Design Jan Mendling, EMISA-Sprecher seit 2016, WU Wien
14:00h	50 Years EMISA 2029 und Verabschiedung
Internet:	Zugangsdaten erhältlich am Empfang der ev. Akademie
Apotheke:	Hauptstraße 43, 200m
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Hausarzt:	Hausärztliche Gemeinschaftspraxis, Hauptstraße 93, 700m
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Donnerstag, 16. Mai 2019: Musiksaal
Forschungsgruppen präsentieren sich:

Ambient Assisted Living	Fachhochschule Kärnten
Application Engineering	Universität Klagenfurt
Business Process Technology	Hasso Plattner Institut Potsdam
Databases and Information Systems (DBIS)	Universität Ulm
Digitalization and Information Systems	Université de Fribourg
Enterprise Modelling Research Group (Evis)	FernUniversität Hagen
Knowledge Engineering (DKE)	Universität Wien
Project Management and Information Modeling	Hochschule Landshut
Theoretische Grundlagen der Informatik	Universität Hamburg
Wirtschaftsinformatik	Universität Rostock

Conference & Program Chairs: Heinrich C. Mayr, Stefanie Rinderle-Ma und Stefan Strecker
Panel Chairs: Jan Mendling und Gottfried Vossen
Exhibition & Demo Chairs: Agnes Koschmider und Matthias Weidlich













We owe the photos to Dr. Hansjürgen Paul, a longtime member of the EMISA Steering Committee. You can admire more of his photos under this link:

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