Evaluation of Domain-Specific Languages in Practice

Proposal for a Habilitation at the Technische Universität München

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In this document we introduce our research topic of interest for pursuing a habilitation at the Technische Universität München.

1. Document Structure

We will start by providing background information on the topic of Domain-Specific Languages in section 2. We then go on in section 3 to discuss the state of the art of the domain and to highlight the running trends during the last two decades. In section 4 we introduce our topic of interest and finally in section 5 we lay out the operational context under which our projected research will take place.

2. Background

Computer languages are very often domain-specific, in the sense that they specialize in enabling the description of specifications, operational or not, of certain technical artifacts. Domain-Specific Languages (DSLs) are often presented in opposition to General-Purpose Languages (GPLs), which are all-purpose generic programming languages such as Java or C. The main premise for DSL construction is that such languages should explicitly address a domain of interest by taking the concepts of that domain first-class citizens [30]. This can imply a trade-off in generality, meaning some DSLs may not be Turing-complete as such computational power may not be required for a specific application. The advantages put forward by the proponents of the DLS approach are increased productivity for language users and reduced maintenance costs of DSL programs. Additionally, DSLs are expected to lower the barrier of computer language usage for non-experts, thus allowing users from other domains to more easily specify the artifacts and computations they require [37].

DSLs have a rich history of contributions in different areas of knowledge. Some notable examples of DSLs that left permanent marks in their domains are *lex* and *yacc* [25] for compiler construction, HTML [9] as a markup language for the world-wide web, VHDL [5] for hardware specification, Excel for spreadsheets, Latex [32] for typesetting, SQL [10] for database querying or MATLAB [18] for technical computing.

During the past decade a number of DSL workbenches saw the light of day. The Eclipse Modelling Framework (EMF) [12] had significant impact in the academia and became one of the most popular frameworks for DSL construction. More recently, the MPS workbench from Jetbrains [24] has delivered a powerful DSL construction workbench with professional support and possibilities to design attractive GUIs that provide a very interesting complement to the notion of domain specificity. Professional DSL workbenches such as MetaEdit+ [38] have repeatedly made strong cases for the industrial adoption of DSLs and have carved a niche market in the domain.

During the past few years, DSLs have raised considerable interest among software developers [14]. The paradigm speaks directly to engineers who wish to build their systems ground-up while making as much use as possible of domain knowledge that is typically hard-earned. In this context, software clients often regard DSLs as key-in-hand solutions. They encompass simplified means to express domain-specific computations while abstracting from accidental complexity linked to the software or the hardware running underneath.

Companies such as itemis AG, PROTOS GmbH or MetaCase have successfully developed business models around DSLs. They leverage their knowledge of modelling and DSL workbenches to deliver to customers key-in-hand software solutions. Such solutions have been developed for disparate domains such as the automotive, avionics, power tools, health, biology, among many others. In practice they help either software developers or final users in achieving their tasks.

Despite these successes, the potential and real impact of DSLs in industry is still ill understood. A recent compelling report from Tolvanen and Kelly [49] states that their company, MetaCase, can affirm with certainty that the gains in productivity of their clients range from 5-fold to 10-fold. In the same article, the authors go on to claim that academic research in the domain has thus far not been unable to validate such gains in general.

Anecdotally, at the PAINS workshop at MODELS 2018 [1], an interesting discussion raged between a high-profile DSL proponent and a top-level BMW manager. While the DSL proponent insisted that the (MPS-based) technology was ready and could serve as a "silver bullet" of sorts, the BMW manager replied that the attempts of using DSLs at his company where "hit-and-miss", and that even when DSLs did prove successful, it was not understood why. A question from that same manager that was particularly thought-provoking was: "how do I build an abstraction and know that it is

a good one?". A more general criticism to the DSL approach in general was: "quality standards are missing, how do I to judge or trust your processes of building DSLs while making decisions that will benefit my company?".

3. State of the Art

In 2000, a landmark white paper from the company MetaCase claimed that, using their commercial tool MetaEdit+, the company developed DSLs for Nokia increased their software productivity 10-fold [39]. Such early claims spawned a large amount of interest in DSLs by both the industry and academia.

Following such interest, authors such as Spinellis or Völter pursued the idea of proposing patterns for DSLs construction [45, 52], much in the light of what had been very successfully done by the "gang of four" for design patterns [17]. Such patterns concentrate mainly best practices for DSL design and implementation. This research culminated in the very well-cited work of Mernik *et al.* [37], which builds on the work of Spinellis and aims at enabling the DSL developer with the understanding of where and when design and implementation decisions matter in DSL development. Also, reports on industrial best practices in DSL usage such as the work from Wile [53] started to emerge at this time.

The raise in interest in DSLs also brought upon a number of DSL workbenches, both open-source and commercial, such as the Eclipse Modelling Framework (EMF) for Eclipse [12], Microsoft's DSL tools [40], GME [3] or AToM3 [2]. In particular, EMF was heavily adopted by academia for pursuing research on DSLs and together with GMF [13] soon became the platform of choice for academic DSL development.

While the enthusiasm around DSLs continued strong throughout the 00s and work on how to develop good languages kept on being published [51], other authors began to question the state of practice in general. In particular Kelly from MetaCase raises in [28] the point that DSL development often takes a standpoint of self sufficiency, ignoring pitfalls that mostly have to do with taking the domain for which the language is developed or its final users too lightly. This was in the same year corroborated by work from Gabriel *et al.* [16] who reviewed a significant amount of literature related to the evaluation of DSLs. The authors claim that, while the benefits of DSLs in terms of increased productivity in well-defined domains were often put forward in the literature, little to no evidence to back up such claims was offered.

Having recognized the fact that DSLs were critically missing supporting evaluation that would back up the promises from the early days, authors such as Kolovos and Paige [30] proposed sets of characteristics that "good" DSLs should exhibit. Examples of such generic characteristics are conformity to the domain of choice, supportability by tools, integrability with other languages,

longevity, simplicity, quality, scalability, learnability or usability. Several studies from the late 00's and beginning of the 10's have concentrated on proposing means to quantitatively assess such and other characteristics [44, 20, 7, 26]. A notable study dating from this period from Kosar *et al.* [31] provides empirical evidence that programs written using DSLs are more easily comprehensible by programmers than programs written using GPLs, one of the original claims of the DSL community.

During this same period several contemporary DSL workbenches made their first appearance: the Meta Programming System (MPS)[1] from JetBrains [24], Sirius (used by Obeo as a core technology [43]), Xtext from itemis AG [22], among others [29]. Benefiting from the previous decade of development of the DSL domain and professional software development teams, these tools exhibit a level of maturity that allows them to be used in industrial settings with success. For instance Sirius, based on the Eclipse platform, has been used to develop DSLs for the aerospace, transportation or energy industries [42]. MPS [24], one of the first DSL workbenches using projectional editing, has been used to develop commercial tools for branches such as software development, health, insurance companies and automotive, among others. Xtext [22], a language for developing textual DSLs, is currently used by large players such as Google, SAP or Bosch.

While the above seems to indicate that DSLs have successfully permeated the industry, authors from recent surveys remain very critical of the actual state of the art. Mernik [36] published a systematic mapping study in 2017 where he shows that the *maintenance* and *validation* phases of DSL development are grossly under-studied in the literature when compared to *domain analysis*, *design* and *implementation* (see figure 1).

Equally, Tolvanen and Kelly who have been active members DSL community since its inception, have recently published a summary of their experiences with their commercial tool MetaEdit+ [48]. There, they state that although they can consistently claim a 5 to 10 times improvement in productivity for their customers, the DSL community has not been able to do the same in general. Note that this does not contradict the paragraph above on adoption by the industry, as: 1) adoption does not mean increased productivity, and 2) it is to be expected that if productivity increases do exist, corporate secrecy would be put in place to avoid losing competitive edges. Tolvanen and Kelly do mention in [48] that the reason why the academic community has failed so far to prove or disprove most of the fundamental claims for advantages of DSLs lies in the poor quality of the overall tooling and of the DSLs used developed by academic research. This notion is shared by us.

Nonetheless, modern DSL workbenches have provided the means for experimenting with the construction of DSLs in a systematic manner. Based

[1]Note that while the MPS project exists since 2003, its mainstream appearance dates to a decade later.

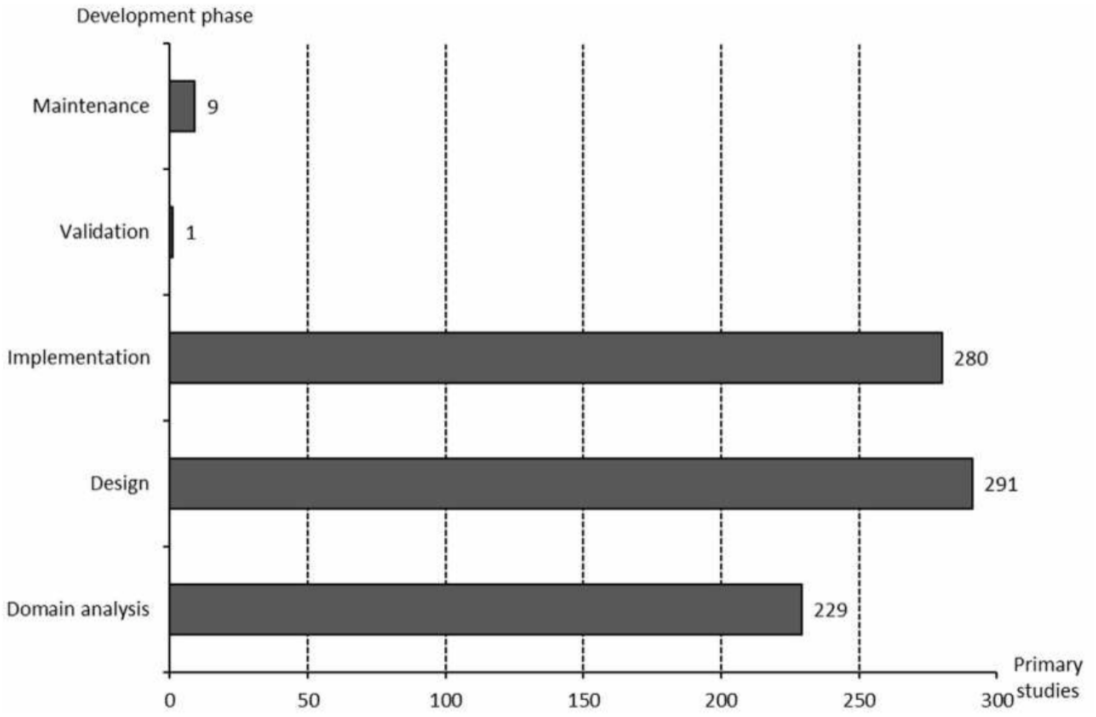

Figure 1: Distribution of 810 scientific contributions according to the phases of DSL construction they cover (extracted from [36])

on the work of Freire *et al.* [15] on formalizing software engineering experiments, Häser and his colleagues have proposed in [19] a framework in MPS that allow defining and conducting experiments for validating DSLs. Very recently, work has started to emerge on concrete frameworks for the evaluation of usability during DSL development [6] and DSL maintenance [47] – thus responding to the issues identified by Mernik [36] and that are illustrated in figure 1.

Summary From the condensed state of the art above, we can identify the following tends:

- For almost two decades professional DSL workbench builders have consistently reported case studies of application of DSLs to industrial problems, some of those case studies being highly successful. The same DSL builders do nonetheless mention that obtaining the data for validating the DSL after shipment is difficult [50].
- During that same period academia as struggled to provide evidence that the promises of DSLs in terms of increased productivity hold. Only recently, partly due to the arrival of mature DSL workbenches produced

by professional software, is actual quantification of properties of DSLs such as e.g. usability becoming possible. Experimental validation of DSLs based on established theory is still under-explored [36].

- The DSL workbenches developed by academia are, thus far, insufficient to scientifically validate the premises of the DSL-based software development. This is on the one hand due to the poor quality of the tooling produced by academia [48], and on the other hand to very low access to real industrial use cases. Most of the surveys we describe above use as study material other academic papers, leading to starvation of information on real DSL commercial usage.
- With the notable exceptions of the work of Tolvanen and Kelly and Vlter mentioned above in this section, the bridges between the academia and industry in the DSL domain are brittle.

4. Proposed Topic of Research

Following section 3, it is clear to us that a substantial gap exists between academic research in DSLs and their usage in practice. We wish to address this gap with our research. We thus formulate our main research question as:

How can we identify, measure and use characteristics of DSLs to support their sustained and sustainable adoption by the industry?

Such a research naturally leads to a number of sub-research questions, namely:

- What are the characteristics of a DSL that can be quantitatively assessed in order improve the chances of a real increase in productivity by the industry?
- Which tooling is adequate to do such quantitative assessment?
- How can those characteristics be summarized in a way that is convincing for software-agnostic staff (domain experts or management), leading to the qualification of the DSL development process?

Regarding the tooling used to perform the quantitative assessment, we are firmly convinced that areas such as formal methods and machine learning have an important role to play. This outlook stems from evidence collected by our past work (see section 5). We thus formulate a corollary research questions as: how can formal methods and machine learning help in the qualification and production phases of a DSL?

Our mid-to-longterm goal is to inseminate the academic community with the practical experiences and struggles of making DSLs used practice, leading to the theoretical establishment of the domain.

5. Context for Development of the Research

We have significant experience in the design and implementation of DSLs for areas such as software testing [33], model transformations [8], verification [41, 27], process management [34], software refinement [46] and embedded sytems [35]. These languages were developed using a variety of DSL workbenches, e.g. the Eclipse EMF framework, MPS or AToM3. Some of the DSLs were developed for academic purposes, while other were or are being developed with and for industrial partners such as Diehl Aerospace, Airbus and Rolls-Royce.

The role that fortiss itself plays and will play on this research is not to be understated: we currently have the kind of access to projects and industrial and academic partners that occurs very seldom in academia or industry. This access to real industrial settings, with their time and budget constraints and expert knowledge, will be determinant in the success of the research we propose here. Also, we cultivate relationships with our customers, meaning it is likely they will be ready to partly share their DSL validation data with us.

Not to be understated also is the existing body of research on the topic we are proposing. Although the gap between academia and industry is clear as per section 3, exciting results on validating DSLs such as the ones recently presented by Lara *et al.* [23], Freire *et al.* [15], Haser *et al.* [19] or Barisic *et al.* [7] are starting points for our research. Also, systematic work by Mernik [37, 31, 36] on assessing the state of the art as well as the clear-cut reports from the industry from Kelly and Tolvanen [49, 28, 44, 29, 48, 50] and Völter [51] provides an excellent basis for this research. Finally, our large academic network will allow us to continue collaborating with other scientists in order to improve and validate our scientific results.

Regarding the usage of machine learning during this research, we have already started efforts in this direction through the MAGNET project. This project aims at using machine learning to improve the usability and learnability of the AutoFOCUS3 tool [11], a collection of DSLs for the development of embedded systems. The same can be said for formal methods: beside our background in the domain, the running CBMD project focuses on using a model checker as the semantic domain for a contract DSL (used at PROTOS GmbH) for runtime verification [27] . Additionally, in the past year we have produced a survey on the usage of machine learning in formal verification [4] as well as a survey of machine learning in requirements engineering [21].

In the annexes of this document we provide detailed information about the context in which our research will be developed:

- Synergies with groups at fortiss (appendix A)
- Completed and running projects at fortiss (appendix B)

Appendix A Synergies with groups at fortiss

Domain-Specific Languages are a cross-cutting theme at fortiss. All competence fields at fortiss deal with DSLs in one form or the other, even or despite doing it unknowingly.

- The obvious synergy of our research topic is with the Model-Based Software engineering (MbSE) group: MbSE has a model-centric view on systems and software engineering and builds languages using model-driven techniques. Its main current theme is design-space exploration and the modelling of embedded systems, but other themes such as requirements engineering, formal methods or security are also being pursued. DSLs can be of great assistance to MbSE by bringing systematic notions of language construction and evaluation to the development table. A collaboration that is already ongoing is the exploration of machine learning (in the context of the MAGNET project) to deliver support to users of AF3.
- Common work is also ongoing with the Autonomous Systems (AS) group, in the form of the FaktorBUILD project proposal to be submitted to the BMBF. Some of the work of AS relies on probabilistic programming to model situations where incomplete knowledge must be reliably used to make decisions in real-time. Here, we help in constructing DSLs at an adequate level of abstraction such that the IDE provided to users of factor graphs can leverage good abstractions, static analyses and formal methods to increase the productivity of factor graph programmers.
- The collaboration with the Industry 4.0 (i4) group has been so far very successful, having lead to the implementation of a tool providing DSLs to express industrial capabilities. Such capabilities, or skills, can be subsequently be matched to automatically automatically synthesize controllers for industrial machines. Upcoming work for 2019 in the area will aim at connecting the completed DSL-based tool to AutomationML and 4Diac in order to connect the work with outside formats while providing simulation capabilities.

Appendix B Completed and Running Projects at fortiss

Completed projects:

- IETS3 (DSLs for requirements engineering)
  - Role: project leader
  - Consortium: fortiss, itemis, ZF, Diehl aerospace, Rolls-Royce

  - Running time and personnel: 2 years / 3 people
- CELT (Verification of model transformations via contracts and formal methods, developed in MPS)
  - Role: project leader
  - Consortium: fortiss
  - Running time and personnel: 6 months / 2 people

Running projects:

- CBMD (Contracts expressed as DSLs for runtime verification of control software)
  - Role: project leader
  - Consortium: fortiss, PROTOS, itemis, SQMi, University of Augsburg
  - Running time, personnel: 2 years / 2 people
- MAGIC (DSLs for industrial automation)
  - Role: project leader
  - Consortium: fortiss, University of Montral
  - Running time and funding: 2 years / 3 people
- MAGNET (Machine learning for usability and learnability in AutoFOCUS3)
  - Consortium: fortiss
  - Running time, funding and personnel: 6 months / 8 people
- ARTEMIS (DSLs for engineering and formal verification of software requirements for fighter jets)
  - Role: project leader
  - Consortium: fortiss, Airbus
  - Running time, funding and personnel: 6 months / 2 people (Levi + HiWi)
- BaSys4.0 (industrial automation)
  - Role: developer of DSLs to describe and operationally match industrial capabilities
  - Consortium: fortiss, Festo, Kuka, ABB, among others.

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