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Technology Transfer Concepts

In software engineering, transferring innovative concepts, techniques and methods into the practice of existing organizations is an expensive and complex task. This chapter gives an overview on the transfer of the SPES XT modeling framework to different organizations. The focus of this chapter is threefold: first, it addresses the characterization of technology transfer in applied software engineering research. Second, it focuses on the concept of guidelines that we have specifically developed for technology transfer. Third, this chapter presents the artifact quality assessment framework, a tool developed to assess the successful introduction of results from software engineering research allowing us to measure the quality of engineering artifacts created by introduced concepts, techniques, and methods.

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13.1 Introduction

Importance of technology transfer

Technology transfer subsumes activities which enable potential users to adopt and apply solutions from research, such as concepts, techniques, methods, or tools, in practice (cf. [Teece 1977]). In software engineering in particular, technology transfer is essential since past evidence shows that technology developed in research projects can take up 15-20 years to achieve widespread adoption [Redwine and Riddle 1985]. Hence, appropriate technology transfer concepts have to be developed and implemented to support a light-weight and seamless integration of state-of-the-art techniques into practice. In this regard, the positive evaluation results in industrial case studies presented in Chapter 12 indicate the feasibility of concepts and techniques of the SPES XT modeling framework. However, this does not automatically imply that this technology is ready to be transferred into a real industrial setting as it is. Therefore, we have analysed and characterized how technology transfer occurred in the SPES XT project, understanding its limitations, how to improve it, and trying to facilitate it.

Technology transfer in SPES XT

Given the importance of evaluating the technology transfer of developed technological solutions [Pressman 1988], in this chapter we present central concepts used for assessing the technology transfer of the SPES XT modeling framework into industry. In doing so, we present the patterns observed, with a main focus on the benefits and barriers of the techniques developed and on the media used to transfer them to practice (Section 13.2). Regarding the latter, in Section 13.3 we present the guideline documents which were developed specifically for supporting technology transfer in the SPES XT project. Finally, in Section 13.4, we describe the *artifact quality assessment framework* (AQAF) which aims at supporting the comparison of the quality of different engineering artifacts.

13.2 Technology Transfer in SPES XT

Goal of technology transfer study

Based on the execution of two surveys [Diebold and Vetrò 2014] [Diebold et al. 2015] and on a linear model of technology transfer widely used in literature [Teece 1977], our goal was to *characterize the current state of practice in technology transfer in SPES XT, the transfer media used, and to identify directions for improvements.* Here we report the patterns observed.

SPES XT techniques need customization to fit industrial contexts

An important and practical implication of this finding was to understand which techniques developed in SPES XT could be adopted as they are and which encounter the typical barriers to the adoption of model-driven development (MDD) (see [Torchiano et al. 2013]), meaning that strong customization and post-project-specific support is required. In general, the barriers to the adoption of certain techniques are mainly the lack of supporting tools, the lack of proper competencies, and the high effort required to introduce the techniques (the latter might be a consequence of the first two). In support of these barriers, we found that the two most frequently cited benefits of the existing model-based engineering approaches are the tool support and the ease of use. On the benefits side, the most frequently cited expected incentives for investing in the adoption of the SPES XT techniques are design support, better quality of software, and documentation.

Technology transfer takes place without an explicit process

Beyond a lack of a well-defined process, some respondents also reported informal ways of conducting a transfer: we know from literature that informal transfers are more probable in the case of spatial proximity. In addition, the answers revealed that technology transfer is not perceived as a continuous process, especially by the transferees. Future effort can be devoted to the creation of an ad-hoc process for the transfer to practice.

Industry organizations gain new knowledge mainly on their own

Although there is abundant evidence that external knowledge has a positive impact on product development and innovation [Katila et al. 2002], the main trigger for innovation in the SPES XT project occurred from within the boundaries of the organizations. Future effort should be devoted to reinforcing the communication flows between the partners.

Human-intensive media are favored

This finding was surprising because of the guidelines which were the main transfer medium in SPES XT (see Section 13.3). Nonetheless, a detailed investigation divided into the organizational types — that is, academia vs. industry — showed that guidelines as a transfer medium were among the media most commonly used by industry partners. In general, we observed that unsuitability and low resources were the main motivation for low attendance at events, while lack of awareness of existence was the main reason for not using artifact-oriented media. Regarding the achievement of purpose when using a medium, we can report that the most successful media were the SPES XT website, the mailing lists, the publications, and the SPES 2020 conference in 2012. Technical artifacts (scenarios, building blocks, guidelines), the SPES wiki, SPES results for academic courses, surveys, and individual dissemination activities had a positive success rate.

Heterogeneous drivers for transfer

We observed that the motivation for technology transfer differs heavily between industrial and academic organizations, as expected. Technology transfer in industry is to a large extent motivated by economic and strategic objectives. In contrast, in the academic area technology transfer is driven by more personal reasons — for example, intellectual growth.

Transferor and transferee are not clearly distinguishable

We believe that the traditional way of modeling technology transfer is not precise enough to capture the complexity of the interactions involved in the transfer. In fact, many of our respondents identified themselves on both sides — as transferors *and* as transferees. Based on this observation, we reworked the original definition of technology transfer given by [Teece 1977] to produce a new one [Diebold et al. 2015] which should correspond more closely to what we expect to hold true for software engineering projects:

A new definition for technology transfer

> *Technology transfer is the process of sharing or developing a technology object between two or more actors via one or more media so that the technology recipient sustainably adopts the object in the recipient's context in order to evidently achieve a specific purpose.*

13.3 Guideline Concepts

Using a guideline concept has been proven as a comprehensible approach for transferring technology (cf. [Vieira et al. 2012]). The results from the previously presented study in Section 13.2 support this idea of using guidelines as transfer media, especially for the industrial partners.

This section presents generic recommendations which support the creation of domain-specific guidelines for the automation, avionics, and automotive industries. These recommendations define a generic guideline concept that addresses key requirements for the applicability of research results collected from industry and literature.

Process of creating the recommendations

The guideline concept is developed in an iterative way which allows the integration of feedback from the application in industry in order to incrementally increase its maturity. Further details on the guideline concept and the corresponding recommendations can be found in [Heuer et al. 2014].

13.3.1 Key Requirements for Guidelines

Requirements for guidelines cover, amongst other things, the structure of the document with respect to technology introduction phases and activities and the use of examples to illustrate the concepts. In addition, general considerations about technology transfer also constitute valuable sources for requirements, since guidelines aim at facilitating and supporting change processes. Goal-orientation — for example, benefit analysis — and addressing the management are key factors for successful technology transfer and should be reflected in guidelines. An excerpt of the resulting set of requirements from specific application domains is shown in Tab. 13-1.

Tab. 13-1 *Representative subset of guideline requirements (cf. [Heuer et al. 2014])*

Req.	Title	Domain(s)
R-1	A guideline should consider the organizational context of a given technology.	automation, automotive
R-2	A guideline should emphasize the goals and benefits of the technology that is to be introduced.	automation, automotive
R-5	A guideline should enable an estimation of the effort for technology introduction.	automation
R-16	A guideline should be independent of specific tools.	avionics

13.3.2 Recommendations for Writing Structured Guidelines

Based on the requirements, a reference structure for guidelines was designed. Although all requirements should be addressed, not all of them are directly reflected in chapter headings in the structure. For instance, R-16 from Tab. 13-1 is addressed by a guideline document as a whole. The generic reference structure of guidelines is mainly driven by two aspects: (1) the use case of the guideline, and (2) the target audience of the guideline.

First, the audience of the desired guideline has to be defined, (i.e., whether it is used within a company or across several companies). Company-internal guidelines can be more specific and tailored to the company's needs. In contrast, cross-company guidelines should not mention specific contact persons or departments of a company and might stay at a more abstract level. In each guideline, a set of reader groups, in terms of roles within a company, is addressed by the guideline. The following groups of guideline users are addressed:

Different reader groups for guidelines

- *Decision makers* decide whether the proposed technology should be introduced in the company/department or not.

- *Coordinators* are responsible for introducing a new technology after a positive decision by the decision makers.
- *End users* are those employees who have to apply a new technology within the company.

Tab. 13-2 shows the table of contents that constitutes the reference structure. Most chapters in this structure reflect the majority of requirements, as, for example, requirement R-2 from Tab. 13-1: this requirement is addressed by including a chapter that describes the purpose, that is, the goals and benefits of the technology that is to be introduced.

Tab. 13-2 *Reference structure of guidelines, including chapter titles*

Chapter	Target audience		
	Decision makers	Co-ordinators	End users
Preamble	✓	✓	✓
1. **Introduction**	✓	✓	✓
1.1. Classification			
1.2. Motivation and problem description			
1.3. Purpose of the technology			
2. **Management**	✓	✓	-
2.1. Field of application			
2.2. Risks and challenges			
2.3. Effort for introduction and usage			
2.4. Pilot project			
3. **Technology context**	-	✓	-
3.1. Organizational context			
3.2. Process context			
3.3. Technical context			
3.4. Social context			
4. **Technology application**	-	-	✓
4.1. Preconditions			
4.2. Methodological process			
4.3. Postconditions			
5. **Glossary**	✓	✓	✓
6. **References**	✓	✓	✓

Guiding questions support authoring of guidelines

Within this reference structure, the specific guideline chapters are augmented by questions. Those guiding questions should support the author for each of the chapters. The concept of guiding questions is borrowed from education and didactics. Here, these questions should enable authors to properly design a guideline, achieving their goals to successfully transfer research results to industry. The guiding questions address different aspects concerning the required information, structures to be created, decisions to be made, and expected effects on the part of the organization.

13.4 Artifact Quality Assessment Framework

Ensuring quality of models

Coverage of viewpoints and granularity layers in model-driven development (MDD) processes requires the use of different models that cover, for example, structural and behavioral aspects of the embedded system under development. Ensuring the quality of these models requires the mapping of abstract quality attributes such as maintainability, extensibility, and traceability to specific rules that conserve knowledge regarding model quality. While these rules exist for defined contexts, a transfer is challenging, however, due to a lack of formalism and expressiveness. Standards only provide high-level quality goals that cannot be easily mapped to specific metrics. This is also due to the fact that specific quality measurements depend on model elements and metamodels; they cannot be distributed as plug-ins because they need to be adapted.

Knowledge transfer therefore has to address this problem on a different level. Rules have to be specified on a more abstract level: multiple modeling languages are used for embedded systems specification. Standard modeling languages (such as UML and SysML) are too generic to cover all specialized aspects of embedded systems modeling — they have to be adapted and extended for project and domain contexts. Conservation and transfer of quality knowledge in reuseable quality rules must be sufficiently abstract to allow reuse in the context of different modeling languages and language profiles, as well as flexible tool chains that may be adapted with respect to modeling languages and quality indicators.

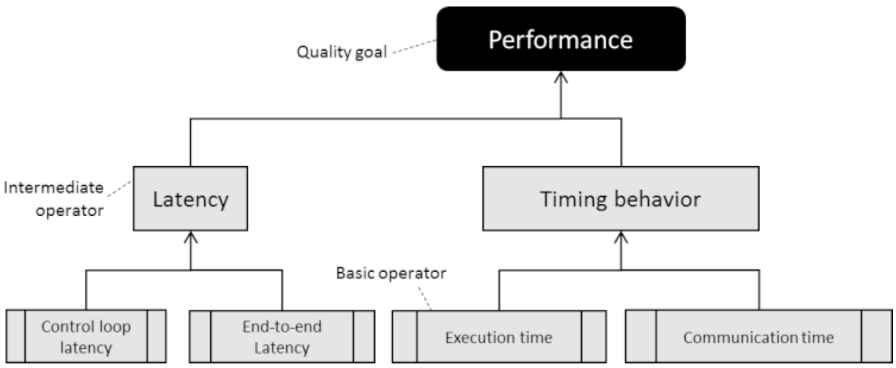

Fig. 13-1 *Quality tree example for performance*

Quality trees

Quality trees provide a high-level and implementation-independent description of quality attributes and therefore enable this transfer. They define data dependencies and operations for quality measurements. Leaves of quality trees define the collection of quality metrics from models. The example in Fig. 13-1 illustrates a quality tree that describes the calculation of expected performance based on base metrics that are collected from input models. Basic operators extract basic metrics from models. Intermediate operators calculate derived metrics — for example, expected latency and timing behavior. Quality attributes are calculated based on the outputs of these operators. Each operator can be specified using a data flow graph that defines its algorithm.

To support the setup of tailored quality measurement programs, existing and proven quality metrics have been collected from literature and project partners.

Evaluation of quality indicators

One tool that enables the evaluation of models according to quality indicators is INProVE [Basili and Rombach 1988]. The INProVE (Indicator-based Non-functional Property-oriented eValuation and Evolution of software design models) tool supports the implementation of tailored quality measurement programs that use an adapted goal question metric (GQM) [Kemmann et al. 2010] approach. Its overall structure is illustrated in the figure below. INProVE uses model adapters to connect to design models — this enables the integration of new model types that were initially not supported. Model adapters need to convert input models into Eclipse Modeling Framework (EMF) models. As an option, model adapters may target an existing metamodel, for example, EMF-UML2. This enables the use of existing INProVE operators for these metamodels with the newly integrated models. INProVE already defines a set of operations for the implementation of quality indicators, including basic operations such as mathematical and set operations, as well as more advanced operations including fuzzy logic. Quality indicators are defined in a graphical data flow language that resembles the structure of quality trees. These support the development of basic metrics that directly relate to model elements — for example, checking the consistency of two or more models — as well as the development of more complex derived metrics that are based on the basic metrics and combine them using fuzzy logic, for example. This enables developers to predict the impact of design decisions — for example, to evaluate the change in unit cost depending on deployment decisions and the derived need of hardware devices. Results are stored in a database. Standard tools (e.g., Matlab, Excel) may connect to this database and visualize the results depending on project needs.

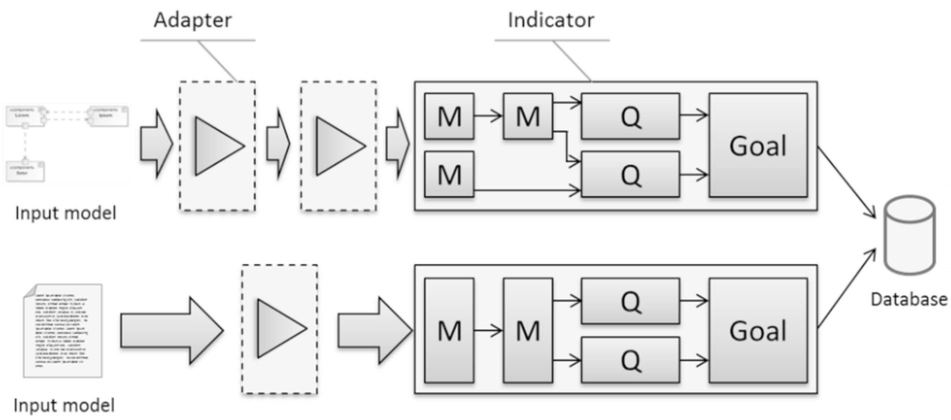

Fig. 13-2 *Concept of the INProVE tool*

13.5 Summary

The technology transfer concepts presented in this chapter can serve as a foundation for more advanced and elaborate concepts. Method specialists (either company-specific or independent), for example, could train employees of the companies in workshops for specific methods. Based on workshops, guidelines can act as a reference. In addition, existing guidelines, and thus the guideline structure, could be extended by cheat sheets. The guidelines itself are specifically tailored for specific domains. However, as the SPES XT modeling framework could also be used in other domains, the technology transfer concepts, especially the guidelines, may need to be adapted to deal with further domain-specific requirements.

13.6 References

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