ACTIVE Technologies in IC Design: Acquiring, Articulating, and Sharing Design Process Knowledge

A White Paper

Vadim Ermolayev[1], Eyck Jentzsch[1], Richard Sohnius[1], and Paul W. Warren[2]

[1] *Cadence Design Systems, GmbH, Mozartstr. 2 D-85622 Feldkirchen, Germany*
vadim@ermolayev.com, jentzsch@cadence.com, rsohnius@cadence.com
[2]*Centre for Information & Security Systems Research, BT Innovate, BT Adastral Park, Martlesham Heath, Ipswich, Suffolk, UK, IP5 3RE*
paul.w.warren@bt.com

Introduction

This white paper is about using the technologies that are developed in the ACTIVE Integrating Project[1] in an Engineering Design domain for increasing the performance of knowledge workers in their core activities. The knowledge workers in this domain are design project managers, designers, and design support engineers. Their core activities are respectively the activities those categories of knowledge workers are involved in while working for industrial engineering design processes in microelectronics and integrated circuits. In a nutshell, ACTIVE technologies help solving one of the bottlenecks of engineering design performance management – making the knowledge about design processes explicit and shared. By solving that we hope that we shall be able to facilitate the transition from the art of handcrafting integrated circuit (IC) designs to a more industrially strong design system with design process knowledge enabled for re-use.

We believe that the white paper will be of interest to all those who perform and manage engineering design projects in their everyday work: the knowledge workers mentioned before. Though we do not address the senior management directly, we still hope that the approach presented in this paper is general and high-level enough to be interesting for the decision makers in the domain.

Background to ACTIVE

The goal of ACTIVE is to materially improve the productivity of knowledge workers in all sectors. Our work is focussed on three areas which we believe are key to that productivity improvement:

- Improving knowledge sharing

[1] ACTIVE – **Enabling the Knowledge Powered Enterprise** (http://active-project.eu/) is the EU FP7 Integrating Project. It aims at increasing the productivity of knowledge workers in a pro-active, contextualised, yet easy and unobtrusive way. The approach is to convert tacit and unshared knowledge – the "hidden intelligence" of enterprises – into transferable, interoperable and actionable knowledge to support seamless collaboration and to enable problem solving. A key aspect is the support for informal process knowledge – the informal collaboration and problem-solving tasks that drive much knowledge work in the enterprise.

- Managing information by taking account of the user's task context; and
- Supporting knowledge workers in their use of informal processes

This section briefly describes our response to these three research challenges, gives an overview of the ACTIVE architecture, and describes how ACTIVE technology is being used in case studies of the project. For more detail on the work of ACTIVE, see [4].

Knowledge sharing

Improving the effectiveness of knowledge sharing within organisations has been widely studied, both from a technological and an organisational perspective. Our work is combining two approaches to knowledge representation; the formal and the informal. The former, based on the use of ontologies, possesses rich descriptive power and enables inferencing to make deductions from the knowledge; however there is a cost associated with creating, maintaining and using the ontologies. The latter, based on the use of informal tags, produces shallow folksonomies with no potential for reasoning; however associated costs are low and there is little barrier to use. Our research challenge is to create light-weight ontologies from the users' tags; and to create simple ontology editors to enable the easy creation and maintenance of light-weight ontologies.

Task context

The word 'context' has a variety of meanings. Here we are concerned specifically with 'task context', i.e. the user's current activity as he or she works at a computer or similar device. Our intuition is that the effective information delivery requires our systems to understand our current context. At any given time we want the information which is relevant to our current task to be prioritised over information which is relevant to other tasks which are not currently occupying us. Our solution to this is twofold: manual and automatic. We give the user the ability to explicitly associate information objects with contexts and to define his current context. We also use machine intelligence techniques to automatically associate information objects with contexts and to learn the user's current context.

Informal processes

By informal processes we mean the processes which all knowledge workers create. These range from organising a meeting to creating a bid proposal or, as in the case discussed in this paper, designing a complex engineering artefact. They are distinguished from formal business processes in that they are created by individuals, not organisations; as a result they can be changed at will. However, they are frequently not well documented and therefore often not shared and reused. They may even be forgotten by their own creators, necessitating reinvention. Our challenge is to automatically learn these repeated processes, to make them explicit so they can be shared, reused and managed, and to guide future users through the processes.

The ACTIVE architecture

ACTIVE has adopted a service-oriented approach to its architecture; services are defined at a number of levels, as illustrated in Fig. 1. At the bottom level are infrastructure services which undertake housekeeping functions such as ensuring that all relevant applications are aware of switches of task context.

At the level above this, machine intelligence technology is used. The context mining service automatically associates information objects with contexts, and learns the user's current context. The process mining service learns repeated sequences of actions which constitute processes, and guides the user through these learned processes. The metadata recommender service identifies potential metadata to be associated with information objects, based for example on the contents of those objects.

The next level provides three services which draw on the machine intelligence services in the layer below and also allow manual intervention. For example, the context service enables the manual switching of context and association of information objects with context.

Finally at the top level are the applications. These fall into a number of categories. Generic applications are the everyday applications which all knowledge workers use, e.g. e-mail and word processing. Specialised applications are proprietary applications which are specific to a particular implementation of ACTIVE. In the example discussed in this paper, these would be computer aided design (CAD) applications for IC design. The philosophy of ACTIVE is that the user continues to use all his existing applications, but within the ACTIVE framework. However, some applications do need to be developed in ACTIVE to complement the pre-existing applications. These are the ACTIVE applications shown in the third box from the left in our top level. Finally, the ACTIVE taskbar provides the user interface for actions such as manually switching context.

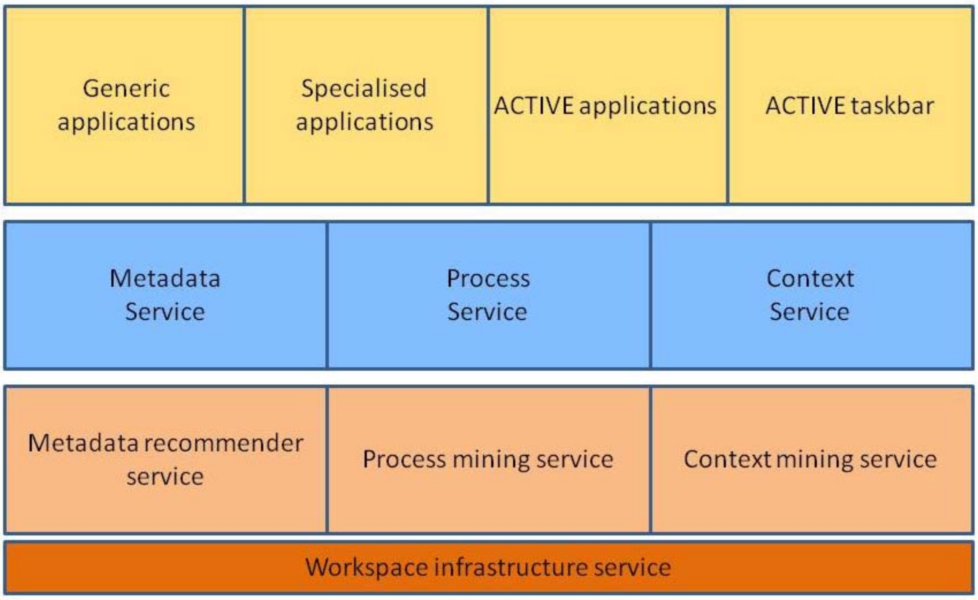


Figure 1: The ACTIVE architecture.

The Case Studies

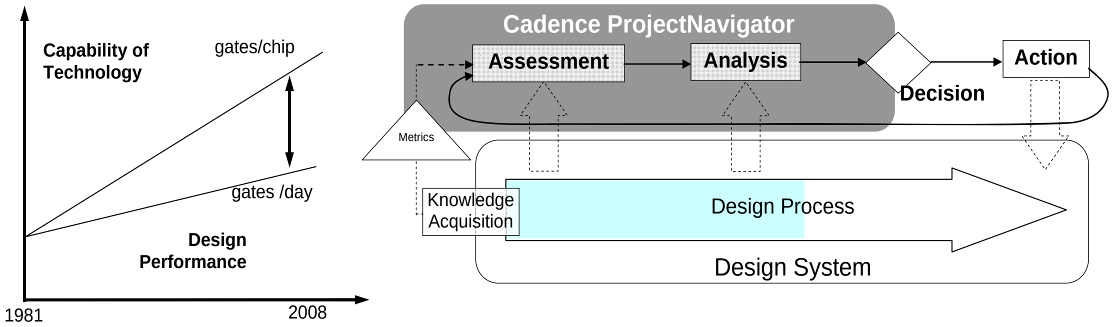
ACTIVE technology is being used and validated in three case studies. Within BT and Accenture we are working with customer facing technical specialists and consultants. They need to share information so as to respond more rapidly and more proactively to customers; to negotiate a range of informal processes, including the bid proposal process; and to have their information managed and delivered by context, which often means by customer or by project. The needs being addressed here are mostly generic. The industries are telecommunications and consulting, but much of what we are doing is applicable to a wide range of sectors. In the case study with Cadence Design Systems, described in this paper, we are using our technology to satisfy requirements specific to a particular sector and category of knowledge workers. Throughout these case studies we are using our technology for the benefit of end-users and at the same time validating, and through feedback, improving that technology.

ACTIVE in Microelectronic Engineering Design

ACTIVE case study on managing knowledge and processes in microelectronics and integrated circuits design is lead by Cadence Design Systems GmbH (http://www.cadence-europe.com/), an engineering design services provider in this domain.
As many experts in microelectronic and integrated circuits design point out (e.g., [1]), one of the main industrial challenges is the gap between the capability of design technology and the productivity of design systems. As pictured in Fig.2a, the capability of the design technology e.g. to accommodate digital gates on a chip is growing much faster than the capability of design teams using this technology and the corresponding design environments to produce these gates in their designs. The consequence is that the effort required to be spent for designing a typical microelectronic device is growing substantially. Indeed, it is known that the average industrial effort spent for designing a chip in 2008 is about 50 person years. It is estimated that in 2016 the average effort will be around 25,000 person years[2]. Those companies who are able to narrow this gap gain substantial advantage in this very competitive market. Therefore, tools and methodologies for improving the performance of design systems are demanded. One challenge in developing such instruments is ensuring the robustness and trustworthiness of such tools. Industrial experts point out that the solutions developed in the past are not fully satisfactory because they "…lack the option to work in detail on the variants of tool flow and methodology. Leaving it up to the design teams leads to local optimizations and point solutions, not necessarily applicable for several teams and inefficient to maintain. Consequences are lack of support, delays, budget overshoot and overall sub-optimal product solutions." (cf. [1]).

Cadence attempts the assessment and management of engineering design performance in a manner outlined in Fig. 2b. A design system is denoted as *a holonic system*[3] *providing the environment in which design processes are performed*. This environment comprises actors rationally collaborating in design teams, a normative framework providing regulations and policies, material resources, and tools. A design process executed in this environment and the environment itself are also controlled by the specific cyclic performance management process comprising knowledge acquisition, measurement and assessment, analysis, decision making, and action phases. Provided that there is a software tool facilitating knowledge acquisition, assessment, and analysis, an informed decision based on the results provided by the software can then be made. This decision suggests the action influencing the design system in a way to improve performance.

[2] Source: http://www.edacentrum.de/produktivplus/en/content/overview.htm. Though the absolute figures may be disputable, the tendency and the ratio are correct. The reason for this is the continued increasing chip density, as described by Moore's law [2].
[3] A holon is a system (or phenomenon) that is a whole in itself as well as a part of a larger system (or phenomenon). Source: http://en.wikipedia.org/wiki/Holon_(philosophy)



a) Design performance gap in microelectronics: The capability of design technology measured in gates per chip is growing faster than the capability of design systems to produce these gates in their design processes (based on [1])

b) Engineering Design Performance Management cycle used in PSI: ProjectNavigator is an intelligent agent-based software tool for the assessment and predictive analysis of design systems and design processes in microelectronic engineering design.

Figure 2: IC design performance challenge and the solution developed by Cadence.

The Case Study focuses on the use and customisation of the ACTIVE technologies of pro-active knowledge process support and knowledge articulation and sharing. As far as this work is primarily focused on the processes at the project level we do not plan the use of dynamic contexts for in-context knowledge delivery. Indeed, the contexts in our domain are statically pre-defined and separated by design projects: by the type of the artefact in design or by the use of a particular design technology. We do not aim at supporting cross-project activities of knowledge workers and consider projects independently.

Even having this substantial simplification in mind, there are still many aspects related to engineering design process performance that require optimisation. One important facet is the dynamic character and dynamic ramification of an engineering design process. Another one closely related to process dynamics is the requirement to seek for the best productive process continuation among the many possible alternative paths.

Though design technology in the branch of industry is well defined, design processes are very "stochastic" in terms of developing their paths in solution spaces. Some important reasons for process dynamics, specifically for their dynamic ramification, are:

- Design goals may change in the course of a process
- Involved designers may have different skills, capabilities and tool experiences
- The order of some phases (activities) can not be deterministically pre-set for any possible type of an artifact under design

A design process therefore develops dynamically. At every step, a decision needs to be made concerning which of the admissible follow-up design process paths are more productive. In that sense an engineering design process is an informal knowledge process. Each execution of such a process is developed and performed by the team of knowledge workers (design engineers, design support engineers, project managers) in a unique fashion. It is not a challenging problem for experienced team members to make follow-up decisions and choose more productive paths because they use their tacit knowledge based on the past experience. However, for those whose experience in designing this or that particular type of a chip or a circuit is limited, an expert adviser may substantially lower the risk of a mistake. It is very similar to using a navigator system for finding a route on a map, but on a map displaying design technology stages. In an ongoing effort in parallel to and independently of ACTIVE Cadence is currently developing such a “navigation system” for monitoring, evaluating, and simulating design processes for suggesting project continuations with better performance – **ProjectNavigator**.

ProjectNavigator is a tool to plan, assess, and manage IC design projects. To accomplish this it consists of several components: a knowledge base keeping knowledge about the design system, a partial automated project planner, and a project tracker. The knowledgebase contains the facts about the design system and the performance of the past and the ongoing design projects in the form of OWL ontologies. This knowledgebase is used for analysis to make informed decision on how to further execute design processes. **ProjectNavigator** is part of the key performance indicator (KPI) management system and serves as a front-end intended for project and product managers. The KPI Management system gathers the data needed for the project tracking and assessment as well as provides the knowledge base and updates to it.

How ACTIVE technologies contribute to the overall goal?

Technologies developed in ACTIVE are used in the development of Cadence **ProjectNavigator** for several important purposes.

One of the challenges is acquiring and managing explicit and finely grained knowledge about the development of the processes of electronics design (in terms of methodologies, processes, activities, actors, best practices, software tools etc.). The problem is that the knowledge supporting designers’ decisions on how to continue the process is tacit, subjective, can not be fully elicited and made explicit by interviewing the knowledge workers. In particular, designers often employ their intuition and experience when reasoning about facilitation dependencies among design activities executed in design environments.

Accurate and finely grained data on actual design process execution is required both for calibrating the system and for monitoring purposes. At the same time, the data acquisition routine must meet practical and legal constraints and therefore must neither add a significant burden to the engineers nor slow down the design process or violate privacy laws and policies. To achieve that, the software providing the work environment (also referred to as Cadence **WorkBench** (Fig. 3 (1)) has been ACTIVated – ie modified in a way that it generates log entries at the beginning and the end of typical designer tool program runs. These entries are called *ticks* (2).

At the other end of the system the knowledge base (7) has been created which contains among other things the facts about the tasks and activities admissible within the design system in terms of the ontology

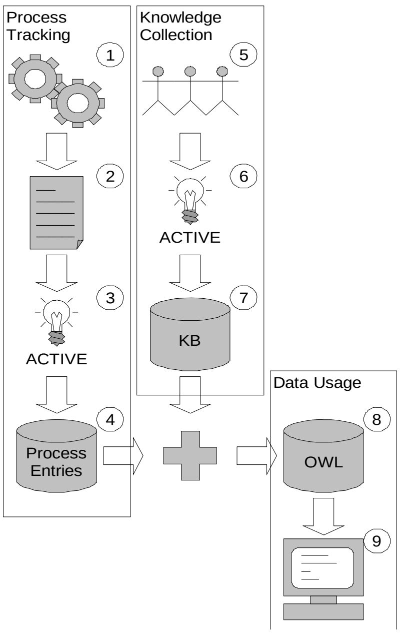


Figure 3: The outline of the knowledge acquisition process

Suite that has been developed by Cadence in the course of PSI[4] and the PRODUKTIV+[5] projects.

The challenge is now to make these ends meet and express the course of a process, tracked in the form of *ticks*, in terms of the knowledge base. This semantic expression (8) can then be loaded into the graphical tool (9) being developed and presented to the users for verification, monitoring, evaluation and planning.

Another point is the creation and maintenance of the knowledge base. The design engineers (5) have their tacit knowledge of the design processes but are not supposed and are not fully capable to articulate this knowledge in terms of the ontology. On the other hand, the knowledge engineers, being the owners of the ontology lack the insight into the design processes. Several ACTIVE technology components – for example enterprise knowledge structures, dynamic temporal knowledge process model, Semantic Media Wiki (6) – will help mediate between both groups.

How ACTIVE technologies can help?

ACTIVE develops several interlinked technologies which can be broadly classified as (i) knowledge representation models and ontologies; (ii) software development components and kits; (iii) customized software components for the use in Case Studies; (iv) methodologies. The Cadence Case Study exploits several of these for solving the problems of design process Knowledge Acquisition, design process Knowledge Articulation, and design process Knowledge Sharing as pictured in Fig. 4.

Knowledge Acquisition. Using Data Collection component, Probabilistic Temporal Process Model, Process Mining Component, and Enterprise Knowledge Structures.

Before the *ticks* can be transformed into the instances of the ontology (6), they require extensive pre-processing (1-5): Unfortunately, the granularity of the data presented as ticks does not match the granularity of the facts (the instances) in the knowledge base, neither in work steps nor in terms of iterations. Furthermore, the mapping of the ticks to corresponding design activities is a non-trivial task. This is one point where ACTIVE technology is employed. First, the raw tick data is collected (1) in the ticks database by the means of the ACTIVated **ICD WorkBench**[6] – the Data Collection Component. Secondly, the data is filtered semi-automatically (2) in order to select only those records that contain complete and accurate information. This information is further on used (3) as a training data set[7] for the Process Mining Component. After the Process Mining Component is trained on this set it is fed with the entire tick collection (4) for: (i) inferring the missing values such as milestones; and (ii) mining the elements of the tracked design processes in terms of design activities and tasks – i.e. having the granularity required by the ontology (6). Process maps are generated by the Process Mining component and further used for the verification of the correctness of the mined data (5). This verification is performed manually by comparing the basic process maps generated at the training phase (3) to the process maps built using the complete and enriched set of ticks (4). The process instances that have been mined by

[4] Performance Simulation Initiative (PSI) is a research and development project of Cadence Design Systems, GmbH.
[5] PRODUKTIV+ is a research and development project funded by the German Bundesministerium für Bildung und Forschung (BMBF).
[6] ICD WorkBench is a Cadence VCAD IP.
[7] Our first experiments with the data collection show that the size of the training set is about 20 per cent of the whole volume of the collected tick records.

the Process Mining component are further transformed to the representation in terms of the ontology (7) and stored to the knowledge base.

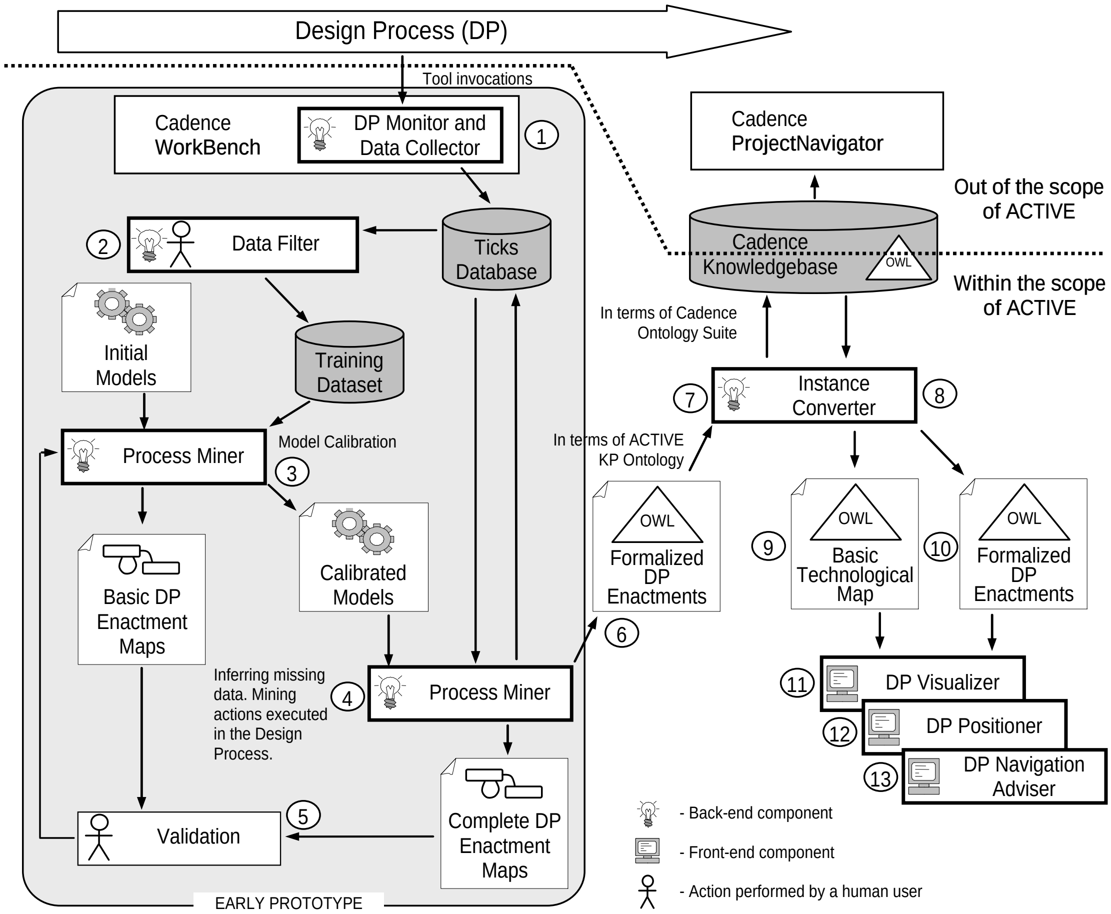


Figure 4: The use of ACTIVE technology components in design process knowledge acquisition, articulation and sharing.

Knowledge Acquisition phase solves the problems of (i) process knowledge mining; and, partially, (ii) process knowledge articulation[8] preparing the ground for the subsequent phase of Knowledge Articulation.

Knowledge Articulation. Using: Enterprise Knowledge Structures, Cadence Suite of Ontologies, Dynamic Process Model, and Semantic Media Wiki.

The major objective of the Knowledge Articulation phase is representing the informal knowledge processes of engineering design in the form appropriate for human users. The executions of the design processes (10) are visualized in the Semantic Media Wiki [5] (11) that is used as a lightweight community tool and infrastructure for design teams. Semantic Media Wiki uses the ontology of design technology steps as the basic technological map (9). Design processes, mined as explained for the Knowledge Acquisition phase, are visually superimposed over the basic technological map on the Wiki pages (11). The members of the development team (the designers, design support engineers, and their managers) can therefore be informed about the progress of their process (12). They can also use this representation for assessing how productive they were or their design tools were in particular design operations by, for example, comparing the number of executed iterations. The managers can also make

[8] **Articulation** – the process through which tacit skills and **knowledge** are made explicit [3]

use of this knowledge for correcting the plans for the follow-up steps in the design process.

Knowledge Sharing. Using: refined Enterprise Knowledge Structures, Probabilistic Temporal Process Model, and Dynamic Process Model; customized components for Privacy Preserving Process Mining, Security-Aware Process Treatment.

Through sharing knowledge about the execution of design processes among the members of development teams their best practices could be collected (1-7), articulated (8-12), and delivered to those knowledge workers who require expert advice (13). Semantic Media Wiki can be used as a technology enabling the sharing of such knowledge using lightweight knowledge models and in an informal way. These lightweight representations could be used by the members of the development team for making their decisions on the choice of the follow-up operation that is deemed to be more productive due to the evidence provided by the best practices (13). Indeed, the follow-up action A could be considered as a more promising alternative if it has been chosen in, say, 70 per cent of the practices presented by the Wiki pages. More elaborated knowledge representation in the form of ontologies will be used in the **ProjectNavigator**.

One of the emphases in the Knowledge Sharing phase is the assurance of users' privacy preservation and enabling appropriate security policies for distributed development teams that may involve the members from different company subsidiaries or even different organizations across different countries with various legal systems.

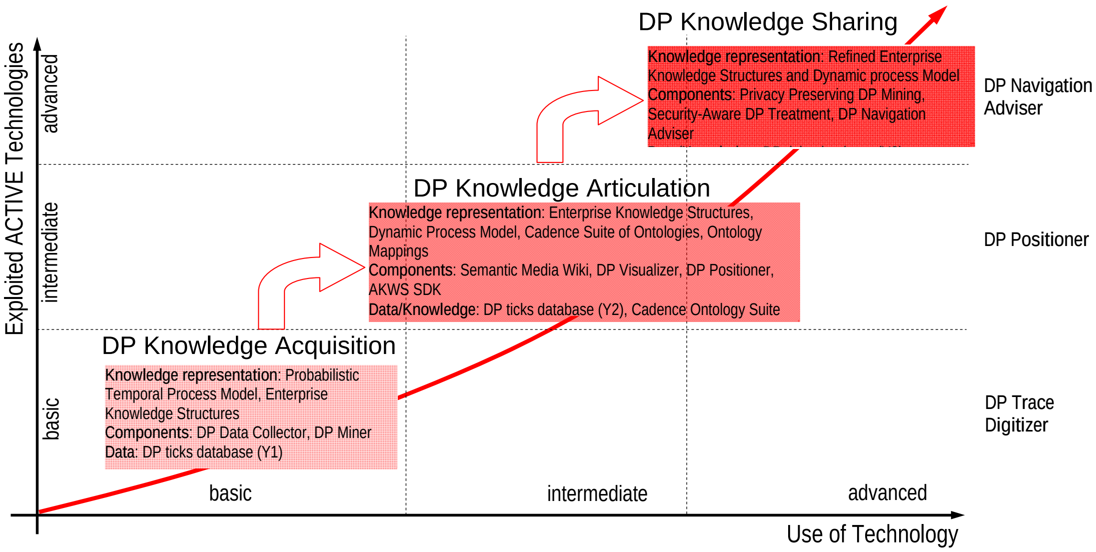


Figure 5: The roadmap of exploiting ACTIVE technologies in managing knowledge on engineering design processes (DP) in microelectronics and integrated circuits.

Development approach

Our approach in building up the usage of ACTIVE technologies in managing design performance knowledge could be qualified as evolving prototyping. The use of ACTIVE technologies will be incrementally extended and refined in the project lifetime and beyond. The strategy (Fig. 5) is:

(i) To start with incorporating the basic subset of technologies, allowing us to solve the design process Knowledge Acquisition problem and partially solving the design process Knowledge Articulation problem.

(ii) To continue by extending and refining this technology core for capturing, explicitly representing, and visualising the knowledge about design process executions. Knowledge processes will be visualised as superimposed on the basic design technology map. This is deemed the complete solution of the Knowledge Articulation problem.

(iii) To follow-up by providing the infrastructure for design process knowledge sharing and re-use, thereby providing an environment for the best practices in microelectronic design.

The intended users of the KPI management system and the **ProjectNavigator** are the project and program/product managers within Cadence and its customers. They are concerned with planning and tracking of projects as well as assessing the performance of them and reporting the state to the different stakeholders in the organization.

Currently there exist systems aiming to support the management of projects and programs but these merely rely on practices and policies and create additional burden to the designers being required to provide input. Moreover those systems lack sufficient automation for routine tasks and a stringent SW support, e.g. many rely on Microsoft Project which requires a significant amount of manual input which is prone to errors. **ProjectNavigator** and the KPI management system aim to fill in this gap. ACTIVE technologies play a pivotal role here since they provide means to take burden off the designer being required to do status reports. By automating the capture of the as-is state this step becomes more objective and can be done continuously thus allowing a quicker response to significant deviations from the plan of the project or the desired performance of the design system. This cycle from event to evidence to reaction ranges in current systems from days to weeks; the KPI management system is supposed to reduce this to less than a week even in large design systems accommodating several hundreds of designers.

Next steps

The prototypical application of ACTIVE technologies is evaluated regarding the suitability of the components provided by ACTIVE research partners. The results of this evaluation will be used to guide further development of the algorithms and components as well as the Cadence specific data acquisition infrastructure.

As the evaluation yields sufficient results the ACTIVE components being of general use (e.g. Semantic Media Wiki) will be rolled-out in the Cadence Worldwide Services Organization to facilitate the knowledge exchange within the group and to allow more efficient project management. This internal usage provides the seed and experiences for customer deployment enabling IC design organizations to unleash their productivity and performance.

Acknowledgement

The work described in this paper has been funded in part by the IST-2007-215040 EU project, ACTIVE.

References

[1] P. van Staa and C. Sebeke, “Can Multi-Agents Wake Us from IC Design Produktivity Nightmare?”, *Proc. 3rd Int’l Conf. Industrial Applications of Holonic and Multi-Agent Systems (HoloMAS-2007)*, LNAI 4659, Springer, 2007, pp. 15-16.

[2] G. E. Moore, “Cramming More Components onto Integrated Circuits”, *Electronics*, 38(8), 1965, pp. 114-117

[3] Ha°kanson, L. (2007), ”Creating knowledge: the power and logic of articulation”, *Industrial and Corporate Change*, 16(1), 51–88.

[4] Warren, P.W. et al., (2009) “Improving knowledge worker productivity – the ACTIVE integrated approach”, BT Technology Journal. Vol 26, no 2, February 2009.

[5] Krötzsch, M.,Vrandecic, D., and Völkel, M. “Semantic Media Wiki“, International Semantic Web Conference, ISWC2006, http://korrekt.org/papers/KroetzschVrandecicVoelkel_ISWC2006.pdf