COMMIT

WORKPLAN

WORKPACKAGES

DELIVERABLES

BUDGET

COMPOSABLE EMBEDDED SYSTEMS FOR HEALTHCARE (P11)

Projectleider prof.dr. Jozef Hooman, Radboud University Nijmegen

1. Background

Embedded software has evolved from small control programs written using low-level assembly code to very large distributed programs (often millions of lines of code) written in high-level programming languages. Complex embedded software solutions can be found controlling high-speed printers, cars, phones, medical devices, consumer electronics, airplanes, industrial robots, etc. Typically, the functionality of these devices has been extended over many years by many incremental changes. Because of the accumulated complexity of the software, it is often extremely difficult to add new features. Small changes may have large unexpected consequences and lead to a long and costly development process.

End users constantly request performance improvements and additional features to be added to the system. This concerns, for instance, increased safety, additional environment requirements and increased speed & resolution. These requirements often have a strong impact on the complexity of the software. In addition, there are frequent requests for customized adaptations, leading to many different configurations of the software, which results in the need for frequent updates in the field.

The main aim of this project is to increase the innovation rate in the face of increasing complexity whilst maintaining safety and performance characteristics.

Embedded software is usually specified and designed using natural language, with informal visual notations. Large parts of the software are frequently developed independently, in other business units or bought as “off-the-shelf” components. This results in many errors appearing during the integration and test phases. Academic research into this problem has led to a number of methods and techniques that aim to eliminate errors much earlier in the development process and to improve the structure of the software. In this project we consider formal methods that enable mathematical specification and logical verification of component architectures. The introduction of these formal techniques during the early phases of system development should have an impact on the testing process. Hence, we also investigate model-based testing techniques that use formal models to automate the testing process. Given the importance of non-functional properties, such as evolvability and performance, we study this in relation to advanced performance analysis methods and scientific techniques to assess the impact of changes on architectures. These approaches show great promise and leading expertise in these fields will be used and extended by the partners in this project.

The evaluation and verification of these advanced methods in industrial practice is far from trivial and requires significant research. Scalability is a well-known problem with a number of these methods; they work well on small examples but the application to millions of lines of code leads to new challenges. Given the hundreds of man years invested in existing software archives, it is highly unlikely that the software can be redesigned from scratch. Hence, research is needed to address the problems of migrating legacy code. Another blocking factor is that it is difficult to integrate these techniques in a coherent development process.

To integrate different techniques that address various system qualities and to detect errors early, the definition and modelling of the software components plays a central role. The project will address techniques to model components formally and to verify their functional correctness in a scalable way. In addition, other important quality aspects of components are addressed, such as their place in the global system architecture, their functional correctness, safety, and performance. To rigorously evaluate the project research results, Philips Healthcare provides relevant case studies in the context of their Cardio-Vascular X-Ray systems.

This project fits into the COMMIT societal priority area Health, cure and care, and the ICT science area Embedded Systems. It is strongly related to the Bsik project Darwin led by ESI. The academic partners in Darwin are collaborating with Philips Healthcare to make software changes easier. The project ended in 2010 and has mainly focussed on improving inter-disciplinary communication and enhancing the understanding at the system architectural level. Currently, the project results are being transferred to Philips Healthcare. This provides an excellent basis for the current project, in which the next step is taken to improve the structure of the software as well as its development process.

2. Problem description

Industrial practice shows that it is extremely difficult to keep improving devices by adapting and extending the embedded software. Small changes often lead to unexpected consequences, due to unknown interactions and dependencies between parts of the system. The complexity of millions of lines of legacy code makes it almost impossible to predict the impact of changes. The replacement or integration of new software components often leads to errors that become visible only late in the software development process. This in turn causes a long and unpredictable time to market. Projects can significant exceed their budget and cancelled projects are no exception in the domain of embedded systems.

The objective of this project is to define an integrated set of methods and techniques that supports a systematic “Right by Design” component-based software design approach for complex embedded systems. This ensures that incremental changes become predictable and meet the required system qualities such as performance and safety. The main scientific challenge is to overcome tensions between parts of this objective:

- Current academic “Right by Design” software design techniques are very labour intensive and significant steps need to be made to achieve scalability to large embedded systems.
- Typically, concepts for flexible and adaptable software have a negative impact on timing behaviour and predictability. Hence, a careful trade-off has to be made between evolvability and performance demands. Since these global system qualities are usually

- Strong safety constraints make it extremely challenging to deal with large number of customized configurations and frequent upgrades of components.

This leads to the following list of key research questions:

- How to decompose systems into components such that the global system requirements can be derived from the properties of the components? What are appropriate coherent systems views to reason about various system qualities such as evolvability, performance and safety?
- How to define interfaces of components that enable verifiable composition, re-use, configuration management, and replacement? How to include evolvability and safety aspects and how to characterize performance in a modular way?
- How to reason about correctness aspects of large complex embedded systems. How to analyze the trade-off between system qualities early in the design process?
- How do model-based verification techniques relate to model-based testing? What is the relation between the models that are suitable for these techniques? Does the verification reduce the testing effort? Can the testing results improve the scalability of the model checking techniques?

3. Objectives

Project's goal

Complex embedded software solutions can be found controlling high-speed printers, cars, phones, medical devices, consumer electronics, airplanes, industrial robots, etc. Typically, the functionality of these devices has been extended over many years by many incremental changes. Because of the accumulated complexity of the software, it is often extremely difficult to add new features. Small changes may have large unexpected consequences and lead to a long and costly development process. The main aim of this project is to increase the innovation rate of high-tech embedded systems in the face of increasing complexity whilst maintaining evolvability and performance characteristics. The approach is to formalize component interfaces, to remove faults early in the development process by using models, and to exploit these models during testing. The objective of this project is to define a coherent set of methods and techniques that supports systematic component-based design of complex embedded systems with reduced test and integration time. To rigorously evaluate the project research results, Philips Healthcare provides relevant case studies in the context of their Cardio-Vascular X-Ray systems. In this domain many innovations are targeted at providing early diagnosis and better treatment of patients.

Planning of all dimensions

A number of methods, tools and techniques will be developed to support the design of component-based embedded systems, such that faults are detected early and innovations can be incorporated easily. To achieve the project goals the research is split into work packages that concentrate on different phases of the development and different aspects. WP1 aims at improving the system definition, using budget-based techniques to improve the communication between different state holders and to avoid integration problems. WP2 addresses the main development phases and investigates the consistent use of models for design and test. WP3 concentrates on evolvable software architectures which support fast innovation. Detailed design is addressed by WP4 where the focus is on the formal verification of component design, again with the aim to detect faults as much as possible before the test and integration phase starts. WP5 is concerned with performance as a cross-cutting aspect, aiming at an early assessment of performance aspects which is a relevant for all development phases. Integration and dissemination of results is addressed in WP6, with an emphasis on demonstrators that show the applicability of the developed tools and techniques.

Ten important end goals of the project:

- Guidelines on the use of executable behavioral models for) system architecting.
- Tool support and guidelines for model-based testing.
- A method on the use of budgeting for system design and management.
- Tool support and guidelines to manage relations between different types of design models.
- A methodology on interface design and change impact analysis.
- Tool support for scalable formal methods that allow the verification of data aspects of component-based architectures.
- A performance analysis method, including tool support, which is closely linked to component-based development.
- More than forty published papers and four PhD dissertations.
- Demonstrators which show how the results can be used in the healthcare domain to improve system engineering, to detect faults earlier, and to improve the speed of innovation.
- The adoption of project results into the workflow of Philips Healthcare and the identification of possible transfer possibilities to other companies.

Results

To obtain a component-based development method for complex embedded systems which increases the speed of innovation, especially by reducing the test and integration time, the project aims at papers, tools and demonstrators that address the following aspects:

- System definition techniques that clarify the requirements for the design phases and improve the communication with non-technical state holders (WP1).
- Model-based design techniques, including simulation and formal verification, which allow early detection of design problems (WP2 and WP4).

- Model-based testing techniques with improved visualization, domain-specific modeling, test selection, data coverage, and diagnosis (WP2 and WP4).
- Interface analysis, complexity analysis, and evolvability analysis (WP3).
- Performance techniques that are coupled to the design phases and allow early detection of performance bottlenecks (WP5).
- Definition of a coherent component-based development methodology which combines improved design and analysis techniques (WP6).

Deliverable Impact and Valorization

Axini and ESI are specifically committed to bring valuable project results to a wide range of high-tech industries. Axini will include new research results on model-based testing in their Axini TestManager. In this way, these new techniques become available for the Dutch industry by means of a commercial tool. ESI will focus on industrializing the methods and techniques developed in this project. Transfer of results to interested companies will take place via special workshops and dedicated transfer activities. This will ensure that the results are incorporated in a new 'way-of-working' benefiting the economy and society at large. As a follow-up activity, industrial courses will be developed by ESI research fellows and knowledge managers based on project results. These courses are part of the ESI competence development programme for professionals working the high-tech industry. The TU Eindhoven is planning to set up re-educational courses for professionals that want to learn about new methods. This will be done via the laboratory of quality software (www.laquso.nl). The tools developed by the TU Delft and the University of Twente will be free available. The mCRL2 tool set of the TU Eindhoven can freely be downloaded and is distributed under the boost license, which is extremely liberal. We expect at least a few thousand downloads of the toolset. Impact on the European embedded systems agenda will be achieved via ESI's membership of the ARTIST DESIGN Network of Excellence on Embedded Systems Design and the ARTEMIS Industry Association on Research & Technology for Embedded Intelligence and Systems. Philips is a member of the steering board of ARTEMIS and both ESI and Philips participate in discussions to prepare the Artemis Strategic Research Agenda. Note that the WP6 delivers a Valorization Plan at the end of the project.

Deliverable Dissemination

The central source of all information about the project will be the project web site, which contains information about project partners, project goals, project results, and scientific publications. Scientific results are disseminated to the international community via presentations and publications in high-quality journals, such as the Journal on Software Tools for Technology Transfer, Performance Evaluation, IEEE Software, Systems Engineering, Formal Methods in System Design, IEEE Transactions on Software Engineering, The Computer Journal and conference proceedings, such as QEST, TACAS, ICSE, ICSP, DAC, CSER, ISoLA, MODELS, FM, EMSOFT, DATE, CONCUR, and FORMATS. The academic partners will also disseminate their results by incorporating them in software tools. Results will be highlighted to the scientific community by means of presentations and tutorials at international conferences and workshops. Dissemination to industry proceeds via special meetings for industrial engineers with an emphasis on usage scenarios, required investment, and industrial benefits. For instance, ESI and Philips Healthcare will report about project results in a Special Interest Group (SIG) on model-based development. Especially relevant in this context are user stories, demos, and videos about tool usage. ESI will organize a yearly symposium for the embedded system industry which also includes an information market where project results can be demonstrated. The same holds for the yearly Bits & Chips Event on Embedded Systems, where ESI is co-organizer. Both events typically attract hundreds of industrial participants. We also aim at popular papers in the Bits&Chips magazine and the Technische Weekblad, because these are an important media for dissemination to the Dutch high-tech industry.

International Imbedding

The main ingredients of this project, such as model-based design and testing, component-based development, formal methods, and performance, are topics of many international projects. Project partners also collaborate in international projects on their area of expertise. In this respect, we build upon existing knowledge and improve the state of the art with special emphasis on industrial applicability, scalability and suitable tool support. New results in this direction are expected, since the main project members work together on a single location in industry, which is unique compared to the international competition. The main new results are obtained from the combination of model-based techniques for component based development with analysis techniques for non-functional aspects such as performance and evolvability. This leads to a new coherent combination of design models and analysis models, supported by tools, and integrated in an industrial workflow. It enables new possibilities to related design models to performance models, to use design models for the testing phase in a systematic way, and to exploit the relation between formal verification and testing.

Deliverable Synergy

The budgeting techniques of WP1 (of P11) will be applied to the system definition in WP1 of project P12. Furthermore, we will investigate the possibilities to use the model-based testing techniques of WP2 (of P11) for health monitoring in WP2 of project P12. Furthermore, we will explore the possibilities to apply the application of budgeting and performance techniques, as developed in WP1 and WP5 of P11, to the work packages of WP5 and WP6 of P20 where the trade-off between performance and energy consumption is important.

4. Economic and social relevance

1. *Societal problem:* An aging and increasingly unhealthy population is driving the strong demand for additional healthcare provision. This in turn drives up the total cost of providing this care. In the long term (> 30 years) prevention initiatives should pay-off but in the short to medium term more efficient ways need to be found to treat a wide variety of medical

2. *Societal objectives*: Society would like to minimize the effects of medical complaints by fast efficient diagnosis, risk free surgical procedures and all at an affordable price. These objectives can be brought closer by quickly bringing advances in medical research into mainstream clinical use. For example, it is now commonplace to treat some form of coronary heart disease by the insertion of stents into the affected arteries. This innovative procedure replaces the much more costly and risky open heart surgery carried out some years ago. This type of procedure is made possible by the use of advanced medical imaging equipment. With this equipment surgeons are able to "see" interactively the passage of various devices through the body's venous system. A few hours after these types of operations, patients are able to walk around unaided.

3. *Technical challenges:* Bringing complex systems with high performance and safety requirements to market is costly and time consuming. The architecture of these systems should enable upgrades and feature enhancements to take place over the long service life, which is typically >10 years. There is a general lack of methods, guidelines and analysis techniques to evaluate the correctness of design at an early stage of development. A method needs to be devised to describe coherent system views that provide analyzable system decomposition. An important challenge is to develop techniques for the rigorous mathematical specification of components that are scalable and allow verification in terms of functionality, performance, reliability and safety.

4. *Economic objectives:* This project provides methods for the flexible use of medical equipment in new applications. This represents a significant economic benefit.
    a. The R&D investments of the high-tech systems industry in the Point One ecosystem is estimated at 1,5 B€/year, with a production value of about 28 B€/year. With an average lifetime of a system of 8 years this represents a capital investment of at least 220 B€. Improved reuse of at least 10% could be envisaged on the basis of a well-validated research program. Assuming that about 1% of this market could be reached through such measures, this would represent a total value of 220 M€.
    b. The project aims at an efficiency improvement of at least 10% of the development time for new high-tech systems. For an organization with 1000 software engineers, this leads to a direct saving of more than 10 million euro per year.
    c. The export value of the Dutch high-tech industry is at least 18 B€/year. A faster and cost effective innovation rate ensures the competitiveness of the individual companies and maintains or increases the future export value.

5. *Opportunities:* An adaptable component-based system architecture paradigm provides excellent new business opportunities :
    a. Open system architectures that facilitate distributed component development creates so-called network spill-over, due to the new market opportunities for third party component development (e.g. by SMEs).
    b. For medical imaging equipment, the objective is to reduce the release cycle time from 18 months to 12 months using the same development resources. This strongly increases the competitiveness of Philips Healthcare and creates the opportunity to increase their global market share.

6. *Public funding*
    a. Stimulating the development of a component-based development paradigm provides a generic infrastructure that can be used by many high-tech industries involved in complex system development as well as for societal applications that heavily rely on embedded technology. The solution is not core technology for any of the partners involved, but it nevertheless provides significant advantages in terms of cost, time and quality.
    b. Industrial innovation in high-tech systems requires major investments. At the same time, the required knowledge, expertise and skills for successful product innovation are difficult to obtain. Dutch international companies have lost substantial parts of their R&D skills to emerging countries. In order to maintain a knowledge-intensive economy in The Netherlands and Europe, stimulation of innovation capabilities has become a critical success-factor. Innovation is increasingly added to the political priorities with a focus on strategic strengths, such as ICT. Addressing these challenges in a structural way is extremely important for the Dutch high-tech industry to remain competitive, given the fact that this industry constitutes a major economic value in the Netherlands (especially regarding export).

7. *Knowledge: infrastructure*: A research impulse is required to address the complex issue of adaptable architectures. Such a complex subject cannot be resolved by individual parties alone, to achieve several distinctive goals for the knowledge infrastructure of the Netherlands requires:
    a. Increased problem awareness within academia and industry to further the understanding of the involved complexity. Aspects of scalability and legacy code are difficult to study in an academic environment. Only by combining industrial and academic research in a single project with continuous interactions, as done in this industry-as-lab project, can the required breakthroughs be achieved.
    b. Valuable advances in the state-of-the-art to enable academia to better educate the next generation of engineers as well as to provide necessary knowledge to industry.

   c. Ability to train the Dutch engineering force on systems of this nature to ease the transition to next-generation solutions for the ever increasing demands of a complex and connected world.

8. *Urgency:* Over recent years, the cost of healthcare has been growing steadily. Clinical research into new diagnostic and therapeutic techniques is driving the demand for new or improved medical diagnostic equipment. Therefore, optimization of cost-of-ownership of the associated capital investments has become an urgent issue. The activities in this project address an important problem in system architecting that hampers innovation. The fact that Philips Healthcare significantly invests in the project, although it will not result in proprietary Intellectual Property (IP) and budgets being limited by the economic crises, gives an indication of the urgency. Moreover, Philips Healthcare is currently experimenting with technology of its local suppliers into component-based design. This provides an excellent opportunity to combine fundamental research on component-based architectures with a broad application by Dutch SME's.

9. *Consolidation.*
   a. The project will be organized as an industry-as-lab project led by ESI and Philips Healthcare, i.e., the industrial context of Philips Healthcare will be used as laboratory for the researchers to develop new ideas, to experiment with them, and to validate the results. This guarantees that the research activities will have the required ties to the Dutch high-tech industry ensuring that the results are relevant, that they will become beneficial to subsequent development activities, and will be consolidated within Philips Healthcare.
   b. ESI's tight links with the Dutch high-tech industry will guarantee that the results, where applicable, will be used in other contexts and domains. During the project, ESI will define separate transfer projects, which will continue after the project end. This will ensure that the results are incorporated in a new 'way-of-working' benefiting the economy and society at large.
   c. Axini will consolidate the project results in tool support which is available for the Dutch industry.
   d. ESI provides an extensive industrial course program; the results of this project will be included in new course developments benefiting future course attendees.
   e. A number of ESI research fellows are at the same time lecturers or professors at universities in Holland and will ensure that the results of the project will flow into university courses.
   f. ESI maintains knowledge repositories for knowledge of ESI projects. These repositories consist of documents that describe methodologies and techniques, supporting software tooling in maintainable (SW) libraries, relevant HW sets, industrial reference cases and demonstrators, designs, documentation, manuals, etc. The results of this

5. Consortium

The consortium consists of seven partners. Four groups of the three technical universities are an excellent fit for the problem statement at hand:

- UT-DE: The Design Engineering group from the University of Twente (Bonnema) focuses on multidisciplinary design processes and synthesis-based engineering tools that support engineers to translate requirements into solutions. This group also participates in the Bsik project Darwin and will use their expertise on system views of medical machines in the current project.
- TUD-SERG: The Software Engineering group of the TU Delft (Van Deursen) has an impressive expertise on methods, techniques and tools that advance the way in which software is built and modified. This group participated in Bsik projects with ASML and NXP and will focus in the current project on evolvable software architectures and the management of software configurations.
- TU/e-DAS: The Design and Analysis of Systems group of the TU/e (Groote) is well known for its expertise on formal methods. Especially relevant for this project are their techniques to automate the reasoning about the correctness of software designs.
- UT-DACS: The Design and Analysis of Communication Systems group of the University of Twente (Pras) has a large experience with the design of dependable networked systems and the analysis of performance aspects. In this project, the main emphasis will be on performance analysis techniques that are scalable, making a proper trade-off between analysis time and the accuracy of results.

The consortium contains two industrial partners:

- PHC: Philips Healthcare is a high-tech company lead by the mission to provide their customers with integrated healthcare systems that deliver value throughout the complete cycle of care from disease prevention to screening & diagnosis, to treatment, health management & monitoring.
- Axini: Axini B.V. is a young Dutch company specialized in model-based testing. Formal models are used to automate the test process, leading to more thorough testing in less time compared to manual testing and other test-automation approaches.

The seventh partner acts as a bridge between the academic partners and the Dutch industry.

- ESI: The mission of the Embedded Systems Institute is to advance industrial innovation and academic excellence in embedded systems engineering for high-tech systems. In previous Bsik projects, ESI has acquired extensive knowledge on system architecting and system qualities such as performance and evolvability. In addition, ESI will use its unique

6. Work plan

In Figure 1 the main project activities are positioned on top of the classical V-model for software development.

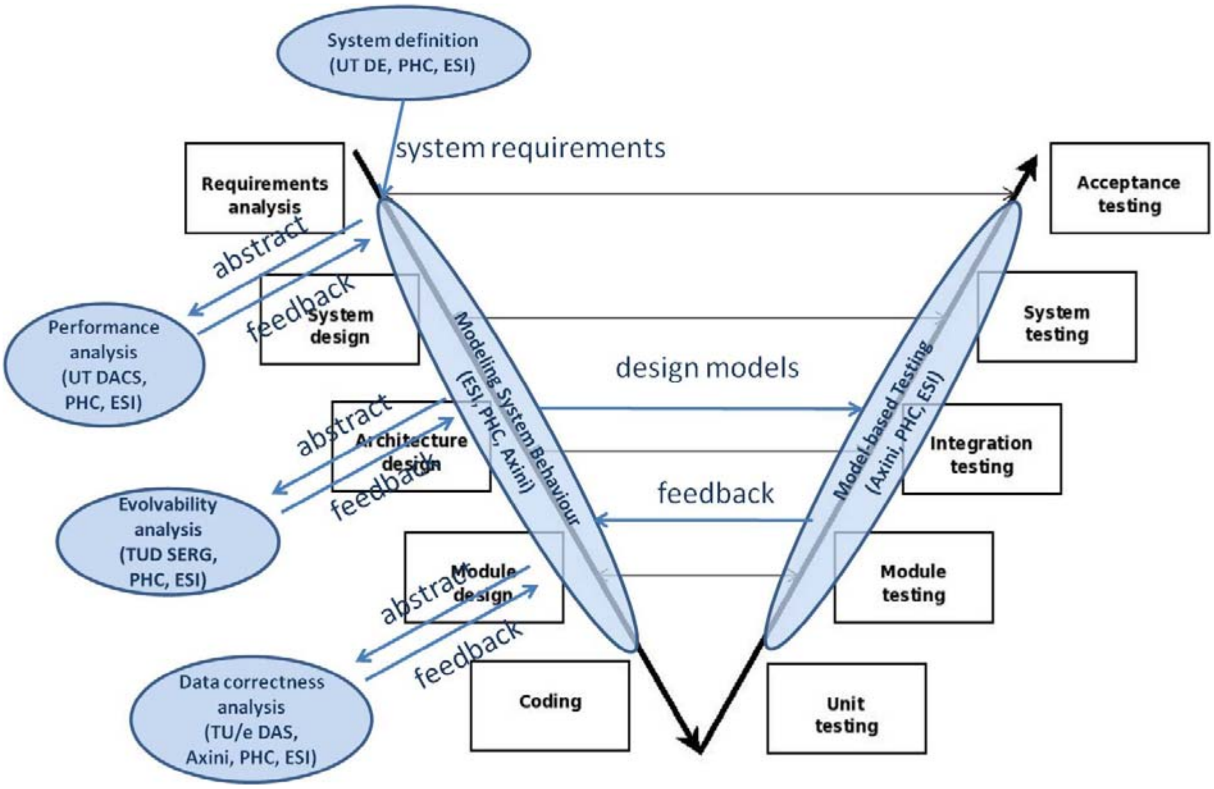

Figure 1 Project activities on top of V-model

To ensure that the right system is built, techniques to improve the system definition phase are developed. This leads to clear requirements and budgets for important system aspects that can be discussed with other state holders and are input to the design activities. During the design phases, the main emphasis is on modeling system behaviour and validating design steps by simulation. The aim is to establish a close link with the testing phase by reusing models and improving model-based testing techniques. To detect problems and remove faults as early as possible, a number of analysis techniques are applied to the design models. This project will devise tools and techniques for the analysis of evolvability, performance, and data correctness.

The project activities are organized in six work packages (WPs):

- *WP1 – System Definition*

  WP1 is led by UT-DE and delivers tools and techniques for high-level system definition, with an emphasis on complex high-tech systems that are part of a product family and are based on existing products. Budget-based techniques will be developed to deal with important systems concerns. Also techniques to discuss system views with non-technical stakeholders will be devised.

- *WP2 - Model-based Design and Testing*

  WP2 is led by ESI and provides tools and techniques to improve the design and testing phases of model-based development by the systematic use of models. Models will be used to validate design steps and to automate and improve the testing phase.
- *WP3 – Evolvability*

  WP3 is led by TUD-SERG and delivers (1) a method to define evolvable software architectures (2) techniques to evaluate interfaces and architectures.
- *WP4 – Component Verification and Testing*

  WP4 is led by TU/e-DAS and delivers methods and tools to (1) verify a method by model-checking techniques, with a focus on behavioural aspects such as data-dependent properties (2) test components based on models in close connection with the model checking activities.
- *WP5 – Performance*

  WP5 is led by UT-DACS and delivers performance methods that support component-based development and can be used in parallel with other development tools that address other system aspects such as functional correctness. The method includes an efficient analysis and/or simulation technique to predict the performance of software tasks running on hardware architecture with different possible resource mappings.
- *WP6 – Integration and Dissemination*

  WP6 is led by ESI and delivers demonstrators that show (1) scalability of results of the previous work packages (2) integration of these results (3) application of an integrated method for evolvable embedded systems. All partners collaborate to achieve these results. PHC will provide domain knowledge, feedback on the use of the techniques developed, facilities to realize industrially relevant demonstrators, and support for applications in an industrial context.

The main relations between the work packages can be found in Figure 2. More details can be found in the appendices.

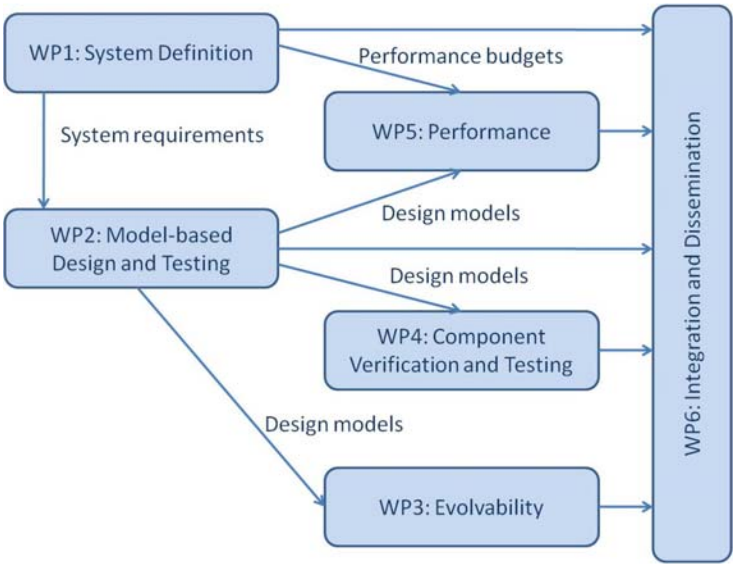

Figure 2 Relations between work packages

At the end of each of the first three years there will be a considerable effort on the integration of results, industrial case studies and the construction of demonstrators. In parallel with work on work packages 1 through 5, PHC will work on the preparation, evaluation, and improvement of demonstrators.

A general risk of these research projects is that the research activities are carried out rather independently and tend to drift away from the original problem statement. This might lead to results that are difficult to integrate and that are not easy to transfer to industry later. To avoid such problems, all full-time researchers will be located on a single location most of the time (at least three days per week). Weekly meetings are used to align the activities and to maintain the right focus. Joint work on common demonstrators ensures that results can be integrated.

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WORKPACKAGES

Project number P11	
WP title & acronym	System Definition
WP leader	Maarten Bonnema, Design Engineering, University of Twente
Objectives The main aim of WP1 is to provide methods and techniques for system modelling that support design decisions and trade-offs, especially related to evolvability, performance and safety. ESI will work on executable system models that (1) capture domain knowledge (2) visualize externally visible system behaviour (3) allow exploration and validation of architectural concepts by simulation. Moreover, ESI will propose a framework to manage collections of different types of models and their relation to architecture. Axini concentrates on the use of models for testing and the extension of their TestManager tool with new techniques.	

Project number P11	
WP title & acronym	WP2: Model-based Design and Testing
WP leader	Jozef Hooman, Embedded Systems Institute
Objectives The main aim of WP2 is to improve the design and testing phases of model-based development by the systematic use of models. Models will be used to validate design steps and to automate and improve the testing phase. ESI will work on executable system models that allow exploration and validation of architectural concepts and design steps by simulation. Axini concentrates on the use of models for testing and the extension of the Axini TestManager with new techniques. PHC investigates the practical application of these techniques, applying and evaluation them on concrete industrial cases, and studies the incorporation in the development process.	

Project number P11	
WP title & acronym	WP3: Evolvability
WP leader	Martin Pinzger, Software Engineering Research Group, Delft University of Technology
Objectives The objective of WP3 is to define techniques to assess and improve the evolvability of software architectures. Important aspect of the research is interface analysis, (1) including interface complexity metrics, (2) interface re-factoring strategies, and (3) models for estimating impact of changes, with a focus on changes of interfaces and data types. A method for architectural analysis will be developed, including change impact analysis based on a change scenario catalogue.	

Project number P11	
WP title & acronym	WP4: Component Verification and Testing
WP leader	Jan Friso Groote, Design and Analysis of Systems, Eindhoven University of Technology
Objectives WP4 defines a formal framework to develop components that are verifiable by design, with a focus on the formal verification of data aspects of components and model-based testing. It delivers methods and tools to (1) verify a method by model-checking techniques, with a focus on behavioural aspects such as data-dependent properties (2) test components based on models in close connection with the model checking activities.	

Project number P11	
WP title & acronym	WP5: Performance
WP leader	Anne Remke, Design and Analysis of Communication Systems, University of Twente
Objectives WP5 aims at a performance techniques that support component-based development. The approach will be supported by an analysis tool which can be used in parallel with other development tools that address other system aspects such as functional correctness. The techniques includes an efficient analysis and/or simulation technique that can be used to predict the performance of software tasks running on a hardware architecture with different possible resource mappings.	

Project number P11	
WP title & acronym	WP6: Integration and Dissemination
WP leader	Robert Huis in ‘t Veld, Philips Healthcare
Objectives The main objective of WP6 is to consolidate project results in the form of demonstrators, to integrate results into a system design methodology, and to stimulate dissemination to industry. To relate different types of models to each other and to the architecture under study, a framework and tool support will be developed. To transfer academic results, a number of activities are needed, such as improving tool support, documenting evidence of industrial applicability, and formulating guidelines on how to incorporate results in the industrial workflow and how to adapt the approach in a different context. Demonstrators will be used to make the results visible and show their industrial applicability. Note that dissemination of scientific results takes place in the other work packages.	

DELIVERABLES

Number of important journal paper
5

Number of important conference contributions
17

Products

1. Axini Test Manager with visualization and simulation

   D2.1.3 (t0+12 months, Axini) Major release of the Axini Test Manager with focus on visualization and simulation In this release of the Axini Test Manager the emphasis will be on improving the usability of the tool for industrial engineers, especially concerning the construction of the model that serves as the basis for the model-based testing techniques. Since correctness of this model is crucial for reliable test results, visualization and simulation techniques will be investigated to increase the confidence in the model. Visualization can also be used to get better insight in the test results.

   - Work package 2, Year 2011

2. Axini Test Manager with coupling to domain specific modeling

   D2.2.3 (t0+24 months, Axini) Major release of the Axini Test Manager with coupling to domain specific modeling The Axini Test Manager automatically generates tests based on a model of the desired input-output behavior. To facilitate the construction of such models, the Axini Test Manager will be extended with a coupling to domain specific modeling techniques. In this way, an engineer can construct an intuitive model of the system under test, in terms of his own domain. By means of automatic transformations this domain model is then translated to the proper format for the basic Axini Test Manager framework.

   - Work package 2, Year 2012.

3. Axini Test Manager with improved test selection and data coverage

   Major release of the Axini Test Manager which contains improved test selection and data coverage. For any realistic system it is impossible to generate all possible test sequences. Hence, the selection of tests is an important aspect of the automatic generation of tests based on models. In this release of the Axini Test Manager tool the selection of tests is optimized to increase the confidence in the system under test. This especially concerns the treatment of data and the selection of proper data values, based on deliverable D.4.2.4 about data coverage. Also relevant is the relation with the treatment of data in formal verification techniques in WP4.

   - Work package 4, Year 2013

4. Axini Test Manager with diagnosis

   Major release of the Axini Test Manager which includes a coupling to diagnosis techniques to support fast correction of faults In this major release of the Axini Test Manager the test results are coupled to a diagnosis technique called spectrum-based fault diagnosis. The aim is to support debugging in case the test results show problems. The main idea is that during the tests data is collected about the use of program parts for all tests. This data is correlated to both successful and failing tests, leading to an indication of which program parts are mostly involved in failing tests. This provides a ranking of software parts that most likely may contain a bug, reducing the time needed to search for bugs that cause a failing test scenario.

- Work package 2 Year 2014

Software

1. Prototype tool to facilitate budgeting

   Prototype software tool to facilitate budgeting in System-design and management. The developed budgeting techniques, as demonstrated in D1.1.3, will be supported by a prototype tool which shows how these techniques can be used in an industrial context. Based in deliverable D1.2.2, it addresses the communication of budgets to many different stake holders, including nontechnical state holders, and facilitates discussions about changes and alternatives. Moreover, the tool interfaces with the design process, by relating the overall system budget to budgets for the main system components.

   - Work package 1, Year 2012

2. Tool to facilitate budgeting

   Release of tool to facilitate budgeting in system design and management Based in user studies on performance budgets, as delivered by D1.2.1, and an evaluation of the prototype tool D1.2.4, an improved version of the tool is released. The interface to various stake holders will be improved, based in user experiences which are mainly obtained from the Healthcare domain. Also the relation to the design phases with be strengthened, with an emphasis on component-based design. Finally, a connection with the performance analysis techniques of WP5 will be established.

   - Work package 1, Year 2013

3. Prototype tool to support interface analysis

   Release of prototype tool to support interface analysis A prototype tool is delivered which supports interface analysis. The tool can be used to analyze dependencies between interfaces and the propagation of data. It allows the exploration of alternatives and allows easy inspection by visualization. The prototype is intended to be evaluated on a large part of an interventional XRay system, and hence scalability is an important aspect.

   - Work package 3, Year 2012

4. Tool for change impact analysis

   Release of tool support for change impact analysis Based on the techniques developed for interface analysis (D3.3.1) and change impact analysis (D3.3.2), a supporting tool is released.

Component-based architectures with clear interfaces can be analyzed based on expected product changes, e.g. as reported in D3.1.2. The tool allows what-if analysis and indicates potential bottlenecks in architectures. Important aspect is the effort needed to realize the expected changes.

- Work package 3, Year 2013

5. Tool for interface complexity metrics and change impact analysis

   Release of improved tool support for interface complexity metrics and change impact analysis This deliverable improves tool with respect to usability in an industrial context, scalability, and accuracy of the results. Results of user studies in the Healthcare domain, will be incorporated. Additionally, metrics to measure the complexity of interfaces will be incorporated to improve theassessment of the quality of component-based architectures.

   - Work package 3, Year 2014

6. Tool for verification of data aspects

   Release of tool for the verification of data aspects A major of the mCRL2 tool will be released, which extends the existing tool with new algorithms to improve the verification of data aspects. Aiming at automatic verification, a proper treatment of data is crucial to avoid the well-known state explosion problem. Based in case studies at Healthcare, new algorithms and heuristics will be developed to support the verification of data aspects of component-based architectures. These new techniques will be implemented in the mCRL2 release of this deliverable.

   - Work package 4, Year 2012

7. Improved tool for verification of data aspects

   Release of improved tool for verification of data aspects The mCRL2 tool release of deliverable D4.2.1 will be extended and improved. Again the focus is on the treatment of data aspects. Important aspect of this new release is industrial applicability. Hence, scalability is a very important aspect and new techniques and heuristics will be implemented. Moreover, a coupling with other modeling techniques, such as domain specific modeling is relevant.

   - Work package 4, Year 2014

8. Tool for performance simulation and analysis

   Prototype tool for performance simulation and analysis A prototype tool is delivered to support performance analysis. The tool addresses the performance of the mapping of software components on a hardware platform. It incorporates the techniques developed in deliverable D5.2.1 and experiences with a case study at Philips Healthcare, as reported in D5.2.2. Important is a proper balance between a suitable abstraction from the characteristics of software and hardware and the accuracy of the analysis results. As a first, fast way of getting insight in performance bottlenecks, also simulation techniques will be implemented.

- Work package 5, Year 2012

9. Tool for efficient performance analysis and simulation

   Release of tool for efficient performance analysis and simulation A tool is released to support efficient performance analysis and simulation. The tool improves on the prototype D5.2.4 and incorporates user feedbacks and improvements of the underlying techniques, as described in deliverable D5.3.1. Important aspect is the accuracy of results, based on feedback of measurements on existing systems of Philips Healthcare. Another concern is scalability, which requires suitable abstractions. To be able to incorporate the tool in the industrial work flow, a connection with design models is very relevant.

   - Work package 5, Year 2013

10. Tool for model management

    Release of prototype tool for model management, relating design and analysis tools Observing the large diversity of models, e.g. design models and analysis models for various aspects, a prototype tool will be delivered which allows the management of all these models. This means that models can be related to a structural description of the system. This concerns development models such as, for instance, requirements models, architectural models and detailed design models. Moreover, these models can be related to analysis models, including motivations for the models and resulting design decisions. The tool keeps track of changes and indicates when design changes should lead to changes in analysis models to keep results consistent.

    - Work package, Year 2012

User studies

1. User study on performance budgets

   User study on performance budgets This study describes the experiences with the techniques for performance budgets developed by UT-DE, as demonstrated by D1.1.3. The techniques will be applied on a realistic case study in the context of interventional X-Ray systems and compared with current industrial practice. Two main aspects will be studied: (1) how suitable are the techniques to improve the communication with all stake holders (2) do the techniques improve the treatment of performance during the development process, in the sense that they are taken into account earlier and reveal problems earlier.

   - Work package 1, Year 2012

2. User study on the evaluation of budgeting in practice

   User study on the evaluation of budgeting in practice. This user study evaluates the budgeting approach proposed in WP1 from an industrial point of view.) This is based on the application of the tool (delivered by D1.3.4) in the context of interventional X-Ray systems and improvement made after earlier reports (D1.2.1 and D1.3.3) on industrial usage. Similar to

D1.2.1, both the relevance for the communication with all stake holders and the impact on the development process are investigated.

- Work package 1, Year 2014

3. User study on model-based design and testing

   User study on model-based design and testing, including industrial state of practice and vision on long term strategy This study provides an overview of the industrial practice in the area of model based design and testing. The emphasis is on available commercial tools and an overview of their strengths and weaknesses. Relevant are experiences of users with the approaches, both inside and outside Philips Healthcare. Based on this overview, a long term vision on model-based design and testing is formulated, together with a long term strategy to reach this goal. It is explained how the work of the current project fits into this strategy.

   - Work package 2, Year 2011

4. User study on the application of model-based design and testing

   User study on the application of model-based design and testing. This user study reports about the application of the developed model-based design techniques (see deliverables D2.2.1 and D2.2.2) and the Axini Test Manager (deliverable D2.2.3) on an interventional X-Ray system. The report describes benefits and weaknesses of these approaches, based on experiences of Philips employees. It also contains recommendations for improvements.

   - Work package 2, Year 2013

5. User Study on the evaluation of model-based design and testing

   User Study on the evaluation of model-based design and testing At the end of the project, this user study summarizes the experiences with model-based design and testing and evaluates the impact of the projects results in this area in the healthcare domain. Concerning the model-based design techniques it is important to investigate whether it leads to an improved system structure and less integration problems, i.e., whether problems are indeed detected earlier. The model-based testing tools are compared to current practice with respect to effort, ease of use, and thoroughness of the testing process.

   - Work package 2, Year 2014

6. Tool for model management

   Release of prototype tool for model management, relating design and analysis tools Observing the large diversity of models, e.g. design models and analysis models for various aspects, a prototype tool will be delivered which allows the management of all these models. This means that models can be related to a structural description of the system. This concerns development models such as, for instance, requirements models, architectural models and detailed design models. Moreover, these models can be related to analysis models, including motivations for the models and resulting design decisions. The tool keeps track of changes and indicates when design changes should lead to changes in analysis models to keep results consistent.

- Work package 6, Year 2012

7. User study on performance budgets

   This study describes the experiences with the techniques for performance budgets developed by UT-DE, as demonstrated by D1.1.3. The techniques will be applied on a realistic case study in the context of interventional X-Ray systems and compared with current industrial practice. Two main aspects will be studied: (1) how suitable are the techniques to improve the communication with all stake holders (2) do the techniques improve the treatment of performance during the development process, in the sense that they are taken into account earlier and reveal problems earlier.

   - Work package, Year 2012

8. User study on the evaluation of budgeting in practice

   This user study evaluates the budgeting approach proposed in WP1 from an industrial point of view.)This is based on the application of the tool (delivered by D1.3.4) in the context of interventional X-Ray systems and improvement made after earlier reports (D1.2.1 and D1.3.3) on industrial usage. Similar to D1.2.1, both the relevance for the communication with all stake holders and the impact on the development process are investigated.

   - Work package 1, Year 2014

9. User study on model-based design and testing

   User study on model-based design and testing, including industrial state of practice and vision on long term strategy This study provides an overview of the industrial practice in the area of model based design and testing. The emphasis is on available commercial tools and an overview of their strengths and weaknesses. Relevant are experiences of users with the approaches, both inside and outside Philips Healthcare. Based on this overview, a long term vision on model-based design and testing is formulated, together with a long term strategy to reach this goal. It is explained how the work of the current project fits into this strategy.

   - Work package 2, Year 2011

10. User study on the application of model-based design and testing

    This user study reports about the application of the developed model-based design techniques (see deliverables D2.2.1 and D2.2.2) and the Axini Test Manager (deliverable D2.2.3) on an interventional X-Ray system. The report describes benefits and weaknesses of these approaches, based on experiences of Philips employees. It also contains recommendations for improvements.

    - Work package 2, Year 2013

11. User Study on the evaluation of model-based design and testing

    At the end of the project, this user study summarizes the experiences with model-based design and testing and evaluates the impact of the projects results in this area in the healthcare domain. Concerning the model-based design techniques it is important to investigate whether it leads to an improved system structure and less integration problems, i.e., whether problems are indeed detected earlier. The model-based testing tools are compared to current practice with respect to effort, ease of use, and thoroughness of the testing process.

    - Work package 2, Year 2014

12. User study on usage of tool for interface analysis

    This user study evaluates the use of the tool for interface analysis delivered by D3.2.1. The tool is applied on a part of an interventional X-Ray system of Philips Healthcare. The results of the analysis are compared to experiences of domain experts. By investigating a large part of the system also scalability of the tool is evaluated. The experience of the industrial users is summarized by a set of recommendations for improvement.

    - Work package 3, Year 2012

13. User study on industrial evaluation of techniques to assess software evolvability

    This deliverable reports on the evaluation of project results on software evolvability by industrial users. This concerns especially interface analysis, change impact analysis, and complexity metrics. The resulting techniques and tool, as delivered by D3.4.1, are applied to an interventional X-Ray system of Philips Healthcare. The user experience is summarized and evaluated based on an assessment of the analysis results and scalability.

    - Work package 3, Year 2014

14. User study on the evaluation of data verification

    User study on the evaluation of data verification in the healthcare domain This user study evaluates the techniques for data verification, as delivered in tool D4.4.1, from a point of view of industrial users from the healthcare domain. The tool is applied to case studies which are part of a component-based architecture of an interventional X-Ray system. Relevant aspects are scalability, industrial relevance of the results, and industrial usability. The experience with the applications from the healthcare domain leads to a set of recommendations about future use and possible improvements.

    - Work package 4, Year 2014

15. User study on the evaluation of performance techniques

    D5.4.2 (t0+48 months, PHC) User study on the evaluation of performance techniques. This deliverable reports on a user evaluation of the performance techniques delivered by the project, especially the tool delivered by D5.3.4 and the techniques described in D5.4.1. The tool and techniques are applied to an interventional X-Ray system of Philips Healthcare. The performance results of simulation and analysis are compared to measurements on an existing system. Relevant is whether the results are accurate enough for decisions early in the development process. Other important aspects are scalability and the possibility to incorporate the approach in the industrial work flow.

- Work package 5, Year 2014

Other results

1. Demonstrator of performance budgeting

   D1.1.3 (t0+12 months, UT-DE) Demonstrator of method for performance budgeting. The aim is to demonstrate the use of performance budgeting techniques for system definition. It clarifies the system requirements and supports discussions about important trade-offs with all stakeholders, including non-technical stakeholders such as mangers and marketing. Performance budgets are also important input for the design phase, since it provides the performance requirements for the main components. The approach will be illustrated on an interventional X-Ray system of Philips Healthcare, comparing the new approach with the conventional way of working.

   - Work package 1 Year 2011

2. Report on the relation between model-based design and model-based testing

   D2.2.2 (t0+24 months, ESI) Report on the relation between model-based design and model-based testing. This deliverable describes the relation between the models which are used during the design phases and the models of the Axini TestManager. We study various design models, such as UML-based models, the POOSL models which are used to obtain executable models, and Verum's ASD models which can be used to formalize component interfaces. These models are related to the models that input for the test generation process by the Axini TestManager. We investigate semantics-preserving transformations from design models to test models. The aim is to exploit the common process algebra foundation of most of these models.

   - Work package 2, Year 2012

3. Demonstrator on what-if analysis

   D3.1.3 (t0+12 months, TUD-SERG) Demonstrator on what-if analysis applied to reconstructed architecture This deliverable is based on the reconstructed architecture of a product of Philips Healthcare, as described in deliverable D3.1.1, and the product roadmap provided by deliverable D3.1.2. It is demonstrated how techniques based on what-if analysis can be used to analyze the architecture with respect to the suitability to support the realization of the product roadmap. The demonstrator shows the impact of products changes on the interfaces and the data flow; it indicates the effort needed to implement these changes.

   - Work package 3, Year 2011

4. PhD thesis on software evolvability
   D3.4.5 (t0+48 months, TUD-SERG) PhD thesis on software evolvability. This PhD thesis summarizes all results on software evolvability, including interface analysis, change impact analysis, and complexity metrics. The emphasis is on component-based architectures in the healthcare domain. New techniques and supporting tools are explained and related to the literature. Important aspect is the validation of the results by industrial applications and an evaluation by industrial users.
   - Work package 3, Year 2014

5. Demonstrator on verification of data aspects
   D4.3.2 (t0+36 months, TU/e-DAS) Demonstrator on new techniques for verification of data aspects and application to the healthcare domain New techniques and the supporting mCRL2 tool are demonstrated. Main focus is the verification of data aspects of software components in the healthcare domain. The main improvements are illustrated by case studies of Philips Healthcare. Important ingredients are (1) the formal specification of relevant properties (2) the formalization of a component design (3) automatic verification that a component design satisfies the required properties.
   - Work package 4, Year 2013

6. Report on the relation between formal verification and model-based testing
   D4.4.2 (t0+48 months, Axini) Report on the relation between formal verification and model-based testing Formal verification and model-based testing are two different techniques to increase the confidence in the correctness of a particular system. In this report we discuss the relation between these two techniques, especially how they can complement and support each other. For instance, properties that have been verified exhaustively need not be tested anymore. On the other hand, testing results might be used to improve the scalability of the model checking techniques. The study is supported by case studies from the healthcare domain.
   - Work package 4, Year 2014

7. Demonstrator on efficient performance simulation
   D5.1.2 (t0+12 months, UT-DACS) Demonstrator on first version of tool for efficient performance simulation The demonstrator shows a first version of a tool that can simulate the performance of a set of software components running on a particular hardware platform. The simulation can be used to predict the performance of the system using a certain mapping of software to hardware. Potential performance problems can be detected early and bottlenecks can be identified. The approach is illustrated by a case study of a particular instance of Front End Control components of an interventional X-Ray system that suffered from integration problems with respect to performance.

- Work package 5, Year 2011

8. Report on application of performance analysis techniques

   D5.3.3 (t0+36 months, ESI) Report on application of performance analysis techniques in industrial context with connections to design models In this report we describe the connection between the performance analysis techniques and the models that are used during the design, such as UML-based models, POOSL models, and Verum's ASD models. Important aspects are the abstractions that are required to obtain the characteristics for performance analysis and the ways in which feedback from this performance analysis can be coupled to design models. Also connections to domain-specific modelling will be investigated.

   - Work package 5, Year 2013

9. Dissemination events

   D6.1.2 (t0+12 months, PHC) Dissemination events which use demonstrators to show the results of work packages WP1 to WP5. A dissemination event will be organized to show the demonstrators of the work packages WP1 to WP5 to employees of Philips Healthcare, including managers, system architects, software architects and designers. The aim is to give a first impression of the main techniques developed in the project. The demonstrators illustrate these techniques on parts of an interventional X-Ray system of Philips Healthcare. Feedback of visitors is input for the next steps in the project.

   - Work package 6, Year 2011

10. Golden Demo

    D6.4.3 (t0+48 months, PHC) Golden Demo, showing integrated projects results The Golden Demo at the end of the project demonstrates how the project results together improve the speed of innovation by shortening the test and integration phase. This includes improved techniques for system definition, the use of models for the design phases to detect faults early, analysis techniques for performance, evolvability and data correctness, and model-based testing. The demonstrator also shows the relations and connections between these techniques and supporting tools.

    - Work package 6, Year 2014