

# **Certus** *Annual Report 2014*

# Arnaud Gotlieb

## Leader of the Certus Centre

Since its creation in October 2011, the Certus centre has developed collaborative research and innovation projects in selected areas of software engineering, including model-based engineering of highly configurable systems, the testing of data-intensive systems and real-time embedded systems, the certification of safety-critical systems, and the testing of long-term evolving software systems.

Through strong involvement in the international scientific community, the centre has now reached an internationally leading position in software validation and verification (V&V). Since 2011, the centre has published well over a hundred publications in top-level journals and conferences of the field, which is quite remarkable for a small group of researchers. By focusing on partner-driven research questions and organizing intensive collaboration between the partners, the centre has fostered innovation through the realization of tools and methodologies that are currently being deployed and exploited.

One of these innovations, called TITAN, is already on the way to external commercialization through an additional project funded by the Research Council of Norway (RCN) under the FORNY programme. Through standardization activities and well-developed research networks, the centre has established strong scientific collaborations with leading European institutions such as Inria in France, the University of Luxembourg, and Uppsala University (Sweden), in addition to other collaborations in Europe and the world. Moreover, the centre has attracted visits from dozens of prominent researchers from Europe and abroad and has made substantial strides into the European competition for research funding. In particular, the Horizon 2020 (H2020) project U-Test, funded under LEIT call ICT-1a, will start in January 2015. The project idea originated with work at Certus and will be conducted in close collaboration with the centre, with Simula as technical coordinator. This call was one of the most competitive within LEIT-ICT, with a global success rate of 5.8%. Another Certus-related proposal coordinated by Simula for the same call almost made it, achieving the same score (14.0) as the cut-off for funding within the call.



In 2015, the Certus centre will face its midway evaluation, which is crucial for its future. It is thus time for us to look back at our achievements and also to identify room for improvement. All the researchers, the user partners, and the management team of the centre are mobilized for this evaluation and we are excited and proud to have the opportunity to present our scientific achievements and research-based innovation results. This moment is crucial for us to prepare for the future through the definition of a strong exit strategy for the centre and to convince our partners and others to join us in the long term to establish Certus as a self-sustained centre dedicated to software validation and verification in Norway. This 2014 annual report presents not only our achievements in 2014, but also our vision for the future of Certus.

With the hope that you will share our vision and enjoy reading this report,

Best regards,

**Arnaud Gotlieb**  
*Leader of the Certus centre*

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Certus Centre  
c/o Simula Research Laboratory AS  
P.O.Box 134  
1325 Lysaker  
Norway

T: +47 67 82 82 00  
F: +47 67 82 82 01  
E: [post@certus-sfi.no](mailto:post@certus-sfi.no)  
[www.certus-sfi.no](http://www.certus-sfi.no)

Editor in chief: Arnaud Gotlieb  
Editor: Christian Hemmestad Bjerke  
Production: Blue-C  
Design & layout: Future  
Photo: Sverre Christian Jarild

# The Certus Centre

A man with a beard and short hair, wearing a dark suit jacket over a light-colored shirt, is shown from the chest up. He is holding a tablet computer in his hands and looking off to the side. The entire image is overlaid with a solid blue color. A dotted line graphic is positioned to the right of the title 'The Certus Centre'.



# Growing Up

*After a challenging start, the Certus centre is now about to move from adolescence to maturity; it has delivered a voluminous injection of research-based innovation into the veins of the consortium and the surrounding ecosystem.*

In course of its first three years of existence, Certus has passed expected and unexpected milestones, some highly rewarding and some quite challenging. At a very early stage of the centre's life, the unexpected relocation of the first centre leader to another European research institution, followed by the departure of two well established researchers, caused a challenging start for the centre.

However, such occasions cause not only challenges, but also opportunities. Fortunately, Dr. Arnaud Gotlieb, who had then recently joined Simula, accepted taking over the leadership of the Certus centre. Although the original plan for the development of Certus has been the guiding light for the work over these years, the new centre leader has put his own touch on many aspects of the operation. In the case of Certus, this has led to a very strong focus on the innovation aspect of the centre, including diligent work on transfer of methods and technology from the researchers' workbenches to the office space of the user partners. These mild perturbations of the original plans have been embraced by the board of the centre and also by the scientific advisory board. Furthermore, the Research Council of Norway has been duly informed about the development and has not raised any concerns.

Over the latter years, Certus has closed down some research directions, and added others. The development of the centre has been a dynamic process run in close collaboration with the user partners. With respect to the partners, we have very recently seen the departure of FMC Technologies from the consortium, due to internal reprioritization forced by market changes in the oil and gas sector, which currently undergoes quite dramatic changes. In parallel, ABB Robotics has joined Certus and brought both very relevant research questions and a strong momentum. Starting next year, ABB will start a corporate-wide implementation of research conducted in Certus. For Kongsberg Maritime, the context of the collaboration has changed. Today, Certus is anchored in a different part of the company than what it was initially. Having large responsibilities for software testing, this new group helps us make the value chain short and efficient.

At Simula, the Certus centre is the backbone of the software engineering department, complemented by a fine selection of other projects. Over time we have seen an overall convergence of these additional activities towards the priorities of Certus, and today we could claim that most other software verification and validation activities in the department are somehow piggybacked onto Certus. For instance, over the last year, we have been able to secure both regional and European research funding that extends and complements work done in Certus on model-based testing. The European project, U-Test, is funded by one of the most competitive Horizon 2020 calls in the LEIT-ICT program. This project will address testing of cyber-physical systems that are subject to uncertainty caused by highly varying operational conditions.

Moreover, we have been able to attract funding from the national program FORNY, which provides an excellent opportunity for exploring the potential commercialization of the TITAN technology – one of the five distinct technologies created during the first three years of Certus' operation. This type of additionality, and in particular with the prospect of developing commercial values, is fully aligned with the strategic priorities of the host institution, Simula.

In its report from the recent visit to the centre, the Certus Scientific Advisory Board (SAB) states, "The centre carries out excellent research with a very productive record of publications". The report continues with the observation that "The Center has an excellent structure in terms of collaboration with the industrial users. The partners have the opportunity to present their problems, and the Center has great flexibility and freedom to work on them. The SAB finds such a model very effective and actually quite unique in the research world."

Personally, I find this statement to summarize very precisely the goal and the possibility posed by the Centre for Research-based Innovation (SFI) scheme. To my understanding, Certus has found its way, and grown up.

**Professor Are Magnus Bruaset**  
*Chair of the Board, Certus*

Director of Computing and Software,  
Simula Research Laboratory

# What is Certus?

*Established in October 2011, Certus is a research-based innovation centre dedicated to software validation and verification.*

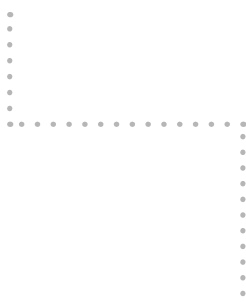
Software failures are unfortunately not uncommon in industry and public sector applications and can be very costly. At Certus, we believe that part of the problem is a lack of technology transfer from the research community to industrial practice. This lack of communication between research and industry goes both ways: academic researchers may sometimes have only a superficial understanding of the challenges faced by industry within software validation and verification, while software engineers may not be trained enough or sufficiently well equipped with methodologies and tools to prevent the introduction of software faults.

To overcome these challenges, the Certus partners maintain high levels of communication between the core group of academic researchers based at the host partner, Simula Research Laboratory, and the industry and public sector partners. The user partners represent a varied swathe of industry and public sector applications in software. Our goal is to produce research that results in useable methodologies and tools for all the partners to test and utilize.

The Certus centre has established a body of methods and tools for the validation and verification of software-intensive systems.

## Three types of system have become the main focus for innovative methods:

- 1** Real-time embedded software systems, that is, software and hardware integrated systems with limited resources and means of communication with their environment. Typically, these systems embed a set of dedicated applications running over a real-time operating system and are subject to real-time constraints.
- 2** Highly configurable software systems, that is, families of software and hardware systems for which software reuse is a major concern; many commonalities and variables exist between products in a family. Facilitating such reuse will significantly improve the overall quality and productivity of product development.
- 3** Data-intensive software systems, that is, software applications built on one or several database management systems that deal with large amounts of data. These applications typically have to store, retrieve, and process millions of data entries.





The centre's scientific activities are focused on four projects addressing model-based engineering for highly configurable systems, testing of data-intensive systems, testing of real-time embedded systems, and smarter testing of evolving software systems. In addition, there are three other projects dedicated to administration, communication, and dissemination. A final project is related to industrial exploitation.

Already after its first three years of operation, Certus can boast not only that its partners have implemented tools developed in the centre, but also that its first tool – TITAN – is headed for commercialization. Focus on international collaboration in 2013 has led to Certus developing ties with institutions worldwide, while application for competitive funding for projects in 2014 has gained financing for two new large projects: a Certus centre collaboration with the Cancer Registry of Norway (CRN) and U-Test, an EU-funded project that will be conducted in collaboration with Certus.



# Certus Centre Partners

## Scientific Projects

- 2** Industrial Exploitation
- 5** Model-Based Engineering for Highly Configurable Systems
- 7** Testing of Data-Intensive Systems
- 8** Testing of Real-Time Embedded Systems (RTES)
- 9** Smarter Testing of Evolving Software Systems

## Host Institution

[ **simula** . research laboratory ]

**Projects: 2, 5, 7, 8, 9**

**Simula Research Laboratory** is a non-profit public utility enterprise that performs leading international research within selected fields of information and communications technology (ICT). In 2012, Simula was ranked first in the national evaluation of ICT research conducted by the RCN.

Certus' long-term perspective and strong industrial profile give Simula a unique opportunity to further expand and enhance its position as a leader in software validation and verification research. The Certus centre is one of several research-based innovation projects at Simula within this field.

## User Partners



**Projects: 7, 8**

**ABB Robotics** is a leading supplier of industrial robots and modular manufacturing systems and services. Their work in the Certus centre focuses on painting systems embedded in industrial robots. Robotics software is a complex, configurable, and highly distributed embedded system. As with other technologies and domains, there is a trend to implement more functionality in software running on general hardware. One of the areas identified for adaptation to new requirements is the improvement of testing speed and quality. ABB Robotics believes that the key features of a new testing infrastructure should include extensive automatic testing, continuous integration, and the smart selection of test cases. To address this, an ABB Robotics principal engineer started an industrial PhD in 2012 as part of a Certus project, supervised by the Certus centre and University of Stavanger. The PhD will conclude in 2015 and the results will be exploited at ABB Robotics. Moreover, ABB is also aiming at implementing this research within ABB Robotics' global research and development organization. ABB Robotics became a full partner of Certus in 2014 and will rely on continuous support from researchers at the centre for its implementation project.





**Projects: 2, 7, 8, 9**

**Cisco Systems Norway** specializes in videoconferencing systems (VCSs) and manufactures a broad selection of products designed to achieve telepresence. Cisco's communication systems play a central role in several business and safety-critical domains, including healthcare and energy. As companies become more global, effective ways to support remote collaboration and minimize travel become essential.



**Projects: 2**

**ESITO** is an ICT company that develops and markets the model-based software development tool Genova. This tool is mainly used to develop administrative mission-critical applications. ESITO's vision is to provide its customers with lower costs and better quality in the development and maintenance of their applications.



**Projects: 5**

**FMC Technologies** is a leading global provider of technology solutions for the energy industry. One of its key technologies is Subsea Production Systems, large-scale integrated and highly configurable systems for managing the exploitation of oil and gas production fields. The subsea industry's need for high quality and improved recovery rates has led FMC Technologies to utilize software to further improve its subsea technology. FMC Technologies has been an active partner in the Certus centre since its establishment; their collaboration will end in December 2014.



**KONGSBERG**

**Projects: 5, 8, 9**

**Kongsberg Maritime** is one of the largest suppliers of programmable marine electronics worldwide. They deliver systems for dynamic positioning and navigation, marine automation, cargo management and level sensors, maritime training simulators, and position reference systems. These products are paramount in ensuring the reliability and correct functioning of offshore and shipyard systems.



**Projects: 2, 7**

**Customs and Excise** is an agency under the Ministry of Finance. Customs and Excise assesses and collects customs and excise duties, value-added tax on imported goods, and special taxes for the state treasury. The agency also carries out a number of enforcement tasks related to the import and export of goods. Customs delivers and maintains a large portfolio of systems for handling customs and excise in Norway. Their systems have high requirements regarding data integrity, availability, and security.



# Innovation Results

*The Certus centre project for industrial exploitation focuses on further developing research results into tools that are more readily available for industrial use and on devising and implementing strategies to create an industrial impact from these results. Several technologies have emerged from the Certus centre, including tools that have industrial value and the potential for commercialization and widespread use.*

## TITAN

Companies developing families of software-based products that undergo an intensive testing phase face the challenge of implementing efficient test strategies under conditions of limited resources, low test budgets, and ever-shortening cycle times. Simultaneously, the market demands a constant increase in product quality and complexity, which in turn increases the volume of testing.

TITAN is a novel technology initially developed within the Certus centre that aims to reconcile these opposing goals. Through efficient test optimization techniques, TITAN technology helps enhance product quality and reduces risks and control testing costs. The technology automates and optimizes several stages in software testing processes, balancing expenditure and testing quality. TITAN has been pilot-tested in industrial environments at Cisco and other technology partners outside of the Certus centre. The pilot projects verify TITAN's potential to reduce testing efforts by 20%. Extensive technology development and business modelling activities have been undertaken to develop a unique value proposition to ensure TITAN's success on the market. The TITAN project has received financial support from the RCN through the FORNY2020 program, which aims to create value and benefits for society from research results. The program funds the results from projects conducted at publicly funded institutions such as Certus and helps bring research closer to the market.

## ABB Constraint Model

Testing complex industrial robots is challenging, especially robots performing process-intensive tasks such as painting or gluing, since their dedicated process control systems can be only loosely coupled with the robot's motion control. Current practices for validating such robot control systems involve manual test case design and execution. To reduce testing costs and improve quality assurance, a trend has developed to automate the generation of test cases.

Together with Certus centre researchers, ABB has developed a methodology to fully automate the testing of the paint control system used for their robots. This approach draws on continuous integration principles and well-established constraint-based testing techniques. The approach is based on a novel constraint-based model for automatically generating test sequences that are both generated and executed as part of a continuous integration process. The core of the testing methodology is to validate that physical actuators related to the paint process are activated at the correct time relative to the robot's dedicated movement path. One testing cycle performed at ABB validates approximately 20,000 such activations.

The model developed has now been in full production at the ABB Robotics facility at Bryne for over a year and the results show that the model can not only detect purposely reintroduced known faults, but also spot completely new faults.

## Depict

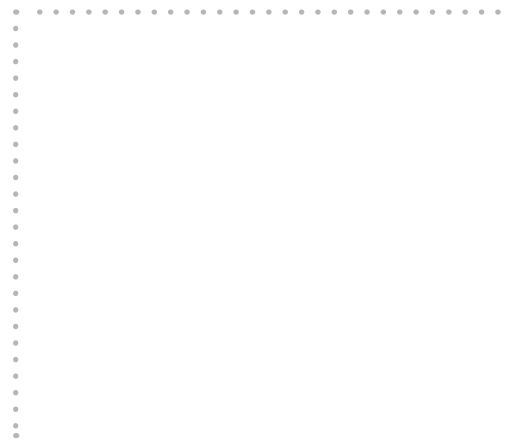
Depict – Discovering Patterns and Interactions in Databases – is an innovation that emerged from the collaboration of the Directorate of Norwegian Customs and Excise (TAD) within the Certus centre. Depict is based on the scientific idea of modelling and verifying expected or unexpected data interactions in big data spread over large organizational databases. Depict takes the form of a fully fledged tool that takes as input a visual and easily comprehensible model of data interactions that is automatically transformed to several thousands or even millions of queries that are extremely difficult to create manually. These queries are executed in real time over a database to produce visualizations of data interaction coverage. Test managers at the Directorate of Norwegian Customs and Excise have developed models to verify a number of business rules, such as the correct archiving of declarations and the correct generation of fault codes sent to declarants. Modelling and verifying data interactions helps TAD to effectively verify the completeness of their testing effort as their information systems undergo constant evolution. The long-term impact of Depict is possible reduction in the manual effort of testing by a projected minimum of 20%.

## jDART

Based on research results obtained by Simula researchers, ESITO has developed the jDART technology, which aims to automatically select and execute complex test cases for the regression testing of database applications. This technology addresses the testing of database applications belonging to TAD and other public administrations. Though no business case has yet been formulated for this technology, its development has led to intensive and fruitful collaboration paving the way for further co-development.

## Zen-RUCM

Managing user requirements in different application domains (real-time systems, distributed systems, communication systems) is challenging when considering the requirement specifications of different typologies, such as variability in highly configurable systems, non-functional requirements, and cross-cutting concerns. By analysing several industrial case studies (e.g. FMC's oil and gas subsea production systems), the Certus researchers have created Zen-RUCM, an automated technology to achieve analysable and verifiable requirements while still maintaining usability.





# Certus 2014





# Scientific Activities 2014

## 2014 Certus Centre Workshops

**The Certus User Partner Workshop (UPW)**, a two-day annual event, was held in October this year. The UPW is an opportunity for everyone involved at the Certus centre to meet and discuss ideas, needs, achievements from the past year, and plans for the future.

In 2014, the main focus of the UPW was the midway evaluation of Certus by the RCN and the planning of the activities of the second half of the Certus funding life span, leading up to an exit strategy.

The UPW provided time for user partner representatives to share perspectives on both technical work done at the Certus centre and industrial challenges and trends. The second day of the UPW saw the start of work on the Annual Work Plan for 2015.

**Certus Open Courses** were run in November for the second time since the establishment of the Certus centre. These courses were held at Simula Research Laboratory for user partner collaborators and researchers, with the aim of promoting the application of cutting edge research in the software engineering industry.

Five courses were held during a two-day period, covering topics on system design, software engineering, and software testing. The courses were presented by Simula-based researchers and attended by researchers and user partner collaborators.

### Certus Open Courses 2014

A modern approach to the design of CPSs  
– Bran Selic

Introduction to search-based software engineering  
– Shaukat Ali

Symbolic methods in software testing  
– Arnaud Gotlieb

Test coverage and data quality in information systems  
– Sagar Sen

From myths to fashion to evidence-based software testing  
– Magne Jørgensen

## Program Committee Memberships and Chairing 2014

### Arnaud Gotlieb

#### Program chair

- 36th International Conference on Software Engineering, Software Engineering in Practice Track, India

#### Program Committee Member

- Seventh IEEE International Conference on Software Testing, Verification and Validation, Cleveland, Ohio, USA
- 38th IEEE Annual International Computer Software & Applications Conference, Västerås, Sweden
- 25th IEEE International Symposium on Software Reliability Engineering, Naples, Italy
- Sixth Workshop on Constraints in Software Testing, Verification and Analysis, ICSE Workshop, Hyderabad, India
- 24th International Symposium on Logic-Based Program Synthesis and Transformation, University of Kent, Canterbury, UK
- Ninth International Conference on Tests and Proofs, York, UK
- Workshop on Horn Clauses for Verification and Synthesis, Vienna, Austria
- Sixth Workshop on Constraints in Software Testing, Verification and Analysis, Hyderabad, India
- 14th International Conference on Quality Software, Dallas, Texas, USA

**Leon Moonen****Program Chair**

- 22nd IEEE International Conference in Program Comprehension

- 30th IEEE International Conference on Software Maintenance and Evolution

**Program Committee Member**

- International Conference on Evaluation and Assessment in Software Engineering

**Steering Committee Member**

- IEEE International Conference on Program Comprehension
- IEEE International Working Conference on Source Code Analysis and Manipulation

**Tao Yue****Program Committee Member**

- ACM/IEEE 17th International Conference on Model-Driven Engineering Languages and Systems
- European Conference on Modelling Foundations and Applications
- 14th International Conference on Quality Software
- IEEE International Computers, Software, and Applications Conference

**Sunil Nair****Program Committee Member**

- Third Workshop on Next Generation of System Assurance Approaches for Safety-Critical Systems
- 14th International Conference on Quality Software

**Jose Luis de la Vara****Program Committee Member**

- Third Workshop on Next Generation of System Assurance Approaches for Safety-Critical Systems
- Second International Workshop on Quality and Measurement of Software Model-Driven Developments
- 26th International Conference on Software Engineering and Knowledge Engineering

**Shaukat Ali****Program Committee Member**

- IEEE International Conference on Software Testing, Verification and Validation
- European Conference on Modelling Foundations and Applications
- ACM/IEEE 17th International Conference on Model-Driven Engineering Languages and Systems
- 14th International Conference on Quality Software
- Eighth Conference on System Analysis and Modelling

**Sagar Sen****Program Committee Member**

- 36th International Conference on Software Engineering 2014 – Software Engineering in Practice
- 1st International Workshop on Software Engineering Research and Industrial Practices
- 14th International Conference on Quality Software

**Dusica Marijan****Program Committee Member**

- 14th International Conference on Quality Software

**Workshop Chair**

- 14th International Conference on Quality Software

# Model-Based Engineering for Highly Configurable Systems

## Background

Model-based Engineering (MBE) technologies offer a promising approach to reducing the complexity of developing cyber-physical systems (CPSs), which are often highly configurable. They improve the quality and productivity of a product development process by capturing information at a higher level of abstraction, reducing complexity, providing a knowledge-sharing platform for communication between stakeholders, and enabling automated analysis. This project aims to develop practical MBE methodologies to support requirements engineering, architecture modelling, and the configuration and certification of large-scale and highly configurable CPSs.

## Activities

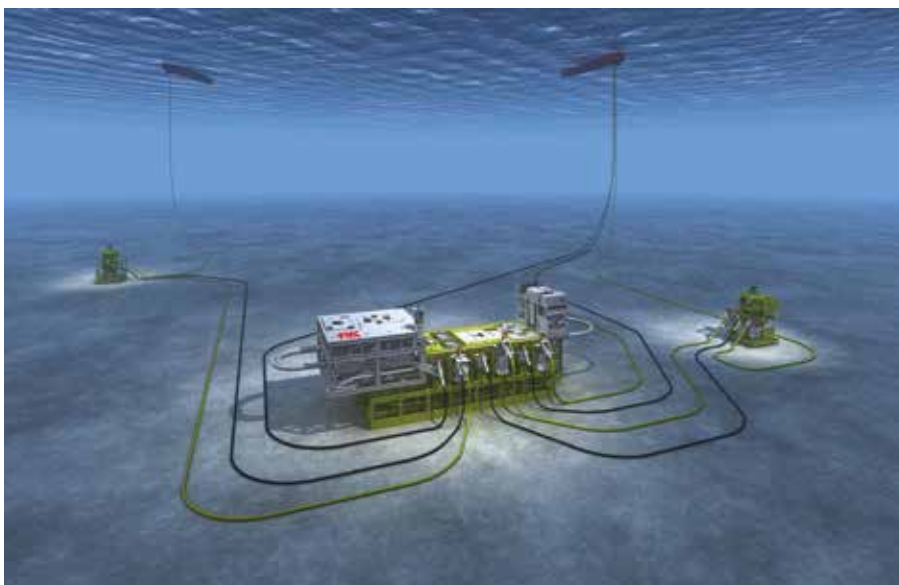
In 2014, Certus applied MBE technologies to the subsea oil and gas production systems of FMC Technologies with the aim of supporting requirements engineering, validation and verification, evidence management of large-scale and highly configurable CPSs, and the architectural modelling of such CPSs.

## The main focus was on the following three activities:

- 1** Devising a set of requirements, specifications, and validation and verification methodologies to improve the overall quality and productivity of requirement engineering and testing practice.
- 2** Investigating challenges in safety evidence management (for supporting certification), focusing on aspects related to safety evidence traceability and evolution.
- 3** Investigating challenges of the current architecture-level system integration process of FMC Technologies, with a particular focus on facilitating effective and unified communication based on high-level models, with a suitable perspective of the system architecture context or domain among relevant stakeholders.

## Impact

Based on a previously developed requirement specification methodology together with a user-friendly editor (the Zen-RUCM software tool), an automated, requirement-based test generation solution has been proposed and evaluated through multiple industrial case studies. To date, Zen-RUCM has been used by two universities and two companies. A series of tools have been developed under the umbrella of Zen-RUCM for specifying/modelling requirements and generating and specifying test cases.







# Testing of Data-Intensive Systems

## Background

The project for testing of data-intensive systems is developed along the scientific theme of understanding, managing, and testing variability in data-intensive and highly configurable systems. The participating partners are TAD, Cisco, and ABB Robotics. That these industry partners with seemingly unrelated activities all benefit and contribute to this project is a demonstration of the widespread need for such testing. TAD addresses the challenge of improving testing efficiency by using model-driven approaches to manage the high variability in the TVINN database. Cisco's VCSs are highly configurable and Cisco is interested in reducing the number of tests to cover a maximum number of configurations. ABB aims to reduce the number of test cases and, consequently, testing times in continuous integration of their painting robot software.

## Activities

- 1 New features such as self-referential relationships and surrogate relationships in Depict were developed to model and verify data interactions in large databases.
- 2 Investigation of the automatic generation of test cases representing data interactions and their verification were undertaken. This required a change in mindset from the manual creation of tests to thinking declaratively.
- 3 An approach based on maximum flow to reduce test suite size while maximizing testing requirement coverage was developed.
- 4 Investigation of a formally certified constraint solver that aims to eventually ensure the certification of tax computations has begun.

## Impact

- 1 Test managers at TAD created several data interaction models to test business rules on fault codes and archiving.
- 2 Test managers also started thinking in terms of representing their needs in a declarative model and automatically generating tests by solving constraints in the declarative model.
- 3 Valuable feedback from the test managers has included new features such as self-referential or recursive interactions, custom views, and tips for performance improvement.
- 4 Experimental use of Depict to model and verify data quality was implemented at the CRN. Properties such as data completeness, correctness, and anonymity were evaluated.
- 5 A plan to use 288 man-hours to spread the use of Depict throughout TAD in 2015 was proposed.



# Testing of Real-Time Embedded Systems

## Background

Real-time and embedded systems (RTEs) are extensively used in varied application domains, including communications, aerospace, transport, maritime, and energy. In addition, RTEs have been increasingly used as business, safety, and mission-critical systems. A typical RTE environment can consist of several physical components (e.g. sensors and actuators) and can even consist of other RTEs. It is important to ensure that the system is reliable, robust, safe, efficient, and secure to avoid posing undue risks to its users or the environment. This project aims to devise practical, scalable, cost-effective, automated, and optimized model-based testing techniques for RTEs that meet the requirements of industrial systems.

## Activities

### The project addresses around three main topics:

- 1** The testing of VCSs developed by Cisco. These VCS systems are embedded highly configurable systems with real-time requirements. In 2014, the focus was on two parallel activities in the context of product lines: test minimization and test prioritization. Based on collaboration with Cisco, test minimization aims at the cost-effective elimination of redundant test cases to reduce costs while preserving high effectiveness. Test prioritization deals with the efficient prioritization of test cases for one or more products, requiring clear consideration of the trade-off of various costs and effectiveness objectives.
- 2** A collaboration with Kongsberg Maritime that focuses on devising the cost-effective selection of test cases that can break a system as quickly as possible, with the ultimate aim of improving system robustness.
- 3** In collaboration with ABB Robotics, research focused on the cost-effective model-based testing of ABB industrial robots. The solution developed in 2014 extends the use of constraint modelling for test execution scheduling.

## Impact

### 1 Industrial Impact

- a** By actively sharing knowledge related to search-based software engineering, as well as skills on how to apply various search techniques in terms of test minimization and prioritization, the Certus centre's goal of implementing cutting edge research in industry is strongly supported. Furthermore, current test scheduling practices at Cisco have been improved by a proposed test prioritization technique integrated into Cisco's test scheduling system.
  - b** The test selection tool developed with Kongsberg Maritime is being transferred to industrial use. This will take place in the beginning of 2015.
  - c** The model developed with Kongsberg Maritime, in full production since over one and a half years, is now a full part of ABB Robotics' testing process. Internally, at ABB, our work has inspired other groups to start looking at model-based testing.
  - d** Initiations of collaborations with other parts of ABB currently look promising. Other organizations have expressed interest in our work and a new research direction (test case scheduling) is being pursued.
- 2** Standardization: An initial version of the UML Testing Profile standard has been submitted to the OMG, an international open-membership non-profit standardization body for modelling standards.



# Smarter Testing of Evolving Software Systems

## Background

This Certus project is aimed at devising practical, scalable, cost-effective automated techniques that enable the smarter testing of evolving software systems, based on an analysis of trends in historical data about changes made and characteristics observed in successive releases of a system.

## Activities

- 1 An understanding of current practices of software development and regression testing at Kongsberg Maritime was sought to determine necessary developments.
- 2 A manual survey of internal documents at Kongsberg Maritime was performed and an overview of dependencies between tests and systems was generated. This mapping will be used as a starting point for further exploration and refinement.
- 3 The mining and analysis of software repositories at Kongsberg Maritime has led to the development of the matrix visualization of co-changes, showing patterns in how files across the software system change together. Based on this, an early prototype for history-based test recommendations was developed and presented at Kongsberg Maritime.
- 4 The development and implementation of HaRT was initiated.

## Impact

As a new project in Certus, many of the 2014 activities involved the initiation of research and the determination of the industrial needs for testing evolving systems. Data collection for this purpose is well under way and the development of methods to reduce the amount of time spent on regression testing has already begun and been presented to the user partners. Required activities for 2015 that have become obvious from work performed this year are a more detailed evaluation study and generalization of the approach to a more finely grained development and testing context, which will be investigated in collaboration with Cisco.

We started devising novel algorithms for frequent pattern mining in software repositories, and implementing them in a more mature web-based tool. We hope to present an initial version of these algorithms and the prototype tool in January 2015.

**Leon Moonen**



# Industrial Exploitation

## Background

The prime objective of the Industrial Exploitation project is to generate high industrial impact for the research activities performed at the centre. To achieve that goal, the project activities are organized along three main lines: identifying the research prototypes developed at the centre that have the potential for industrial exploitation, managing their transformation into industry-relevant results in the form of software tools or research expertise captured in methodology documents, and ensuring that such results are effectively transferred to and exploited by the centre's user partners. The exploitation activities at the centre are governed by the Certus Exploitation Policy, comprehensive guidelines for organizing the transfer and exploitation of promising research results through a set of structured phases, and the provision of metrics for measuring the performance and success of their exploitation.

## Activities

Parallel streams of activity characterized 2014: first, work has been done on further development and refinement of the Exploitation Policy. The Exploitation Index was developed as a systematic metric system to support the evaluation of innovations created at the centre in terms of exploitation potential and adoption progress, which enables consistent and criteria-based comparisons between different technologies at the centre. The Exploitation Index is based on the well-known Technology Readiness Level (TRL) scale, which is used to assess the maturity of technologies during their development, joined with previously developed Certus metrics for evaluating a technology's exploitation potential and the performance of its adoption. The development of the Exploitation Policy is performed as a collaborative effort between Certus user partners, establishing a shared vision for the centre's exploitation strategy.

Second, throughout 2014, the Exploitation Project continued to manage the exploitation of innovative tools by Certus' partners. One such tool, TITAN technology, was further developed in close interaction with Cisco and other technology partners outside the centre. Since 2014, TITAN technology development and commercialization for the partners outside Certus has been managed as a separate project, with the goal of preparing the technology for a wider market.



Since the beginning of 2014, the Exploitation Project has been focusing on the management of another of the centre's innovations: the Depict tool. Throughout the year, researchers have worked on the technology's development and exploitation by TAD. In this context, Depict has the potential to effectively verify the completeness of partners' testing efforts as their information systems undergo constant evolution.

## Impact

The activities performed in the Exploitation Project demonstrate Certus' commitment to research-based innovation through the development of promising research prototypes into industry-ready tools capable of producing an economic benefit for the user partners, whether in terms of financial assets or strategic positioning. In the first three years of the centre's operation, the Industrial Exploitation project has been managing the exploitation of three innovations – TITAN, Depict, and DART – and will strive to extend its activities for the other research results with promising exploitation potential in the coming years.







# Scientific Advisory Board

*Based on its visit 6-7 November, 2014, the Scientific Advisory Board (SAB) has provided its assessment of three aspects of Certus: research, innovation, and education. This assessment is accompanied by recommendations for future work.*

Based on its visit 6-7 November, 2014, the Scientific Advisory Board (SAB) has provided its assessment of three aspects of Certus: research, innovation, and education. This assessment is accompanied by recommendations for future work.

The SAB findings are based partly on reports and documentation provided by the Certus centre and partly on information gathered during its visit. The on-site input provided to the SAB was given in the form of presentations on research topics, as well as overviews of Certus' structure and objectives. Time was set aside for questions and the clarification of open issues. The SAB members were introduced to representatives from the user partners in an informal setting and given the opportunity to discuss Certus from their perspective.

The 2014 report positively assessed the quality of research, collaborative efforts – both international and between the host and user partners – and the supervision of education. The report also included recommendations for further improving education in the centre's topics and suggestions for further research opportunities.

## The members of the Scientific Advisory Board for Certus are:

Professor Antonia Bertolino  
CNR-ISTI, Italy

Professor Laurence Duchien  
University of Lille, France

Professor Franz Wotawa  
Graz University of Technology, Austria

The Center has an excellent structure in terms of collaboration with the industrial partners. [...] The SAB finds such a model very effective and actually quite unique in the research world.

**SAB, on innovation at Certus**

# Automating the Cancer Registry System

*The Certus centre, and its collaborator the Cancer Registry of Norway (CRN), were granted funding by Regionale Forskningsfond Hovedstaden in 2014, for a two-year project titled “An Innovative Approach for Longstanding Development and Maintenance of the Automated Cancer Registry” (MBE-CR), to commence in 2015.*

*(Certus affiliated project)*

The innovation planned in the MBE-CR project is an addition to the digitization project currently being undertaken by the Cancer Registry of Norway. The project started in 2009 and aims to transform the current paper-based/manual system into an ICT-based Automated Cancer Registry System (ACRS). The planned innovation project proposed in collaboration with Certus aims to develop a systematic and automated way of developing the ACRS to significantly improve its quality and productivity. This will positively affect all its end users, including researchers, patients, doctors, and government officials. Such innovation is crucial for the CR, since the registration process is constantly evolving: new treatments and new ways of detecting cancers are continuously being added, and older treatments are becoming obsolete.

Such evolution in ACRS must be handled in an efficient and systematic way without significantly affecting the functioning system. The proposed innovation will be realized as a software tool that aims to constantly ensure the quality of the new system in the future by allowing its users to seamlessly deal with evolution in the ACRS. Consequently, the innovation project proposed holds the potential for securing the original investment in the ACRS, in that the system will become more robust and more adaptive to future requirements. Thus, the system is likely to remain operative and functional for a much longer period before major modifications or replacement become an issue. With moderate effort, the core of the innovation would also be applicable to other health registry systems.

This will be the first instant of direct implementation of the validation and verification tools and methodologies that are the focus of the Certus centre into a system under development. Previous technology has been developed for existing systems. The Certus centre researchers participating in MBE-CR will apply experience from these when working with the CRN.

The MBE-CR project aims to improve the quality and productivity of the evolving Cancer Registry (ACRS) system by automated, systematic, and cost-effective model-based approaches for improving the efficiency of the patient history registration process. Specifically, the project will:

- Propose an innovative, easy-to-use, and model-based repository engineering methodology for developing a repository of evolvable rules (rule models) by applying the proposed specification methodology to facilitate the implementation of the Cancer Registry;
- Define model-based, systematic and automated change impact analysis solutions, for efficient and effective maintenance of rules, rule models and patient history data; and
- Systematically evaluate the improved quality of the ACRS and of the data it produces, which is used by end users (independent researchers, scientists, the general public, patients, doctors, and government-level Norwegian healthcare decision makers).



REGIONALE  
FORSKNINGSFOND

# U-Test

## *Testing CPSs under Uncertainty: Systematic, Extensible, and Configurable Model-Based and Search-Based Testing Methodologies*

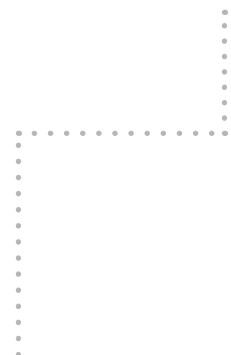
*(Certus-affiliated project)*

U-Test, a project proposal by Certus researchers Shaukat Ali and Tao Yue, was granted funding by H2020 under the LEIT-ICT programme. This funding was highly competitive and securing it was an achievement that marked the success of the 2013 agenda of promoting the Certus centre's international presence and collaboration. Although U-Test will be scientifically led by Certus researchers and is adjacent and related to scientific activities within the centre, it is not a Certus project; rather, it is the next generation of research, related and inspired by work done at Certus.

On 8 March 2014, Malaysia Airlines Flight 370 (Boeing 777-200ER, with a near-to-perfect safety record), a CPS fully capable of communicating via different methods (e.g. emergency locator transmitters) with air traffic controllers, satellites, and other planes, was lost with 239 passengers and crew on board less than an hour after takeoff. What happened to the flight is still uncertain, but what is certain is that the incident took place due to uncertain behaviour involving controls, communications, and/or human error that the plane was not equipped to properly handle. Not only is the aircraft's fate unknown, but there is also a high probability that there are no survivors of the incident. As estimated by experts, several hundreds of millions of dollars have been spent in vain in search of the plane. History is full of examples of the uncertain behaviour of CPS operations that have caused severe damage, such as airplane crashes and patients deaths due to incorrect medication, to mention but a few.

Uncertainty is a CPS state that cannot be described, a future outcome of the state that cannot be determined, or the possibility of more than one outcome from the state (non-determinism). Risk is an uncertainty state whose outcome has an undesired effect that can result in negative impacts on various concerns, such as cost. An uncertain behaviour is the behaviour of a CPS resulting from an uncertainty state that can potentially lead to an undesired effect. In the presence of uncertain behaviour, a CPS must continue to operate properly, possibly at a reduced level, rather than fail completely, also referred to as graceful degradation. Uncertainty is inherent in CPSs, since such systems usually consist of heterogeneous embedded systems interconnected via heterogeneous networks, often supported by cloud-based infrastructures. Such cloud-based infrastructures result in novel interactions between communication, computing, control, and humans and involve discrete and continuous signals operating synchronously or asynchronously.

Our daily life has been increasingly dependent on CPSs, with applications in safety-/mission-critical domains such as healthcare, handling systems, and the oil and gas and maritime industries. Dealing with uncertainty at an acceptable cost is vital to avoid undue threats to a system's users and environment. To ensure their correct function at acceptable cost, even in the presence of uncertainty, CPSs must be reliable, robust, efficient, safe, and secure. All these properties are facets of a more general property often known as dependability. Improving system dependability first and foremost relies on the ability to verify and validate CPSs cost-effectively and one way of doing so is via systematic and automated testing.





## Two new FRINATEK projects

*Certus is looking forward to a busy 2015, with two projects already awarded by the Research Council of Norway:*

The ideas for U-Test emerged as a result of work done at Certus, specifically, Project 8, 'Testing of Real-Time and Embedded Systems'. U-Test aims to improve the dependability of CPSs by defining extensible model-based testing frameworks supporting the holistic testing of systems under uncertainty in a cost-effective manner. The project aims to achieve this through the following:

- Providing a comprehensive and extensible taxonomy of uncertainties, classifying uncertainties, their properties, and their relationships.
- Creating an Uncertainty Modelling Framework (UMF) to support modelling uncertainties at various levels (relying on existing modelling and testing standards).
- Defining an intelligent way to evolve uncertainty models developed using UMF towards realistic models of unknown uncertainty using search algorithms.
- Generating cost-efficient test cases from uncertainty and evolved models.

U-Test will be an international undertaking by a consortium encompassing domain experts from various facets of CPS use: software, embedded systems, distributed systems, and cloud infrastructure. Two CPS developers with interesting case studies have been chosen to assess U-Test's cost-effectiveness: ULMA handling systems, in Spain, and Future Position X, in Sweden, with geosports. The solutions will be integrated into two key commercial tools available on the market: ModelBus/Fokus!MBT (Fraunhofer FOKUS, Germany) and CertifyIt (Smartesting, France). The CPS test bed will be provided by Nordic Medtest, Sweden. Solutions will also be deployed within logistics, geosports, and healthcare to achieve a wider impact and facilitate interoperability among tools and technologies. Commercialization aspects of the project will be investigated by Ikerlan of Spain. Oslo Medtech will manage the overall administration.

Having sprung from research undertaken at the Certus centre, U-Test will be a collaborative effort not only between industry and academia, but also between nations.

### **Zen-Configurator: Interactive and Optimal Configuration of Cyber Physical System Product Lines** *(Certus-affiliated project)*

The goal of the Zen-Configurator project is to increase the efficiency and effectiveness, and reduce the cost of configuring large-scale Cyber Physical System (CPS) product lines. To this end, the project will work toward maximum automation of error-prone and costly manual configuration activities, and optimum assistance of the interactive configuration process.

On the one hand, the project relies on advanced technologies of constraint solving/evaluation, optimization using search algorithms, and proposing state-of-art algorithms to enable automated configuration activities. On the other, the project is committed to address real challenges faced by industry, and will propose a practical and applicable solution and apply it in at least one application domain.

The Zen-Configurator project is scheduled to run from the first of July 2015 to the end of June 2018. Tao Yue will serve as project manager, together with Certus colleague Shaukat Ali.

### **Evolving, Modelling and Testing Realistic and Risky Uncertain Behaviours of Cyber-Physical Systems (MBT4CPS)** *(Certus-affiliated project)*

Cyber-Physical Systems (CPSs) are a new, more complex generation of embedded systems. Increased functionality, integration, and networking interoperability are some of the characteristics, along with a heightened reliance on software, and an increased number of non-functional constraints (e.g., robustness, scalability).

MBT4CPS aims to devise novel model-based testing techniques to support functional and non-functional testing of CPSs with a specific focus on uncertain behaviours. The ultimate goal of the project is to improve the quality and dependability of CPSs, a critical factor since these systems have safety and mission-critical applications.

The project will run from the first of July 2015 through June 2018. Shaukat Ali will serve as project manager, along with Certus colleague Tao Yue.

# Highlights 2014

## *Industrial Exploitation Highlights*

The Industrial Exploitation Policy has been revised based on experience and an exploitation index is defined according to standardized practices in the evaluation of innovation. In particular, the partners have classified these technologies according their own exploitation index, as indicated in the table below.

Innovations	Producing partners	Exploiting partners	Evaluation of value creation or commercial potential	Exploitation index (with a max of 5.0)
<b>TITAN</b> Test suite optimization for highly configurable systems	Simula	Cisco, ABB	Engaged	3.8
<b>DEPICT</b> Test quality assessment over data-intensive systems	Simula	TAD, CRN	Engaged at TAD, assessed positively at CRN	3.0
<b>ABB's constraint model</b> Automatic test case generation for complex industrial robots systems	ABB, Simula	ABB	Engaged at ABB, assessed positively to be deployed at a larger scale	3.2
<b>Zen-RUCM</b> Requirement management system	Simula	CRN, KM	Assessed positively	n/a
<b>jDART</b> Automated regression testing of data-intensive systems	ESITO	n/a	Assessed negatively	n/a

The Exploitation Index is a systematic metric system that supports the evaluation of innovations developed at the centre in terms of exploitation potential and adoption progress. This enables consistent and criteria-based comparisons between different innovations developed at the centre. The index is a multidimensional framework that subsumes a set of metrics providing a comprehensive assessment of different factors involved in technology transfer and exploitation, one of which is the Technology Readiness Level, used to assess the maturity of technologies during their development.

The 2014 Software Product Line Conference (SPLC) in Florence, Italy, selected TITAN as an innovative technology to be presented jointly with Pure::systems.

Pure::systems is the leading provider of software product line and variant management engineering tools and solutions. Their core product, pure::variants, is a tool for managing variant-rich software systems that enables systems engineers, architects, and developers to better manage complexity within their software systems.

TITAN is an innovative test suite optimization technology that is able to efficiently manage testing complexity, reduce testing effort, and avoid test redundancy. Project manager Dusica Marijan received great interest from industry participants following the technology presentation at the Software Product Line Conference that she hopes will amplify its ongoing industrial adoption.

Certus exploitation activities, with a focus on TITAN, were presented by research scientist Dusica Marijan at the Norske Dataforening Test Conference.

## Other Certus Highlights

- Strong Certus presence at the International Conference on Software Engineering (ICSE) 2014:
  - In June 2014, Certus researchers participated in the most important annual venue in software engineering: the ICSE, organized in Hyderabad, India, from June 1 to June 7. Arnaud Gotlieb, leader of Certus SFI, co-chaired the program of the Software Engineering in Practice track of the ICSE and chaired a goldfish bowl panel on the importance of data mining in data-intensive systems.
  - Leon Moonen, senior research scientist at Simula, co-chaired the ICSE-co-located event International Conference on Program Comprehension.
  - Sagar Sen, research scientist at Simula, presented a paper titled ‘Certus – Glimpses of a Centre for Research-based Innovation in Software Verification & Validation’ at SERIP, a satellite workshop of the ICSE.
- Based on Certus centre activities, the project ‘An Innovative Approach for Longstanding Development and Maintenance of the Automated Cancer Registry System (MBE-CR)’ received regional funding (12.91 million NOK) from the ‘RFF Hovedstad’ programme.
- The Simula researchers Tao Yue and Shaukat Ali were nominated for COST Action IC1404: Multi-Paradigm Modelling for Cyber-Physical Systems (MPM4CPs) committee membership.
- International collaboration was started with the National Natural Science Foundation of China with senior research scientist Tao Yue as co-PI on the project Software Product Line Variability Modelling and Configuration, NSFC-61370058.

- The Simula researchers Shaukat Ali and Tao Yue gave a talk on search-based software engineering at JavaZone 2014, a software development conference organized in Norway. JavaZone is a forum for knowledge exchange, recruitment, and branding and was attended by 2500 software developers. The topic of JavaZone 2014 was closely related to Certus' research activities and search-based software engineering is an emerging field that has produced excellent results in recent years for solving complex industrial problems requiring optimization, such as model-based testing and requirements engineering.
- Collaboration was started with Certus user partner ESITO to investigate advanced testing techniques for automatically generating unit tests and model transformation testing for flagship ESITO product G9.
- M. Mossige (ABB/Certus), A. Gotlieb (Simula/Certus), and H. Meling (University of Stavanger) received the Best Paper award for 'Using CP in automatic test generation for ABB Robotics' Paint Control System', in Proceedings of Principles of Constraint Programming (CP'14), Lyon, France, September 2014, Best Application Track Paper, edited by Springer, Lecture Notes in Computer Science, 2014.
- The project 'Testing Cyber-Physical Systems under Uncertainty: Systematic, Extensible, and Configurable Model-based and Search-based Testing Methodologies' (U-Test), based on a proposal by Simula researchers Shaukat Ali and Tao Yue, was recently awarded funding by the European Commission's H2020 program. This project is a spin-off from research in Certus.
- The paper 'Exploring Model-Based Repositories for a Broad Range of Industrial Applications and Challenges' was accepted at the 14th International Conference on Quality Software, in Dallas, Texas, USA, October 2 and 3, 2014. Co-authored by several Certus partners, the paper demonstrates how leading expertise from user partners and academia can come together to address key industrial challenges. The main authors from Simula's side are Tao Yue and Shaukat Ali and the co-authors are from a wide range of companies: Kongsberg Maritime, FMC Technologies, Cisco Systems of Norway, Akershus University Hospital, the CRN, and Attensi.
- UTP Standard Submission:  
Simula, together with other international academic and industrial partners, recently submitted an initial version of the UML Testing Profile Standard (UTP) V.2, to the Object Management Group (OMG). The OMG is an international open-membership non-profit standardization body for modelling standards, established in 1989. A subset of the work performed in Certus' projects in the last years has been put forth for standardization.
- History-based Recommendation for Testing (HaRT) was commenced in collaboration with Kongsberg Maritime and an early stage prototype of HaRT has been presented.







# Looking to the future



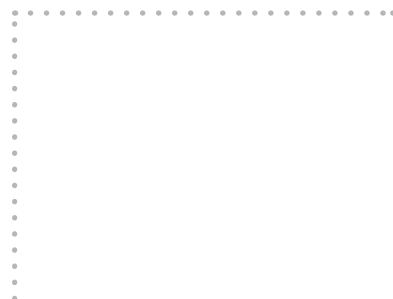
# From Occasional to Continuous

## *A Viewpoint on the Industrial Implementation of Research by Morten Mossige, Principal Engineer at ABB Robotics and Industrial PhD Student*

This rather cryptic title covers in four words the core of ABB Robotics' research in collaboration with the researchers at the Certus centre for the two last years. So what lies behind these four words? It is, of course, related to testing. Testing is, after all, our shared passion with Certus and the other industrial partners. The pure, basic idea is to continuously perform testing as part of the development process, not just as part of the process performed upon the product's release. A critical person might ask what is new about this idea. Where is the research? Software development in which testing is performed continuously as part of the process has been around for many years. However, ABB Robotics has taken the idea to a new level, where complex testing methodologies have been tightly integrated in an automatic process so that advanced tests that could previously only be executed manually are now both generated and executed in a fully automatic process. This new testing process even covers testing in complex distributed real-time embedded control systems.

Together with Certus, ABB Robotics has been involved in two different approaches: the conversion of manual testing at the product release phase and automatic testing in the product development phase. The first project ABB undertook in collaboration with Certus was automatic test case generation for ABB Robotics' paint control system, the IPS. The second project is related to the scheduling of test cases.

When a robot is painting along a set path, many different processes need to be tightly synchronized. The actual paint fog from the spray gun can sometimes involve up to six different physical processes, such as airflow, paint flow, valves, and high voltages. When turning a spray pattern on or off, synchronization between the processes is critical. Imagine starting a pump and being a few milliseconds late in turning on the output valve. This will result in splashing the object being painted. In the opposite case, opening the valve milliseconds too early will result in paint dripping from the paint gun. To make matters even more complicated, all of the processes are controlled by different embedded controllers at different locations on the robot. The challenge for IPS testers for many years was that the testing was a highly manual task. Testing typically involved setting up a robot to spray-paint a piece of paper or the use of other instruments, such as oscilloscopes, to measure the timing of IPS signals and processes. Since this testing process was highly manual, the frequency of testing was low. Usually such testing was performed close to the release phase of a new version of the IPS. A big problem with late testing is that the time from when a bug is introduced into the source code until its detection can be on the order of months. This time delay in bug detection makes it difficult to track each one back to the source code that caused the error.





To improve testing of the IPS, ABB Robotics and Certus developed a general model of the IPS based on constraint programming. With this model, we can generate different scenarios, both scenarios where the IPS behaves correctly and scenarios where the IPS is forced into an error condition. The model we developed has been integrated into ABB Robotics' Continuous Integration environment. By using this model, we can perform realistic tests on actual embedded systems as part of the IPS software. The model is dynamic and will adapt automatically to changes in hardware, software, and IPS configuration. As far as we know, this is the first time a constraint model has been integrated into a continuous integration cycle where the model is solved dynamically as part of the process of building the software. The model we have developed has now been in full use at ABB Robotics for more than one year. At least once every day, the model is launched and test cases that include the configuration of the IPS are generated.

So what does the model do? It checks that process outputs are turned on and off or changed at the correct time, with sub-millisecond accuracy. In total, the model checks close to 20,000 correctly timed process changes in each cycle. To test that the model is able to detect errors, we also reintroduced some old, hard to find timing-related errors into the IPS. The model was able to detect all of the errors, including some completely new errors.

Our second project at Certus is related to test case scheduling. Like our IPS timing test project, this project also aims to become part of a continuous integration cycle. When a new version of software is built, we would like to conduct as much testing as possible. However, testing can be time-consuming and there must always be a trade-off between the time spent on testing and the time a change in source code takes until the developer receives feedback on the results of the build. One way to reduce testing time is to execute several tests in parallel. If we look at ABB Robotics' product portfolio, this means setting up several robots for test execution; however, we must also be aware of the trade-off between how many robots to use and the test execution time. A complete robot is an expensive piece of equipment, limiting the number of robots available for test execution. Furthermore, not all test cases can be executed on all types of robots. Some test cases are designed to run on a special type of robot, while others are designed to run on any type of robot. To complicate things even more, some test cases require the use of external equipment. An example of such external equipment is a sensor of some type or an instrument. This means that any one test case using such an external resource must be coordinated so that no other test case requires the use of the same resource at the same time. To summarize, we end up with a complex scheduling problem in which we try to find the shortest execution time for a given number of test cases, where each test case can be run on one or several machines and some test cases require exclusive access to external resources.

This complex problem can be modelled by constraint programming and solved optimally by sophisticated algorithms. Together with Certus, ABB Robotics has developed a first approach for solving such problems. Our further plan is to integrate this process as part of a continuous integration process at ABB Robotics where the test case schedule is solved just ahead of test execution.







# The Future of Certus

Since its creation in 2011, the Certus centre has focused its research activities on the software validation and verification of highly configurable systems and data-intensive software systems. The centre has achieved advanced results in the modelling and certification of these systems, using model-driven engineering techniques, innovative software testing methods of safety-critical CPSs and industrial robotic systems, assessment of the test quality of large and complex database management systems, and software evolution methodologies. By gathering passionate researchers and software engineers from different companies and public administrations, Certus has created a unique forum where a targeted, dedicated interest in software validation and verification can be pursued. Certus partners have observed a trend in Norwegian society of intensive modernization of its public digital infrastructures and that many of the main Norwegian industries – energy production, maritime construction, robotized systems, networked communication systems – have strong requirements in term of validation and verification competence. This has led to a desire to increase their efforts far beyond the initial creation of the RCN-funded research-based innovation centre. Based on reflections about the centre's future, an ambition and vision have developed to establish Certus as a testing laboratory in the upcoming three years, that is, the Certus Testing Laboratory (CT-Lab).

## The CT-Lab will have three main missions:

- 1** The CT-Lab as a test facility, a physical space offering a set of assets and software equipment, providing Certus partners the opportunity to test and evaluate their software systems and use innovative testing tools in collaboration with specialists. CT-Lab will be a place where innovative software testing tools will be produced and existing testing tools will be tuned for specific usage by the Certus partners.
- 2** The CT-Lab as an expertise centre, offering expert consulting services and master classes for industry and public administrations in software testing, software quality evaluation, standardization, and preparation for third-party certification.
- 3** The CT-Lab as a research-based innovation centre where future research directions in software validation and verification will be explored and where master's and PhD students in the field will be educated with access to the most advanced tools and relevant industrial case studies.







The CT-Lab will be physically located at Simula Research Laboratory and will feature different activities such as research, consulting, education, and services for industrial and public sectors. Facing profound and rapid mutations due to the usage of software systems in everyday life, Norwegian society relies on high-quality numeric services and infrastructures. Unfortunate experiences have revealed the weaknesses of poor validation and verification procedures. Benefitting from the international and national status of the current Certus centre, the CT-Lab will conduct directed research in selected areas of software validation and verification where its impact can be maximized. Unique in Norway, the CT-Lab will conduct high-level research work in the automated analysis and testing of complex software systems deployed on mixed architectures, the testing of highly configurable systems, the testing of CPSs evolved in uncertain environments, the testing of quality assessments and test campaign evaluations, and the testing of long-term evolving systems. Several dimensions of software testing will be explored, including performance testing, test case generation, test suite optimization and prioritization, test cases execution scheduling, model-based testing, and variability testing.

During the remaining three-year period of the RCN-funded Certus centre, the necessary infrastructure and background to establish the CT-Lab as a viable entity will be created. Funding will be provided from different sources, including national public-private funding through research-based innovation programmes, European funding through the current H2020 programme and upcoming programmes, and through international industrial collaboration and private revenue.

The CT-Lab stakeholders will comprise not only the Certus centre's current partners, but also other industrial partners and public sector institutions seeking to evaluate and improve their software testing processes.

In terms of research, the CT-Lab will play a leading role at the national level by organizing conferences (the first of these will be the upcoming national event High-Integrity Days, organized at Simula Research Laboratory in 2015), developing its partnership with major Norwegian universities through the co-supervision of PhD students, and collaborating with industrial partners, the public sector, and small and medium enterprises in project proposals and consultancy or teaching activities. The CT-Lab will present its activities at national industrial and research events (e.g. the Norwegian Computer Society's sponsoring of Formal Methods 2015 at the University of Oslo) and seek commercialization routes for the technologies it produces. An initial proposition discussed among current Certus partners for such activities is the creation of a data repository where test data, case study data, models, and test artefacts will be stored and maintained in a structured way that is easily reusable. A second proposition suggests the building of a test virtualization structure in which researchers and software engineers can deploy systems to conduct experiments and evaluations. A third proposition consists of testing new software technologies and devices such as VCSs or industrial robots.

Following Certus' efforts in H2020 proposal writing in 2014, the CT-Lab will benefit from its de facto European status to attract highly qualified personnel, scientific collaboration, and funding. On the industrial side, following partnerships already engaged with major companies in building European proposals, the CT-Lab will develop its business network in Europe. Several actions will be undertaken to reinforce the centre's existing European strategy: organization of a summer school in the domain of software testing (the TAROT summer school) and participation in large industrial European consortia such as ITEA-3. The CT-Lab will be represented at major European events and its participation in European consortia for different H2020 programmes will be systematically encouraged.

# People and Publications

A man with short hair, wearing a headset with a microphone, is shown from the chest up. He is wearing a dark-colored shirt with horizontal stripes. He is holding a small, dark object in his right hand and gesturing with his left hand. A name tag is pinned to his shirt, displaying the word "Certus" and the name "Sugli". The entire image is overlaid with a solid blue color.



# International Collaboration

*In the rapidly moving field of software validation and verification collaboration with carefully selected partners is crucial to achieving internationally leading competence*

Since its creation the Certus centre has recognized the importance of international presence and cooperation. The centre's strategy for this rests on two pillars: long-term and focused collaboration with other world-class institutions and research groups; and maintaining an active presence in the international arena through researchers serving on selective committees, publishing in competitive journals, and presenting at prestigious conferences.

The year of 2014 has seen continued collaboration with international institutions and researchers, participation of Certus centre researchers in externally funded international projects, and as a first, a project lead by Certus researchers received a grant from an international funding system.

An aspect of being competitive in the international arena is securing funding from international funding systems. In 2014 efforts were made towards obtaining funding from the new European framework programme for research, Horizon 2020. Several proposals were made in response to calls in the Leadership in Enabling and Industrial Technologies (LEIT) pillar of the framework programme. One of these was successful in securing funding: the project U-Test will be headed by Certus researchers. U-Test is adjacent and related to scientific activities within the centre.

Researchers from international institutions taking part in Certus projects have been a staple occurrence in the centre. This year Certus centre researchers Shaukat Ali and Tao Yue confirmed their participation in research projects funded by the National ICT R&D Fund, Ministry of Information Technology, Pakistan, and the National Natural Science Foundation of China, respectively.

## Researchers actively taking part in Certus centre projects in 2014, either at their home-institution or as visiting researchers:

Name	Organisation	Country
Mathieu Acher	Inria	France
Roberto Bagnara	University of Parma	Italy
Benoit Baudry	Inria	France
Lionel Briand	University of Luxembourg	Luxembourg
Rafael Caballero	Complutense University of Madrid (UCM)	Spain
Catherine Dubois	Inria	France
Tim Kelly	University of York	UK
Hong Lu	Beihang University	China
Ji Wu	Beihang University	China

## Personnel in 2014

### *Certus Leader*

Arnaud Gotlieb

### *Administrative Manager*

Christian Hemmestad Bjerke

### *Key Researchers*

Andrea Arcuri (adjunct)

Leon Moonen

Sagar Sen

Tao Yue

Shaukat Ali

Dusica Marijan

### *Postdoctoral researchers working on projects at the SFI with financial support from other sources*

Jose Luis de la Vara

Razieh Behjati

### *Engineers*

Carlo Ieva

### *PhD students with financial support from the SFI budget*

Shokoofeh Hesari

Shuai Wang

### *PhD students working on projects at the SFI with financial support from other sources*

Stefano di Alesio

Sunil Nair Mohan

Morten Mossige

Erik Rogstad

Thomas Rolfsnes

### *Research Assistant*

Arnab Sarkar

### *External Consultants*

Bran Selic

## Gender distribution

*Only 15% of MSc graduates in software engineering are women. By making a systematic effort Certus is working to promote gender equality in this heavily male-dominated field.*

Certus' host institution Simula is also committed to this goal. Encouraging women to pursue higher education in fields with a large gender discrepancy is part of its Gender Action Plan.

To date, 33% of SFI funded researchers at Certus are female. Of the five Master's students supervised at Certus in 2014 one was female. Certus therefore did better than average both for female research staff and female Master's students this year. Since 2012 the Certus board has had a 50 - 50 gender distribution.

# Supervision of Master's Students

*An important part of the Certus concept is to support research in higher education. To that end Certus researchers supervise Master's students in the field of software engineering. The centre also offers summer internship positions through Simula Research Laboratory.*

Name	Supervisor
Davlet Dzhakishev	Sagar Sen, Magne Jørgensen
Alexandre Pétillon	Arnaud Gotlieb
Dipesh Pradhan	Shaukat Ali, Tao Yue
Man Zhang	Tao Yue, Shaukat Ali
Summer interns	Supervisor
Ruihua Ji	Tao Yue
Alexandre Pétillon	Dusica Marijan



# Publications and Proceedings

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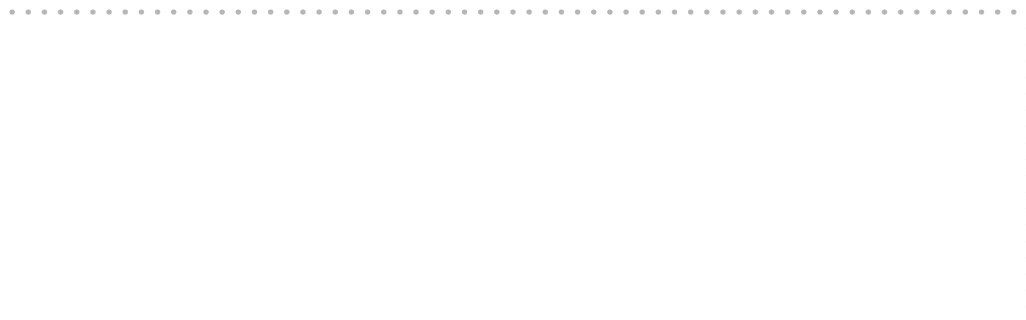
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**For more information,  
contact us at:**

Certus Centre  
c/o Simula Research Laboratory AS  
P.O.Box 134  
1325 Lysaker  
Norway

T: **+47 67 82 82 00**  
F: **+47 67 82 82 01**  
E: **[post@certus-sfi.no](mailto:post@certus-sfi.no)**  
**[www.certus-sfi.no](http://www.certus-sfi.no)**