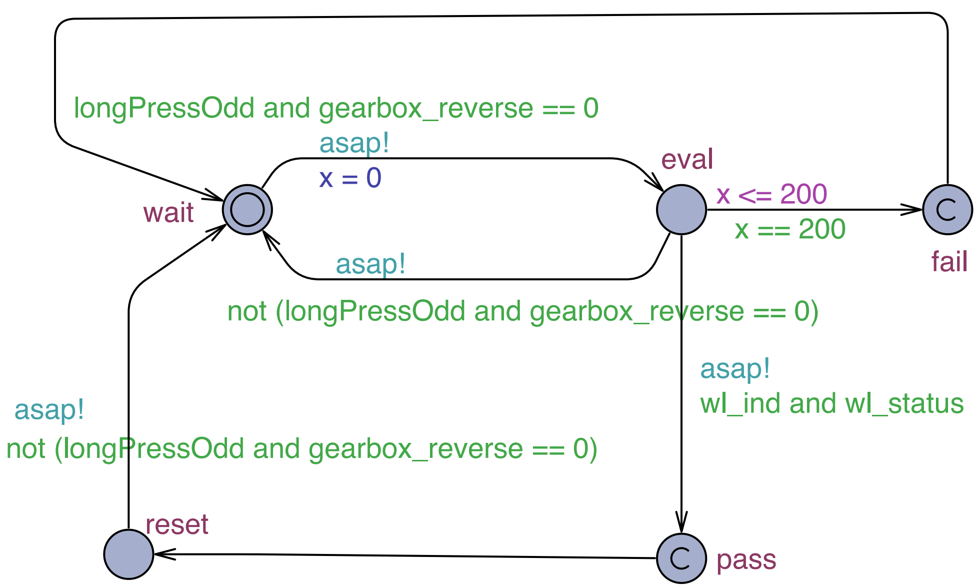
Parallelization of Integration Tests (PINT)



Project within Vehicle Development / Facilitating Electronics

Daniel Sundmark, Thomas Gustafsson, Daniel Flemström

2015-09-30

FFI

Content

1. Executive summary **3**

2. Background **4**

3. Objective **4**

4. Project realization **5**

5. Results and deliverables **6**

5.1 Delivery to FFI goals 7

6. Dissemination and publications **8**

6.1 Knowledge and results dissemination 8

6.2 Publications 8

7. Conclusions and future research **9**

8. Participating parties and contact person **9**

1. Executive summary

Electrical systems in modern vehicles are increasingly complex and software intensive. This makes integration- and system-level testing, where all different vehicular subsystems are interconnected and tested together, highly challenging. Typically, when testing automotive systems, the system under test is divided into separate functional parts that are tested in isolation in a sequential manner. This approach however poorly mimics the real-world operation conditions where several functions are often used in parallel. In the PINT project, SICS Swedish ICT and Scania CV have spent two years focusing on developing methods and tools for parallelization of integration- and system-level tests that improve the overall test quality.

The main result of PINT is a method for expressing; executing and analyzing parallelized automotive system test cases in a laboratory environment. In particular, in the project, we have proposed a way of monitoring the execution of the system under test in order to be able to tell whether system requirements hold or not during testing. Using our proposed approach, we are able to show how to facilitate parallel execution of test cases by breaking up the tests into smaller parts, each of which can operate in isolation from the other parts.

The overarching goal of PINT was to achieve increased real-world representativeness, reduced time for testing, and increased defect detection in automotive system testing. In particular, test cases should be possible to execute in parallel, as repetitive sequential execution of scenarios are considered to poorly mimic real-world situations; the effort involved in running a set of parallelized test cases should be less than that of running the original set of individual test cases; and the execution of a parallelized set of test cases should detect more defects than the individual test cases would have done if executed in sequence in their original format.

With respect to these objectives, we have experimentally shown that our method allows for parallel execution test cases is possible (thereby meeting the first objective of increased real-world representativeness), reduced test case execution time (thereby meeting the second objective of reduced time for testing), but (so far) not increased defect detection. The experimental studies has been undertaken in the Scania full vehicle integration testing laboratory, and the proposed method is hence tested in a real setting using a real automotive electrical system. However, in order to be fully automatable and adoptable by industry, our method requires further maturation. We currently evaluate it to be on a TRL level of 3.

2. Background

Over the last decades, automotive systems have been subjected to a rapid increase in complex and autonomous functionality, and there are no indications suggesting that this trend will change in a foreseeable future. Much of the complexity introduced today in a vehicle's electrical system originates in Advanced Driver Assistance Systems (ADAS). The functionality of ADAS is dependent on an increasing amount of sensor data. Furthermore, the scope and complexity of the situations that the system needs to handle is growing.

In addition to the challenge of designing and implementing such functionality, the quality assurance of these increasingly complex and interdependent systems is a growing concern. Today, testing is the primary means of assessing the quality of such automotive systems. Testing is typically done at several stages throughout system development, ranging from unit-level testing of smaller functions in isolation, to full-vehicle integration testing of the fully interconnected vehicular system. Testing is normally conducted in model-in-the-loop (MIL), software-in-the-loop (SIL), and hardware-in-the-loop (HIL) test environments, using use-case based test sequences derived from system requirements. This type of testing is commonly referred to as *scenario-based testing*.

Scenario-based testing has a number of drawbacks. Test cases are **repetitively executed without much variation**, and **little emphasis is put on testing the interaction between different scenarios**. Further, test cases are typically based on requirements defining how the system **should behave during normal operation**, a strategy that is not likely to maximize fault-detection. These drawbacks are further highlighted by the introduction of ADAS, where the verification needs to consider scenarios that put the system under test into normal, dangerous as well as unforeseen situations.

In the PINT project, we have explored the feasibility of using test case parallelization in order to address the above issues of scenario-based integration testing. The underlying hypothesis of this approach is that parallel execution of test cases that would otherwise have been executed in sequence and isolation may reduce execution time of testing, while increasing the fault detection and the degree of exploration of the behavioral space of the system under test.

3. Objective

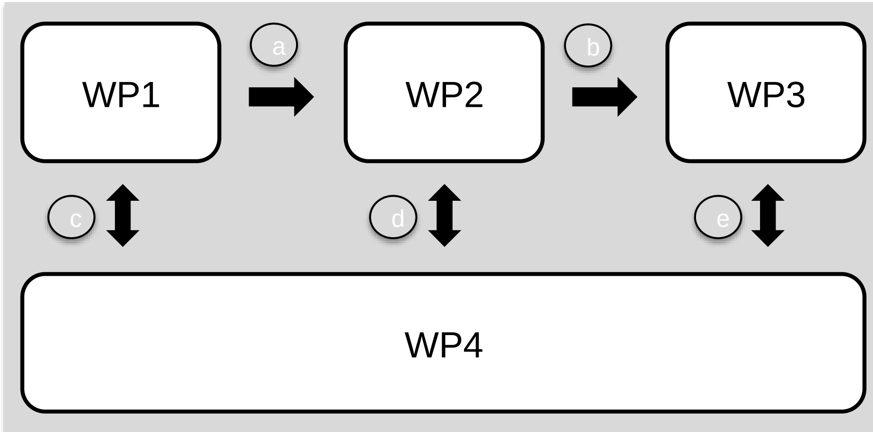
The overarching goal of PINT was to develop a method and supporting tools for automated preparation and execution of integration test cases that fulfill the following objectives:

- **Increased "real-world representativeness"**
  Test cases should be possible to execute in parallel, as repetitive sequential execution of scenarios are considered to poorly mimic real-world situations.
- **Reduced time for testing**
  The effort involved in running a set of parallelized test cases should be less than that of running the original set of individual test cases. The assessment of effort should also take test preparation and analysis into account.
- **Increased defect detection**
  The execution of a parallelized set of test cases should detect more defects than the individual test cases would have done if executed in sequence in their original format.

4. Project realization

The original project plan of PINT included an envisioned organization of the research work. In particular, in order to address the challenges posed in integration testing of vehicular systems, and to meet the PINT objectives, we identified the need for a number of research activities and divided these into four technical work packages (WPs):

- **WP1: Test Case Dependency Detection and Modeling,** focusing on development and evaluation of methods for detection and modeling of dependencies between test cases.
- **WP2: Test Case Parallelization,** focusing on development and evaluation of methods for parallelization of test cases by means of analysis of test case models and models of test case dependencies.
- **WP3: Multi-Objective Optimization,** focusing on building and evaluating heuristics for test case parallelization.
- **WP4: Experimentation,** focusing on empirical assessment of PINT methods, specifically with respect to dependency detection (serving WP1), validation of parallelization methods (serving WP2) and optimization of PINT objectives (serving WP3).



An overview of how the WPs interconnect in PINT is provided in the above figure. The project has been run as an iterative process, with recurring experimentation of preliminary results and prototypes included in the loop. During the project, we have held bi-weekly half-day working meetings with all operational project members. These working meetings have been held at SICS in Kista or at Scania in Södertälje, and focused on technical discussions and joint work on solutions or dissemination activities (e.g., writing research papers).

In addition, we have held quarterly steering group meetings with all project members, including the members of the steering group of the project. The steering group meetings have had a more strategic focus, reviewing the technical progress in the project and discussing the long-term directions of research activities.

As a sidenote, as can be seen from the above organization of work, a large emphasis was put on the management between **dependencies** between test cases, i.e. situations where individual test scripts are interrupted or negatively affected by other test scripts that run in parallel. The fact that such dependencies would pose the main challenge to achieving the PINT objectives was identified even before the start of PINT.

However, during the early phases of the project, we realized that the envisioned approach for addressing the dependency problem would not be practicable. Thus, while maintaining the original objectives of the project, we altered the focus of pars of the project (WP1 and WP2 in particular). Specifically, instead of focusing on methods for extracting and explicitly modeling dependencies between test cases, we chose a direction where we developed mechanisms in the way of writing test cases and the testing infrastructure, that allow for the development and execution of tests that are more robust and capable of handling interference for other test cases executing in parallel.

5. Results and deliverables

The main result of PINT is a method for expressing; executing and analyzing parallelized automotive system test cases in a laboratory environment. In particular, by using previous results in temporal logic we have defined *Guarded Assertions* [1] as a way of monitoring the execution of the system under test in order to evaluate the extent to which system requirements hold during testing. Using Guarded Assertions, we were able to show how to facilitate parallel execution of test cases by separating the test case stimuli from the requirement-checking assertions.

With respect to the overall objectives of PINT (i.e., increased real-world representativeness, reduced time for testing, and increased defect detection), we have experimentally shown that by using guarded assertions, parallel execution test cases is possible [1] (thereby meeting the first objective of increased real-world representativeness). We have further shown that parallelization of test cases allows for a reduced test case execution time [1][2] (thereby meeting the second objective of reduced time for testing). Regarding the final objective (increased defect detection), we have not yet been able to experimentally show such an effect of our method. However, by using Guarded Assertions, the number of evaluations of requirements performed during the same testing time vastly increases, with many evaluations of the same requirement being performed when the system under test is in different states. This effect of using our method should allow for increased fault detection.

It should also be noted that the technology readiness level (TRL) of our proposed method is relatively low (estimated at 3), and that further research proposed in part focuses on the evaluation of the method in a production-type environment with real testers rather than researchers utilizing the method (see text on future work below).

5.1 Delivery to FFI-goals

By its results, PINT furthers the knowledge on how to effectively and efficiently establish an adequate assessment of the quality of the system being developed, and is thus highly relevant for the overall FFI objectives of **shortened time-to-market** and **road and vehicle safety**. By its focus and design, PINT also indirectly addresses the FFI objectives of **increasing Sweden's research and innovation capacity, furthering cross-domain collaboration**, as well as **furthering collaboration between industry and research institutes**.

PINT primarily targets the **Facilitating Electronics** strategic area of the **Vehicle Development** FFI programme. Within this area, PINT first and foremost targets efficient and effective utilization of the **MIL, SIL and HIL chain**. In particular, the main PINT result will be a toolchain for automated generation and analysis of MIL, SIL and HIL tests, expected to facilitate *detection of defects earlier in the development process*, more *cost-effective testing*, and *higher quality products*. In addition to the above, PINT contributes to knowledge and method development in the strategic domains of **software engineering**, as well as **model-based development**.

6. Dissemination and publications

PINT dissemination activities include presentations of the project at Mälardalen University, SICS Swedish ICT, Scania CV, SAAB Group and some other minor companies. PINT has also been presented through a talk by Thomas Gustafsson at Scania TestForum (internal dissemination forum for test-related knowledge transfer at Scania), a poster at SICS Open House (external dissemination activity at SICS in Kista, attracting 400+ visitors), and through a talk by Thomas Gustafsson at the Software Technology Exchange Workshop (STEW) in Kista (technology transfer workshop arranged by Swedsoft).

6.1 Knowledge and results dissemination

PINT connects to a larger body of ongoing related projects on integration- and system testing of embedded systems involving industry partners like Volvo, ABB HVDC, Bombardier Transportation, and Scania, as well as academic partners Mälardalen University (MDH), Skövde University (HIS), Blekinge Institute of Technology (BTH), and SICS Swedish ICT. Along with MDH, HIS, and BTH, SICS are members of the TOCSYC distributed research environment[1], funded by the Swedish Knowledge Foundation. TOCSYC is a five-year project focusing on non-functional testing of embedded systems. Related projects led by TOCSYC partners include the Vinnova/FFI-funded VeriSpec (MDH, Scania, and Volvo), the VR-funded EXACT (MDH), and the Vinnova-funded IMPRINT (Volvo Construction Equipment, ABB HVDC, Bombardier Transportation, and MDH). Operating in this context, with e.g., annual joint industry day workshops, has allowed for knowledge transfer, interaction and collaboration between different business sectors, projects and partners.

6.2 Publications

The results from PINT have so far been published in the two following research papers:

[1]. Gustafsson, T.; Skoglund, M.; Kobetski, A.; Sundmark, D., "Automotive system testing by independent guarded assertions," in *Software Testing, Verification and Validation Workshops (ICSTW), 2015 IEEE Eighth International Conference on*, vol., no., pp.1-7, 13-17 April 2015

[2]. Rodriguez-Navas, G.; Kobetski, A.; Sundmark, D.; Gustafsson, T.; "Offline Analysis of Independent Guarded Assertions in Automotive Integration Testing," in *Embedded Software and Systems (ICESS), 2015 IEEE 12th International Conference on*, 24-26 August 2015

[1] www.tocsyc.se

A final research paper, describing the overall approach and the remaining challenges, is in preparation, but has not yet been submitted for publication.

7. Conclusions and future research

In the PINT project, we have addressed the problem of lack of variability and interaction between different functionalities in integration testing of automotive systems. In particular, we have proposed parallelization of integration tests using Guarded Assertions as a strategy for increasing real-world representativeness, reducing testing time, and increasing defect detection. Experiments undertaken in the project have shown that our proposed method provides improvement with respect to the two former objectives, but we have so far been unable to show positive effects on defect detection.

Future research in this area (most notably as proposed by the recently submitted SAGA FFI funding application) will primarily focus on automated generation of sequences of test stimuli based on state of the art test objectives, more lightweight methods for expressing Guarded Assertions, and further general maturation of the approach in a way that facilitates easier industrial adoption.

8. Participating parties and contact person

The PINT project partners were SICS Swedish ICT AB and Scania CV AB. For more information about PINT, please contact:

Jakob Axelsson, SICS Swedish ICT, jax@sics.se

Thomas Gustafsson, Scania CV, thomas.gustafsson@scania.com