> Semantic Web Use Cases and Case Studies

Use Case: How Ontologies and Rules Help to Advance Automobile Development

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General Description

Nowadays, cars have become very challenging to develop, which is partly due to the increasing use and complexity of electronic components and software. This trend has an impact on all phases of the life cycle of automobile development. However, this is especially the case during the testing phase of development. Semantic based approaches can allow more tests to be undertaken through the use of automation, thereby helping to find the needle in the haystack. Ontologies in combination with rules can be used to check specifications against test results and therefore deliver new insights.

A multiplicity of today's innovations in the automotive industry are the result of new and more efficient electronic systems (e.g., multimedia, drivers' assistance systems, safety systems, etc.). The number of integrated controllers is rapidly increasing, especially for premium class cars where there are now commonly up to 60 electronic control units (ECU). This makes not only the development of such control systems, but also their integration into many models of cars more complex. The requirement for reduced time-to-market for new models and thus shortened development cycles is also intensifying the problem.

Testing is an essential part in the development of a new car to ensure the outstanding quality of the final product. To be able to cope with the increasing number of electronic components and associated software, car manufacturers, and their suppliers, have to implement highly efficient test methods. An important task in the overall testing process is the simulation of a physical ECU in a virtual car environment, which is also known as the Hardware–in–the–Loop (HiL) test. Unlike tests in real prototypes, critical situations and system states can be covered without any risk. Targets during HiL tests are the validation of the ECU against its specification and other given requirements. The main challenge is collecting and analysing the huge amount of data which is being generated and recorded during each test run. Which is not only time-consuming, but has the potential for faults to be overlooked.

Existing software solutions do assist the engineers in performing the analysis by providing different visualizations of the recorded data. However, they lack a standardized way to define the desired system behaviour on the one hand and known error cases on the other. The application of ontologies to provide a uniform vocabulary for the domain, and for rules to specify the system behaviour and error cases, have shown promising results in light of these issues.

Use Case

In 2006, AUDI AG announced the first engines to include the Audi valvelift system. This innovation varies the valve lift between two levels. To achieve this, sets of sliding cams are mounted directly on the intake camshafts. These feature two sets of adjacent cam contours for small and large valve lift. Which cam is used to open the intake valves depends on the power demand at any one time. The effect is an appreciable increase in engine efficiency. The driver benefits from greater power and improved driveability, while enjoying a marked reduction in fuel consumption.

The valve lifts are controlled by the engine management system. A deterministic finite automaton internally represents the possible states of the valvelift system and specifies the conditions for switching the valve lifts. This automaton has 6 different states. The state transition functions ultimately define when to switch between the valvelifts. An example for such a transition function is: "If the engine speed is greater than 4000 the valvelift system must switch to state 4 if it is in state 1". These details are defined in the specification of the engine management system.

Without knowing any internal details about the engine management system an engineer could also specify the expected behaviour of the valvelift system from another point of view - e.g.: "at idle speed the small valvelift must be used". During expert interviews we have been able to elicit 18 of these kinds of rules that need to be kept in mind when testing the engine management system.

The Solution

The main challenge for the solution is to merge the sources of knowledge about the valvelift system and to provide a way to automatically validate and analyse the data being recorded during the HiL tests. Therefore, a flexible way of formalizing the given rules for the transition functions as well as the system constraints is required.

Adopting ontologies for defining a uniform domain vocabulary and then using rules is proving to be a promising way to meet these demands. Both have recently gained increasing attention from researchers as well as the industry, because they are considered key technologies for enabling the vision of a Semantic Web. Cutting edge companies, such as ontoprise, are also beginning to provide professional support in these technology areas.

The first task in the development of the solution was the modelling of a domain ontology that provides a common vocabulary for the definition of rules. While doing this we took the format of the recorded data from HiL tests into account, since they will be the facts of our domain ontology.

Using a special tool we were able to take snapshots of internal variables of an ECU (e.g., current state of the finite automaton, engine speed, oil temperature) during the HiL tests with a minimum time interval of a few milliseconds.

To keep the first prototype quite simple, we defined two concepts:

- *Situation*: represents a single snapshot of the ECU at a given time including the recorded variables and a relation to the successor snapshot if present.
- *State*: the facts of this class represents the possible states of the finite automaton.

The basic idea for defining rules on top of the domain ontology was to simulate the expected state that should be present at a given snapshot.

The OntoBroker inference engine from ontoprise was used to retrieve the proof tree for a specific query result — i.e., which variables and values have been used in which rule. This feature can be utilized to define explanations for rule.

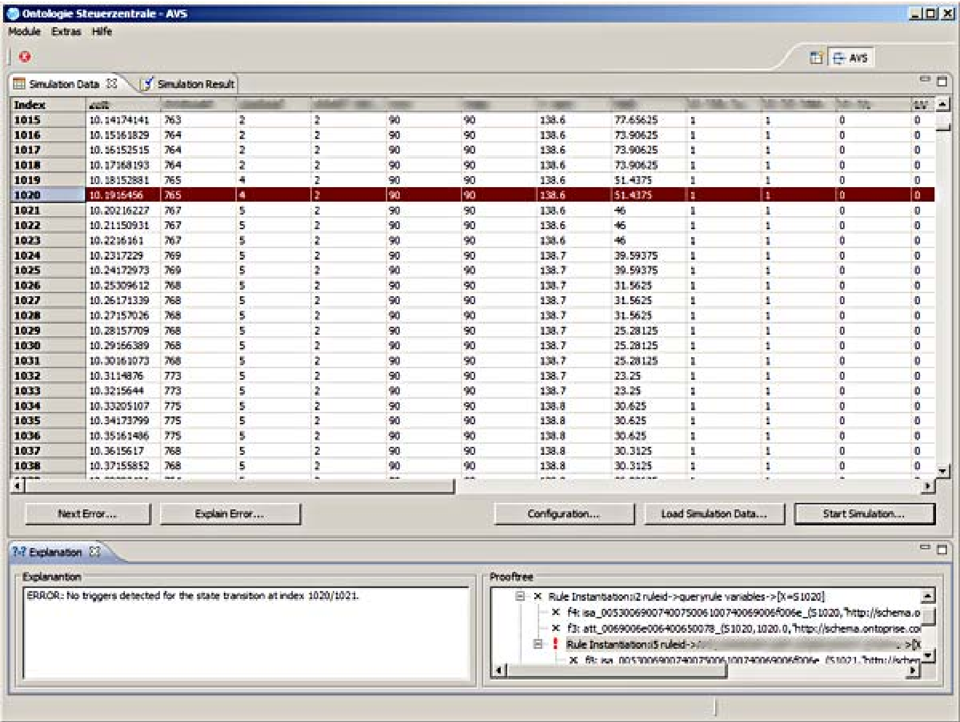

Figure 1: Screenshot of the system showing the test results, the errors and the explanations for the errors (a larger version of the screenshot is also available).

Figure 1 shows the prototype system, embedded as a plugin in an Eclipse-based application, and which also includes a module to manage ontologies and rules. The main features are:

- Import HiL test data: The data recorded with INCA can be transformed into instances of the domain ontology.
- Simulation Run: By applying the defined rules, the test data instances are checked for possible errors, which are then highlighted.
- Explanation of results: If available, an explanation for a detected error is presented. Tests with real data from HiL tests have shown reasonable results. Furthermore, some minor errors could be detected as well as explained. Even with a large number of instances (approximately 50,000) the prototype performed very well.

The prototype system has been accepted very positively by the responsible engineers and it does address their current needs. We have also been able to show the value of the application of ontologies and rules. The most important benefits are thereby:

- Integration of specification and expert knowledge: with an ontology and rules, it has been possible to merge two completely different sources of knowledge and make them processable by computers. Therefore, data analysis of HiL test results could be achieved with a high level of automation.
- Evolving rule bases: the rule base does not necessarily need to be complete at any time. However, the better the rules are the more errors could be detected automatically. Changing a rule can also be done very quickly. It is important to stress that the presented prototype does not aim to replace current testing technologies or experts but to support the engineers in doing their job more efficiently.
- Sharing and reuse of knowledge: rules that capture specific knowledge can be centrally stored and made available to a broader audience. Knowledge islands could thus be avoided. In addition, each data analysis is able to apply all previously defined rules. Thus the knowledge about why an error has occurred is not getting lost.
- Explanation of results: The usage of appropriate inference machines allows a detailed explanation of the used rules with only a minimal amount additional work. This may give an engineer a clue for finding and solving an error.

Conclusion and Outlook

The complexity of specifications of car components is steadily growing due to the increasing number of software and electronic components in cars and due to the dependency of these components to each other. Each additional electronic component may add up to exponential growth in complexity of dependencies. This makes it impossible for humans to track all dependencies. State of the art algorithms lack the ability to formalize the underlying knowledge in both a human and a machine processable way — thus leading to a reduced analysis during the test process. Additionally the formalized knowledge has to be connected with physical test results in a scalable manner.

To overcome these obstacles an ontology and rule based approach founded on F-Logic has been chosen. This approach combines

- a formalization mechanism close to technical language,
- powerful modelling primitives, that are strong enough to express the dependencies and complexities of technical specification,
- the ability to describe technical formulas and functions,
- an integration mechanism, even capable of ad-hoc integration of current test results,
- support for existing paradigms such as deductive databases, logic programming, ontologies and descriptive rules.

With the use of ontologies the existing knowledge can be formulated in a separate layer, aside from the application and the data.

The application of ontologies and rules for supporting the testing process of ECUs has shown promising results. We have successfully convinced the decision makers and are now working on the integration of additional ECU functions. Future plans and ideas for evolving the presented approach are:

- Support of different vendors: various electronic control units are offered by different vendors with exactly the same functionality but different internals. Thus, an adequate support by layered vendor ontologies would be desirable.
- Support regulatory requirements: every market (e.g. European Union, US) has different regulatory requirements. Instead of defining rules for each market, the regulations could be modelled in market ontologies. Depending on the market an ECU should be tested for, the appropriate ontology can be applied dynamically during data analysis.
- Automated extraction of rules: since technical specifications are highly formalized, it could be possible to automate the extraction of the essential rules and therefore provide a seamless integration into today's testing infrastructure.

We have shown that ontologies may very well be used to enhance business processes in the testing of electronic control units in cars. It has been shown that complex dependencies as well as compliance rules are very well represented using ontologies represented in F-Logic. Rules play a crucial role in this application.

This application accelerates the testing process and increases quality at our customer and thus enhances and accelerates the development of new cars. This ultimately reduces time-to-market which is so critical for today's consumers

Key Benefits of Using Semantic Web Technologies.

- Semantic Web Technologies ease the exchange of knowledge between various IT systems as well as between systems and users
- By describing the meaning of information and their logic separately from the underlying data and applications they allow for the creation of highly flexible and dynamic solutions
- Also, the transparent description allows every employee to understand the structure and logic which is normally hidden in Java code, SQL Statements etc.
- This knowledge can be shared and reused as well as enhanced or modified anytime

Acknowledgements

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