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The Case for Using Simulation to Validate Event-B Specifications

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Abstract

This paper addresses the validation of formal specifications in Event-B through the execution of the specification. Current tools for Event-B, animators and translators, can execute only a restricted set of specifications. So, we propose a third technique, simulation, in which users and tools co-operate to produce an executable instance of the model. After a short presentation of Event-B and our simulation framework, JeB, we show how to use it on two reasonably complex specifications. Observations and analysis from the point of view of validation are presented and discussed.

1. Introduction

Asserting the correctness of a piece of software relies on two activities: verification–Have we built the piece right?–and validation–Have we built the right piece?– The strength of refinement-based methods such as B or Event-B [1] is to break down the huge task of formal verification into a sequence of manageable proofs. Each refinement generates small proof obligations (POs) and if new refinements are introduced only when all previous POs are discharged, the whole sequence produces a verified piece of software.

This procedure has two major advantages: first, it requires only "small" proofs to carry out the formal verification; second, errors are detected very close to the point where they are introduced. With the advent of usable support tools, such as Rodin1, practitioners have far less reasons to shun formal methods. However, there is still the problem of validating the formal models. The verification process is too costly to allow for a trial-and-error kind of procedure.

We think that validation should be organized like verification: along the refinement chain. In principle, validation is simple: experts or potential users read the formal specification to judge if it represents a good model of the expected system. In practice, this does not work well since we, as humans, are not very good at reading and analyzing long mathematical texts. A better way is to look at executions of the specification and to judge whether the observed behaviours are consistent with the expected ones [2], [3]. The problem then becomes technical: how to execute the model?

Within the Rodin platform, several animators have been developed to execute Event-B specifications. Unfortunately, the class of directly animatable specifications is limited. We have shown how to safely transform specifications [4] to extend this class. However, many specifications are still non-animatable. To further extend the class of executable specifications, we propose to use simulation, i.e., the generation of a prototype of the model in a programming language.

JeB (JavaScript simulation framework for Event-B) is based on an observation and a simple idea. We observed that while some of our specifications are hard to animate, we could easily write programs to emulate them. The explanation is that using non-animatable features such as non-determinism and high abstractions in early refinements is recommended, even when we know how they will be reified. The idea was then to associate users to the generation of the simulation so their intelligence would assist the translator in the few cases where automatic solutions could not be applied.

This paper discusses the validity of the simulation approach for the validation of Event-B specifications. We analyze the use of JeB on two case studies. Both refer to the same problem: an algorithm for controlling a platoon of vehicles [5]. A simplified version in 1 Dimension [6] is used as a reference as it is easy to animate. The realistic version in 2 Dimensions [7] is hard to animate but is easy to simulate.

The following presents Event-B (Section 2) and related work (Section 3). After, Section 4 presents JeB with a particular emphasis on its design and its organization. Next, Section 5 details how to generate and set-

1. Rigorous Open Development Environment for Complex Systems: http://www.event-b.org
and one event variable (a platooning system in 1D. It consists in a state with one
and to transform or animate the specifications.
generate the proof-obligations, to discharge the proofs,
environment which allows users to edit models, to
be proven. Event-B is supported by the Rodin
through a sequence of refinements whose correctness
crete implementation of an abstract model is derived
a pseudo-event which describes the starting state of
END
all_moves
INITIALISATION
BEGIN
act1 : xpos0 := initial_xpos
END
all_moves
ANY
magic_xpos
WHERE
typing : magic_xpos ∈ 1..VEHICLES → Z
non_collision : ∀ v . v ∈ 2..VEHICLES ⇒
xpos0(v-1) - xpos0(v) > CRITICAL_DISTANCE
THEN
act1 : xpos0 := magic_xpos
END
END

Figure 1: Event-B model of a platoon
up the simulations. Then, Section 6 analyses how the simulations can be used for validation. Last, Section 7 gives some research directions.

2. Event-B Language

Event-B is a formal framework to specify complex systems. It is a state-based method: a system is modeled as a mapping from names to values (a state) constrained by invariants. Events make the state evolve; they model behaviours. Event-B is a formal method: a model can be mathematically proven correct. The proofs concern mainly the preservation of the invariants. Event-B is a refinement-based method: a concrete implementation of an abstract model is derived through a sequence of refinements whose correctness can be proven. Event-B is supported by the Rodin environment which allows users to edit models, to generate the proof-obligations, to discharge the proofs, and to transform or animate the specifications.

Figure 1 shows an abstract Event-B model of a platooning system in 1D. It consists in a state with one variable (xpos0), an invariant with two predicates, and one event all_moves. INITIALISATION is a pseudo-event which describes the starting state of the model. The event all_moves has a parameter: magic_xpos. It expresses a guarded substitution on the state. Six POs are generated, the most important being the preservation of the non_collision predicate. In this present case, the proofs are easy.

An intuitive operational interpretation of an Event-B model consists in the repeated execution of a four step procedure: (1) to pick (or compute) and assign values to the events’ parameters, (2) to compute the set of enabled events, (3) to choose one enabled event, and (4) to pick (or compute) and assign values to the substituted variables.

The model can be validated by observing the evolution of the state’s values and the sequences of events fired during executions. Technically, assigning values to parameters, choosing an event to fire and picking the substituted values introduce non-determinism.

3. Related Work

Two kinds of techniques to execute Event-B models have been developed: animation and translation.

Brama [8], ProB [9] or AnimB² are animators which interpret directly the Event-B specification. As a main advantage, these tools have the shortest path between the specification and the observations of system behaviours. Their main limit comes from abstract types (Section 5.3.1) and non-determinism. The execution engine needs actual values for abstract types and for parameters of events. Brama and AnimB use enumerations of potential values; ProB uses constraint-solving techniques. Both strategies fail either through combinatorial explosion (complex, unconstrainted domains) or lack of value.

Animators have another limit: they often require changes in the formal text before its execution. Brama requires complex transformations [10]; ProB requires one refinement to give explicit values to constants if we want set up realistic animations. This preparation step is time-consuming: it is also a source for errors. B2C [11] and B2ALL [12] are translators. They transform Event-B models into programs written in a mainstream language such as C or Java. On the one hand, translators provide us with a safe translation: the program implements the model. On the other hand, the translation can only be made on deterministic models. So, only the last refinement of the development can be executed using translators.

Validation requires a good visualization of the behaviour of the system. Animators provide us with API toward graphic systems, however, their limitation makes the construction of a nice display a complex and time-consuming activity. Programs generated by translators can be augmented with graphics by using standard graphic libraries. This is also time-consuming.

Our approach mixes the advantages of both approaches by producing simulatores. From animators, we retain the general execution model and the management of non-deterministic features. From translators, we retain the generation of programs in a mainstream language. Our major contribution is to provide users

2. AnimB is available at http://www.animb.org
Table 1: Requirements for JeB

<table>
<thead>
<tr>
<th>Requirement</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>REQ-1</td>
<td>Easy and cheap building of simulations</td>
</tr>
<tr>
<td>REQ-2</td>
<td>Simulation consistent with model</td>
</tr>
<tr>
<td>REQ-3</td>
<td>Integrated graphic interface</td>
</tr>
<tr>
<td>REQ-4</td>
<td>Possibility to guide the generation</td>
</tr>
<tr>
<td>REQ-5</td>
<td>Generated code extendable by users</td>
</tr>
<tr>
<td>REQ-6</td>
<td>Full user-control on simulations</td>
</tr>
<tr>
<td>REQ-7</td>
<td>Easy building of ad-hoc graphics</td>
</tr>
</tbody>
</table>

with facilities to guide the translation (annotations), to provide hand-coded functions to generate non-deterministic values, and to set easily graphic displays.

4. JeB: a Simulation Framework

The JeB simulation framework is intended to complement animators and translators when they cannot be used. Table 1 summarizes the main requirements.

4.1. Design Philosophy

The model validation is a three-step process: (1) generate the simulator, (2) set up a particular simulation environment, including visualization, and (3) run the simulator.

We use JavaScript/HTML as the target language. Modern browsers provide us with the graphic-rich environment we need for our simulations. JavaScript was also chosen because of its technical features. Objects allow the JeB translator to produce code whose structure is close to the Event-B text structure. It is easy to instrument the code for specific observations. Prototypes allow users to provide their own functions to override the generated ones. We use this feature to separate the generated function stubs from the main simulator code; so, users need only to work with files separated from the main code.

Methodological and technical reasons account for why refinement-based methods promote a slow introduction of determinism and concrete data-structure during the development. Yet, specifiers have often clear ideas about possible implementations for abstract entities. JeB allows specifiers to add annotations in Event-B to help generate reasonably efficient code.

We consider that simulation should be a collaborative process between automated tools and humans. Specifiers, experts and users are involved at four levels: (1<sup>st</sup>) specifiers provide the annotations prior to the translation in the Event-B text, (2<sup>nd</sup>) specifiers provide hand-coded functions in the user configuration files, (3<sup>rd</sup>) experts may provide functions, typically for generating event parameters in different scenarios, and extra graphic visualizations, and (4<sup>th</sup>) users can interact during the simulation.

4.2. Simulator User Interface

The user interface of the simulator consists of six views (Figure 2.) The top-most area is a graphic, ad-hoc, view of the state. Below is a toolbar view to set up general parameters. The lowest area is organized in three columns. On the left, variables and invariants are shown. In the middle, all events, with their parameters, guards, actions and activation status, are displayed. On the right, the history of the simulation is kept as a sequence of events and parameters.

5. Creation of Simulations

5.1. Event-B Specification of Platooning

JeB was motivated by our studies on platooning where we aimed at proving that some control algorithms are safe. The safety condition we retained is the absence of collision between a vehicle and its predecessor. This definition of “safe” is of course a simplified version of what would be needed for moving on actual roads, but it is highly representative.

We developed in Event-B a local version of a well known platooning algorithm [5]. It uses only perceptions of the preceding vehicle to take decisions, hence, it is very robust. The hypothesis that longitudinal (i.e., speed) and lateral (i.e., turning) controls are independent prompted us to develop two models. The first model considers only longitudinal control, as if vehicles move on a rail. It allowed us to study the general structure of the specification, within and between refinements, and to identify critical issues. In the second, we develop the more realistic bi-dimensional model.

Both models have the same structure which consists of an abstract machine and four refinements. Each refinement introduces a clearly identified concept.
As ProB and Brama can animate the 1D model, it serves us as a benchmark. As animators fail on the 2D model, it serves as a test-bed for assessing the feasibility of the simulation approach

### 5.2. 1D Simulations

The JeB translator is applied as the level of Rodin projects. Each machine, either abstract or refined, and each context is translated into a file in a common directory, “<Rodin wkp/<Ev-B project>/jeb”. A simple naming scheme facilitates the navigation in the simulator code.

#### 5.2.1. Minimal Simulation

After the simulator of the most abstract machine platoon0 has been generated, we must provide some values for the abstract constants. This can be done in one of four ways:

1. annotate the constant in the specification text with 
   ```javascript
   @value=<integer>; before running the JeB translator,
   ```
2. set the value in the jeb.user.js file after running the JeB translator;
3. set the value in the <context>.js file;
4. set the value in the <machine>.user.js file.

With (1) and (2) the values of constants are permanently kept. With (3) and (4), the values need to be set again after each run of the translator since new instances of the files <context>.js and <machine>.user.js are then created. With (1), (2) and (3) the values are available to all machines while, with (4), they are restricted to only one.

By using the second technique, we add the following two lines in the jeb.user.js file (the prefix $ctx denotes constants):

```javascript
$ctx.VEHICLES = 4;
$ctx.CRITICAL_DISTANCE = 20;
```

The button INITIALISATION turns then green, indicating an enabled event. The next step is to provide an implementation for the magic_xpos parameter. Events’ parameters model either true parameters or local variables in the usual programming sense. JeB translates each true parameter `pari` as a function `get_par(i)`. By default, those functions are called at the beginning of each simulation cycle. Since parameters are highly non-deterministic, the JeB translator generates only function stubs that should be replaced in the <machine>.user.js file, for instance:

```javascript
// TODO Auto-generated function stub;
// argument generator
var get_magic_xpos = function(event) (-1);
```

Assuming we replace this stub by a probabilistic value generator, we can put the simulation in Auto Run mode and observe how the state evolves. Another possibility is simply to enter values manually at each simulation cycle. We could then drive the simulation toward certain specific configurations. We can switch from one mode to the other at any time during execution of the simulation.

#### 5.2.2. Graphic Display

The JeB simulator includes an HTML5 canvas to display graphically the state. Users can provide two functions: jeb.animator.init which initializes the display, and jeb.animator.draw which draws an image of the system state at each simulation cycle.

#### 5.2.3. Simulation of the Refinements

All refinements in the 1D model can be executed with JeB. The work required on each refinement is similar to what is presented above and summed up in Table 2, with the number of entities, constants or functions provided by the user. It should be noted that the functions for the graphic animation are defined only once for all simulations.

### 5.3. 2D Simulations

The 1D and 2D models share the same structure, but not the same complexity. Animators cannot execute the 2D model because of two features: abstract or “too big” carrier set, and functions defined by properties. The following analysis explain how simulation provides users with possibilities to execute the models.

#### 5.3.1. Carrier Sets

The 2D specification requires the modeling of a notion of space. For the most abstract refinements, we used an abstract carrier set, Point, as we did not want to commit specific characteristics too early in the specification. Further down the development, Point will be refined into a kinematic space with 6 dimensions: $(x, y, \gamma, \theta, v, \kappa)$ representing the geometric position, the orientation, the velocity and the trajectory’s curvature. Animators cannot execute with either symbolic Points or 6-uplets. The former cannot be instanciated by meaningful enumerable values; the latter leads to combinatorial explosion. Yet, implementing Point as objects with six access functions is simple and sufficient for simulation.

#### 5.3.2. Functions Defined by Properties

The 2D specification uses several functions associated with the notion of distance, such as the distance between two vehicles, the deviation from the trajectory, or
6.1. Observations

6.1. Observations

To be useful as a validation tool, JeB must allow users to detect anomalous behaviours or to experiment with them. Here are presented some observations on the simulations of our 2 models.

6.2. Analysis from a Validation Point of View

The 1D specification consists of 15 events and contains around 140 individual logical formulas. Many of these formulas are very simple as they express some typing properties. Yet, getting the specification right was a difficult task. In this section, we discuss how JeB would have helped in this task.

The backward movement problem was found by an informed human reader. Platoon 2 was defined by a machine with a casual reader, and JeB can execute all refinements we have introduced since. The issue of deadlock is a complex one. The standard POs do not protect from deadlocks when we use the concrete model with backward movements. JeB can detect the issue earlier.

The issue of deadlock can be avoided by using a higher-level abstraction model. JeB can execute this model, and thus, avoiding the problem. Yet, the specification of the model is complex, and JeB can detect the issue earlier.

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small. Furthermore, it is spread over all the refinements since large parts of user’s code can be reused. The cost of using ProB on 1D model is low if we use it only for deadlocks detection, but it would sharply increase if we try to set up a graphic display. Because JeB is based on a rich graphic substrate, we could build a simple informative display in a few lines.

With the 2D model, only Jeb allows us to analyze the system’s behaviours. The issue raised in the observations about the distance functions is actually a crucial one for the direction of next refinements. In practice, trajectories are not continuous lines, but sequences of points perceived through imperfect sensors. We can expect that the tracking behaviour of the vehicles is dependent of the actual computations of the distances. JeB allows us to experiment several practical algorithms before we commit them to the next refinement.

Table 3 gives the relative effort needed for creating the simulations on three models. It is worth noting that the amount of user-provided code is small: around 1%. Also, although the simulations of the refinements are independent, user-provided code can often be shared. This is particularly true of the argument generator functions. Preliminary observations on the simulation of the specification of a pacemaker developed outside of our group confirm the figures.

### 7. Conclusion and Future Work

JeB proves that the generation of simulations for validating Event-B models is feasible. We were able to use it successfully on several large models realized outside our group. JeB calls for news work on several direction. The efficiency of the simulations depends on the quality of the generation and of the run-time libraries. Efficient set-manipulation libraries and big integer libraries are needed. The second direction is to provide safe-guards to users when they introduce hand-coded functions. It requires a formal of behaviours and observations. The last direction concerns the integration of validation activities into refinement-based methods. The issue is to connect the validation of each refinement with the validation of the final system.

### References


