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Automated Translation from Event-B specifications to Recursive Algorithms

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Abstract

Event-B is a modelling language. It allows the user to develop software or algorithm in a step-by-step manner, i.e. refining an initial high level specification into a final concrete specification. In previous work, one of the author and her colleague describes an approach that translating the final concrete specification into recursive and iterative implementation. In this document, we provide technical details of how the translation is performed. Moreover, we interest in the visualization of recursive algorithm for better readability and understandability.

Keywords: Event-B, Recursive Algorithm

1 Introduction

Event-B is a formal modelling language, based on refinement calculus. It uses set theory as a modelling notation, and use refinement to represent software systems at different abstraction levels. The use of mathematical proof will verify consistency between refinement levels.

Rodin platform is a tool set that help organize the information for systems written in Event-B. In addition, it provides theorem proving facilities that allow mathematical proofs to be semi-automatically discharged.

An Event-B model consists of the *contexts* and *machines*. The *contexts* give static information about the model, which will be referred in the *machines*. The *machines* express dynamic information about the model via *events*. They can modify state variables and cause the Event-B model moving into a particular state. Optionally, the machine can express other properties, such as invariant and safety properties of the model.

Each event can be triggered by conditions (i.e. *guards*) to take *actions*. When the Event-B model is in a state that satisfies all the guards of an event, such event will take effect by performing defined actions.

The control variable is a mechanism to control how the events interact with each other. The user defines a set of control labels in the context, and declare a state variable (namely the control variable) in the machine to refer these labels. The control variable does not serve any purposes to the state of Event-B model. It only keeps track of an implicit control flow of the Event-B model. More specifically, if an event's guard refer to the control variable, it implies which events that lead to the current event. If an event's actions refer to the control variable, it suggests which events the current event can move into.

In this document, we draw on the control variable mechanism in Event-B model, and present a plugin that read in an Event-B model to produce recursive algorithm and its visualized representation.

2 The Translation Procedure

To allow our plug-in understand that how to process an Event-B machine, the user needs to define a configuration file. This configuration file should specify at least:

- The method signature under consideration.
- The name of the control variable (a.k.a label).
- The name of the start label.

Our plugin reads in the configuration file and starts to process the Event-B machine. To reduce the translation complexity from a Event-B machine to its corresponding recursive algorithm, the plug-in extracts required information out of each event in the original Event-B machine, and stores it in a data structure called **bEventObject** (see Fig 1).

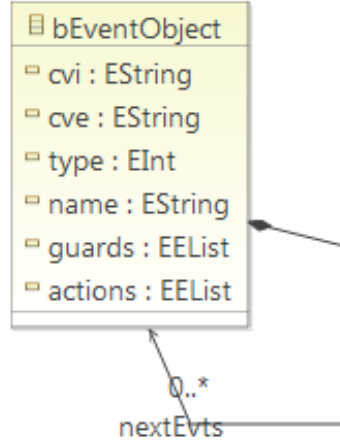


Figure 1: The Data Structure of bEventObject

The bEventObject is a 7-tuple $E_o = (cvi, cve, type, name, guards, actions, nextEvs)$, which consists of:

- The initial control variable (cvi).
- The end control variable (cve).
- The type of the event (type).
- The name of the event (name).
- A set of guards of the event (guards).
- A set of actions of the event (actions).
- A set of E_o (nextEvs).

Next, we describe how to extracted these information from the event under consideration.

Each event can reference the control variable in the guards or actions. This control variable controls the order that events take place. The **cvi** and **cve** in the `bEventObject` (see Fig 1) are short hand for control-variable-initial and control-variable-end. The *cvi* is used to determine which events that lead to the current event. The *cve* is used to determine which events the current event can move into. They are derived from the guards and actions of the original event respectively (i.e. extracting the action/guard that references the control variable).

The **type** of a `bEventObject` is determined by the name of event under consideration:

- An event has a **recursive** type if the event name starts with **REC** (case insensitive).
- An event has a **call** type if the event name starts with **CALL** (case insensitive).
- An event has a **normal** type if it is not one of the above cases.

The **guards** of the `bEventObject` are derived according to the following rules:

- The guards that reference the control variable are not included for the any event.
- The guards are not included for the event of recursive or call type.
- In the case of recursive or call type for the event, additional guards might be added from the event name, depending on whether guards appear in the event name (see Section 2.1).

The **actions** of the `bEventObject` are derived according to the following rules:

- The non-deterministic actions are not included for any event, i.e. `becomes_such_that` assignment and `becomes_in_set` assignment are eliminated when parsing the event actions.
- The actions that reference the control variable are not included for any event.
- The actions is not included for the event of recursive or call type.
- An additional action is added from the event name for an event of recursive or call type (see Section 2.1).

In `bEventObject`, the **nextEvts** association helps the plug-in understand how the transition system progress (i.e. where an event moves to the next). An `bEventObject` **x** counts as the next event of target `bEventObject` **y** if it has the following property:

$$x.cvi = y.cve$$

Such an event **y** is then added to the `nextEvts` list of the target event **x**.

2.1 Processing Event with Recursive/Call Type

The recursive (or call) type events must follow the following naming convention, so that the plug-in knows how to process it:

`rec@call_signature@grds@self_destructed`

The **rec** indicates this event is of recursive type. The **call_signature** part indicates the function call to be invoked by the event. It takes the format:

`call_name(in_parameters; out_parameters)`

This signature is easy to turn into a deterministic action, which can then be added to the action list of the `bEventObject`.

The guards of recursive events are not included in the guards of the `bEventObject`. The reason is that we use the **grds** part of event name to show under which the recursive call is allowed to be invoked. In the case that an recursive event has no guards, we specify **NULL** in the grds part of the name.

Notice that it is possible that more than one event's name with the same signature exists, where only the guards of these events differ. They show different outcomes when executing the same recursive call. Thus, they should be combined. The plug-in uses **self_destructed** part in the event name to control which event to display (i.e. among all related events for a recursive call, only one of them is displayed).

Eventually, each event is able to be translated into an `bEventObject` and be related through the *nextEvs* association. Next, we illustrate the algorithms that translate `bEventObjects` into the control flow graph (Section 2.2) and the recursive algorithm (Section 2.3).

2.2 Representing in Control Flow Graph

An intuitive diagram allows easier understanding of the algorithm, and is a prerequisite for modularizing complex algorithms. Therefore, we construct a control flow graph for each Event-B model by using *bEventObjects*.

The control flow graph is defined as $CFG = (G, Act, E_{act}, Grd, E_{grd})$, where:

- G is a directed graph $G = (N, E, S_g, T_g)$, where N is a set of nodes; E is a set of directed edges; $S_g : E \rightarrow N$ is the source function for edges; and $T_g : E \rightarrow N$ is the target function for edges.
- Act is a set of actions.
- $E_{act} : E \rightarrow Act$ is an action function.
- Grd is a set of guards.
- $E_{grd} : E \rightarrow Grd$ is an guard function.

Our plugin iterates over all the *bEventObjects* to construct such a CFG . On traversing each *bEventObject*, our plugin:

1. Instantiates two nodes, N_{cvi} and N_{cve} , corresponding to the *cvi* and *cve* in the *bEventObject*, and adds them to the set N .
2. Adds the *actions* of this *bEventObject* into the set Act .
3. Adds the *guards* of this *bEventObject* into the set Grd .
4. Creates a fresh edge e and add into E , where $S_g(e) = N_{cvi}$ and $T_g(e) = N_{cve}$; Then, adding $\{e \mapsto actions\}$ to E_{act} (i.e. attaches Event-B actions to the edge e); Finally, adding $\{e \mapsto guards\}$ to E_{grd} .

2.3 Representing in Recursive Algorithm

To help generate a recursive implementation from the Event-B specification, we design the pretty print procedure *Print* as indicated in Alg 1.

Algorithm 1 Representing Event-B Machine as Control Flow Graph

```
1: function PRINT(o: bEventObject)
2:   PRINTGUARDS(o.guards)
3:   PRINTACTIONS(o.actions)
4:   for each bEventObject  $e \in o.nextEvs$  do
5:     PRINT(e)
6:   end for
7: end function
```

3 Proof Obligations

We think there are a set of proof obligations that could be generated to ensure that an Event-B machine can be translated into a recursive algorithm:

- The control variable in the actions and guards of each event are different. (i.e. the event progress)
- The labels in the Event-B machine forms an acyclic graph.
- Only one event does not have control variable in its guards (i.e. the start event).
- Only one event does not have control variable in its actions (i.e. the end event).
- The control variable in the events' actions is deterministic (i.e. An Event always know which label it should move into).
- Recursive calls and external function calls are legal (i.e. type checked, signature matched).
- If the *out* label associates with more than one event, all these events should have guard(s) presented. Moreover, these guards should not overlap and should eventually converge.

4 Case Study

4.1 Binary Search Algorithm

The first case study targets the binary search algorithm developed in the Event-B machine (a part of the machine is displayed in Fig 2).

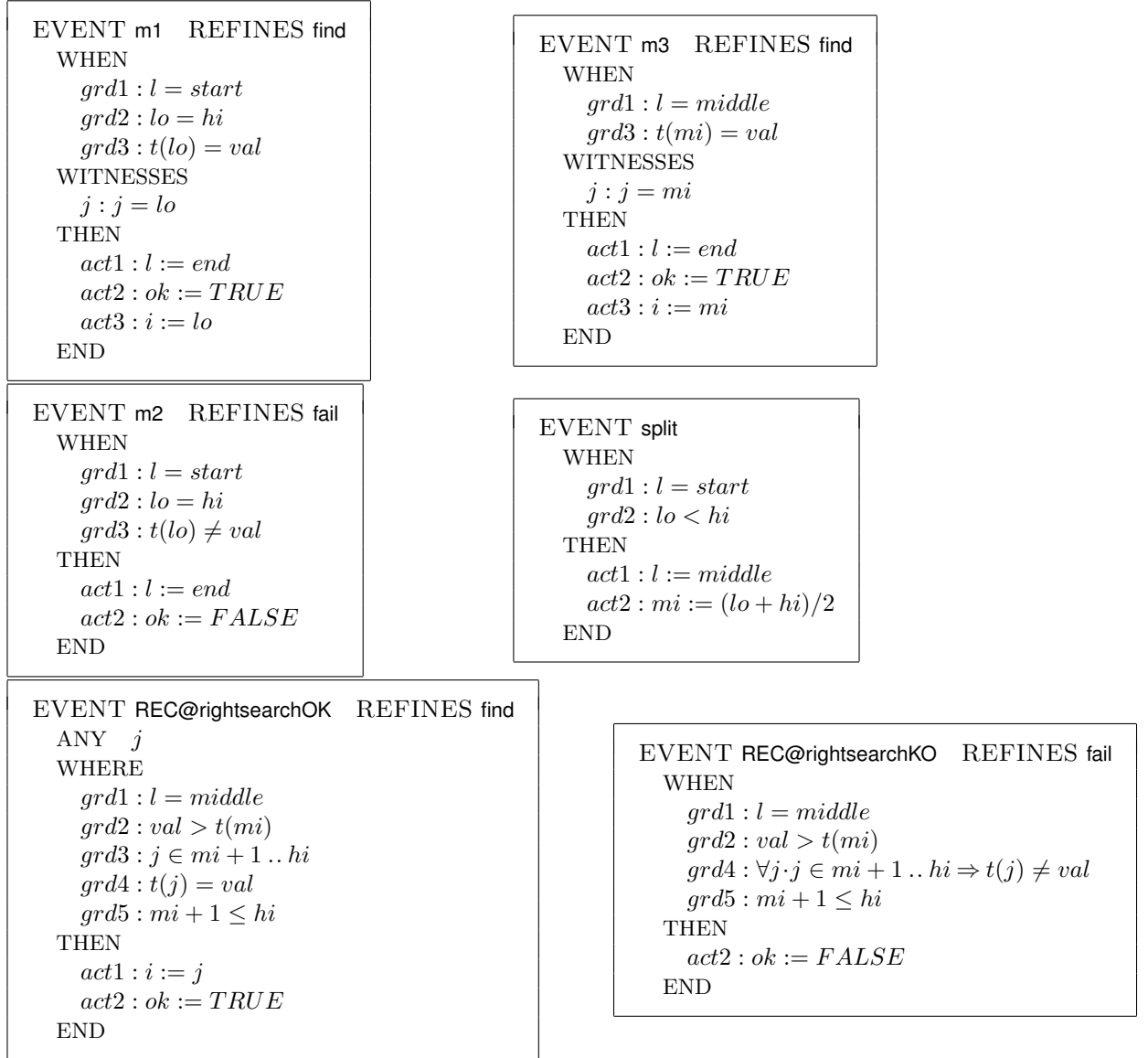


Figure 2: Event-B machine developed for the Binary Search Algorithm

As described in Section 2.1, the event of recursive/call type need to follow a naming convention so that the plug-in knows how to process it. In this example, the **REC@rightsearchOK** and **REC@rightsearchKO** are event of recursive type. Their event name has been shortened in the above machine. The REC@rightsearchOK is a shorthand for:

`rec@binsearch(t, mi+1, hi, val; ok, result)@NULL@SELF_DESTROYED`

and the REC@rightsearchKO is shorthand for:

`rec@binsearch(t, mi+1, hi, val; ok, result)@val>t(mi) && mi+1<=hi`

The result of our translation is two-fold. First, to help people comprehend the algorithm, the plug-in reads in the Event-B machine and visualize it as in Fig 3. This is done by translating an `bEventObject` into the *CFG* as described in Section 2.2. We use the *Dot* tool of *GraphViz* to assist this translation¹. In a nutshell, we draw a circle for each node, and the directed edge between two nodes indicates that an event occurs. The guards of such an event label the arrow, and the event's actions are indicated the text in the square box.

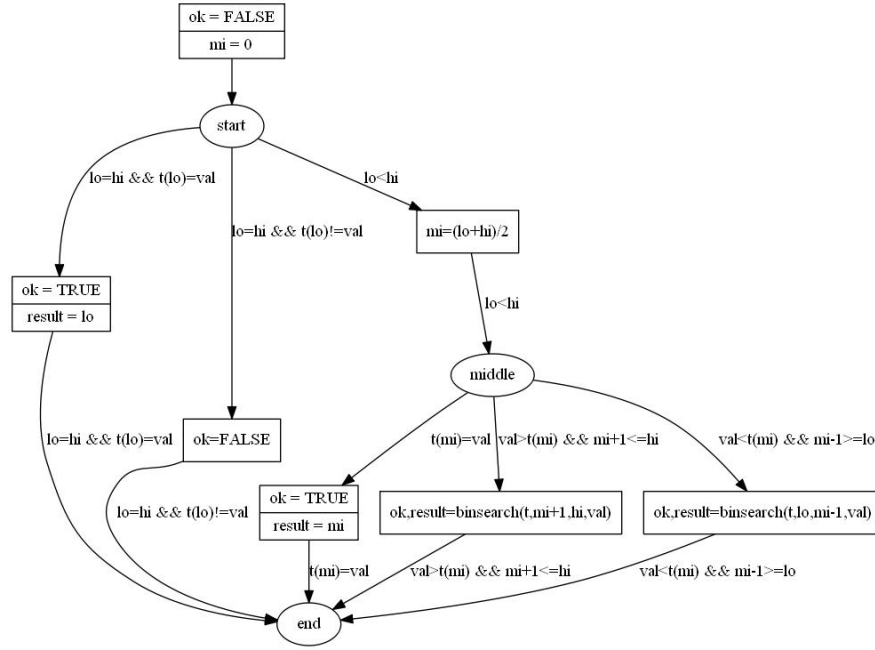


Figure 3: Visualized Representation of the Binary Search Algorithm

Second, in Fig 3, a textual representation of the binary search algorithm is given. It is constructed from the pretty print procedure *Print* as described in Alg 1.

¹<http://www.graphviz.org/>


```

binsearch(t,lo,hi,val){
    ok = FALSE
    mi = 0
    if(lo=hi && t(lo)=val){
        ok = TRUE
        result = lo
    }else if(lo=hi && t(lo)≠val){
        ok=FALSE
    }else if(lo<hi){
        mi=(lo+hi)÷2
        if(t(mi)=val){
            ok = TRUE
            result = mi
        }else if(val>t(mi) ∧ mi+1≤hi){
            ok,result=binsearch(t,mi+1,hi,val)
        }else if(val<t(mi) ∧ mi-1≥lo){
            ok,result=binsearch(t,lo,mi-1,val)
        }
    }
}

```

Figure 4: Textual Representation of the Binary Search Algorithm