Software Construction

The B Method - Event B

J. Christian Attiogbé

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Plan

Event-B : References

- *Modeling in Event-B: System and Software Engineering*,
J-R. Abrial, Cambridge, 2010

- *Modelling and proof of a Tree-structured File System.*
Damchoom, Kriangsak and Butler, Michael and Abrial, Jean-Raymond,
Conference ICFEM 2008.

- *Applying Event and Machine Decomposition to a Flash-Based Filestore in Event-B.*
Damchoom, Kriangsak and Butler, Michael; Conference SBMF 2009.

- *Faultless Systems: Yes We Can!*,
Jean-Raymond Abrial, Computer, vol. 42, no. 9, pp. 30-36, Sept. 2009

Event B Specification Approach

Some hints to formal methods

- Formal methods are rigorous engineering tools.
- Formal methods are means to build executable code from software requirement documents (informal, natural language).
- **Requirement Documents** (provided by clients) should be rewritten after analysis and understanding into Reference Document (where every thing is made clear and properly labelled for traceability).

B Method and Event B

- Event-B is an extension of the B-method (J-R. Abrial).
- It is devoted
  - for system engineering (both hardware and software)
  - for specifying and reasoning about complex systems : concurrent and reactive systems.
- Event-B comes with a new modelling framework called Rodin. (like Atelier B tool for the classic B)
- The Rodin platform is an eclipse-based open and extensible tool for B model specification and verification.
  It integrates various plug-ins: B Model editors, proof-obligation generator, provers, model-checkers, UML transformers, etc

Event B Modelling

Yet used in various case studies and real cases:

- Train signalling system
- Mechanical press system
- Access control system
- Air traffic information system
- Filestore system
- Distributed programs
- Sequential programs
- etc

Event B Specification Approach

Event B Specification ⇒ Abstract systems or Abstract model
An abstract system is a mathematical model of an asynchronous system behaviour

System behaviour : described by events

Events are guarded actions/substitutions The events occurrence

involve a State-transition model.

- Abstract System (or Model) = Specification unit
- Refinement (data and events)
  The parachutist paradigm / microscope paradigm (JR Abrial)
- Decomposition (of a system into sub-systems)

B Abstract System

Variables

Predicate

Events

```
SYSTEM
SETS ...
VARIABLES
...
INVARIANT
... predicate
INITIALISATION
...
EVENTS
...
END
```

but structured more efficiently using Contexts.

Events

An event has one of the following general forms (Fig. 1)

```
name ≙ /* event name */
  WHEN /* formely SELECT*/
    P(gcv)
  THEN
    GS(gcv)
  END
```

(WHEN/SELECT Form)

```
name ≙ /* event name */
  ANY bv WHERE
    P(bv, gcv)
  THEN
    GS(bv, gcv)
  END
```

(ANY Form)

Figure: General forms of events

bv denotes the local bound variables of the event;
gcv denotes the global constants and variables of the abstract;
$P(bv, gcv)$ a predicate.

Events

An event without guards has the following form:

```
name ≙ /* event name */
  BEGIN
    GS(gcv)
  END
```

Abstract System

- The WHEN form is a particular case of the other.
- The guard of an event with the WHEN form is: $P(gcv)$.
- The guard of an event with the ANY form is: $\exists(bv).P(bv, gcv)$.
- The action associated to an event is modeled with a generalized substitution using the variables accessible to the event: $GS(bv, gcv)$.

Abstract System : Semantics and Consistency

An abstract system describes a mathematical model that simulates the behaviour of a system.
Its semantics arises from the invariant and is enhanced by proof obligations.
The consistency of the model is established by such proof obligations.
Consistency of an event B model:

- PO: the initialisation establishes the invariant
- PO: each event of the abstract system preserves the invariant of the model

$I(gcv)$ the invariant and $GS(bv, gcv)$ the generalized substitution modelling the event action.

Abstact System : Semantics and Consistency

- the initialisation establishes the invariant;

$$[U]Inv$$

- each event preserves the invariant :
  In the case of an event with the ANY form, the proof obligation is:

$$I(gcv) \wedge P(bv, gcv) \wedge \text{prd}_v(S) \Rightarrow [GS(bv, gcv)]I(gcv)$$

Moreover the events (e) terminate:

$$Inv \wedge eGuard \Rightarrow \text{fis}(eBody)$$

(note that Inv is $I(Gcv)$)

Abstact System : Semantics and Consistency

The predicate fis(S) expresses that S does not establish $False$:

$$\text{fis}(S) \Leftrightarrow \neg\, [S]False$$

ie

$$Inv \wedge eGuard \Rightarrow \neg\, [S]False$$

The predicate $\text{prd}_v(S)$ is the *before-after predicate* of the substitution S ; it relates the values of state variables just before (v) and just after (v') the substitution S.
The prd_v(ANY x WHERE $P(x, v)$ THEN $v := S(x, v)$ END) is :
$\exists x.(P(x, v) \wedge v' = S(x, v))$

Example : producer/consumer

Features: Concurrency and synchronization

- Concurrent running of a process consumer which retrieves a data from a buffer filled by another process producer.
- The consumer cannot retrieve an empty buffer and the producer cannot fill in a buffer already full.

An event-driven model of the system is as follows:

Example : producer/consumer

system *ProdCons* /* Model */
sets
DATA ; STATE = {empty, full}
variables buffer, bufferstate, bufferc
invariant
bufferstate ∈ STATE ∧ buffer ∈ DATA ∧ bufferc ∈ DATA
initialization
bufferstate := empty || buffer :∈ DATA || bufferc :∈ DATA
events
produce ≙ /* if buffer empty */
any dd **where** dd ∈ DATA ∧ bufferstate = empty
then buffer := dd || bufferstate := full
end ;
consume ≙ /* if buffer is full */
select bufferstate = full
then bufferc := buffer || bufferstate := empty
end
end

Figure: A Producer-Consumer Abstract System

Refinement

- Data refinement
  (as usually)
- Event Refinement (extended):
  - Strengthening guards (unlike with Classical B)
  - Each event of the concrete system refines an event of the abstraction.
  - Introduction of new events.

Refinement

Let A with Invariant: I(av)

$\texttt{evt}_a \widehat{=}$ /* Abs. ev. */
when $P(av)$
then $GS(av)$
end

avec prd_v(...) = Ba(av, av')

Refined with: Invariant J(av,cv)

$\texttt{evt}_r \widehat{=}$ /* Conc. ev. */
when $Q(cv)$
then $GS(cv)$
end

avec prd_v(...) = Bc(cv,cv')

Proof obligation:

$$I(av) \wedge J(av,cv) \wedge Q(cv) \wedge Bc(cv,cv') \Rightarrow \exists cv'.(Ba(av,av') \wedge J(av',cv'))$$

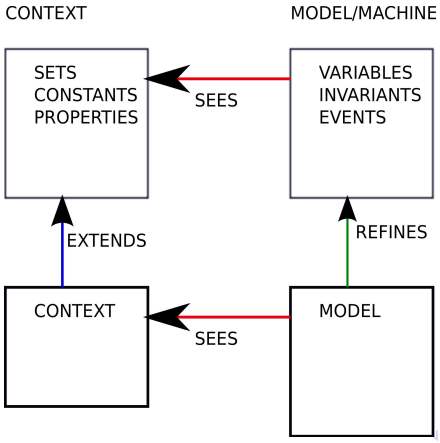
Tools

- First generation tools
  - Translation into classical B
  - B4free
- New generation tools: DataBase, Eclipse Plugins, ...
  - Rodin (Deploy Project)

Structuring Event-B Models

An event-B model is structured with

- Contexts that contain carrier sets, axioms and theorems (seen by various machine)
- Machines which sees the contexts and defines a state space (static part: variables + labelled invariants) and a dynamic part made of some events.
- A context may be extended; A machine may be refined.



Event-B Model Example: File transfer protocol

```
MODEL Transfer
SETS DATA
CONSTANTS n
PROPERTIES n : NAT
VARIABLES
sf /* sender file */
, rf /* receiver file */
, nr /* number of records in the file f */

INVARIANT
nr : NAT
& sf : 1..nr -> DATA /* all records of sf */
& rf : 1..nr +-> DATA /* probably part of
records of sf */
INITIALISATION
sf := {} || rf := {} || nr := 0
```

```
EVENTS
transf = /* instantaneous transfer, from far
way */
BEGIN
rf := sf
END

/* the following events are introduced by
anticipation of the forthcoming gradual
refinement*/
; sendta = skip
; recdta = skip
; sendac = skip
; recvac = skip
/* the followings are events that simulate the
non-releiabiliy of channels */
; rmvData = skip
; rmvAck = skip
END
```


Event-B Model Example: File transfer protocol

```
REFINEMENT
Transfer_R1

REFINES Transfer

VARIABLES

cs /* current record to be sent */
, cr /* current record received */
, rf
, sf /* sender file */
, erf /* effectively received file */
, nr /* number of records in the file f */
, dataChan /* data channel */
, ackChan /* ack channel */
 INVARIANT
cs : 1..nr+1 /* current to be sent */
& cr : 0..nr /* current received */
& cr <= cs /* current received is <= current
sent */
& cs <= cr+1 /* cr <= cs <= cr+1 */
& erf = (1..cr) <| sf
& dataChan <: (1..cs) <| sf
& ackChan <: 1..cr
```

```
INITIALISATION
cs := 1
|| cr := 0
|| rf := {}
|| sf := {}
|| erf := {}
|| nr := 0
|| dataChan := {}
|| ackChan := {}
EVENTS
transf =
WHEN
cs = (nr + 1) /* that is all cs are received
(last ack received) */
THEN
rf := erf /* not necessary, effective copy of
the received file in the receiver */
END

... (continued)
END
```

Event-B Model Example: File transfer protocol

```
/* new events introduced (ie. we "forget" the
anticipation in the abstract model) */
; sendta =
WHEN
cs <= nr
THEN
dataChan(cs) := sf(cs)
/* now wait for the ack, before updating cs */
END

; recdta =
WHEN cr+1 : dom(dataChan)
THEN
erf(cr+1) := dataChan(cr+1)
|| cr := cr + 1 /* the next data to be received
*/
END

; sendac =
WHEN cr /= 0 /* send ack for the received cr
data */
/* may be observed repeatedly until the next
data */
THEN
ackChan := ackChan  {cr}
END
```

```
recvac =
WHEN cs : ackChan /* ack for the already sent
cs */
THEN
cs := cs + 1 /* now the next to be sent */
END
/* Simulating non-relaibility of channels,
data/ack may be loss */
; rmvData =
ANY i, d WHERE
i|->d : dataChan
THEN
dataChan := dataChan - { i|->d }
END
;
rmvAck =
ANY i WHERE
i : ackChan
THEN
ackChan := ackChan - {i}
END
```


Case Study : Multiprocess specification (Readers/writers)

- Description
  - Multiple processes: readers, writers
  - Shared resources between the processes
  - Several readers may read the resource
  - Only one writer at a time
- Property:
  Mutual exclusion between readers and writers
- Improvement:
  no starvation → as a new property
  (using refinements)

Multiprocess specification

```
MODEL
readWrite2
SETS
WRITER /* set of writer processes */
; READER /* set of reader processes */

VARIABLES
writers /* current writers */
, activeWriter
, waitingWriters
, readers /* current readers */
, waitingReaders
, activeReaders /* we may have svrl readers simultan. */
```


Multiprocess specification

```
INVARIANT
writers <: WRITER
& activeWriter <: WRITER
& card(activeWriter) <= 1
& waitingWriters <: WRITER
& writers /\ waitingWriters = {}
& activeWriter /\ waitingWriters = {}
& activeWriter /\ writers = {}
/* merge */
& readers <: READER
& waitingReaders <: READER
& activeReaders <: READER
& card(activeReaders) >= 0
& readers /\ waitingReaders = {}
& activeReaders /\ waitingReaders = {}
& activeReaders /\ readers = {}
/*-----safety properties -----*/
& not((card(activeWriter) = 1)&(card(activeReaders) >= 1))
```

Multiprocess specification

```
INITIALISATION
activeWriter := {}
|| waitingWriters := {}
|| activeReaders := {}

|| readers :: POW(READER)
|| writers :: POW(WRITER)
|| waitingReaders := {}
```


Multiprocess specification

```
want2write = /* observed when a process wants to write */
ANY ww WHERE
ww : writers
& ww /: waitingWriters
& ww /: activeWriter
THEN
waitingWriters := waitingWriters \/ {ww}
|| writers := writers - {ww}
END
;
writing =
ANY ww WHERE
ww : waitingWriters
& activeReaders = {} & activeWriter = {}
THEN
activeWriter := {ww}
|| waitingWriters := waitingWriters - {ww}
END
```

Multiprocess specification

```
endWriting =
ANY ww WHERE
ww : activeWriter
THEN
writers := writers\/ {ww}
|| activeWriter := {}
END
;
want2read =
ANY rr WHERE
rr : readers
& rr /: waitingReaders
& rr /: activeReaders
THEN
waitingReaders := waitingReaders \/ {rr}
|| readers := readers - {rr}
END
```


Multiprocess specification

```
reading =
ANY rr WHERE
rr : waitingReaders
& activeWriter = {}
THEN
activeReaders := activeReaders\/ {rr}
|| waitingReaders := waitingReaders - {rr}
END
;
endReading =
/* one of the active readers finishes and leaves
the competition to the shared resources */
ANY rr WHERE
rr : activeReaders
THEN
activeReaders := activeReaders - {rr}
|| readers := readers \/ {rr}
END
```

Multiprocess specification

```
newWriter = /* a new Writer */
ANY ww
WHERE ww : WRITER
& ww /: (writers \/ waitingWriters \/ activeWriter)
THEN
writers := writers \/ {ww}
END
; leaveWriters = /* a writer leaves the group */
ANY ww
WHERE
ww : writers
THEN
writers := writers - {ww}
END
```


Multiprocess specification

```
newReader = /* a new reader joins the readers */
ANY rr WHERE
rr : READER
& rr /: (readers\/waitingReaders \/activeReaders)
THEN
readers := readers \/ {rr}
END
; leaveReader =
ANY rr WHERE
rr : readers & card(readers) > 1
THEN
readers := readers - {rr}
END
```