



Modelling Software-based Systems

Lecture 2

Proof Obligation Generation

Master Informatique

Dominique Méry
Telecom Nancy, Université de Lorraine

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General Summary

- Overview of machines, contexts and proof obligations
- Proof Obligations for Contexts and Machines

PO thm/THM (context)

PO thm/THM (machine)

PO evt/inv/INV

PO evt/act/FIS

3 Proof Obligations for Refinement

PO evt/grd/GRD

PO evt/act/SIM

PO evt/NAT

PO NAT

PO evt/VAR (arithmetic)

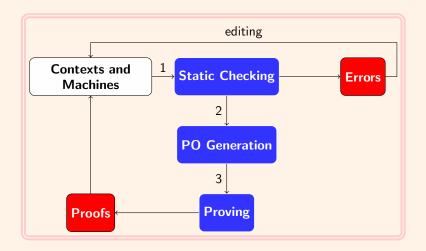
PO evt/VAR (set-theoretic)

PO evt/x/WFIS

Current Summary

- Overview of machines, contexts and proof obligations
- 2 Proof Obligations for Contexts and Machines
- 3 Proof Obligations for Refinement

Analysis of the Event-B Models



Machines en Event B

```
MACHINE
REFINES
 am
SEES
VARIABLES
INVARIANTS
I(s, c, u)
THEOREMS
VARIANT
\frac{exp(s,c,u)}{\text{EVENTS}}
 INITIALIZATION
 е.
END
```

Machines en Event B

```
MACHINE
REFINES
 am
SEES
VARIABLES
INVARIANTS
 I(s, c, u)
THEOREMS
 Q(s, c, u)
 exp(s, c, u)
 INITIALIZATION
 e.
END
```

- $\Gamma(m)$: environment for the machine m defined by the context c and it provides a list of seen axioms Ax(s,c) and a list of seen theorems Th(s,c) for the sets s and constants c.
- $\Gamma(m) \vdash \forall u. \text{Init}(s, c, u) \Rightarrow I(s, c, u)$
- For each event e in E : $\Gamma(m) \vdash \forall u, u'. I(s, c, u) \land BA(e)(u, u') \Rightarrow I(u')$
- For each event e in E: $\Gamma(m) \vdash \forall u. I(s,c,u) \land GRD(e)(s,c,u) \Rightarrow \exists u'. BA(e)(u,u')$
- $\Gamma(m) \vdash \forall u. I(s, c, u) \Rightarrow Q(s, c, u)$
- Generated proof obligations are derived from those conditions.

Checking the well formation of Event-B expressions

- Event-B expressions are contexts, machines, properties, equations, set-theoretical expressions . . .
- e is an Event-B expression and wd(e) is a logical property expressing the well definition of e.
- $\operatorname{wd}(1=2) \stackrel{\triangle}{=} \operatorname{wd}(1) \wedge \operatorname{wd}(2)$
- $\operatorname{wd}(a/b) \stackrel{\triangle}{=} b \neq 0 \land \operatorname{wd}(a) \land \operatorname{wd}(b)$
- $\operatorname{wd}(f(g)) \stackrel{\triangle}{=} g \in \operatorname{dom}(f) \land f \in A \to B$

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PO thm/THM (context)

```
CONTEXTS
EXTENDS
SETS
CONSTANTS
AXIOMS
 Ax(s,c)
THEOREMS
 th_1: P_1(s,c)
 th_n: P_n(s,c)
 th: P(s,c)
END
```

```
\begin{array}{lll} s & \text{seen sets} \\ c & \text{seen constants} \\ Ax(s,c) & \text{seen axioms} \\ Th(s,c) & \text{previous proved theorems} \\ Th(s,c) = \{P_i(s,c)|i \ 1..n\} \\ P(s,c) & \text{property over s and c} \end{array}
```

```
PO th/THM
```

$$Ax(s,c), Th(s,c) \vdash P(s,c)$$

PO thm/THM (machine)

MACHINE

m

VARIABLES

uINVARIANTS

I(s, c, u)THEOREMS

Q(s, c, u)th: P(s, c, u)

END

s seen sets

c seen constants

u variables

Ax(s,c) seen axioms

Th(s,c) seen theorems

I(s, c, u) invariants Q(s, c, u) theorems

P(s,c,u) property over s,c and u

PO th/THM

$$Ax(s,c), Th(s,c), I(s,c,u) \vdash P(s,c,u)$$

PO evt/inv/INV

```
EVENT evt ANY x WHERE G(x, s, c, u) THEN u: |BAP(x, s, c, u, u')| END
```

$$\begin{array}{l} \overline{BA(\mathsf{evt})} \; \widehat{=} \\ \exists x. \left(\begin{array}{c} \wedge \; G(x,s,c,u) \\ \wedge \; BAP(x,s,c,u,u') \end{array} \right) \\ GRD(\mathsf{evt}) \; \widehat{=} \; \; G(x,s,c,u) \\ ACT(\mathsf{evt}) \; \widehat{=} \; BAP(x,s,c,u,u') \end{array}$$

```
\begin{array}{c} s \\ c \\ u \\ Ax(s,c) \\ Th(s,c) \\ I(s,c,u) \\ Q(s,c,u) \\ \text{evt} \\ \times \\ G(x,s,c,u) \\ BAP(x,s,c,u,u') \\ inv:inv(s,c,u') \end{array}
```

```
seen sets
seen constants
variables
seen axioms
seen theorems
invariants
theorems
event name
event parameter
event guard
event before-after predicate
specific modified invariant
```

```
PO evt/inv/INV
```

$$Ax(s,c), Th(s,c), I(s,c,u), G(x,s,c,u), BAP(x,s,c,u,u') \vdash inv(s,c,u')$$

PO evt/act/FIS

```
\begin{array}{c} \text{EVENT evt} \\ \text{ANY } x \text{ WHERE} \\ G(x,s,c,u) \\ \text{THEN} \\ u: |BAP(x,s,c,u,u') \\ \text{END} \end{array}
```

$$\begin{array}{l} BA(\mathsf{evt}) \; \widehat{=} \\ \left(\; \wedge \; G(x,s,c,u) \\ \; \wedge \; BAP(x,s,c,u,u') \; \right) \\ GRD(\mathsf{evt}) \; \widehat{=} \; G(x,s,c,u) \\ ACT(\mathsf{evt}) \; \widehat{=} \\ BAP(x,s,c,u,u') \end{array}$$

```
seen sets
s
                    seen constants
                     variables
u
Ax(s,c)
                    seen axioms
Th(s,c)
                    seen theorems
I(s,c,u)
                    invariants
Q(s,c,u)
                     theorems
                    event name
evt
                    event parameter
G(x, s, c, u) event guard
BAP(x, s, c, u, u') event before-after predicate
```

PO evt/act/FIS

$$Ax(s,c), Th(s,c), I(s,c,u), G(x,s,c,u), \vdash \exists u'.BAP(x,s,c,u,u')$$

Current Summary

- 1 Overview of machines, contexts and proof obligations
- Proof Obligations for Contexts and Machines
- 3 Proof Obligations for Refinement

PO evt/grd/GRD

```
EVENT ae
 ANY x WHERE
   G(x,s,c,u)
 THEN
   u: |ABAP(x, s, c, u, u')|
 END
EVENT ce
 REFINES
    a.e.
 ANY u WHERE
   H(y, s, c, v)
 WITH
   x:W(x,y,s,c,v)
 THEN
   v: |CBAP(y, s, c, v, v')|
 END
```

```
c
u, v
Ax(s,c)
Th(s,c)
I(s,c,u)
J(s,c,u,v)
Q(s,c,u), R(s,c,u,v)
ae. ce
x,y
G(x,s,c,u)
H(y, s, c, v)
ABAP(x, s, c, u, u')
CBAP(x, s, c, u, u')
W(x,y,s,c,v)
```

```
seen sets
seen constants
abstract and concrete variables
seen axioms
seen theorems
abstract invariants
concrete invariants
abstract and concrete theorems
abstract and concrete event name
event parameters
abstract event guard
concrete event guard
abstract event before-after predic
concrete event before-after predic
witness predicate
```

PO evt/grd/GRD

$$Ax(s,c), Th(s,c), I(s,c,u), J(s,c,u,v), W(x,y,s,c,v), H(y,s,c,v), \vdash G(x,s,c,u,u')$$

PO evt/act/SIM

```
seen sets
                            s
EVENT ae
                            c
                                                      seen constants
 ANY x WHERE
                                                      abstract and concrete variables
                            u, v
   G(x, s, c, u)
                            Ax(s,c)
                                                      seen axioms
 THEN
   u: |ABAP(x, s, c, u, u')|
                            Th(s,c)
                                                      seen theorems
 END
                            I(s,c,u)
                                                      abstract invariants
                            J(s,c,u,v)
                                                      concrete invariants
EVENT ce
                            Q(s,c,u), R(s,c,u,v)
                                                      abstract and concrete theorems
 REFINES
   ae
                                                      abstract and concrete event name
                            ae, ce
 ANY y WHERE
                            X, y
                                                      event parameters
   H(y, s, c, v)
 WITH
                            G(x,s,c,u)
                                                      abstract event guard
   x: WP(x, y, s, c, v)
                            H(y,s,c,v)
                                                      concrete event guard
   u': WV(y, u', s, c, v)
                            ABAP(x, s, c, u, u')
                                                      abstract event before-after predic
 THEN
   v: |CBAP(y, s, c, v, v')|
                            CBAP(x, s, c, u, u')
                                                      concrete event before-after predic
 END
                            WP(x, y, s, c, v)
                                                      witness parameter predicate
                            WV(y, u', s, c, v)
                                                      witness variable predicate
```

$$\begin{cases} \textbf{PO} \ \text{evt/act/SIM} \\ \begin{pmatrix} Ax(s,c), Th(s,c), I(s,c,u), J(s,c,u,v) \\ WP(x,y,s,c,v), WV(y,u',s,c,v) \\ H(y,s,c,v), CBAP(y,s,c,v,v') \end{pmatrix} \vdash ABAP(x,s,c,u,u') \\ \text{Master-Informatique 2025-2036 (Dominique Mety)} \end{cases}$$

PO evt/act/SIM

```
EVENT ae

ANY x WHERE

G(x, s, c, u)

THEN

u: |BAP(x, s, c, u, u')|

END

...

VARIANT

exp(s, c, u)
```

```
s
c
u, v
Ax(s,c)
Th(s,c)
I(s,c,u)
J(s,c,u,v)
Q(s,c,u), R(s,c,u,v)
evt, ce
Х
G(x, s, c, u)
BAP(x, s, c, u, u')
exp(s, c, u)
```

seen sets seen constants abstract and concrete variables seen axioms seen theorems abstract invariants concrete invariants abstract and concrete theorems event name event parameters abstract event guard event before-after predicate aritthmetic expression

PO evt/NAT

$$Ax(s,c), Th(s,c), I(s,c,u), J(s,c,u,v), G(x,s,c,u) \vdash exp(s,c,u) \in \mathbb{N}$$

PO evt/act/SIM

```
EVENT ae

ANY x WHERE

G(x, s, c, u)

THEN

u: |BAP(x, s, c, u, u')|

END

...

VARIANT

exp(s, c, u)
```

```
s
c
u, v
Ax(s,c)
Th(s,c)
I(s, c, u)
J(s,c,u,v)
Q(s,c,u), R(s,c,u,v)
evt, ce
Х
G(x,s,c,u)
BAP(x, s, c, u, u')
setexp(s, c, u)
```

seen sets seen constants abstract and concrete variables seen axioms seen theorems abstract invariants concrete invariants abstract and concrete theorems event name event parameters abstract event guard event before-after predicate set expression

PO evt/NAT
$$Ax(s,c)$$
, $Th(s,c)$, $I(s,c,u)$, $J(s,c,u,v)$, $G(x,s,c,u)$ \vdash $finite(setexp(s,c,u)$

PO evt/VAR

```
EVENT ae

ANY x WHERE

G(x, s, c, u)

THEN

u: |BAP(x, s, c, u, u')

END

...

VARIANT

exp(s, c, u)
```

```
s
c
u, v
Ax(s,c)
Th(s,c)
I(s,c,u)
J(s,c,u,v)
Q(s,c,u), R(s,c,u,v)
evt, ce
G(x, s, c, u)
BAP(x, s, c, u, u')
exp(s, c, u)
```

seen sets seen constants abstract and concrete variables seen axioms seen theorems abstract invariants concrete invariants abstract and concrete theorems event name event parameters abstract event guard event before-after predicate aritthmetic expression

PO evt/VAR

 $Ax(s,c), Th(s,c), I(s,c,u), J(s,c,u,v), G(x,s,c,u), BAP(x,s,c,u,u') \vdash exp(s,c,u') < exp(s,c,u)$

PO evt/VAR

```
EVENT ae

ANY x WHERE

G(x, s, c, u)

THEN

u: |BAP(x, s, c, u, u')

...

VARIANT

setexp(s, c, u)
```

```
s
c
u, v
Ax(s,c)
Th(s,c)
I(s,c,u)
J(s,c,u,v)
Q(s,c,u), R(s,c,u,v)
evt, ce
G(x,s,c,u)
BAP(x, s, c, u, u')
setexp(s, c, u)
```

seen sets seen constants abstract and concrete variables seen axioms seen theorems abstract invariants concrete invariants abstract and concrete theorems event name event parameters abstract event guard event before-after predicate set-theoretic expression

PO evt/VAR

 $Ax(s,c), Th(s,c), I(s,c,u), J(s,c,u,v), G(x,s,c,u), BAP(x,s,c,u,u') \vdash setexp(s,c,u') \subset setexp(s,c,u)$

PO evt/x/WFIS

```
EVENT ae  \begin{array}{c} \text{ANY } x \text{ WHERE} \\ G(x,s,c,u) \\ \text{THEN} \\ u:|ABAP(x,s,c,u,u') \\ \text{END} \end{array}
```

```
EVENT ce REFINES ae ANY y WHERE H(y, s, c, v) WITH x: WP(x, y, s, c, v) u': WV(y, u', s, c, v) THEN v: |CBAP(y, s, c, v, v') END
```

```
s
c
u, v
Ax(s,c)
Th(s,c)
I(s,c,u)
J(s,c,u,v)
Q(s,c,u), R(s,c,u,v)
ae, ce
X, y
G(x,s,c,u)
H(y,s,c,v)
ABAP(x, s, c, u, u')
CBAP(x, s, c, u, u')
WP(x, y, s, c, v)
WV(y, u', s, c, v)
```

seen sets seen constants abstract and concrete variables seen axioms seen theorems abstract invariants concrete invariants abstract and concrete theorems abstract and concrete event name event parameters abstract event guard concrete event guard abstract event before-after predic concrete event before-after predic witness parameter predicate witness variable predicate

PO evt/x/WFIS

$$Ax(s,c), Th(s,c), I(s,c,u), J(s,c,u,v), H(y,s,c,v) \vdash \exists x.WP(x,y,s,c,v)$$