'Avoiding Programming' for Safety Critical Systems

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In the last Session ...

- We showed how errors can be introduced by the programming activity.

- We showed some examples of attempts to improve programming languages.

- We suggested that Event-B could help.

What can 'we' do?

- With Event-B tools (+ Tasking Event-B)
  - we can generate code automatically.
  - formal modelling helps to highlight/remove systematic errors.

- Using automatic code generation we
  - do less coding.
  - encourage re-use (using code templates).

How to do this ...

- As you know, Event-B is modelling, not programming.
  - Developers focus on the design, not code.

- To produce source code, we add 'extra' information to Event-B.
  … and still we need a trusted compiler.
  … and, ideally, 'certify' the translator.

- We could still verify the code with JML, SPARKAda etc

Targets for Translation ...

Targets: Ada, OpenMP C, FMI C, Java ....

- The approach is suitable for
  - single threaded implementations.
  - multi-threaded implementations (using decomposition).
  - not currently OO, but could be done.

Current Focus is on embedded systems.

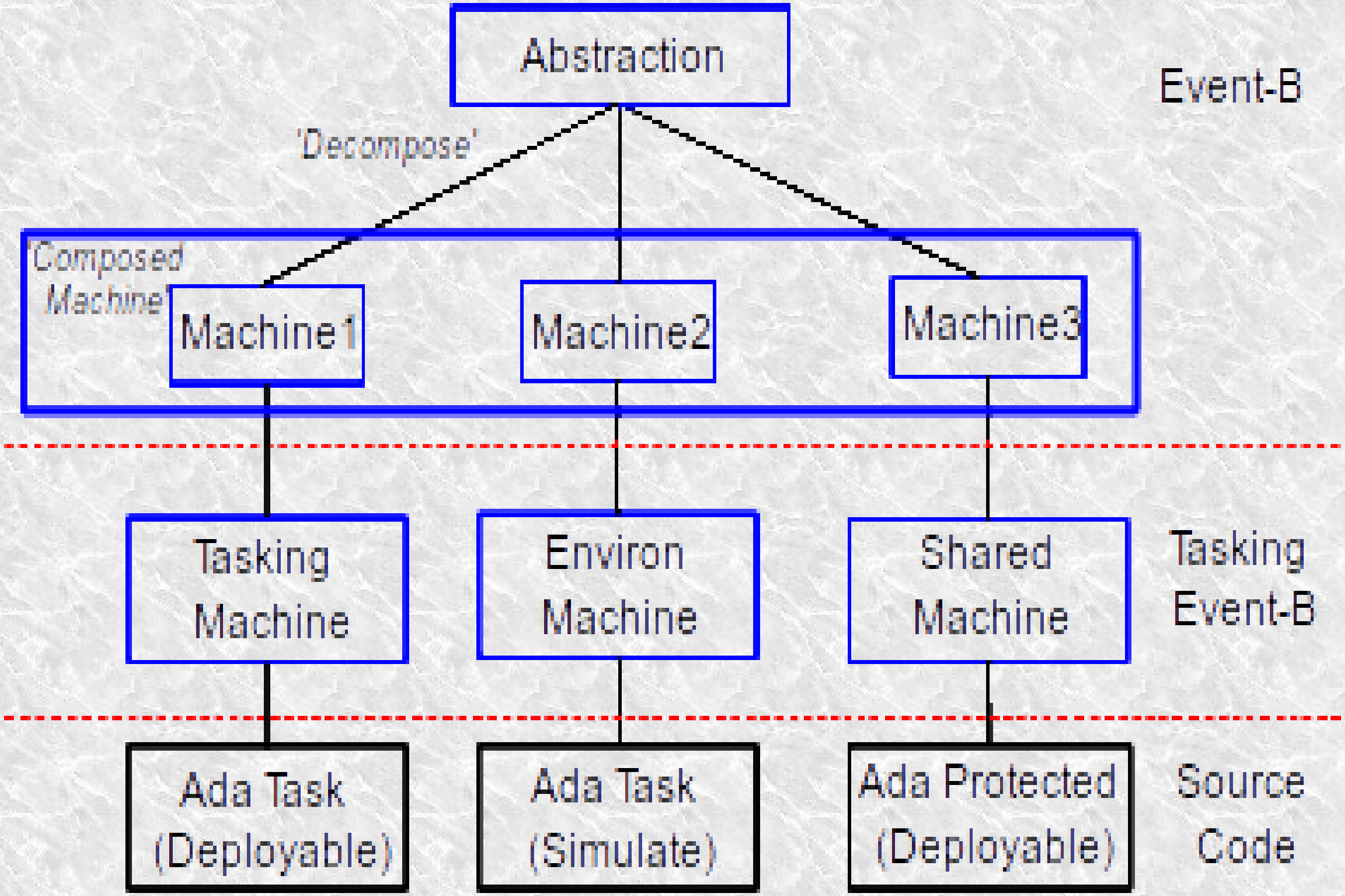
- 'Implementable' controller code
- Environment simulation.

Event-B at the implementation level

- Tasking Event-B
  - Event-B models:
    - Controller Tasks (AutoTask Machine).
    - Shared Protected Objects (Shared Machine).
    - Environment Tasks (Environ Machine).

- Use Decomposition to partition the system.
  - Shared Event Style.
  - Shared Events model communication, between
    - Controller tasks and Environment tasks.
    - Controller tasks and Protected Objects.
    - Environment tasks and Protected Objects.

Where Tasking Event-B Fits in.



Abstraction

Event-B

'Decompose'

'Composed Machine'

Machine1

Machine2

Machine3

Tasking Machine

Environ Machine

Shared Machine

Tasking Event-B

Ada Task (Deployable)

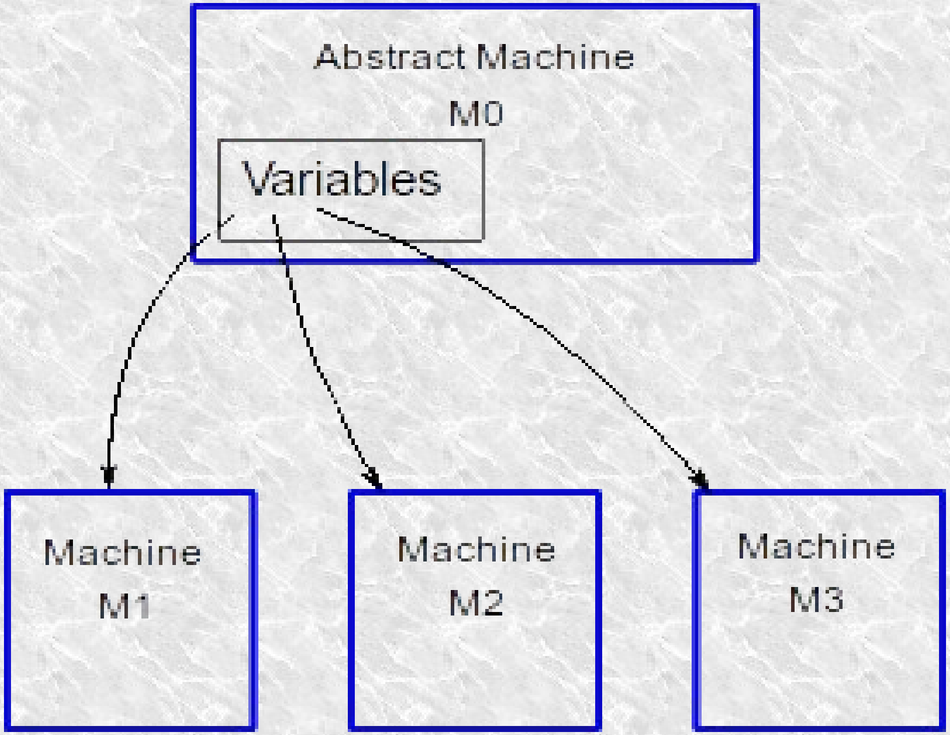
Ada Task (Simulate)

Ada Protected (Deployable)

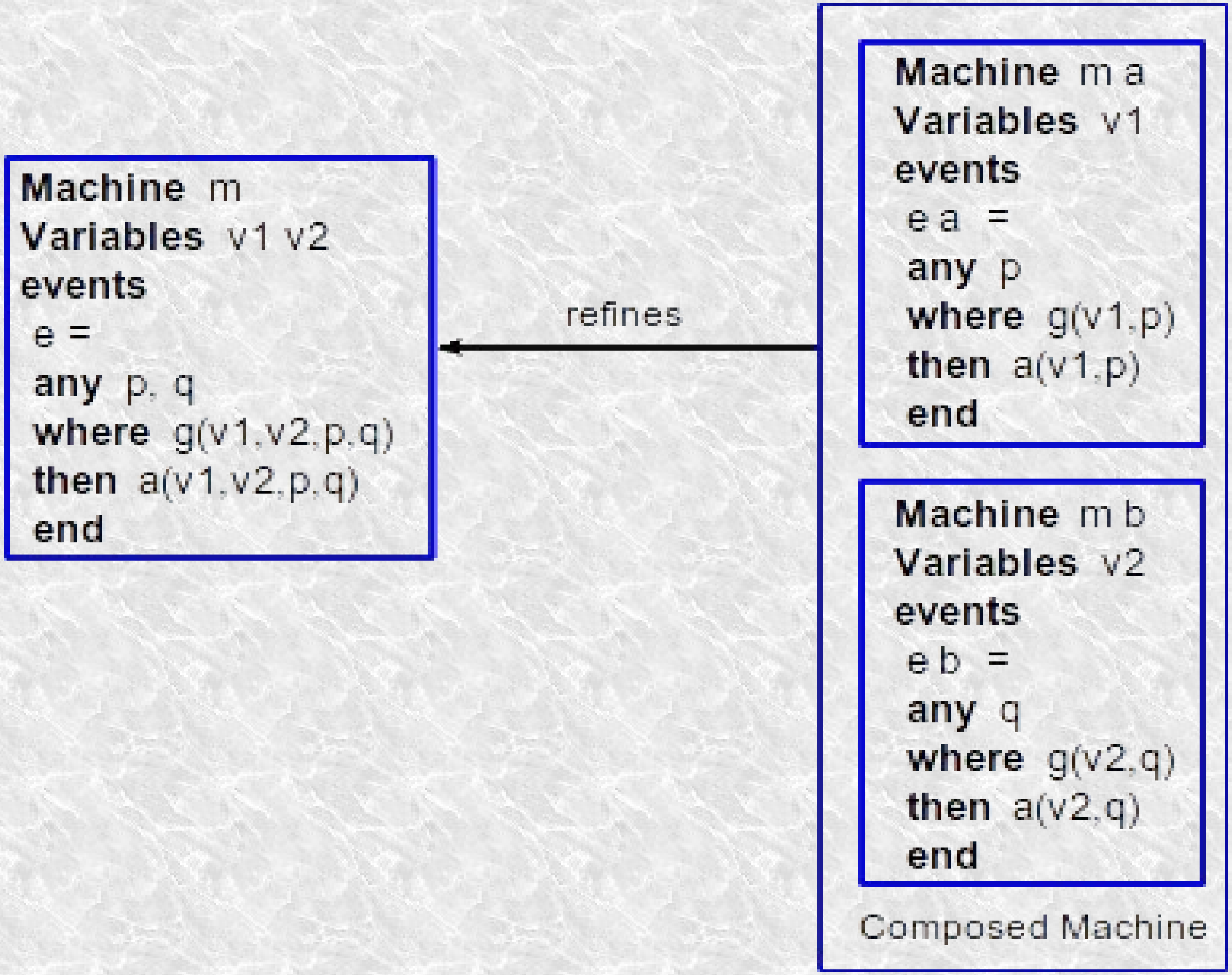
Source Code

Shared Event Decomposition

Tool-driven decomposition



Event 'Synchronization'



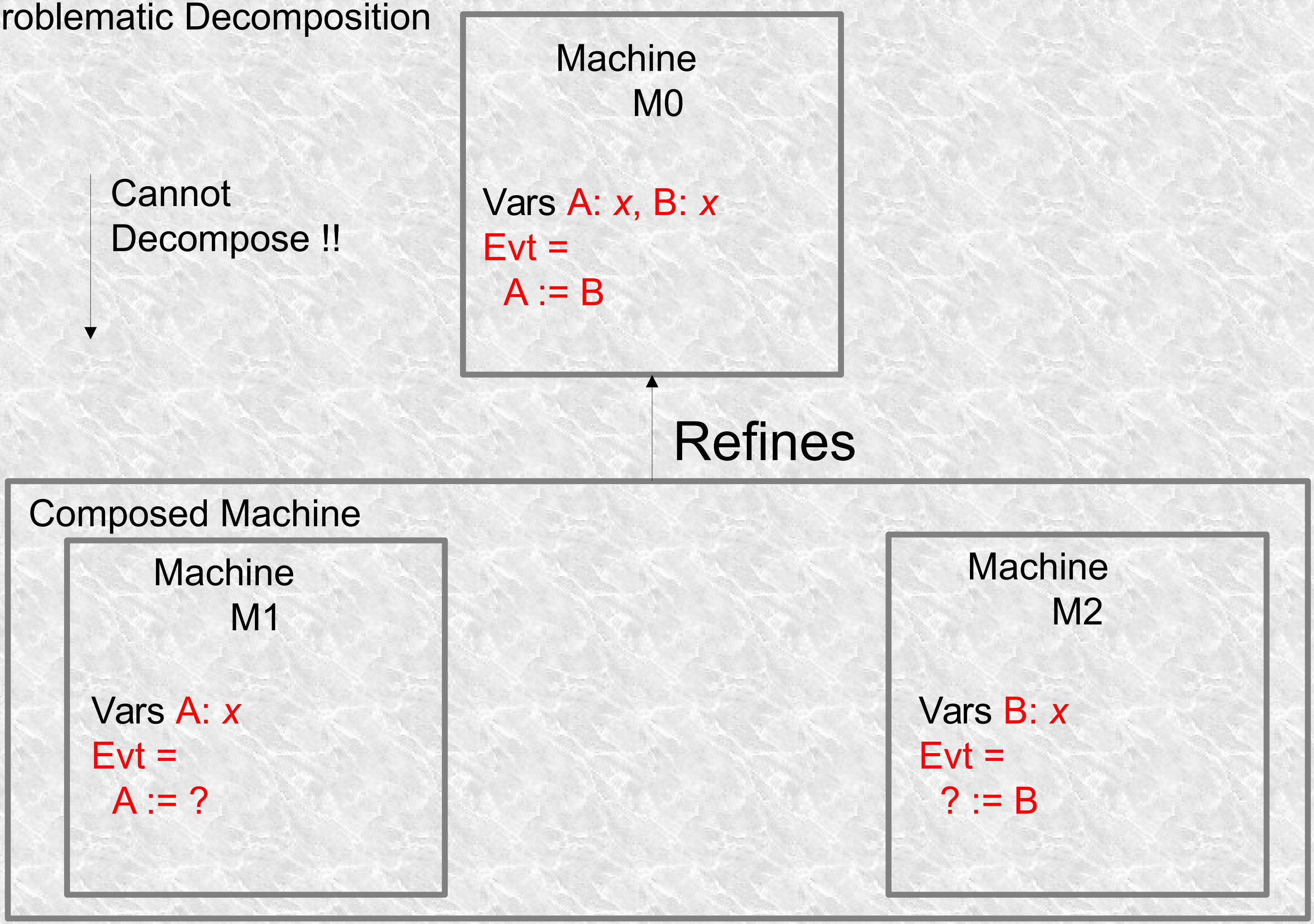
```
Machine  m
Variables  v1 v2
events
 e =
 any  p, q
 where  g(v1,v2,p,q)
 then  a(v1,v2,p,q)
 end
```

```
Machine  m a
Variables  v1
events
 e a  =
 any  p
 where  g(v1,p)
 then  a(v1,p)
 end
```

```
Machine  m b
Variables  v2
events
 e b  =
 any  q
 where  g(v2,q)
 then  a(v2,q)
 end
```

Preparing for Decomposition

A Problematic Decomposition



Machine M0

Vars A: *x*, B: *x*

Evt =

A := B

Cannot Decompose !!

Refines

Composed Machine

Machine M1

Vars A: *x*

Evt =

A := ?

Machine M2

Vars B: *x*

Evt =

? := B

Preparing for Decomposition

Introduce Parameters

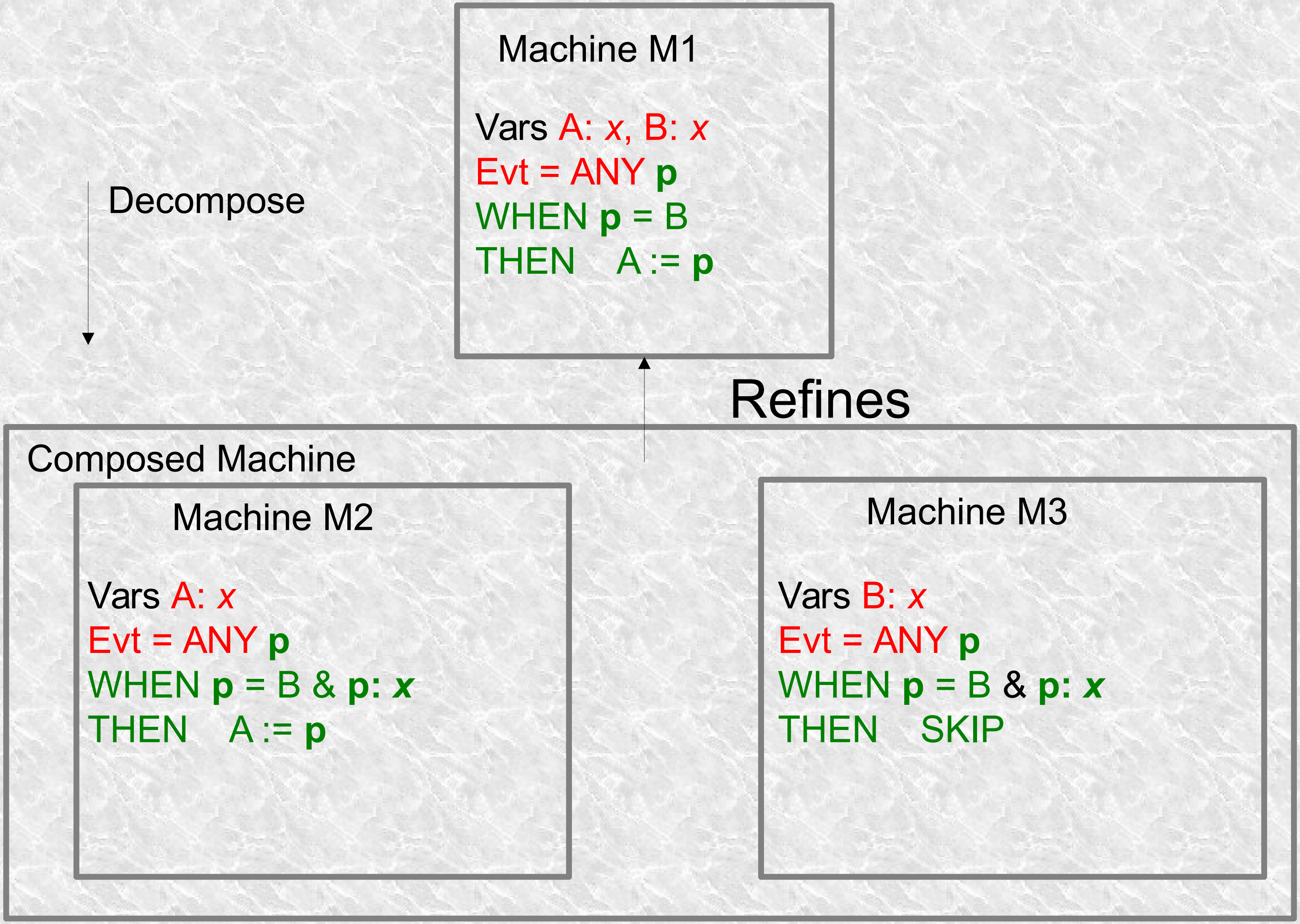
Machine M1

Refines M0

Vars A: *x*, B: *x*
Evt = ANY **p**
WHEN **p** = B
THEN A := **p**

Was A := B

A Model of Communication



Machine M1

Vars A: *x*, B: *x*
Evt = ANY **p**
WHEN **p** = B
THEN A := **p**

Decompose

Refines

Composed Machine

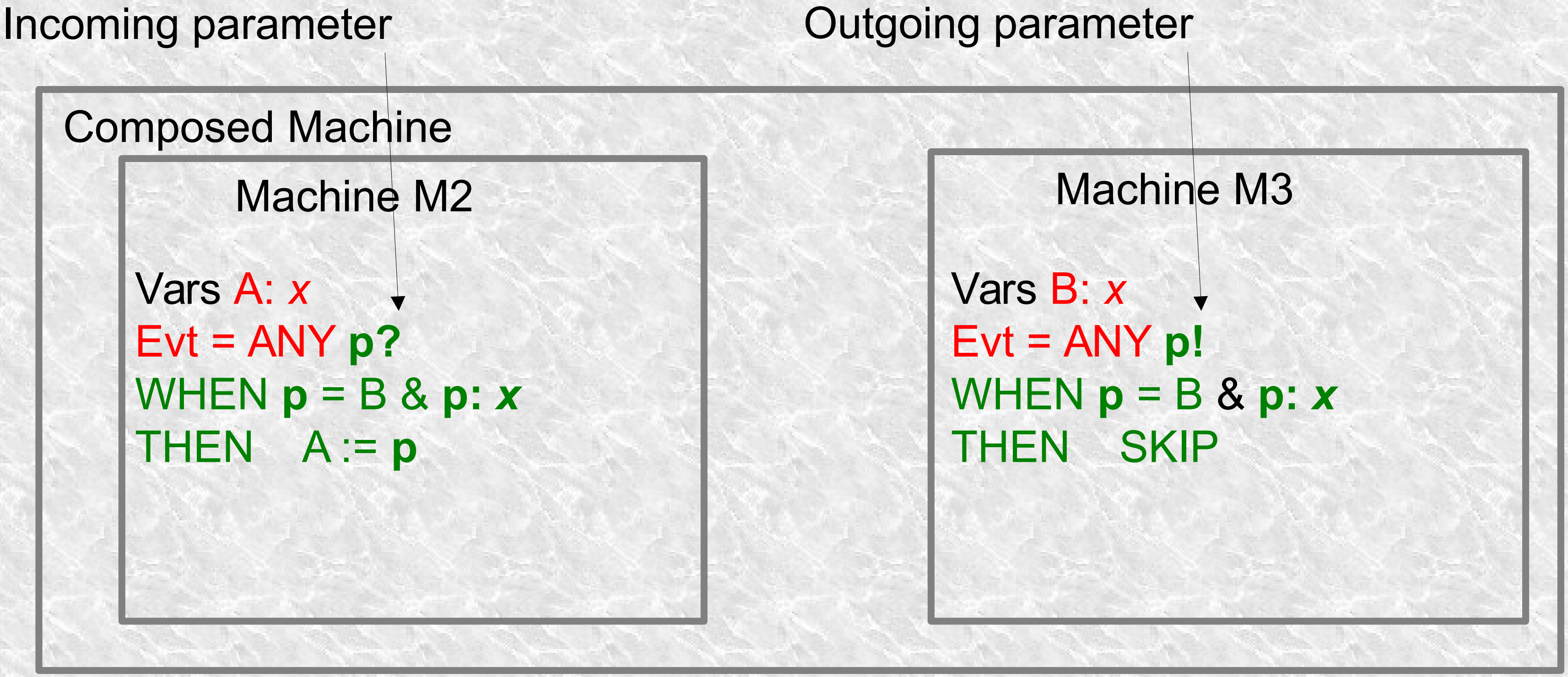
Machine M2

Vars A: *x*
Evt = ANY **p**
WHEN **p** = B & **p: *x***
THEN A := **p**

Machine M3

Vars B: *x*
Evt = ANY **p**
WHEN **p** = B & **p: *x***
THEN SKIP

A Model of Communication



Incoming parameter

Outgoing parameter

Composed Machine

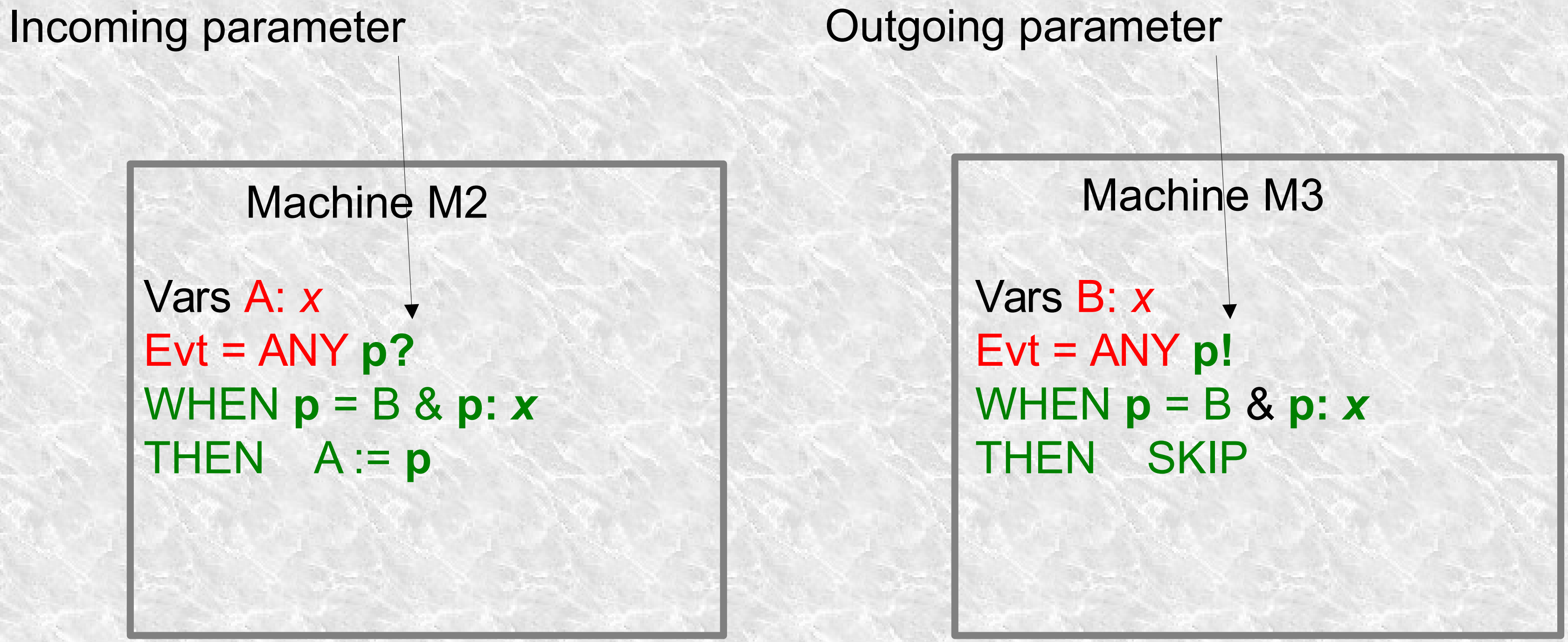
Machine M2

Vars A: *x*
Evt = ANY **p?**
WHEN **p** = B & **p:** ***x***
THEN A := **p**

Machine M3

Vars B: *x*
Evt = ANY **p!**
WHEN **p** = B & **p:** ***x***
THEN SKIP

An Implementation of the Communication



Incoming parameter

Machine M2

Vars A: *x*
Evt = ANY **p?**
WHEN **p** = B & **p:** ***x***
THEN A := **p**

Outgoing parameter

Machine M3

Vars B: *x*
Evt = ANY **p!**
WHEN **p** = B & **p:** ***x***
THEN SKIP

subroutine

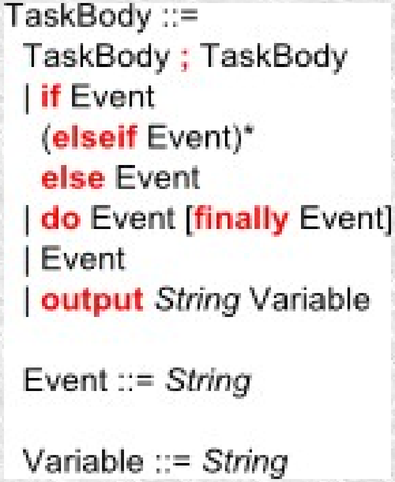
```
Evt(p: x){
  A := p
}
```

call

```
Evt(B);
```

Tasking Event-B

Adds 'Tasking' Implementation Information to Event-B



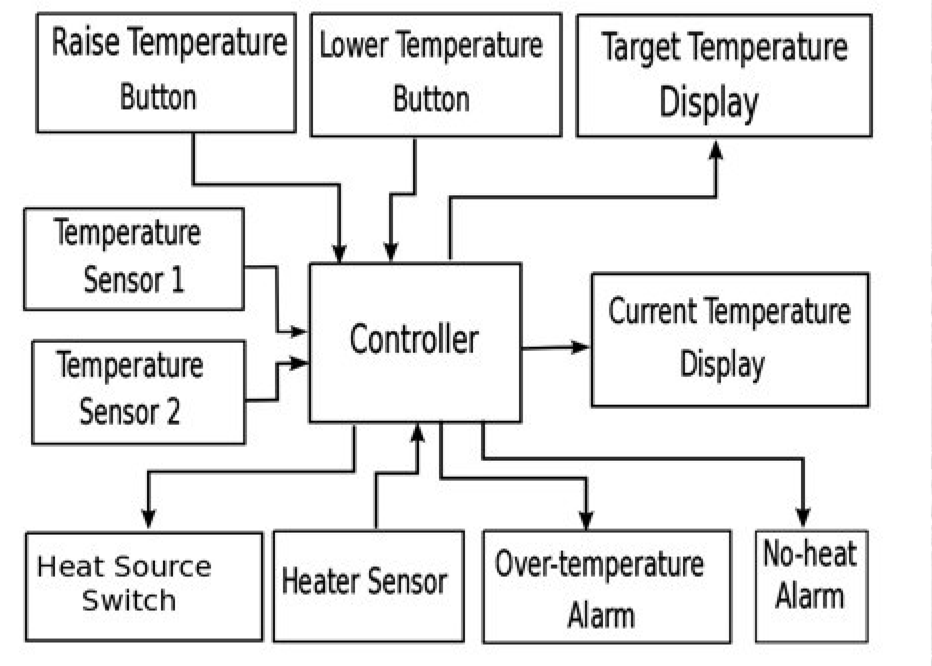
```
TaskBody ::=
  TaskBody ; TaskBody
  | if Event
    (elseif Event)*
    else Event
  | do Event [finally Event]
  | Event
  | output String Variable

  Event ::= String

  Variable ::= String
```

Task Body Syntax:

- Allows use of Branches, Sequence and Loops.
- Has an 'Output' to console.

Heater Controller Example

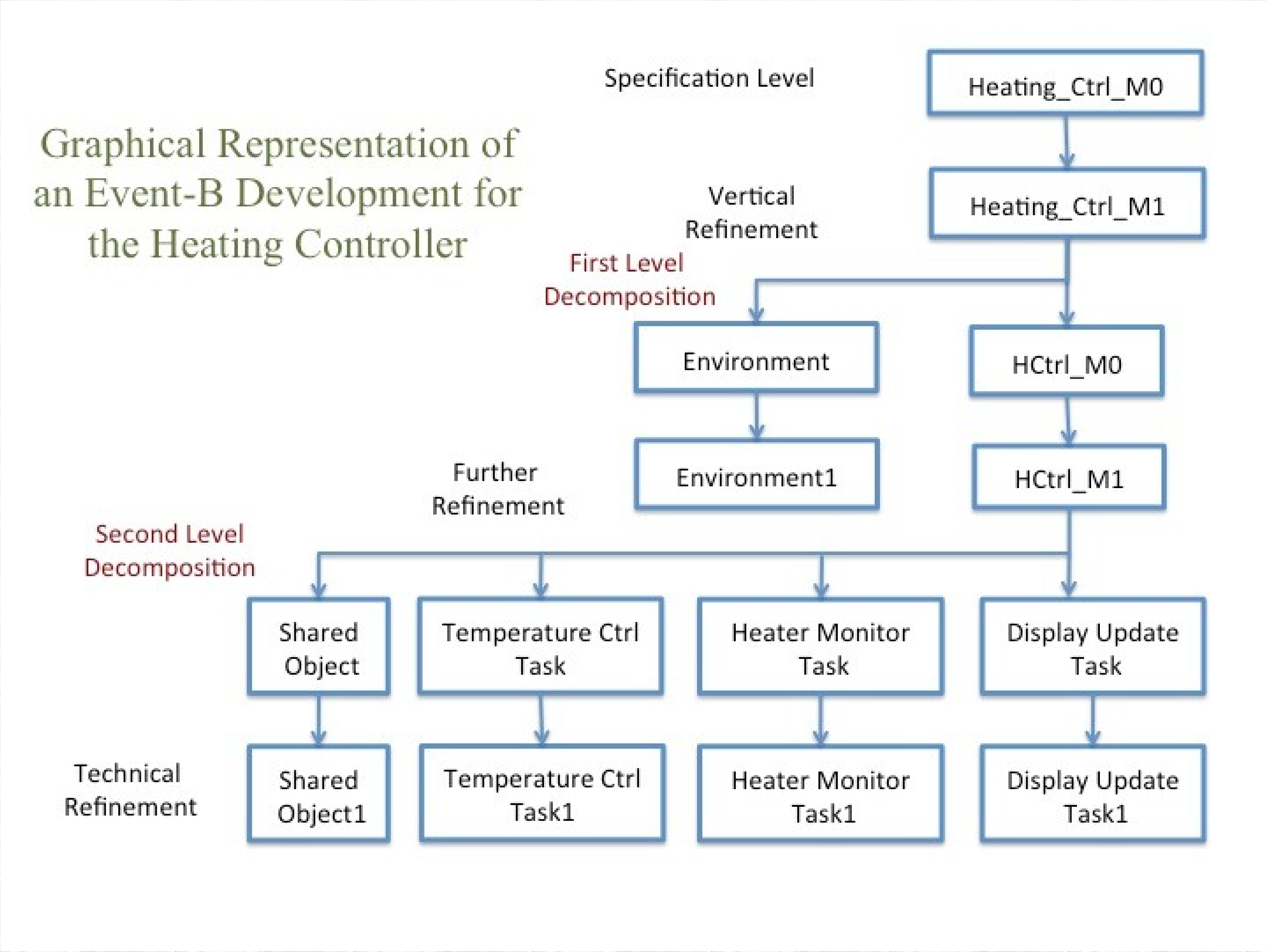
Controller vs Environment



This example is from the Tasking Event-B wiki tutorial.

Heater Controller Example

Another View

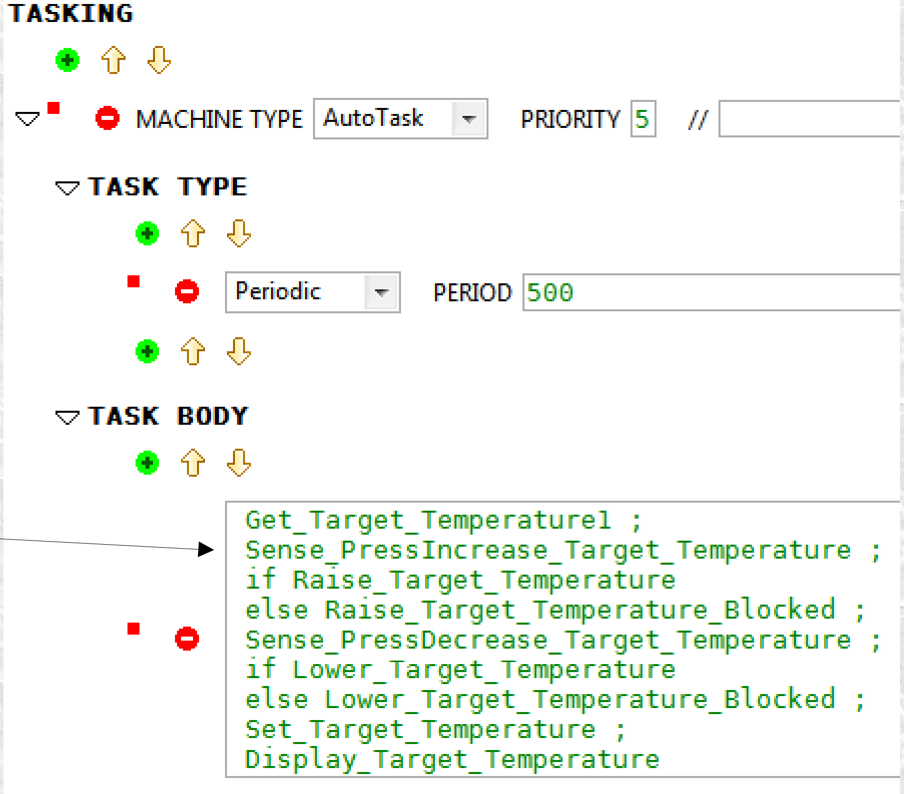


Graphical Representation of an Event-B Development for the Heating Controller

A Tasking Machine

Implementation level Specification

AutoTasks Machines and Environ Machines



TASKING

MACHINE TYPE AutoTask PRIORITY 5 //

TASK TYPE

Periodic PERIOD 500

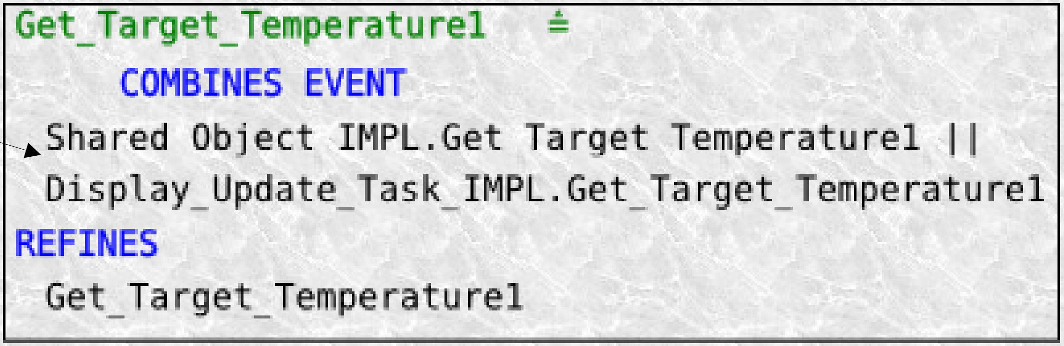
TASK BODY

```
Get_Target_Temperaturel ;
Sense_PressIncrease_Target_Temperature ;
if Raise_Target_Temperature
else Raise_Target_Temperature_Blocked ;
Sense_PressDecrease_Target_Temperature ;
if Lower_Target_Temperature
else Lower_Target_Temperature_Blocked ;
Set_Target_Temperature ;
Display_Target_Temperature
```

Events:

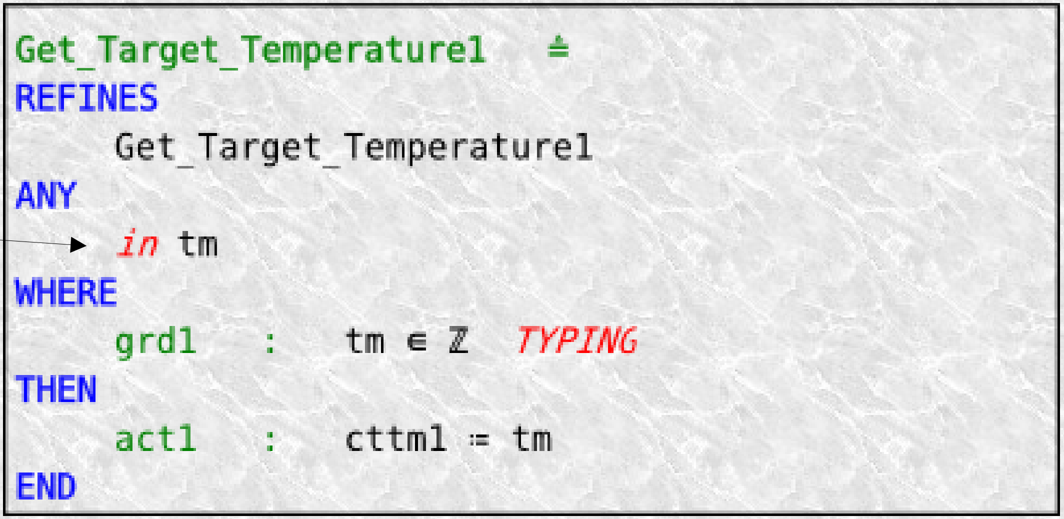
Used in a
Sequence,
Branch,
Loop,
Output

'in'/ 'out' annotations



```
Get_Target_Temperature1  ≙
     COMBINES EVENT
 Shared Object IMPL.Get Target Temperature1 ||
 Display_Update_Task_IMPL.Get_Target_Temperature1
REFINES
 Get_Target_Temperature1
```

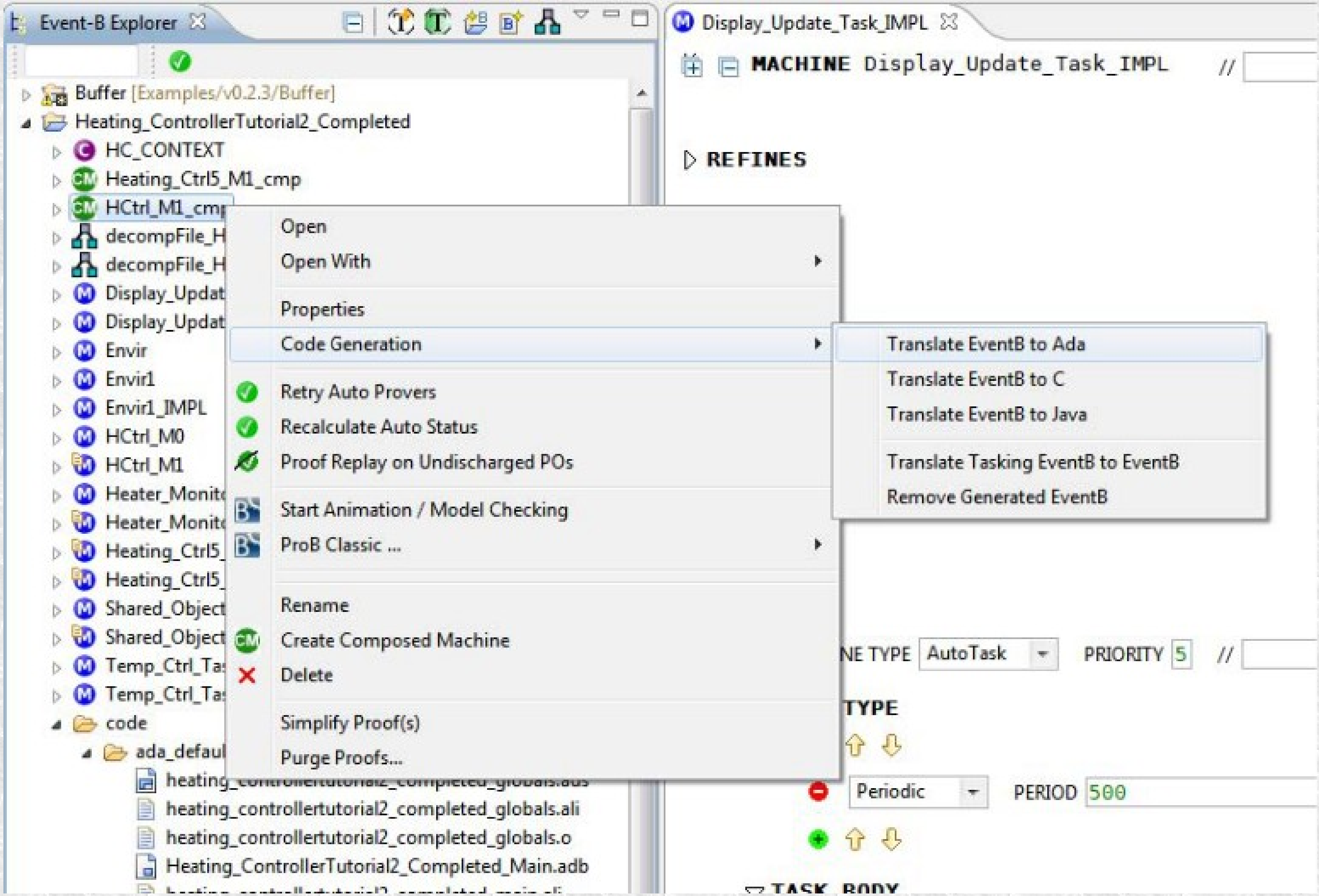
synchronization



```
Get_Target_Temperature1  ≙
REFINES
     Get_Target_Temperature1
ANY
     in tm
WHERE
     grd1  :  tm ∈ ℤ  TYPING
THEN
     act1  :  cttm1 ≔ tm
END
```

Parameter direction

Code Generation



MACHINE Display_Update_Task_IMPL //

NE TYPE AutoTask PRIORITY 5 //

Periodic PERIOD 500

Generated Code

In the Display Task:

```
Shared_Object: Shared_Object_IMPL; ...
task body Display_Update_Task_IMPL is
  cttm1 : Integer := 0;
  period: constant Time_Span := To_Time_Span(0.5);
  nextTime: Time := clock + period;
  begin
    loop
      delay until nextTime;
           Shared_Object.Get_Temperature1(cttm1);
  ...
```

In the Protected Object:

```
procedure Get_Temperature1(tm:  out Integer) is
  begin
    tm := cttm;
  end Get_Temperature1;
```

Types and Translations.

So far,

- translations for built-in Event-B types are restricted to INTs and BOOLs.
- and Event-B INTs are not bounded (wrap-around in implementations?).
- we don't even have arrays as standard in Event-B.

Extending Event-B:
with New Types, and Translations.

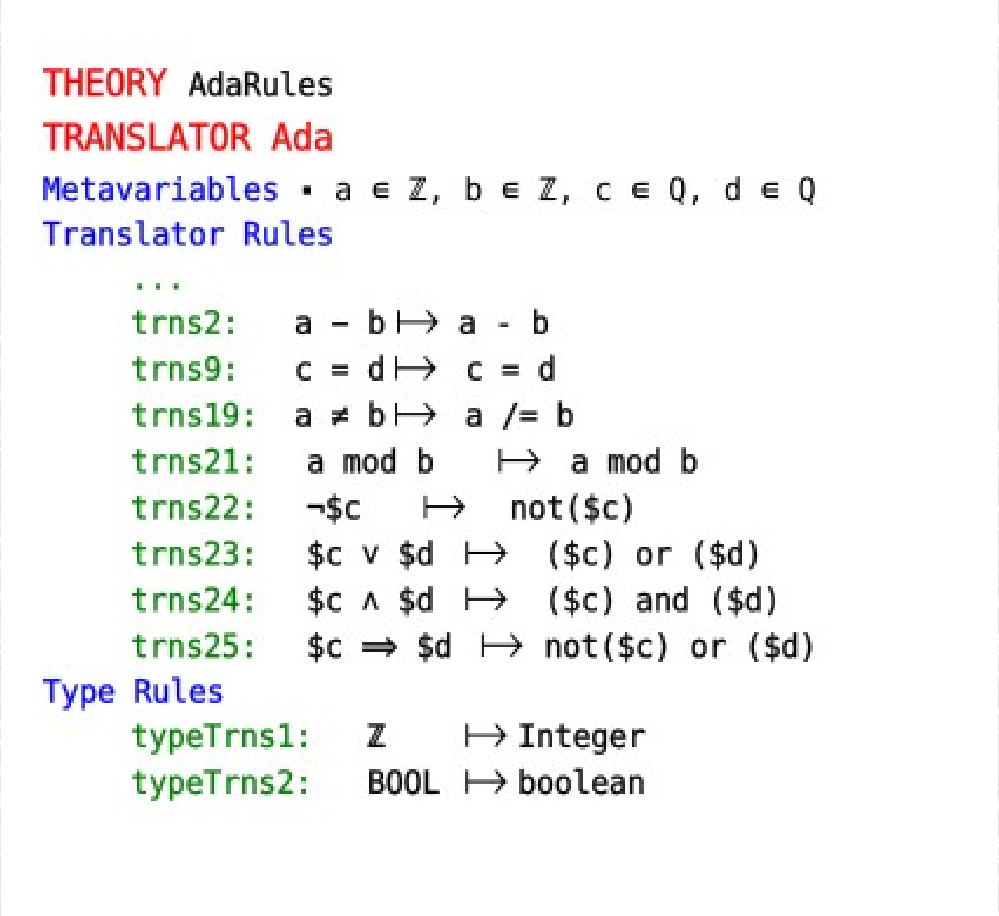
- Use the Theory Plug-in

- Theories are used to define new
  - datatypes
  - operators
  - rewrite rules
  - inference rules

We also use it for code generation,
- to translate predicates and expressions.

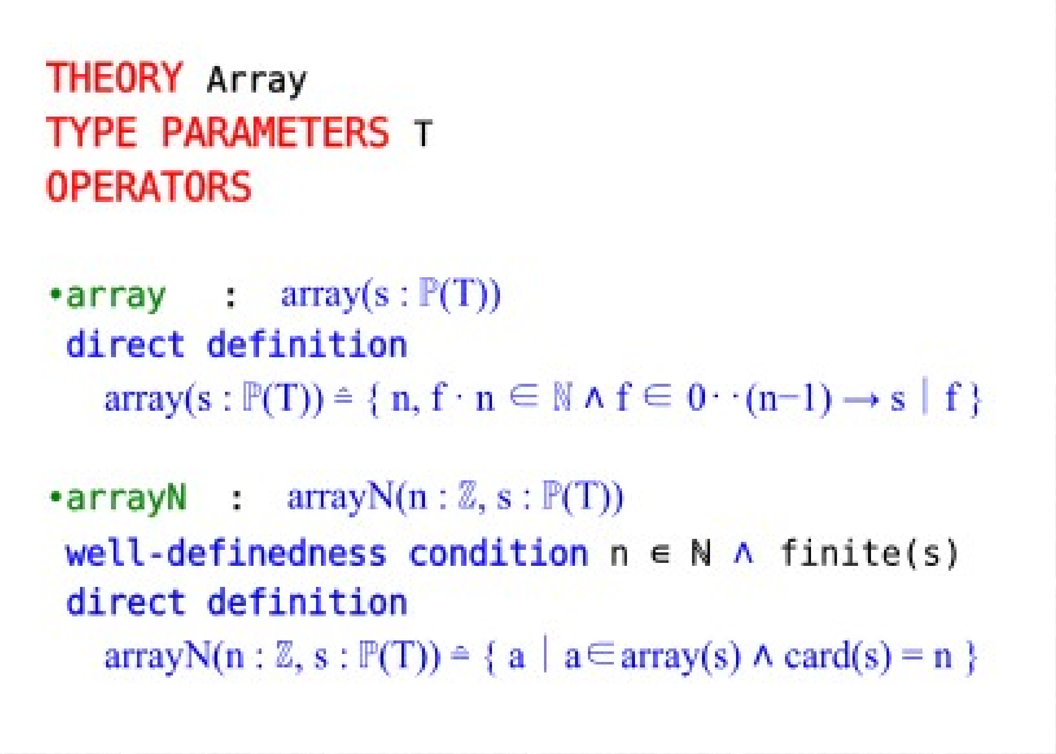
Defining a Translator:

From Event-B to a 'new' Target Language



```
THEORY AdaRules
TRANSLATOR Ada
Metavariables • a ∈ ℤ, b ∈ ℤ, c ∈ Q, d ∈ Q
Translator Rules
     ...
     trns2:   a − b ↦ a - b
     trns9:   c = d ↦  c = d
     trns19:  a ≠ b ↦  a /= b
     trns21:   a mod b   ↦  a mod b
     trns22:   ¬$c    ↦   not($c)
     trns23:   $c ∨ $d  ↦   ($c) or ($d)
     trns24:   $c ∧ $d  ↦   ($c) and ($d)
     trns25:   $c ⇒ $d  ↦ not($c) or ($d)
Type Rules
     typeTrns1:   ℤ    ↦ Integer
     typeTrns2:   BOOL ↦ boolean
```

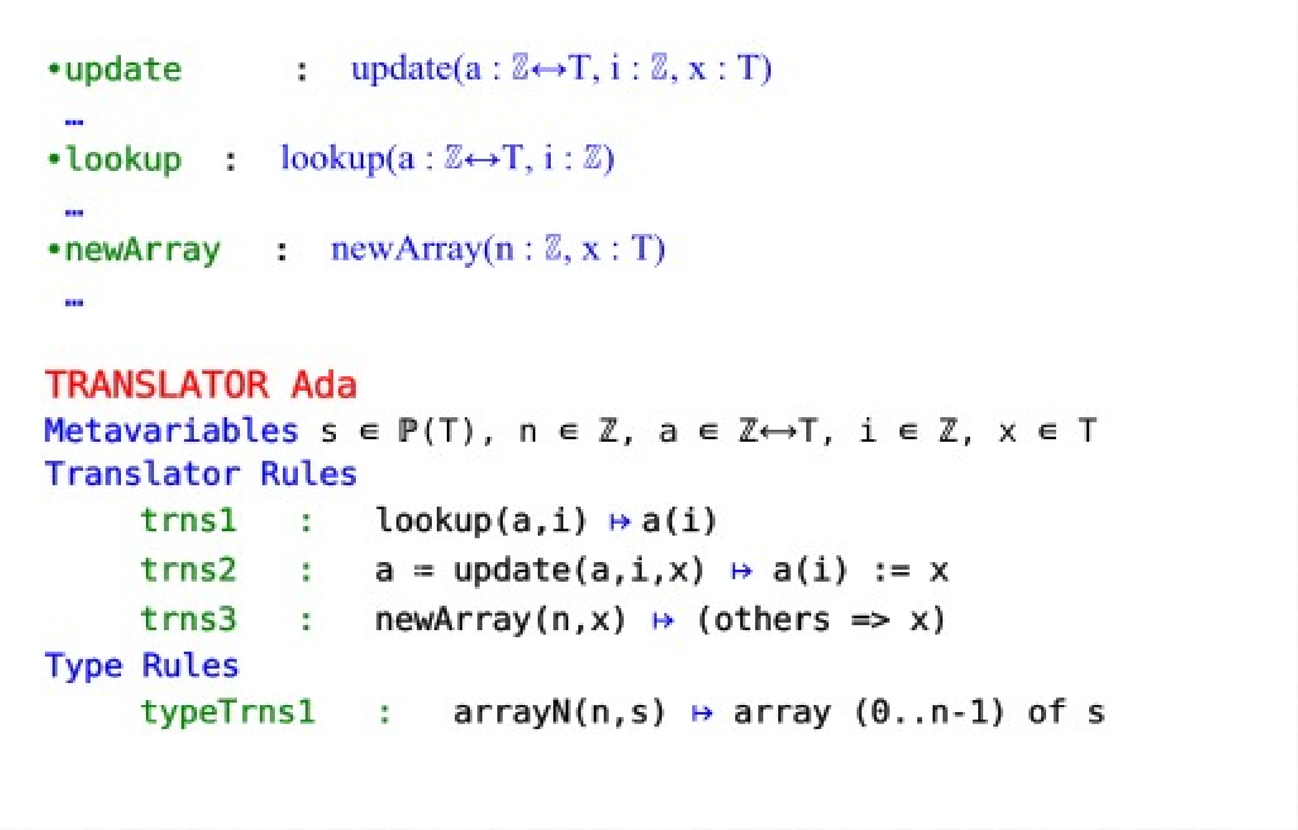
Adding new Types



```
THEORY Array
TYPE PARAMETERS T
OPERATORS

•array   :   array(s : ℙ(T))
 direct definition
   array(s : ℙ(T)) ≙ { n, f · n ∈ ℕ ∧ f ∈ 0··(n−1) → s | f }

•arrayN   :   arrayN(n : ℤ, s : ℙ(T))
 well-definedness condition n ∈ ℕ ∧ finite(s)
 direct definition
   arrayN(n : ℤ, s : ℙ(T)) ≙ { a | a∈array(s) ∧ card(s) = n }
```

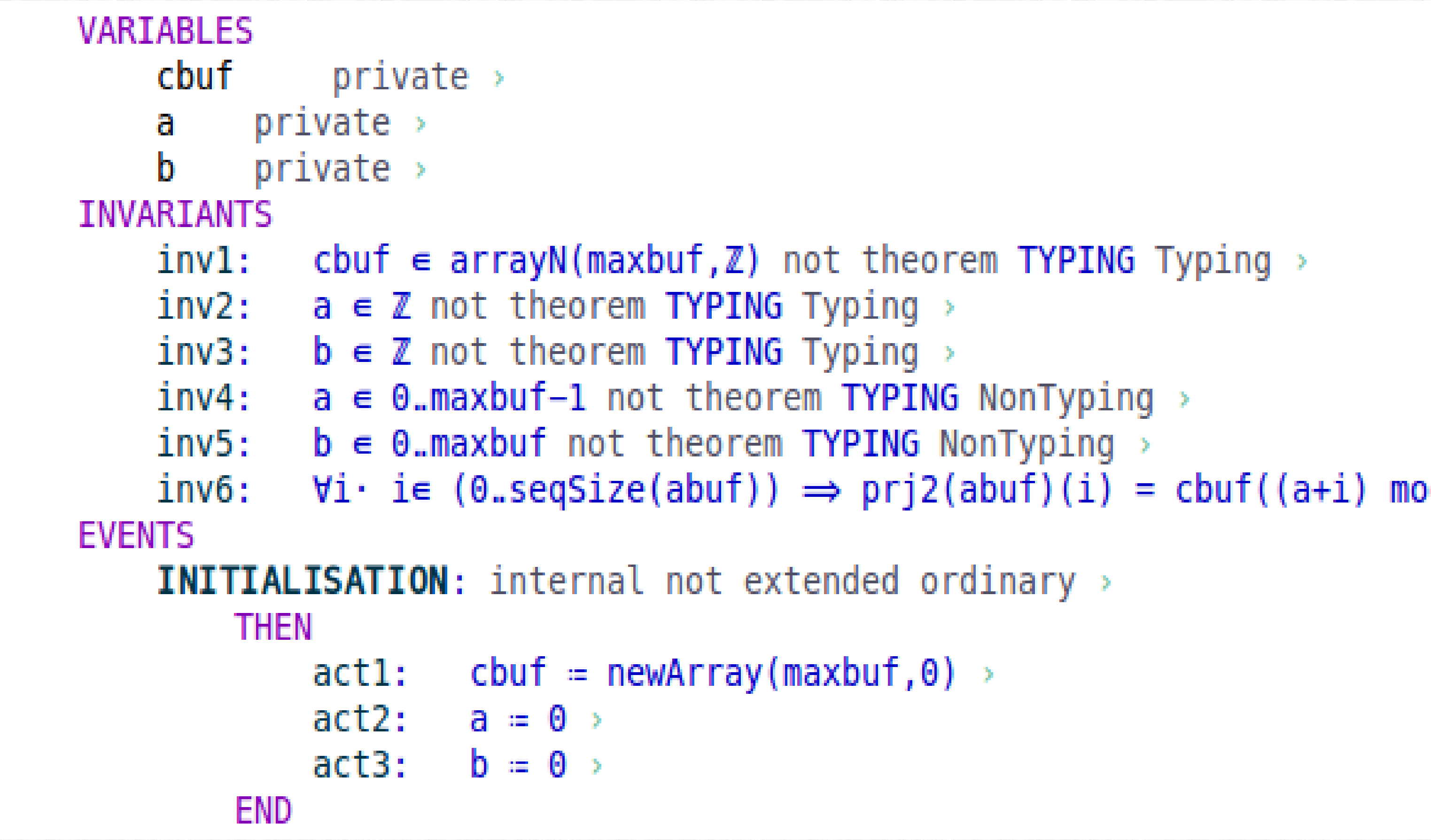
Adding a Translation for the new Type

(In a theory)



```
•update      :   update(a : ℤ↔T, i : ℤ, x : T)
 …
•lookup   :   lookup(a : ℤ↔T, i : ℤ)
 …
•newArray   :   newArray(n : ℤ, x : T)
 …

TRANSLATOR Ada
Metavariables s ∈ ℙ(T), n ∈ ℤ, a ∈ ℤ↔T, i ∈ ℤ, x ∈ T
Translator Rules
     trns1   :   lookup(a,i) ↦ a(i)
     trns2   :   a = update(a,i,x) ↦ a(i) := x
     trns3   :   newArray(n,x) ↦ (others => x)
Type Rules
     typeTrns1   :   arrayN(n,s) ↦ array (0..n-1) of s
```

Using a new Type



```
VARIABLES
    cbuf     private ›
    a    private ›
    b    private ›
INVARIANTS
    inv1:   cbuf ∈ arrayN(maxbuf,ℤ) not theorem TYPING Typing ›
    inv2:   a ∈ ℤ not theorem TYPING Typing ›
    inv3:   b ∈ ℤ not theorem TYPING Typing ›
    inv4:   a ∈ 0‥maxbuf−1 not theorem TYPING NonTyping ›
    inv5:   b ∈ 0‥maxbuf not theorem TYPING NonTyping ›
    inv6:   ∀i· i∈ (0‥seqSize(abuf)) ⇒ prj2(abuf)(i) = cbuf((a+i) mo
EVENTS
    INITIALISATION: internal not extended ordinary ›
        THEN
            act1:   cbuf ≔ newArray(maxbuf,0) ›
            act2:   a ≔ 0 ›
            act3:   b ≔ 0 ›
        END
```

Tasking Event-B - restrictions

- AutoTasks do not communicate with each other.

- Communicate through Shared Machines.

- No nesting, in the Tasking Event-B syntax.

- One machine per 'Object'.

...

And finally … (almost)

- Writing code for Safety Critical Systems is hard.
  - The existing code can be augmented by additional notations for extended static-checking (JML), static checking + proof (SPARKAda)
  - Use safe language subsets.
  - Place restrictions on the implementation.
    - esp. for timing, and concurrency.

- Use Formal Modelling with automatic code gen.
  - also, use Model-checking, SAT/SMT etc. to help discover errors.

… and finally (actually)

If you write code manually
- much of the development effort is invested in eliminating coding errors.

With automatic code generation
- The modelling process helps to eliminate systemic errors.
- If the translator is 'trusted', coding errors should be absent.

- Certifying a translator is possible, but expensive.