

## Tutorial Modelling Software-based Systems

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### Tutorial 4 : Checking annotated algorithms using Event-B

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#### **Exercice 1** *contract-annotations*

For each case, define a contract for checking the soundness or the unsoundness of the annotation.

$$\forall x, y, , x', y'. P_\ell(x, y) \wedge cond_{\ell, \ell'}(x, y) \wedge (x', y') = f_{\ell, \ell'}(x, y) \Rightarrow P_{\ell'}(x', y')$$

You will use a context and a machine for expressing these conditions.

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| $\ell_1 : x = 10 \wedge y = z+x \wedge z = 2 \cdot x$<br>$y := z+x$<br>$\ell_2 : x = 10 \wedge y = x+2 \cdot 10$ |
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— We assume that  $p$  is a prime number.

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| $\ell_1 : x = 2^p \wedge y = 2^{p+1} \wedge x \cdot y = 2^{2 \cdot p + 1}$<br>$x := y+x+2^x$<br>$\ell_2 : x = 5 \cdot 2^p \wedge y = 2^{p+1}$ |
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| $\ell_1 : x = 1 \wedge y = 12$<br>$x := 2 \cdot y$<br>$\ell_2 : x = 1 \wedge y = 24$ |
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| $\ell_1 : x = 11 \wedge y = 13$<br>$z := x; x := y; y := z;$<br>$\ell_2 : x = 26/2 \wedge y = 33/3$ |
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#### **Exercice 2** *(contract-simple)*

Let the following partially annotated algorithm :

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| <b>precondition</b> : $x = x_0 \wedge x_0 \in \mathbb{N}$<br><b>postcondition</b> : $x = 0$<br><br>$\ell_0 : \{x = x_0 \wedge x_0 \in \mathbb{N}\}$<br><b>while</b> $0 < x$ <b>do</b><br><table border="1" style="margin-left: 20px; margin-right: 20px;"> <tr> <td style="padding: 10px;"> <math>\ell_1 : \{0 &lt; x \leq x_0 \wedge x_0 \in \mathbb{N}\}</math><br/> <math>x := x-1;</math><br/> <math>\ell_2 : \{0 \leq x \leq x_0 \wedge x_0 \in \mathbb{N}\}</math> </td> </tr> </table><br>$\ell_3 : \{x = 0\}$ | $\ell_1 : \{0 < x \leq x_0 \wedge x_0 \in \mathbb{N}\}$<br>$x := x-1;$<br>$\ell_2 : \{0 \leq x \leq x_0 \wedge x_0 \in \mathbb{N}\}$ |
| $\ell_1 : \{0 < x \leq x_0 \wedge x_0 \in \mathbb{N}\}$<br>$x := x-1;$<br>$\ell_2 : \{0 \leq x \leq x_0 \wedge x_0 \in \mathbb{N}\}$  |  |

#### **Algorithm 1:** Exercice 2

**Question 2.1** Translate each transition  $\ell, \ell'$  into an event modifying the variables according to the statements.

**Question 2.2** Define an invariant attaching to each label an assertion satisfied at the control point.

**Question 2.3** Verify proof obligations and deduce that the algorithm is partially correct.

**Question 2.4** Prove that the algorithm has no runtime error.

**Exercice 3** (*contract-sqrareroot*)

Let the following annotated invariant.

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precondition :  $x \in \mathbb{N}$ 
postcondition :  $z^2 \leq x \wedge x < (z+1)^2$ 
local variables :  $y_1, y_2, y_3 \in \mathbb{N}$ 

pre :  $\{x \in \mathbb{N}\}$ 
post :  $\{z \cdot z \leq x \wedge x < (z+1) \cdot (z+1)\}$ 
 $\ell_0 : \{x \in \mathbb{N} \wedge z \in \mathbb{Z} \wedge y_1 \in \mathbb{Z} \wedge y_2 \in \mathbb{Z} \wedge y_3 \in \mathbb{Z}\}$ 
 $(y_1, y_2, y_3) := (0, 1, 1);$ 
 $\ell_1 : \{y_2 = (y_1+1) \cdot (y_1+1) \wedge y_3 = 2 \cdot y_1 + 1 \wedge y_1 \cdot y_1 \leq x\}$ 
while  $y_2 \leq x$  do
     $\ell_2 : \{y_2 = (y_1+1) \cdot (y_1+1) \wedge y_3 = 2 \cdot y_1 + 1 \wedge y_2 \leq x\}$ 
     $(y_1, y_2, y_3) := (y_1+1, y_2+y_3+2, y_3+2);$ 
     $\ell_3 : \{y_2 = (y_1+1) \cdot (y_1+1) \wedge y_3 = 2 \cdot y_1 + 1 \wedge y_1 \cdot y_1 \leq x\}$ 
;
 $\ell_4 : \{y_2 = (y_1+1) \cdot (y_1+1) \wedge y_3 = 2 \cdot y_1 + 1 \wedge y_1 \cdot y_1 \leq x \wedge x < y_2\}$ 
 $z := y_1;$ 
 $\ell_5 : \{y_2 = (y_1+1) \cdot (y_1+1) \wedge y_3 = 2 \cdot y_1 + 1 \wedge y_1 \cdot y_1 \leq x \wedge x < y_2 \wedge z = y_1 \wedge z \cdot z \leq x \wedge x < (z+1) \cdot (z+1)\}$ 

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### Algorithm 2: *sqrareroot* annotée Exercice ??

**Question 3.1** Translate each transition  $\ell, \ell'$  into an event modifying the variables according to the statements.

**Question 3.2** Define an invariant attaching to each label an assertion satisfied at the control point.

**Question 3.3** Verify proof obligations and deduce that the algorithm is partially correct.

**Question 3.4** Prove that the algorithm has no runtime error.

**Exercice 4** (*contract-maximum*)

Soit l'algorithme suivant annoté partiellement :

**Question 4.1** Translate each transition  $\ell, \ell'$  into an event modifying the variables according to the statements.

**Question 4.2** Define an invariant attaching to each label an assertion satisfied at the control point.

**Question 4.3** Verify proof obligations and deduce that the algorithm is partially correct.

**Question 4.4** Prove that the algorithm has no runtime error.

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/* algorithme de calcul du maximum avec une boucle while de l'exercice ?? */
precondition :  $\left( \begin{array}{l} n \in \mathbb{N} \wedge \\ n \neq 0 \wedge \\ f \in 0..n-1 \rightarrow \mathbb{N} \end{array} \right)$ 
postcondition :  $\left( \begin{array}{l} m \in \mathbb{N} \wedge \\ m \in \text{ran}(f) \wedge \\ (\forall j \cdot j \in 0..n-1 \Rightarrow f(j) \leq m) \end{array} \right)$ 
local variables :  $i \in \mathbb{Z}$ 

 $\ell_0 : \left\{ \left( \begin{array}{l} n \in \mathbb{N} \wedge \\ n \neq 0 \wedge \\ f \in 0..n-1 \rightarrow \mathbb{N} \end{array} \right) \wedge i \in \mathbb{Z} \wedge m \in \mathbb{Z} \right\}$ 
 $m := f(0);$ 
 $\ell_1 : \left\{ \left( \begin{array}{l} n \in \mathbb{N} \wedge \\ n \neq 0 \wedge \\ f \in 0..n-1 \rightarrow \mathbb{N} \end{array} \right) \wedge i \in \mathbb{Z} \wedge m = f(0) \right\}$ 
 $i := 1;$ 
 $\ell_2 : \left\{ \left( \begin{array}{l} n \in \mathbb{N} \wedge \\ n \neq 0 \wedge \\ f \in 0..n-1 \rightarrow \mathbb{N} \end{array} \right) \wedge i = 1 \wedge \left( \begin{array}{l} m \in \mathbb{N} \wedge \\ m \in \text{ran}(f[0..i-1]) \wedge \\ (\forall j \cdot j \in 0..i-1 \Rightarrow f(j) \leq m) \end{array} \right) \right\}$ 
while  $i < n$  do
   $\ell_3 : \left\{ \left( \begin{array}{l} n \in \mathbb{N} \wedge \\ n \neq 0 \wedge \\ f \in 0..n-1 \rightarrow \mathbb{N} \end{array} \right) \wedge i \in 1..n-1 \wedge \left( \begin{array}{l} m \in \mathbb{N} \wedge \\ m \in \text{ran}(f[0..i-1]) \wedge \\ (\forall j \cdot j \in 0..i-1 \Rightarrow f(j) \leq m) \end{array} \right) \right\}$ 
  if  $f(i) > m$  then
     $\ell_4 : \left\{ \left( \begin{array}{l} n \in \mathbb{N} \wedge \\ n \neq 0 \wedge \\ f \in 0..n-1 \rightarrow \mathbb{N} \end{array} \right) \wedge i \in 1..n-1 \wedge \left( \begin{array}{l} m \in \mathbb{N} \wedge \\ m \in \text{ran}(f[0..i-1]) \wedge \\ (\forall j \cdot j \in 0..i-1 \Rightarrow f(j) \leq m) \end{array} \right) \wedge \right.$ 
     $f(i) > m \}$ 
     $m := f(i);$ 
     $\ell_5 : \left\{ \left( \begin{array}{l} n \in \mathbb{N} \wedge \\ n \neq 0 \wedge \\ f \in 0..n-1 \rightarrow \mathbb{N} \end{array} \right) \wedge i \in 1..n-1 \wedge \left( \begin{array}{l} m \in \mathbb{N} \wedge \\ m \in \text{ran}(f[0..i]) \wedge \\ (\forall j \cdot j \in 0..i \Rightarrow f(j) \leq m) \end{array} \right) \right\}$ 
  ;
   $\ell_6 : \left\{ \left( \begin{array}{l} n \in \mathbb{N} \wedge \\ n \neq 0 \wedge \\ f \in 0..n-1 \rightarrow \mathbb{N} \end{array} \right) \wedge i \in \mathbb{Z} \wedge i \in 1..n-1 \wedge \left( \begin{array}{l} m \in \mathbb{N} \wedge \\ m \in \text{ran}(f[0..i]) \wedge \\ (\forall j \cdot j \in 0..i \Rightarrow f(j) \leq m) \end{array} \right) \right\}$ 
   $i++;$ 
   $\ell_7 : \left\{ \left( \begin{array}{l} n \in \mathbb{N} \wedge \\ n \neq 0 \wedge \\ f \in 0..n-1 \rightarrow \mathbb{N} \end{array} \right) \wedge i \in 2..n \wedge \left( \begin{array}{l} m \in \mathbb{N} \wedge \\ m \in \text{ran}(f[0..i-1]) \wedge \\ (\forall j \cdot j \in 0..i-1 \Rightarrow f(j) \leq m) \end{array} \right) \right\}$ 
;
 $\ell_8 : \left\{ \left( \begin{array}{l} n \in \mathbb{N} \wedge \\ n \neq 0 \wedge \\ f \in 0..n-1 \rightarrow \mathbb{N} \end{array} \right) \wedge i = n \wedge \left( \begin{array}{l} m \in \mathbb{N} \wedge \\ m \in \text{ran}(f) \wedge \\ (\forall j \cdot j \in 0..n-1 \Rightarrow f(j) \leq m) \end{array} \right) \right\}$ 

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**Algorithme 3:** Algorithme du manimum d'une liste annoté Exercice 4