Correct deployment and adaptation of software applications on heterogeneous (mobile) devices

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Setting the context

- Heterogeneous (mobile) devices
  - Same basic functionalities
  - Different quantitative and qualitative characteristics
- Possibly infinite device characteristics (screen size, memory size, power, communication protocols, etc.)
- Check application compatibility with respect to a given set of characteristics and perform adaptation in order to prevent runtime execution failures

Setting the context

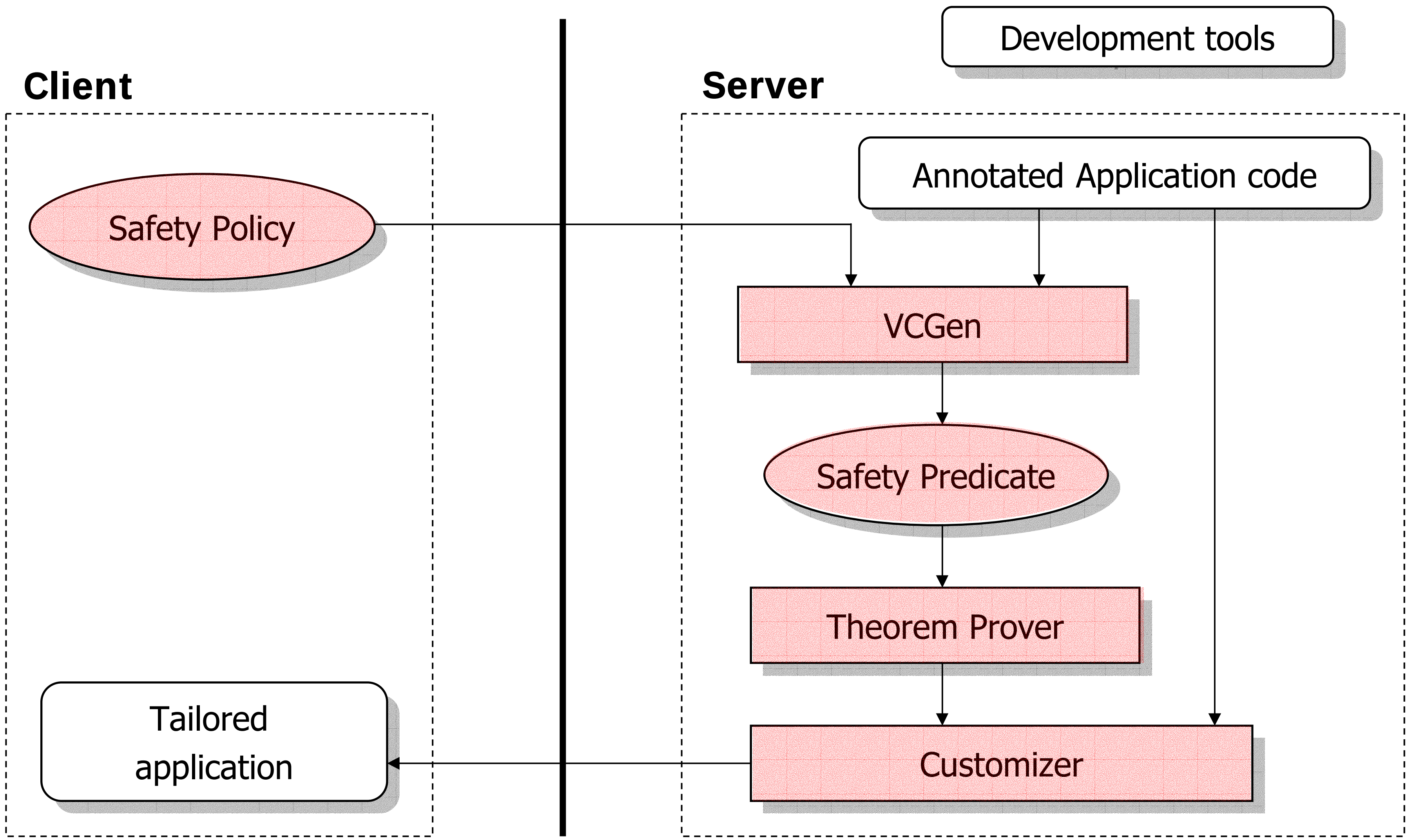
- Formal framework based on an approach to develop and distribute adaptable applications

- Ideas borrowed from Proof Carrying Code (PCC) [Necula,97]

- Chosen reference platform is Java 2 MicroEdition with the MIDP Profile

- Assumptions:
  - Target devices are *limited*
  - Tailored adaptable applications (instead of self contained adaptable applications)
  - Device Functionalities are characterizable in a *discrete* way
  - Applications are relatively *small* and *not so much complex*

Framework architecture



Framework approach characteristics

- Static approach which captures some dynamic properties
- Best fit approach
- Lightweight with respect to the client
- Formal
- Declarative approach to manage qualitative properties

Framework approach

- **Step1:** Annotated source code development, definition of an adaptation policy and source code compilation
- **Step2:** Safety predicate generation
- **Step3:** Proof generation
- **Step4:** Construction of the final adapted code

A case study: the screen

- Different devices
- Different screen capabilities
- Same application with different (possibly incorrect or undesired) behaviours

Step1

Annotated source code development

- Standard annotations
  - Loop/branches invariants

- Adaptation policy:
  - Adaptation points
  - Adaptation alternatives (for each adaptation point)

- Syntactical construct:

ADAPT {c_1}
USE {c_2}
…
USE {c_n}

Step1

Annotated Java source code

```
public void paint(Graphics g) {
  int x; int y;
  x = 10; y = 50;
  g.drawRect(0, 0, subtract(x, y), 50);
  ADAPT { g.drawRect(0, 0, 120, 10); }
  USE { g.drawRect(0, 0, 50, 10); }
  USE { g.drawRect(0, 0, 10, 10); }
}
public int subtract(int x, int y) {
  if(x < y) return 0;
  return (x - y);
}
```

- Code compilation produces an annotated relocatable byte code
- Code compilation should ensure the type correctness of each program version derived using the adaptation policy

Step1

Relocatable annotated bytecode

```
Method void paint(Graphics g)
   0 bipush 10
   2 istore_1
   3 bipush 50
   5 istore_2
   6 aload_0
   7 iconst_0
   8 iconst_0
   9 aload_0
  10 iload_1
  11 iload_2
  12 invokevirtual #2 <Method int
                       subtract(int, int)>
  15 bipush 50
  17 invokevirtual #3 <Method void
                      rect(int, int, int, int)>
  20 ADAPT1(b1, b2, b3)
  20+l1 return

Method int subtract(int, int)
    0 iload_1
    1 iload_2
    2 if_cmpge 7
    5 iconst_0
    6 ireturn
    7 iload_1
    8 iload_2
    9 isub
   10 ireturn
```

b1

```
l  aload_0
l+1 iconst_0
l+2 iconst_0
l+3 bipush 120
l+5 bipush 10
l+7 invokevirtual #3 <Method void
              rect(int, int, int, int)>
```

b2

```
l  aload_0
l+1 iconst_0
l+2 iconst_0
l+3 bipush 50
l+5 bipush 10
l+7 invokevirtual #3 <Method void
              rect(int, int, int, int)>
```

b3

```
l  aload_0
l+1 iconst_0
l+2 iconst_0
l+3 bipush 10
l+5 bipush 10
l+7 invokevirtual #3 <Method void
              rect(int, int, int, int)>
```

Step2

- Given the annotated relocatable byte code and a safety policy, the safety predicate is built by the VCGen

- Adaptation policy alternatives are transparently embedded in the safety predicate

Step2

The safety predicate

$RECT(x, y, z, w)$ Safety policy (provided by the client)

$\Rightarrow$

Predicate obtained from the annotated bytecode

$$(10 \geq 50 \Rightarrow RECT(0, 0, (10-50), 50):Visible \wedge$$
$$10 < 50 \Rightarrow RECT(0, 0, 0, 50):Visible)$$
$$\wedge$$
$$OR(RECT(0, 0, 120, 10):Visible,$$
$$RECT(0, 0, 50, 10):Visible,$$
$$RECT(0, 0, 10, 10):Visible)$$

Step3

The proof system

$$\frac{\triangleright P_1 \quad \triangleright P_2}{\triangleright P_1 \wedge P_2}\,\text{And}$$

$$\frac{\triangleright P_1 \wedge P_2}{\triangleright P_1}\,\text{And\_1} \qquad \frac{\triangleright P_1 \wedge P_2}{\triangleright P_2}\,\text{And\_2}$$

$$\frac{\not\triangleright P_1}{\triangleright P_1 \Rightarrow P_2}\,\text{ImF} \qquad \frac{\triangleright P_2}{\triangleright P_1 \Rightarrow P_2}\,\text{ImT}$$

$$\frac{\begin{array}{c}\triangleright RECT(x^{'}, y^{'}, z^{'}, w^{'}) : Visible \\ \triangleright x^{'} \leq x, z \leq z^{'} \\ \triangleright y^{'} \leq y, w \leq w^{'}\end{array}}{\triangleright RECT(x, y, z, w) : Visible}\,\text{Inc}$$

- Proof system:
  - Proof rules (FOL, Properties specific)
  - Proof Algorithm
- It must be decidable and modular
- Proof $\Rightarrow$ Configuration

Step3

The proof

$$\dfrac{\dfrac{\dfrac{\dfrac{\not\triangleright P_6}{\triangleright P_5}\,\text{ImF} \quad \dfrac{\dfrac{Pre}{\triangleright P_4}\,\text{Inc}}{\triangleright P_3}\,\text{ImT}}{\triangleright P_2}\,\text{And} \quad \dfrac{\triangleright \ldots}{\triangleright P_7}\,\text{OR}}{\triangleright P_2 \wedge P_7}\,\text{And}}{\triangleright Pre \Rightarrow P_1}\,\text{ImT}$$

(a) $$\dfrac{}{\triangleright RECT(0,0,120,10) : Visible}$$

(b) $$\dfrac{Pre}{\triangleright RECT(0,0,50,10) : Visible}\,\text{Inc}$$

(c) $$\dfrac{Pre}{\triangleright RECT(0,0,10,10) : Visible}\,\text{Inc}$$

$P_1 = P_2 \wedge P_7$

$P_2 = 10 \geq 50 \Rightarrow$ RECT(0, 0, (10-50), 50):Visible $\wedge$ $10 < 50 \Rightarrow$ RECT(0, 0, 0, 50):Visible

$P_3 = 10 < 50 \Rightarrow$ RECT(0, 0, 0, 50):Visible

$P_4 =$ RECT(0, 0, 0, 50):Visible

$P_5 = 10 \geq 50 \Rightarrow$ RECT(0, 0, (10-50), 50):Visible

$P_6 = 10 \geq 50$

$P_7 =$ OR(RECT(0, 0, 120, 10):Visible, RECT(0, 0, 50, 10):Visible, RECT(0, 0, 10,10):Visible)

Step4

Tailored application

```
Method void paint(Graphics g)
    0 bipush 10
    2 istore_1
    3 bipush 50
    5 istore_2
    6 aload_0
    7 iconst_0
    8 iconst_0
    9 aload_0
   10 iload_1
   11 iload_2
   12 invokevirtual #2 <Method int
                        subtract(int, int)>
   15 bipush 50
   17 invokevirtual #3 <Method void
                       rect(int, int, int, int)>
   20 aload_0
   21 iconst_0
   22 iconst_0
   23 bipush 50
   25 bipush 10
   27 invokevirtual #3 <Method void
             rect(int, int, int, int)>
   30 return
```

b2

Conclusions and future works

- Effectiveness of a declarative approach

- The approach is thought to have little impact on the devices

- We are extending the adaptation with respect to other characteristics

- Implement all the tools needed by the framework (compilers, ad-hoc theorem prover…)