Model Programs for Preserving Composite Invariants

SAVCBS 2008 Challenge Problem Solution by

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Summary

Problem

- Specify and verify invariants for composite, which extend outside an object.

Approach: JML model programs

- Grey-box [Büchi-Weck97,99] specification
- Verification modular by:
  - Copy rule / substitution [Morgan88]
  - Structurally-restricted refinement

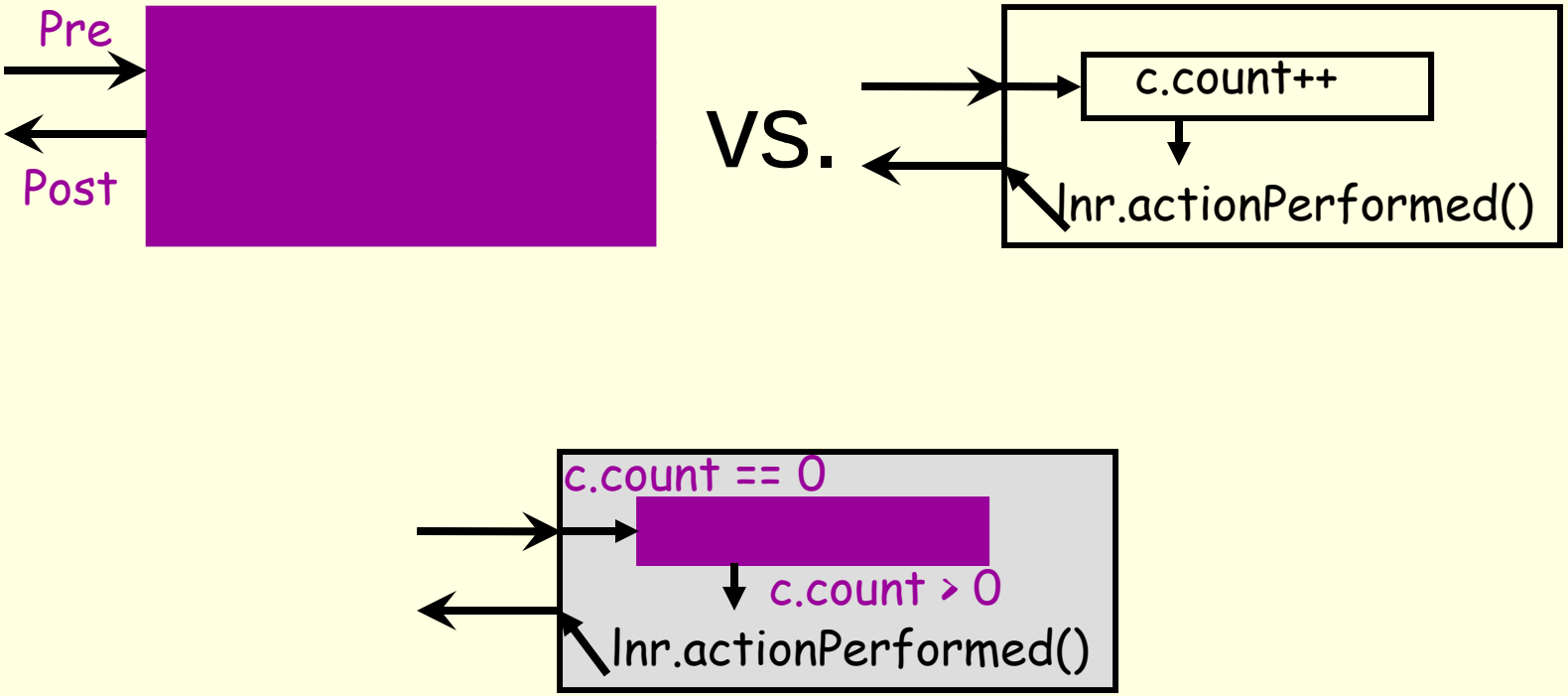
Contribution

- Exposes only code for maintaining invariant

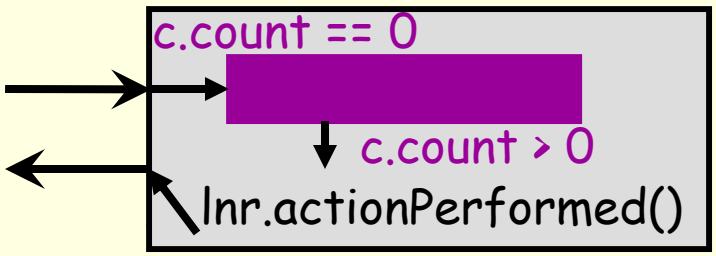
Setting

- JML
  - Pre- and postcondition specifications
  - Several verification tools:
    - ESC/Java2
    - Jack, LOOP, …
- Java
  - Libraries:
    - Swing
    - I/O frameworks
    - Jakarta Commons

Grey-Box (Ref. Calc.) Approach [Büchi-Weck97, 99]



Grey-Box Specifications in JML [Shaner-Leavens-Naumann07]



Specification

```
/*@ normal_behavior
  @   requires c.count == 0;
  @   ensures c.count > 0;
  @*/



lnr.actionPerformed();
```

Code

```
/*@ refining
  @   normal_behavior
  @     requires c.count == 0;
  @     ensures c.count > 0;
  @*/
{  c.count++; }

lnr.actionPerformed();
```

Soundness of JML's Approach [Shaner-Leavens-Naumann07]

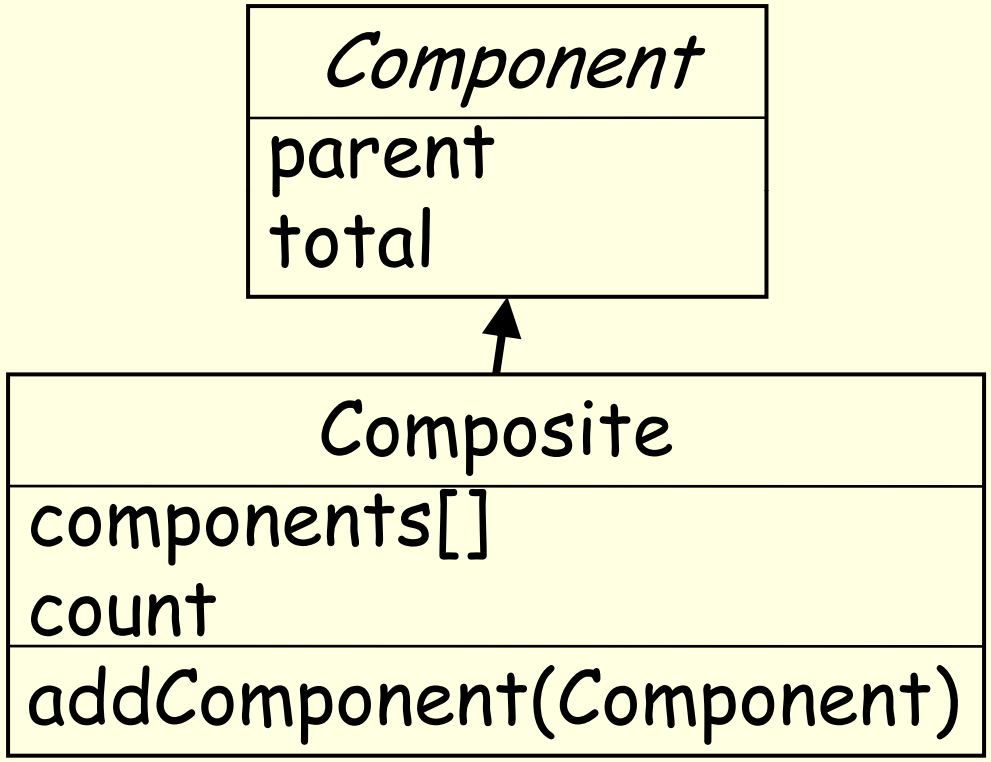
Structural Refinement:

- Exposed code appears exactly as shown
- Specification statements refined by refining statements
  - Cannot call methods with exposed calls

Behavioral Subtyping:

- Overriding methods must structurally refine

Composite Design Pattern



Sample Assertion to Prove

```
Composite root = new Composite();
Composite child = new Composite();
Component comp = new Component();
//@ assume root.total == 1 && child.total == 1;
//@ assume comp.total == 1;
//@ assume root.parent == null && child.parent == null;
//@ assume comp.parent == null;

root.addComponent(child);
child.addComponent(comp);
//@ assert root.total == 3;
```

Specification of Component

```
class Component {
  protected /*@ spec_public nullable @*/
        Composite parent;
  protected /*@ spec_public @*/ int total = 1;
  //@ protected invariant 1 <= total;
}
```

Specification of Composite (Data and Invariant)

```
class Composite extends Component {
  private /*@ spec_public @*/
    Component[] components = new Component[5];
  private /*@ spec_public @*/
    int count = 0;
  /*@ protected invariant
    @   total == 1 + (\sum int i;
    @                 0 <= i && i < count;
    @                 components[i].total); @*/
```

Composite's Specification (addComponent)

```
/*@ public model_program {
      normal_behavior
        requires c != this && c.parent == null;
        assignable this.components;
        ensures this.components.length > this.count;
      normal_behavior
        assignable c.parent, this.objectState;
        ensures c.parent == this;
        ensures this.hasComponent(c);
      this.addToTotal(c.total);
    } @*/
    public void addComponent(Component c)
```

Composite's Specification (addToTotal)

```
/*@ private model_program {
      normal_behavior
        requires 0 <= p;
        assignable this.total;
        ensures this.total == \old(this.total) + p;
       Component aParent = this.parent;
      while (aParent != null) {
        normal_behavior
          assignable aParent.total, aParent;
          ensures aParent.total == \old(aParent.total) + p;
          ensures aParent == \old(aParent.parent);
      }
  } @*/
  private /*@ helper @*/ void addToTotal(int p)
```

Verification Using Copy Rule [Morgan88]

To verify method call:

- Substitute model program specification
- Replace formals with actuals
  - Avoid capture

Usual rules for other statements

Rule for Method Calls (Copy Rule + Substitution)

$$\frac{\begin{array}{c}\text{specFor}(T', m) = mp(S'),\\ \text{methType}(T', m) = \mathbf{y}{:}\mathbf{U} \to \mathbf{void},\\ \mathbf{this}{:}T', \mathbf{z}{:}\mathbf{U} \vdash S',\\ T \leq T',\\ S' \text{ doesn't assign to } \mathbf{y},\\ S = S'[x,\mathbf{z}/\mathbf{this},\mathbf{y}],\\ \Gamma, x{:}T' \vdash P \{ S \} Q\end{array}}{\Gamma, x{:}T \vdash P \;\&\&\; x \;\mathbf{instanceof}\; T' \{ x.m(\mathbf{z}); \} Q}$$

Verification of Sample

```
Composite root = new Composite();
Composite child = new Composite();
Component comp = new Component();
//@ assume root.total == 1 && child.total == 1;
//@ assume comp.total == 1;
//@ assume root.parent == null && child.parent == null;
//@ assume comp.parent == null;

root.addComponent(child);
child.addComponent(comp);
//@ assert root.total == 3;
```

Copy Rule Applied

```
root.addComponent(child);
  →
normal_behavior
    requires child != root && child.parent == null;
    assignable root.components;
    ensures root.components.length > root.count;
normal_behavior
    assignable child.parent, root.objectState;
    ensures child.parent == root;
    ensures root.hasComponent(child);
root.addToTotal(child.total);
```

Copy Rule Applied

```
root.addToTotal(child.total);
→
{ normal_behavior
     requires 0 <= child.total;
     assignable root.total;
     ensures root.total == \old(root.total) + child.total;
  Component aParent = root.parent;
  while (aParent != null) {
    normal_behavior
       assignable aParent.total, aParent;
       ensures aParent.total
                  == \old(aParent.total) + child.total;
       ensures aParent == \old(aParent.parent);
} }
```

Discussion

Argument exposure in invariant:

- Exposed code shows how total is updated
- Precondition of addComponent ==> no cycles
- Special case of visibility technique

Subtypes and overriding methods:

- Inherit model program specifications
- So implementations must refine

Subtypes and new methods:

- Inherit invariant
- Must not make cycles (not specified!)

Conclusions

- Simple specification technique
  - Exposing code needed for invariant
  - Hiding rest of the code
- Simple verification technique
  - Copy rule
  - Limited depth of recursion can be handled

Questions?

jmlspecs.org

Thanks to David Naumann.

Other Solutions

Hallstrom and Soundarajan:

- Requires calls to operation()
  like our calls to addToTotal()
- Can't specify states in which calls made
- **other** specs like JML's history constraints
- More sophisticated mathematics

Other Solutions

Bierhoff and Aldrich:

- Abstraction of functional behavior
- Careful treatment of aliasing issues

Other Solutions

Jacobs, Smans, Piessens:

- Doesn't expose any code
- More mathematically sophisticated
  - Specifies effects on parents using context
- Only treats binary trees