Department of Computing and Systems
University of Pernambuco
Recife, Brazil

Implementing Java Modeling Language Contracts with AspectJ

Henrique Rebêlo
Ricardo Lima
Márcio Cornélio
Sérgio Soares
Leopoldo Ferreira
(hemr,ricardo,marcio,sergio,lpf@dsc.upe.br)

Java Modeling Language

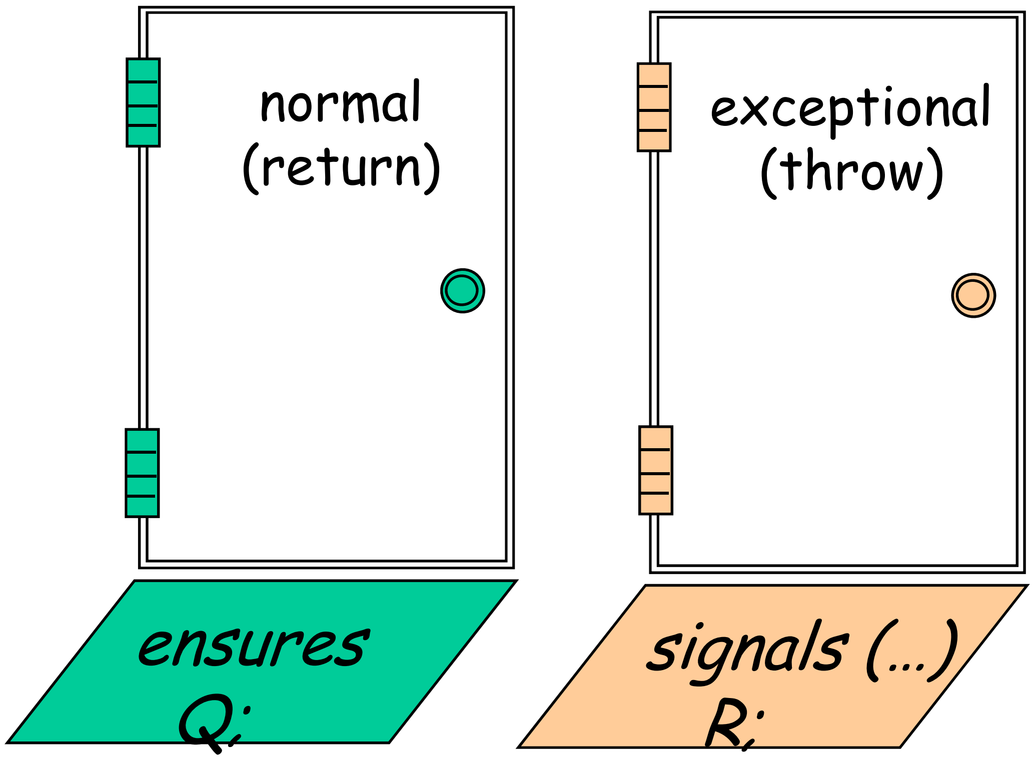
- Formal specification language for Java
  - behavioral specification of Java modules
- Adopts design by contract and Hoare-style with assertions
  - pre-, postconditions and invariants
- Main goal → Improve functional software correctness of Java programs

Java Modeling Language

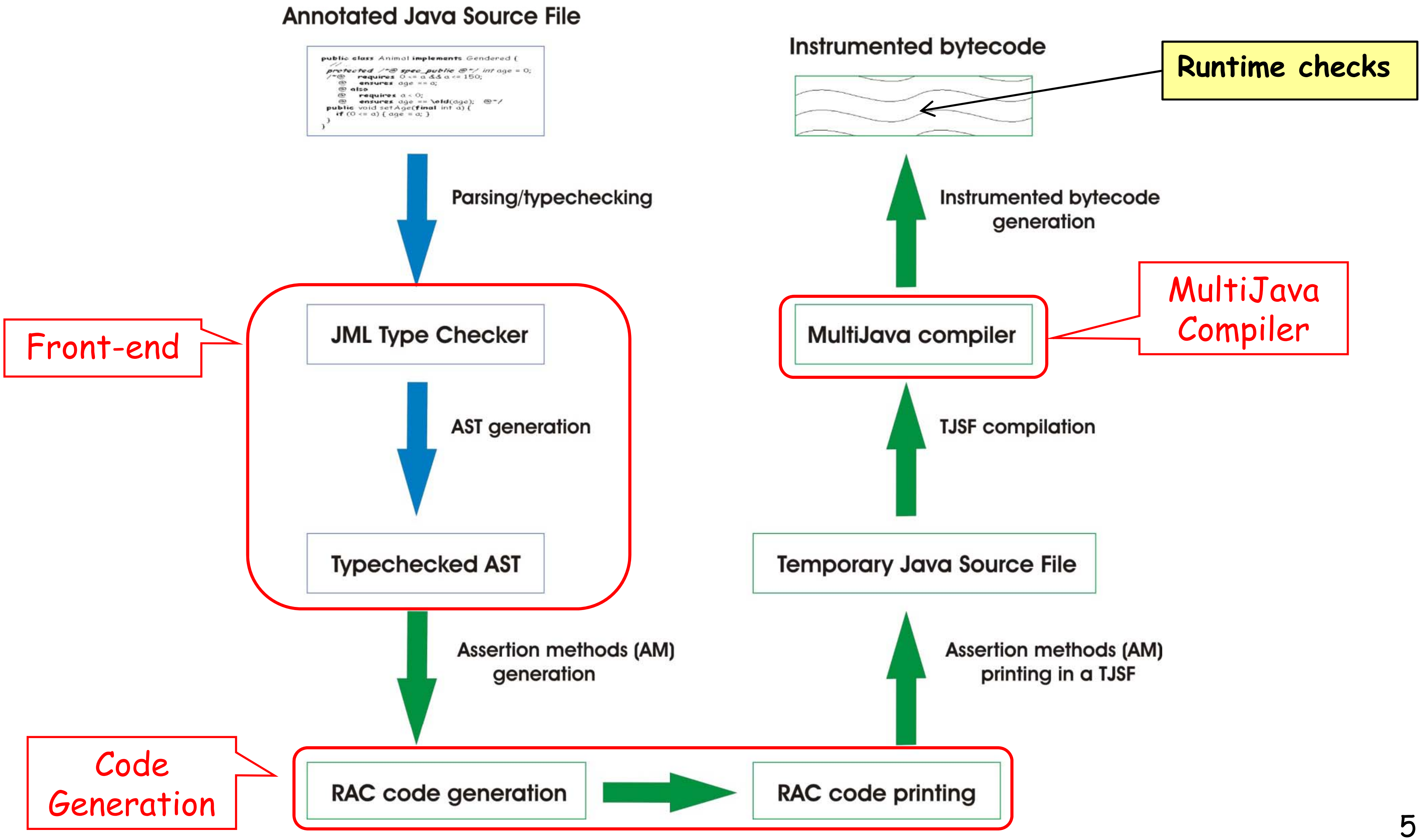
- Assertions are added as comments in .java files
  - between /*@ ... @*/, or //@

```
public class foo{
  //@ invariant S;
  /*@ requires P;
    @ ensures Q;
    @ signals (FooException) R;
    @*/
  public void foo() throw FooException {...}
}
```

Meaning of Postconditions



JML compiler: compilation passes



Problem

- JML limitation
  - The JML compiler does not work properly when applied to other Java platforms
  - Example: Java ME platform
    - Data structures (e.g. *HashSet*)
    - Java reflection mechanism

Our Approach

- Verify Java ME/SE programs with JML
  - AspectJ – AOP extension to Java

We use the AspectJ to
- translate JML contracts into aspects
- generate bytecodes compliant with Java ME/SE
- verify if bytecode respects the JML contracts during runtime

Aspect Oriented Programming with AspectJ

- AspectJ
  - Crosscutting concern modularization
    - persistence
    - distribution
    - ...

"[...] there are many other concerns that, in specific system, have crosscutting structure. Aspects can be used to maintain internal consistency among several methods of a class. They are well suited to ***enforcing a Design by Contract style programming****."*

Gregor Kiczales

http://www.theserverside.com/talks/videos/GregorKiczalesText/interview.tss

Aspect Oriented Programming with AspectJ

- Dynamic crosscutting
  - Define additional code that should be executed
    - before
    - after
    - around
- Static crosscutting
  - ...
  - Add new members to types
  - ...

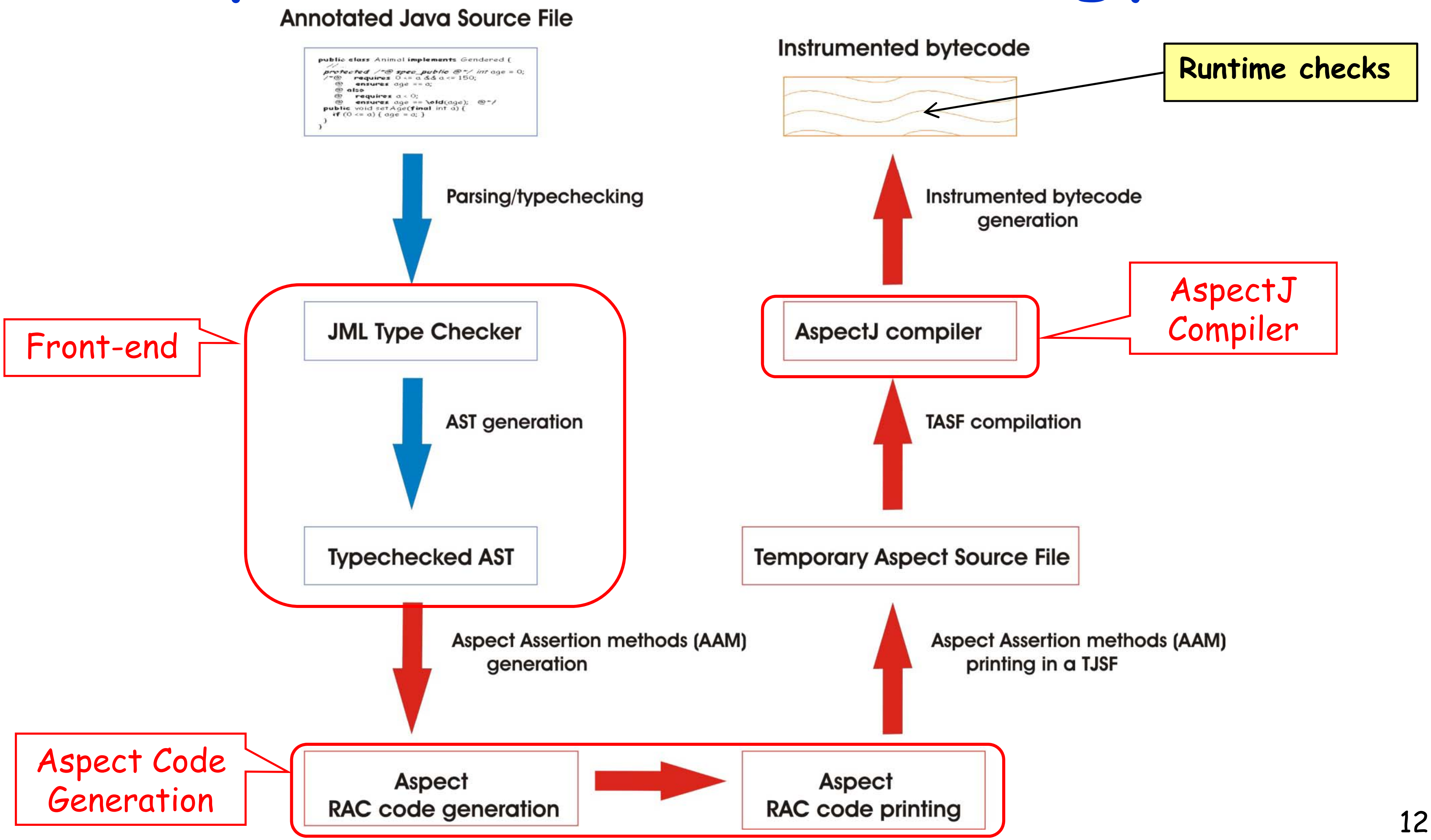
Contributions

- A novel JML compiler compliant with
  - Java ME/SE applications
- The use of AspectJ to implement JML contracts
  - Mapping JML contracts into AspectJ aspects
  - Checking the contracts during runtime

Outline

- Implementation Strategy
- Subset of JML: pre, post, invariant
- Mapping Contracts into Aspects
- Comparative Study
- Conclusion
- Future Work

Implementation Strategy



Subset of JML: pre, post, invariant

- Preconditions (requires keyword)

Properties that must hold before method calls.

- Normal Postconditions (ensures keyword)

Properties that must hold after method calls.

- Invariants (invariant keyword)

Properties that must be maintained by all methods.

Subset of JML: pre, post, invariant

- Inheritance of JML specifications
  - Leavens' definition

If $T' \triangleright (pre', post')$, $T \triangleright (pre, post)$, $S \leq T'$, $S \leq T$, then

$$(pre', post') \sqcup^S (pre, post) = (p, q)$$

where $p = pre' \ \texttt{||} \ pre$
and $q = (\texttt{\textbackslash old}(pre') \ \texttt{==>} \ post') \ \texttt{\&\&} \ (\texttt{\textbackslash old}(pre) \ \texttt{==>} \ post)$
and $S \triangleright (p, q)$.

preconditions are combined by *disjunction*
normal postconditions are combined by *conjunction*
invariants * are combined by *conjunction*

Mapping contracts into aspects

- Assume the following generic JML specification

```
public class S extends T{
  //@ invariant inv;
  /*@ also
    @ requires pre;
    @ ensures post;
    @*/
  public void m(){...}
}
```

class S inherits JML specifications from class T

Mapping contracts into aspects

- AspectJ mapping for precondition

Inter Type declaration: checkPre$m()

```
public boolean S.checkPre$m(){
  return pre || super.checkPre$m();
}
```

AspectJ advice: before

```
before(S current) :
 execution(void S.m()) && within(S) && this(current){
   if(!current.checkPre$m()){
     throw new JMLInternalPreconditionError();
   }
 }
```

Mapping contracts into aspects

- AspectJ mapping for normal postcondition

Inter Type declaration: checkPost$m$C()

```
public boolean S.checkPost$m$S(){
  return !pre || post;
}
```

translation of the JML implication \old(pre)==> post

AspectJ advice: around

```
void around(S current) :
 execution(void S.m()) && this(current){
   ...// saving all old values (pre-state)
   proceed();
   // (post-state)
   if(!current.checkPost$m$S()){
     throw new JMLInternalNormalPostconditionError();
   }
 }
```

Mapping contracts into aspects

- AspectJ mapping for invariant

Inter Type declaration: checkInv$Instance ()

```
public boolean S.checkInv$Instance(){
  return inv && super.checkInv$Instance();
}
```

AspectJ advice: before, after returning
after throwing

```
execution(!static * *(..)) && within(S)
```

Comparative study

- An open source Java ME floating point calculator in three different ways:
  - Using our approach with AOP (our compiler) – *CalcAspSol*
  - Using the original approach (jmlc compiler) – *CalcJmlSol*
  - Using a pure one (with no bytecode instrumentation) – *CalcPureSol*

(→) The open source calculator is available at https://meapplicationdevelopers.dev.java.net/demo box.html

Comparative study

- Metrics
  - MiDlet class size
  - Bytecode size (JAR)
  - Library API size
- Annotations used: pre, postconditions, and invariant
- Enforced properties
  - The calculator yields only positive results
  - The calculator prevents division by zero

The calculator was executed in a real mobile phone!.

Comparative study

- Our analysis were extracted from the following results:

-95.8%

-98.3%

	MidLet class size (KB)	JAR size (KB)	Lib JAR size (KB)
CalcAspSol	21.1	11.8	4.6
CalcJmlSol	39.5	278.0	261.0
CalcPureSol	4.9	2.7	—

Such results provide indication that our compiler generates a bytecode that requires less memory space than one generated by the JML compiler (jmlc).

Conclusion

- A novel JML compiler
  - Java ME/SE applications
- The use of AspectJ to implement contracts written in JML
- A comparative study
  - Our compiler produces smaller code than the jmlc
- Limitation
  - Subset of JML constructs

Future Work

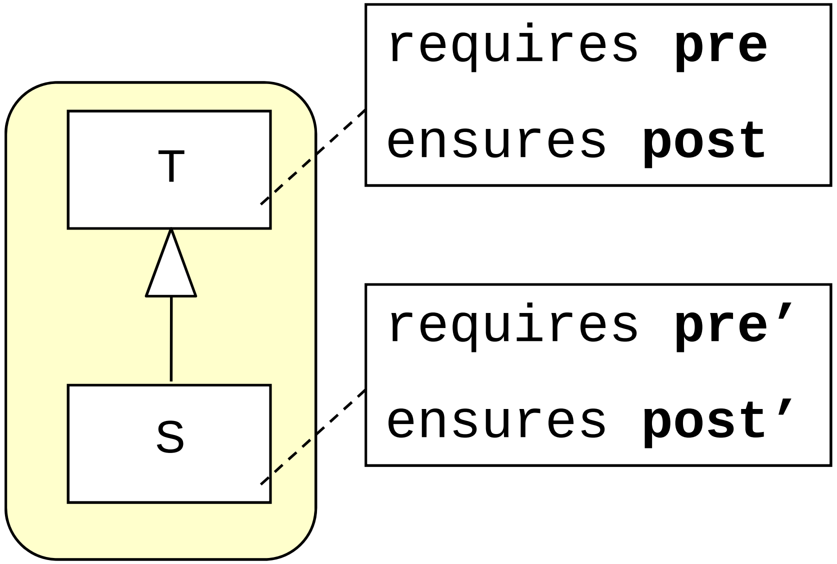
- To extend our compiler to treat other JML constructs
- Optimization techniques for AspectJ advices
- Case studies
- Formalization of the JML/AspecJ mapping

Department of Computing and Systems
University of Pernambuco
Recife, Brazil

Implementing Java Modeling Language Contracts with AspectJ

Henrique Rebêlo
Ricardo Lima
Márcio Cornélio
Sérgio Soares
Leopoldo Ferreira
(hemr,ricardo,marcio,sergio,lpf@dsc.upe.br)

Example: pre and post



Example: pre and post

AspectJ for T

T

AspectJ for S

S

Precondition Checking

```
public boolean T.checkPre$m(){
  return pre;
}
```

```
before(T current) :
 execution(void T.m())) && within(T) && this(current){
   if(!current.checkPre$m()){
     throw new JMLInternalPreconditionError();
   }
 }
```

Precondition Checking

```
public boolean S.checkPre$m(){
  return pre' || super.checkPre$m();
}
```

1

2

```
before(S current) :
 execution(void S.m())) && within(S) && this(current){
   if(!current.checkPre$m()){
     throw new JMLInternalPreconditionError();
   }
 }
```

```
S s = new S();
s.m();
```

Example: pre and post

AspectJ for T

T

AspectJ for S

S

N-Postcondition Checking

1

```
public boolean T.checkPost$m$T(){
   return !pre || post;
}
```

```
void around(T current) :
 execution(void T.m()) && this(current){
   ...// saving all old values (pre-state)
   proceed();
   // (post-state)
   if(!current.checkPost$m$T()){
     throw new JMLInternalNormalPostconditionError();
   }
}
```

N-Postcondition Checking

2

```
public boolean S.checkPost$m$S(){
  return !pre'|| post';
}
```

```
void around(S current) :
 execution(void S.m()) && this(current){
   ...// saving all old values (pre-state)
   proceed();
   // (post-state)
   if(!current.checkPost$m$S()){
     throw new JMLInternalNormalPostconditionError();
   }
}
```

```
S s = new S();
s.m();
```

Complete invariant mapping

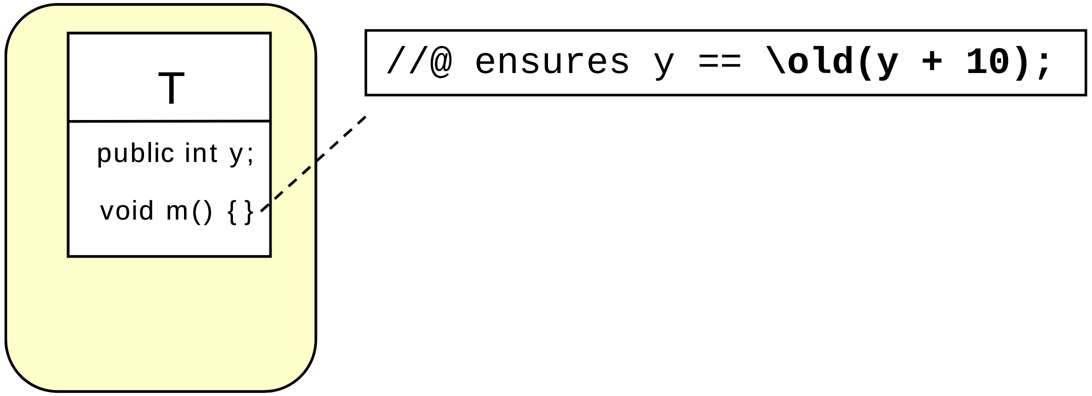
```
public boolean S.checkInv$Instance(){
  return inv && super.checkInv$Instance();
}
```

```
after(S current)returning(Object o) :
 execution(!static * *(..)) && within(S) &&
 this(current){
   if (!current.checkInv$Instance()){
        throw new JMLInvariantError("<@post>");
   }
 }
```

```
before(S current) :
 execution(!static * *(..)) && within(S) &&
 this(current){
   if (!current.checkInv$Instance()){
        throw new JMLInvariantError("<@post>");
   }
 }
```

```
after(S current) throwing(Throwable throwable) :
 execution(!static * *(..)) && within(S) &&
 this(current){
   if(throwable instanceof jmlViolationError){
     throw(jmlViolationError)throwable;
   }
   if(throwable instanceof otherException){
     if (!current.checkInv$Instance()){
       throw new JMLInvariantError("<@post>");
     }
     else{
       throw(otherException)throwable;
     }
```

Example: old construct




```
public int T.old_y;

public boolean T.checkPost$m$T(){
  return !true || y == (old_y + 10);
}
```

```
void around(T current) :
 execution(void T.m()) && this(current){
   // saving all old values (pre-state)
   old_y = y;
   proceed();
   // (post-state)
   if(!current.checkPost$m$T()){
     throw new JMLInternalNormalPostconditionError();
   }
 }
```