

# Formal Methods for Java

## Lecture 17: Advanced Key

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December 21, 2011

# Abnormal Termination in Java

Abnormal termination in Java is caused by

- a `break` statement,
- a `continue` statement,
- a `return` statement,
- a `throw` statement, or
- a statement that throws an exception.

## Reasoning about exceptions

How can we express that statement  $\alpha$  throws an exception?

- The trick is to put an exception handler into the code:

```
⟨{Throwable thrown = null;  
  try { $\alpha$ ; }  
  catch (Throwable ex){thrown = ex; }}⟩thrown ≠ null
```

# Reasoning with try-catch blocks

When an exception is thrown, the surrounding try blocks become important:

```
\find( \< { .. try { throw #se; #slist1 }  
        catch (#t #v0) { #slist2 } ... } \> post )
```

- 1 throwing a handled exception: #se instanceof #t  

```
\replacewith( \< { .. #t #v0 = #se; #slist2 ... } \> post )
```
- 2 throwing an unhandled exception: ! (#se instanceof #t)  

```
\replacewith( \< { .. throw #se; ... } \> post )
```
- 3 throwing a null pointer: #se = null  

```
\replacewith( \< { .. try { throw new NullPointerException(); #slist1  
        catch (#t #v0) { #slist2 } ... } \> post )
```

The KeY system defines a single rule:

```
\replacewith( \< { .. if (#se = null) then  
        try { throw new NullPointerException(); #slist1  
        catch (#t #v0) { #slist2 }  
        else if (#se instanceof #t) then  
            #t v0 = #se; #slist2  
        else throw #se;  
        ... } \> post )
```

# Throw without try-catch blocks

If the surrounding block is not a try block, the block is just removed:

```
\find( \<{ .. #label: { throw #se; #slist1 } ... }\> post )  
\replacewith( \<{ .. throw #se; ... }\> post )
```

If there is no surrounding block it depends on modality:

- 1 total correctness:  

```
\find( \<{ throw #se }\> post )  
\replacewith( false )
```
- 2 partial correctness:  

```
\find( \[ { throw #se } \] post )  
\replacewith( true )
```

# Runtime exceptions

Instructions that throw exceptions are converted to a `throw` instruction:

```
\find( \<{ .. #v[#se]=#se0 ... } \> post )
```

- Normal Execution `#v != null`

```
\add( !#v = null &  
      #se < #v.length & #se >= 0 &  
      arrayStoreValid(#v, #se0) ==> )  
\replacewith( \{#v[#se] := #se0\} \<{ .. ... } \> post )
```

- Null Reference `#v == null`

```
\add( #v = null ==> )  
\replacewith( \<{ .. throw new NullPointerException(); ... } \> post )
```

- Index Out Of Bounds:

```
\add( !#v = null &  
      #se >= #v.length | #se < 0 ==> )  
\replacewith( \<{ .. throw new ArrIdxOOBException(); ... } \> post )
```

- Array Store Exception:

```
\add( !#v = null &  
      #se < #v.length & #se >= 0 &  
      !arrayStoreValid(#v, #se0) ==> )  
\replacewith( \<{ .. throw new ArrayStoreException(); ... } \> post )
```

## Abnormal termination by `break`

The handling of `break` statements is very similar to `try-catch`:

- If the surrounding block has that label, the break is executed:  

```
\find( \<{ .. #label: { break #label; #slist1 } ... }\> post )  
\replacewith( \<{ .. ... }\> post )
```
- If the surrounding block has not the right label the block is removed.  

```
\find( \<{ .. #label2: { break #label; #slist1 } ... }\> post )  
\replacewith( \<{ .. break #label; ... }\> post )
```
- The same for `try-catch` blocks:  

```
\find( \<{ .. try { break #label; #slist1 }  
          catch (#t #v) { #slist2 } ... }\> post )  
\replacewith( \<{ .. break #label; ... }\> post )
```

## Loops with `break/continue`

`break/continue` statements are translated to labelled `break`.

rule `loop_unwind`:

```
\find( \<{ .. while (#expr) {... continue; .... break; ....} ... } \> post
\replacewith( \<{ .. if (#expr) {
    #lab1: {
        #lab2: {
            ....
            continue #lab2;
            ....
            break #lab1;
            ....
        }
        while (#expr) {... continue; .... break; ....}
    } ... } \> post)
```



# KeY and Procedures

In KeY, the default rule is to inline the procedures.

Advantages:

- No function contract needed.
- No separate proof for correctness of function needed.

But it has several disadvantages:

- Proof gets larger (especially important if proof is interactive).
- Proof has to be repeated for every function call.
- No recursive procedures possible.

# The rule Use Operation Contract

The rule “Use Operation Contract” allows compositional proofs.

It opens three subgoals:

- Pre: Show that pre-condition holds (this includes class invariants).
- Post: Show that with the post-condition, the remaining program is correct.
- Exceptional Post: Show that if called method throws an exception, the remaining program is correct.

**Note:** Use Operation Contract cannot be used for the method you are just proving.