

ESC/Java2

Use and Features

David Cok, Joe Kiniry, Erik Poll

Eastman Kodak Company, University College Dublin,
and Radboud University Nijmegen

David Cok, Joe Kiniry & Erik Poll - ESC/Java2 & JML Tutorial - p.1/??

Structure of ESC/Java2

ESC/Java2 consists of a

- parsing phase (syntax checks),
- typechecking phase (type and usage checks),
- static checking phase (reasoning to find potential bugs) - runs a behind-the-scenes prover called Simplify

Parsing and typechecking produce **cautions** or **errors**.

Static checking produces **warnings**.

*The focus of ESC/Java2 is on static checking, but reports of bugs, unreported errors, confusing messages, documentation or behavior, and even just email about your application and degree of success are **Very Welcome**. [and Caution: this is still an **alpha** release]*

David Cok, Joe Kiniry & Erik Poll - ESC/Java2 & JML Tutorial - p.3/??

The ESC/Java2 tool

David Cok, Joe Kiniry & Erik Poll - ESC/Java2 & JML Tutorial - p.2/??

Running ESC/Java2

- Download the binary distribution from <http://secure.ucd.ie/products/opensource/ESCJava2>
- Untar the distribution and follow the instructions in **README.release** about setting environment variables.
- Run the tool by doing one of the following:
 - Run a script in the release: **escjava2** or **escj.bat**
 - Run the tool directly with **java -cp esctools2.jar escjava.Main**, but then you need to be sure to provide values for the **-simplify** and **-specs** options.
 - Run a GUI version of the tool by double-clicking the release version of **esctools2.jar**
 - Run a GUI version of the tool by executing it with **java -jar esctools2.jar** (in which case you can add options).

David Cok, Joe Kiniry & Erik Poll - ESC/Java2 & JML Tutorial - p.3/??

ESC/Java2 is supported on

- Linux
- MacOSX
- Cygwin on Windows
- Windows (but there are some environment issues still to be resolved)
- Solaris (in principle - we are not testing there)

Note that the tool itself is relatively portable Java, but the underlying prover is a Modula-3 application that must be compiled and supplied for each platform.

Help with platform-dependence issues is welcome.

The application relies on the environment having

- a Simplify executable (such as Simplify-1.5.4.macosx) for your platform, typically in the same directory as the application's jar file;
- the **SIMPLIFY** environment variable set to the name of the executable for this platform;
- a set of specifications for Java system files - by default these are bundled into the application jar file, but they are also in **jmlspecs.jar**.
- The scripts prefer that the variable **ESCTOOLS_RELEASE** be set to the directory containing the release.

Command-line options

The items on the command-line are either options and their arguments or input entries. Some commonly used options (see the documentation for more):

- **-help** - prints a usage message
- **-quiet** - turns off informational messages (e.g. progress messages)
- **-nowarn** - turns off a warning
- **-classpath** - sets the path to find referenced classes [best if it contains '?']
- **-specs** - sets the path to library specification files
- **-simplify** - provides the path to the simplify executable
- **-f** - the argument is a file containing command-line arguments
- **-nocheck** - parse and typecheck but no verification
- **-routine** - restricts checking to a single routine
- **-eajava, -eajml** - enables checking of Java assertions
- **-counterexample** - gives detailed information about a warning

Input entries

The input entries on the command-line are those classes that are actually checked. Many other classes may be referenced for class definitions or specifications - these are found on the classpath (or sourcepath or specspath).

- **file names** - of java or specification files (relative to the current directory)
- **directories** - processes all java or specification files (relative to the current directory)
- **package** - (fully qualified name) - found on the classpath
- **class** - (fully qualified name) - found on the classpath
- **list** - (prefaced by **-list**) - a file containing input entries

- Specifications may be added directly to .java files
- Specifications may alternatively be added to specification files.
 - No method bodies
 - No field initializers
 - Recommended suffix: `.refines-java`
 - Recommend a `refines` annotation (see documentation)
 - Must also be on the classpath

Bag demo

```
package java.lang;
import java.lang.reflect.*;
import java.io.InputStream;

public final class Class implements java.io.Serializable {

    private Class();

    /*@ also public normal_behavior
       @ ensures \result != null && !\result.equals("")
       @      && (* \result is the name of this class object *)
       @*/
    public /*@ pure @*/ String toString();

    ....
}
```

modular reasoning

ESC/Java2 reasons about every method individually. So in

```
class A{
    byte[] b;
    public void n() { b = new byte[20]; }
    public void m() { n();
                     b[0] = 2;
                     ...
    }
```

ESC/Java2 warns that `b[0]` may be a null dereference here, even though you can see that it won't be.

To stop ESC/Java2 complaining: add a postcondition

```
class A{
  byte[] b;
  //@ ensures b != null && b.length == 20;
  public void n() { b = new byte[20]; }
  public void m() { n();
                  b[0] = 2;
                  ... }
}
```

So: property of method that is relied on has to be made explicit.

Also: subclasses that override methods have to preserve these.

David Cok, Joe Kiniry & Erik Poll - ESC/Java2 & JML Tutorial – p.13/??

modular reasoning

To stop ESC/Java2 complaining here: add an invariant

```
class A{
  byte[] b;
  //@ invariant b != null && b.length == 20;
  // or weaker property for b.length ?
  public void A() { b = new byte[20]; }
  public void m() { b[0] = 2;
                  ... }
}
```

So again: properties you rely on have to be made explicit.

And again: subclasses have to preserve these properties.

David Cok, Joe Kiniry & Erik Poll - ESC/Java2 & JML Tutorial – p.15/??

Similarly, ESC/Java will complain about `b[0] = 2` in

```
class A{
  byte[] b;
  public void A() { b = new byte[20]; }
  public void m() { b[0] = 2;
                  ... }
}
```

Maybe you can see that this is a spurious warning, though this will be harder than in the previous example: you'll have to inspect *all* constructors and *all* methods.

David Cok, Joe Kiniry & Erik Poll - ESC/Java2 & JML Tutorial – p.15/??

assume

Alternative to stop ESC/Java2 complaining: add an assumption:

```
...
//@ assume b != null && b.length > 0;
b[0] = 2;
...
```

Especially useful during development, when you're still trying to discover hidden assumptions, or when ESC/Java2's reasoning power is too weak.

(requires can be understood as a form of assume.)

David Cok, Joe Kiniry & Erik Poll - ESC/Java2 & JML Tutorial – p.15/??

need for assignable clauses

```

class A{
  byte[] b;
  ...
  public void m() { ...
    b = new byte[3];
    //@ assert b[0] == 0; // ok!
    o.n(...);
    //@ assert b[0] == 0; // ok?
    ...
  }
}

```

What does ESC/Java need to know about `o.n` to check the second assert ?

David Cok, Joe Kiniry & Erik Poll - ESC/Java2 & JML Tutorial – p.17/??

need for assignable clauses

```

class A{
  byte[] b;
  ...
  public void m() { ...
    b = new byte[3];
    //@ assert b[0] == 0; // ok!
    o.n();
    //@ assert b[0] == 0; // ok?
    ...
  }
}

```

If the postcondition of `o.n` doesn't tell us `b` won't be not null – and can't be expected to – we need the assignable clause to tell us that `o.n` won't affect `b[0]`.

Declaring `o.n` as pure would solve the problem.

David Cok, Joe Kiniry & Erik Poll - ESC/Java2 & JML Tutorial – p.19/??

need for assignable clauses

```

class A{
  byte[] b;
  ...
  public void m() { ...
    b = new byte[3];
    //@ assert b[0] == 0; // ok!
    o.n(b);
    //@ assert b[0] == 0; // ok?
    ...
  }
}

```

A detailed spec for `o.n` might give a postcondition saying that `b[0]` is still 0.

David Cok, Joe Kiniry & Erik Poll - ESC/Java2 & JML Tutorial – p.18/??

ESC/Java is not complete

ESC/Java may produce warnings about correct programs.

```

/*@ requires 0 < n;
   @ ensures \result ==
   @          (\exists int x,y,z;
   @          pow(x,n)+pow(y,n) == pow(z,n));
   @*/
public static boolean fermat(double n) {
  return (n==2);
}

```

Warning: *postcondition possibly not satisfied*
(Typically, the theorem prover times out in complicated cases.)

David Cok, Joe Kiniry & Erik Poll - ESC/Java2 & JML Tutorial – p.19/??

ESC/Java may fail to produce warning about incorrect program.

```
public class Positive{
    private int n = 1;  //@ invariant n > 0;

    public void increase(){ n++; }
}
```

ESC/Java(2) produces no warning, but `increase` may break the invariant, namely if `n` is $2^{32} - 1$.

This can be fixed by improved model of Java arithmetic, but this does come at a price (both in specs and in code).

David Cok, Joe Kiniry & Erik Poll - ESC/Java2 & JML Tutorial – p.21/??

ESC/Java is not sound

```
public class A{
    B b;
    int x;
    //@ invariant x <= b.y;
    void decr_x(){ x++; }
}

public class B{
    int y;

    void incr_y(){ y++; }
}

public class D{
    B b;
    void decr_y(){
        b.y--; }
}
```

How can `D` know it might be breaking `A`'s invariant?

David Cok, Joe Kiniry & Erik Poll - ESC/Java2 & JML Tutorial – p.23/??

More fundamental problem: **sound modular verification for OO programs with invariants.**

```
public class A{
    B b;
    int x;
    //@ invariant x <= b.y;
    void decr_x(){
        x--; }
}

public class B{
    int y;
    void decr_y(){
        y--; }
}
```

How can we know that invoking `decr_y` on some `B` won't break the invariant of some `A`, or some object whose invariant depends on a `B` object.

David Cok, Joe Kiniry & Erik Poll - ESC/Java2 & JML Tutorial – p.24/??

Modularity problem

Modular verification for (open) OO programs with invariants is a big & fundamental problem. Most verification tools fail here. Root causes:

1. invariants talking about another object's fields
2. object modifying another object's field
3. possibility of **aliasing**

NB 1 & 2 are unavoidable, eg. think of an object modifying – or its invariant mentioning – the contents of an array field

Alias control and ownership might provide solutions, eg. universes by Peter Müller & co or explicit pack/unpack operations by Rustan Leino & co.

David Cok, Joe Kiniry & Erik Poll - ESC/Java2 & JML Tutorial – p.25/??