Beyond Hoare Logic Assertions

Advanced Specification and Verification with JML and ESC/Java2

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- JML community
  - led by Gary Leavens and major participants Yoonsik Cheon, Curtis Clifton, Todd Millstein, and Patrice Chalin
- verification community
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JML: The Java Modeling Language

- a behavioral interface specification language
- syntax and semantics are very close to Java
- annotations written as comments in code
- JML is a rich language (some say too rich)
  - core constructs include preconditions, postconditions, invariants, etc.
- one language used for documentation, runtime checking, and formal verification

Deconstructing JML

- JML is a *research* specification language
  - if you need a new keyword, just ask for it
  - a very rich specification language, but...
  - JML's size is overwhelming to new users and interested researchers
- thus, JML is being "deconstructed" to document which parts are core with a fixed semantics across all tools
  - JML level 0 (aka JML_0), $JML_{||}$, etc.

JML is an Open Cooperative Project

Leavens's group at Iowa State	Chalin's group at Concordia, Montreal
Cheon's group at UTEP	David Cok
SpEx and SAnToS group at Kansas State (Hatcliff, Robby)	KeY Project at Univ. Karlsruhe
Dwyer at U. Nebraska	Edwards's group at Virginia Tech.
Flanagan at U. California Santa Cruz	Müller's group at ETH Zürich
Jacob's SoS group at Nijmegen (Poll,...)	Poetzsch-Heffter's group at Kaiserslautern
Kiniry at U. Dublin	Logical group at INRIA Futurs & Université Paris-Sud
Ernst's group, and others, at MIT	Huisman's group at INRIA Sophia-Antipolis

ESC/Java2

- ESC/Java2 is an *extended static checker*
  - based upon DEC/Compaq SRC ESC/Java
  - operates on JML-annotated Java code
  - behaves like a compiler
    - error messages similar to javac & gcc
    - completely automated
    - hides enormous complexity from user

We Write more than just Hoare Assertions

- four different method “outcomes” of a method invocation
  - normal termination
  - exceptional termination
  - non-termination
  - JVM Error
- each of these outcomes has a specific specification construct

Specification of Exceptional Behavior

```
public class Point {
  private /*@ spec_public @*/ int x, y;
  /*@ requires x >= 0;
    @ assignable y;
    @ ensures delta > 0 && y == \old(y + delta) &&
    @         \result == \old(y);
    @ signals_only IllegalArgumentException;
    @ signals (IllegalArgumentException e)
    @         delta < 0 && e != null && y == \old(y);
    @*/
  public int moveUp(int delta);
}
```

Case Analysis with “also”

```
/*@ public normal_behavior
  @   requires x >= 0 && delta > 0;
  @   assignable y;
  @   ensures y == \old(y + delta) &&
  @           \result == \old(y);
  @ also
  @ public exceptional_behavior
  @   requires x >= 0 && delta < 0;
  @   assignable \nothing;
  @   signals_only IllegalArgumentException;
  @*/
public int moveUp(int delta);
```

Desugaring

```
/*@ public behavior
  @   requires (x >= 0 && delta > 0) ||
  @            (x >= 0 && delta < 0);
  @   assignable y;
  @   ensures (\old(x >= 0 && delta > 0) ==>
  @           (y == \old(y + delta) &&
  @            \result == \old(y))) &&
  @           (\old(x >= 0 && delta < 0) ==> false);
  @   signals_only IllegalArgumentException;
  @   signals (Exception e)
  @     (\old(x >= 0 && delta > 0) ==> false) &&
  @     (\old(x >= 0 && delta < 0) ==> true &&
  @      \not_assigned(y));
  @*/
public int moveUp(int delta);
```

Specification Inheritance

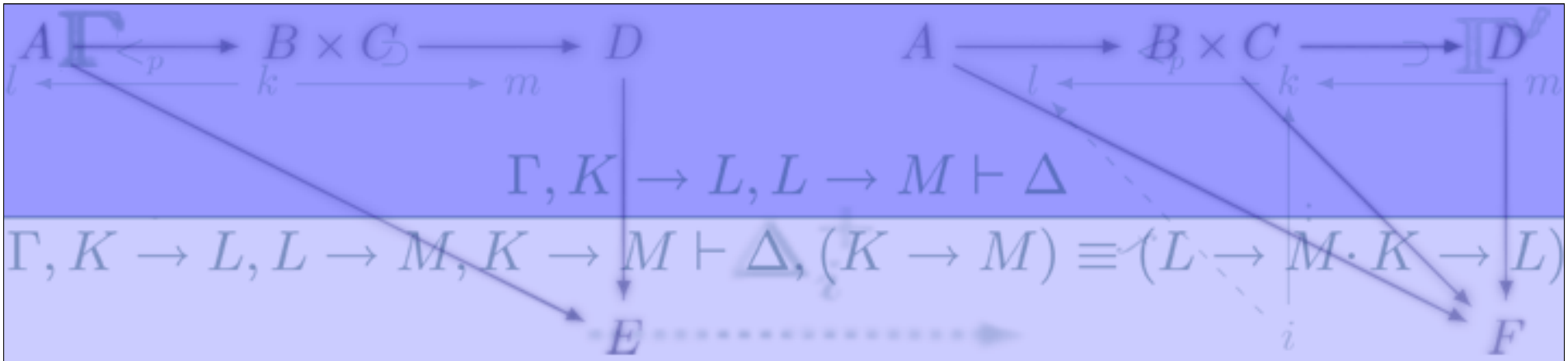
```
public class Super {
  /*@ public behavior B1 @*/
  public T m();
}
public class Sub extends Super {
  /*@ also public behavior B2 @*/
  public T m();
}
```

Completed Specification of Subclass

```
public class Sub extends Super {
  /*@ public behavior B1
    @ also public behavior B2 @*/
  public T m();
}
```

What Gets Inherited?

- specifications of instance methods (with “also”)
- fields and associated specifications
- instance invariants and constraints
- forces behavioral subtyping
  - subtypes are behavioral subtypes
  - if try to avoid it, you get an unimplementable specification
  - thus, need to underspecify supertypes



“Advanced” JML

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Frame Axioms

- necessary for modular reasoning
- default is too loose to be useful
- originally only focused on outbound references (assignable/modifies clauses)
- now must specify inbound references for reasoning about concurrent programs
  - rely-guarantee style

Data Groups

- data groups are used in frame axioms
- they are used to define
  - sets of related fields
  - fields with interdependencies
  - fields are concrete or specification-only
- built-in datagroup is called objectState

Ghost Variables

- specification-only variables from which one can read and to which one can write
- typically used to represent
  - simplified ownership
  - object state
  - element and key types
  - specification-only constants
  - explicit specification variables

Model Variables

- used to model
  - abstractions of classes and objects
  - generic mathematical abstractions
  - implicit specification variables
- can be refined to concrete representations
  - functionally
  - relationally

Other Model Constructs

- specification-only classes, methods, and programs with optional
  - semantics
  - implementation
- sometimes used for
  - fixed base specification for reference and refinement
  - helper methods to shorten or clarity complex specifications

Current Research

- integration of multiple theorem provers
- support multiple logics concurrently
- new (sub)logics for new (sub)problems
- identifying and specifying security properties
- new constructs like functional, immutable, several different kinds of purity, atomicity