Property Specifications - Lecture 2

- Assertions
  - Basics
  - JML
- Verification Conditions,
- Hoare Logics,

Assertations/Specifications

- Assertions/Specifications
  - Precise, formal specifications concerning the behavior of some unit of code
  - Usually written in a language separate from programming language.
  - Used for documentation, verification, runtime monitoring, testing

Assertions - Types

Invariants (from Wikipedia) - A predicate that will always keep its truth value throughout a specific sequence of operations, is called (an) **invariant** to that sequence.

State Invariants

Loop Invariants

Pre-conditions/Post-Conditions - Pre- and post-conditions are constraints that define a contract that an implementation of the operation has to fulfill. A precondition must hold when an operation is called, a postcondition must be true when the operation returns.

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Invariants

- Definition
  - An *invariant* is a property that is always true of an object's state (when control is not inside the object's methods).
- Invariants allow you to define:
  - Acceptable states of an object, and
  - Consistency of an object's state.

```
//@ public invariant !name.equals(“”) && weight
   >= 0;
```

Pre and Postconditions

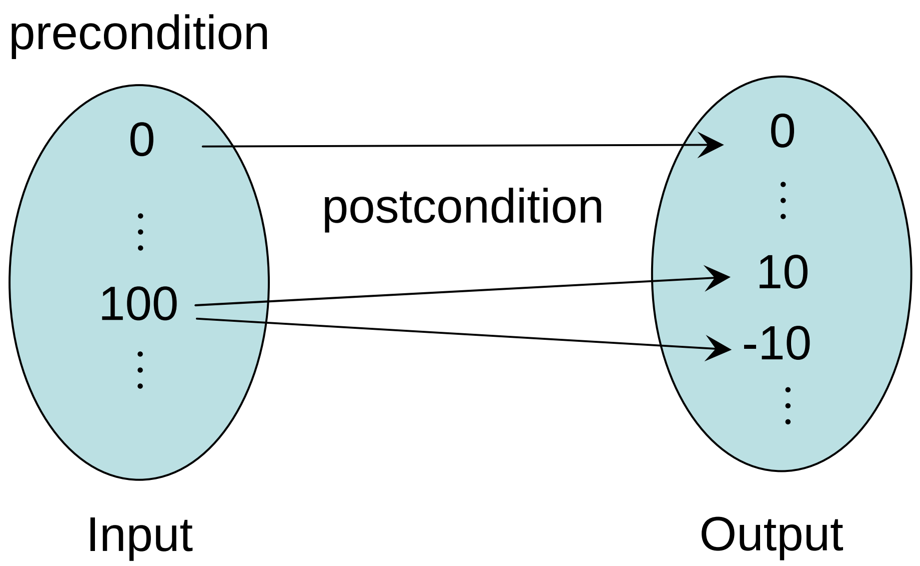
- Definition
  - A method or function *precondition* says what must be true to call it.
  - A method or function *normal postcondition* says what is true when it returns normally (i.e., without throwing an exception).
  - A method or function *exceptional postcondition* says what is true when a method throws an exception.

```
//@ signals (IllegalArgumentException e) x < 0;
```

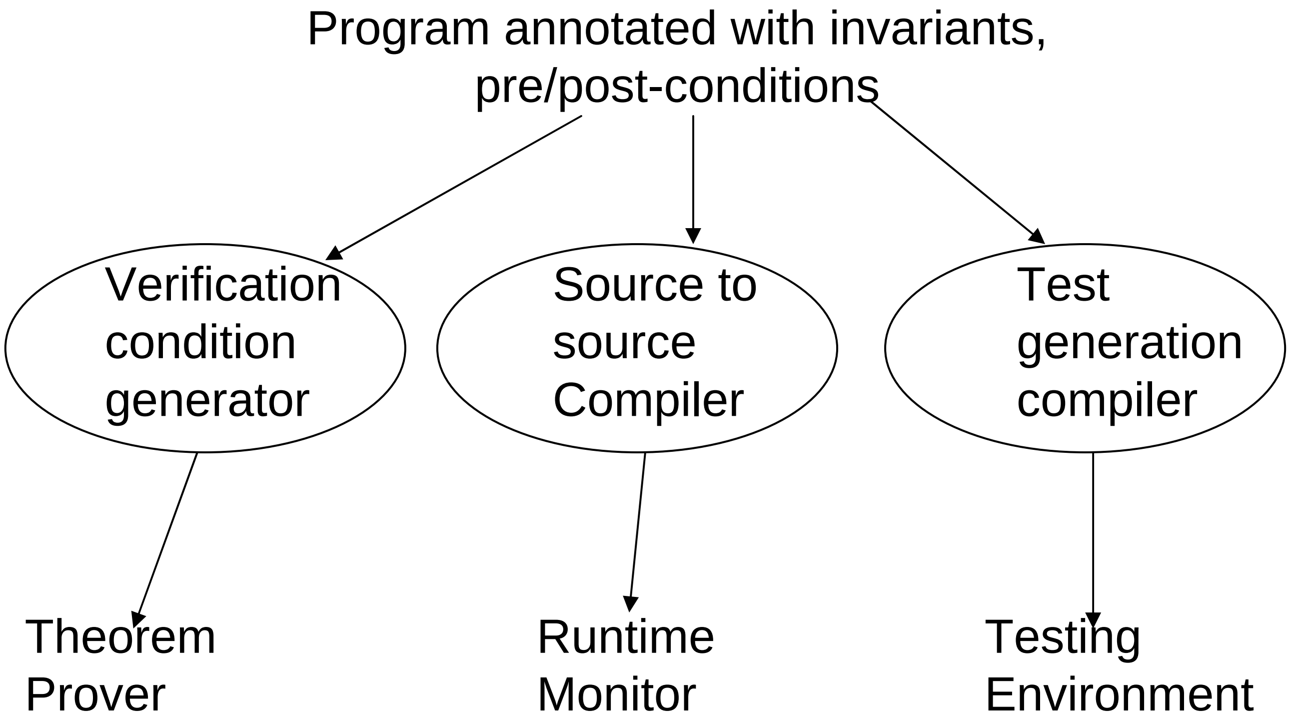
Relational Model of Methods

- Can think of a method as a relation:

  Inputs $\leftrightarrow$ Outputs



Assertions – How Used



Relationship to Temporal Logic

Temporal logic predicates are same as assertion/specfication predicates.

Assertion specifications are local with respect to some code unit (composed by Hoare logic rules)

Temporal logic predicates apply to states during execution of some code unit and are defined on paths or structures of paths

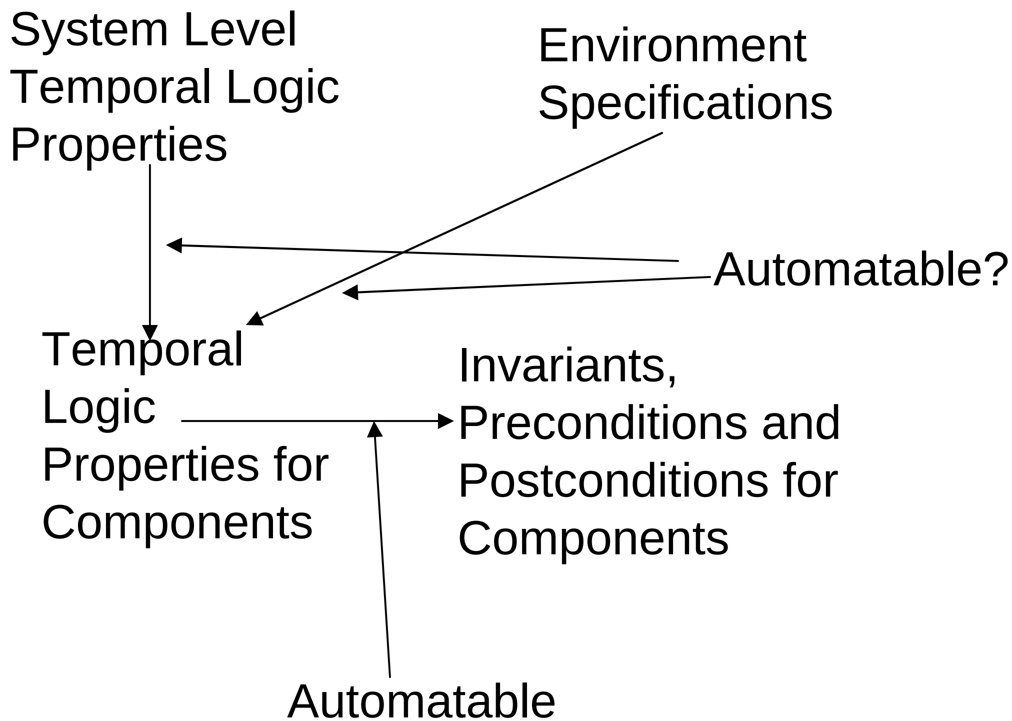
Relationship to Temporal Logic

Temporal logic properties for code units can be composed into properties for larger code units

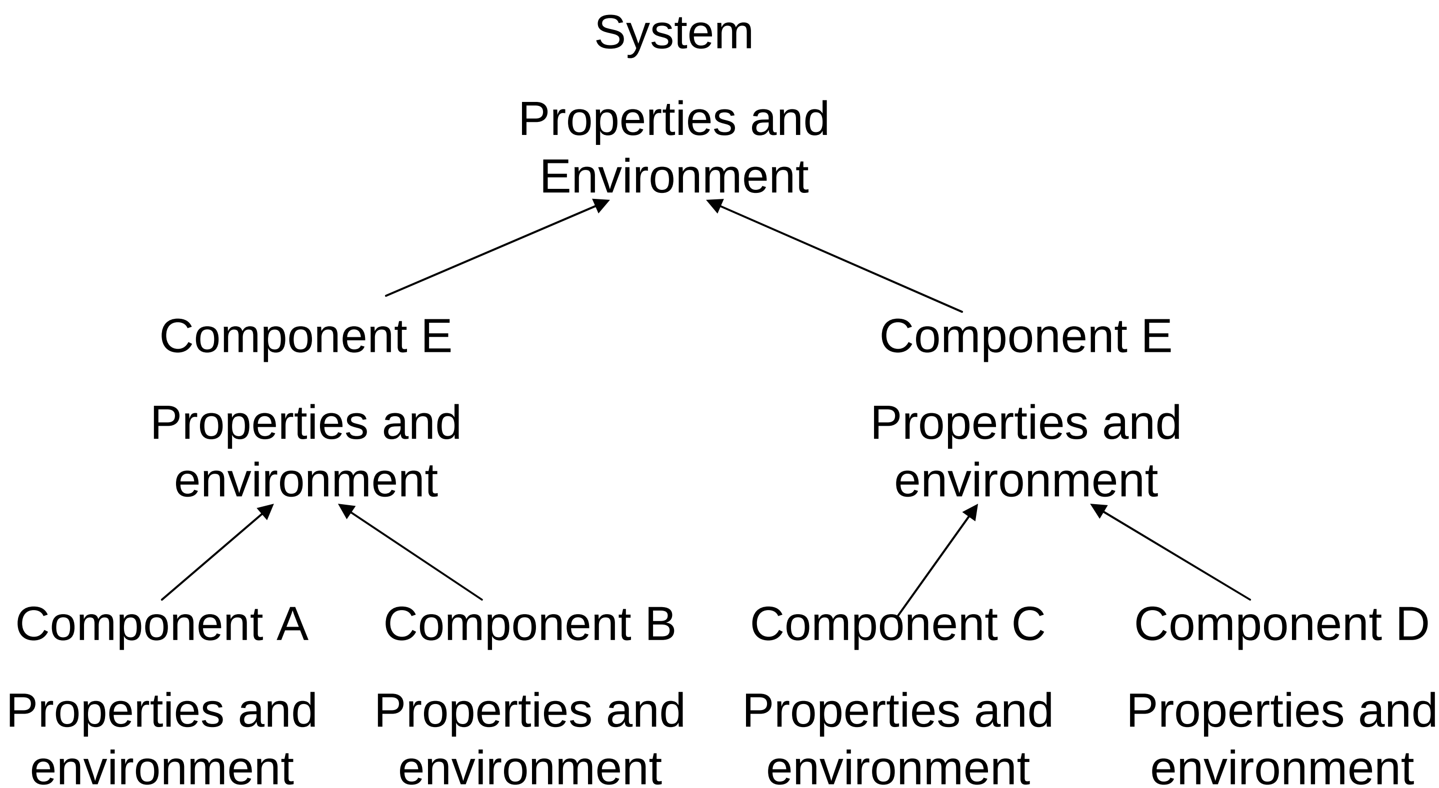
System level temporal logic can be decomposed into component level properties.

Component level temporal logic properties can be translated into invariants, preconditions and postconditions

Relationship to Temporal Logic



Temporal Logic Composition



Decomposition of I/P/P Specifications

System Level Preconditions == Environment Specifications

Automatable?

Component Level Preconditions

Component Level Invariants and Postconditions

Composition of I/P/P Specifications

System Level Preconditions == Environment Specifications

??

Component Level Preconditions

Component Level Invariants and Postconditions

Composition of I/P/P Specifications

System

Invariants, P/P Conditions

Hoare Rules for composition should apply. Automatable??

Component E

Invariants, P/P Conditions

Component E

Invariants, P/P Conditions

Component A

Invariants, P/P Conditions

Component B

Invariants, P/P Conditions

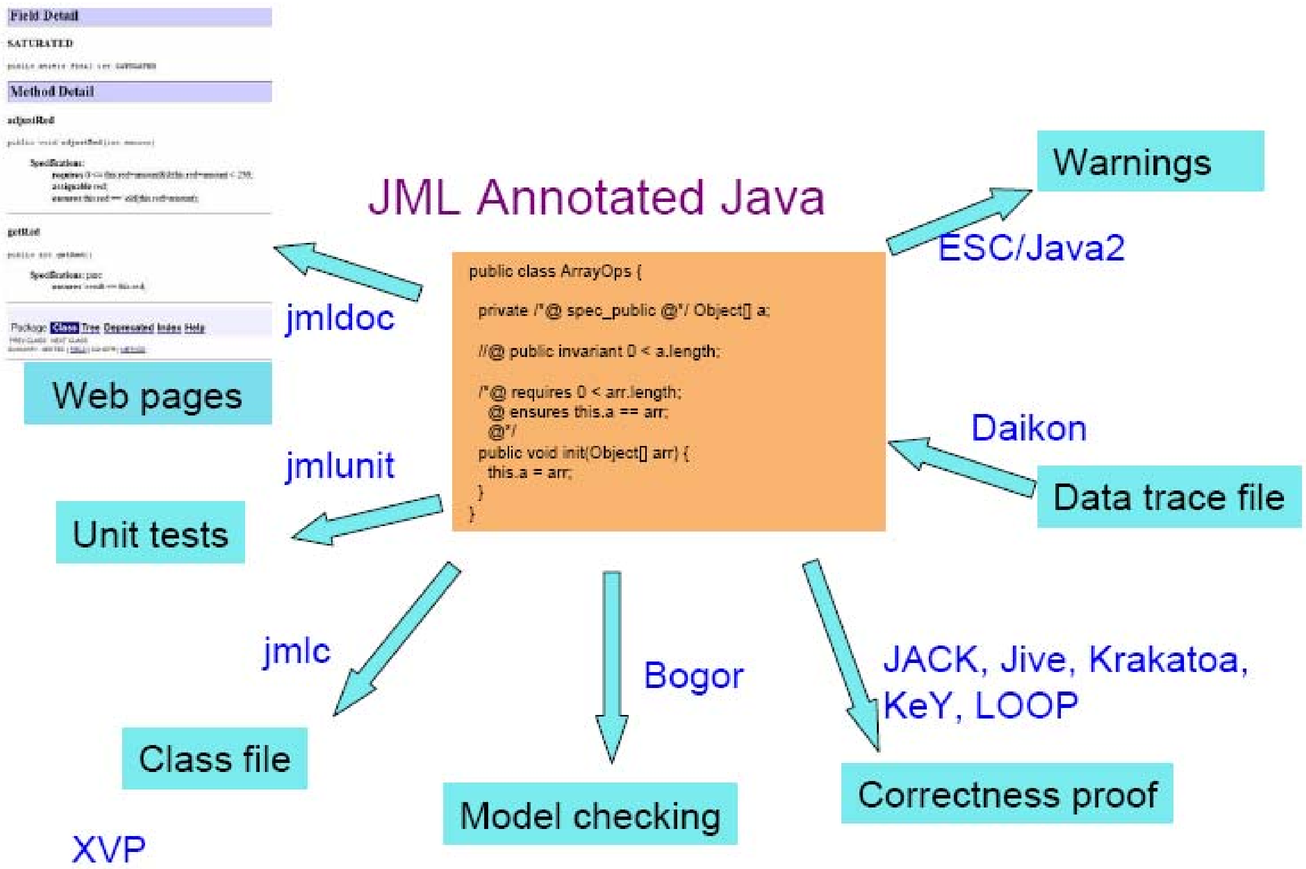
Component C

Invariants, P/P Conditions

Component D

Invariants, P/P Conditions

Tools for JML-Based Verification



Java Modeling Language

Ilustrate Assertions with Java Modeling Language

- Hoare-style (Contracts).
- Method pre- and postconditions.
- Invariants.

Java Modeling Language

- **JML Annotations/Assertions**
- Top-level in classes and interfaces:
  - **invariant**
  - **spec_public**
  - **nullable**
- For methods and constructors:
  - **requires**
  - **ensures**
  - **assignable**
  - **pure**

Example JML

```
public class ArrayOps {
private /*@ spec_public @*/ Object[] a;
//@ public invariant 0 < a.length;
/*@ requires 0 < arr.length;
  @ ensures this.a == arr;
  @*/
public void init(Object[] arr) {
this.a = arr;
}
```

spec_public, nullable, and invariant

- **spec_public**
  - Public visibility.
  - Only public for specification purposes.
- **nullable**
  - field (and array elements) may be null.
  - Default is **non_null**.
- **invariant** must be:
  - True at end of constructor.
  - Preserved by each method.

requires and ensures

- **requires** clause:
  - Precondition.
  - Obligation on callers, after parameter passing.
  - Assumed by implementor.
- **ensures** clause:
  - Postcondition.
  - Obligation on implementor, at return.
  - Assumed by caller.

assignable and pure

- **assignable**
  - Frame axiom.
  - Locations (fields) in pre-state.
  - New object fields not covered.
  - Mostly checked statically.
  - Synonyms: **modifies**, **modifiable**
- **pure**
  - No side effects.
  - Implies **assignable \nothing**
  - Allows method’s use in specifications.

Redundant Clauses

- **ensures_redundantly**
  - Alerts reader.
  - States something to prove.
  - Must be implied by:
    - **ensures** clauses,
    - **assignable** clause,
    - **invariant**, and
    - JML semantics.
- Also **requires_redundantly**, etc.

Formal Specifications

- Formal assertions are written as Java expressions, but:
  - Can't have side effects
    - No use of =, ++, --, etc., and
    - Can only call *pure* methods.
  - Can use some extensions to Java:

Syntax	Meaning
\result	result of method call
a ==> b	a implies b
a <== b	b implies a
a <==> b	a iff b
a <=!=> b	!(a <==> b)
\old(E)	value of E in the pre-state

BoundedStack’s Data and Invariant

BoundedStack’s Data and Invariant

```
public class BoundedStack {
private /*@ spec_public nullable @*/
Object[] elems;
private /*@ spec_public @*/ int size = 0;
//@ public invariant 0 <= size;
/*@ public invariant elems != null
@ && (\forall int i;
@ size <= i && i < elems.length;
@ elems[i] == null);
@*/
```

BoundedStack’s Constructor

BoundedStack’s Constructor

```
/*@ requires 0 < n;
@ assignable elems;
@ ensures elems.length == n;
@*/
public BoundedStack(int n) {
elems = new Object[n];
}
```

BoundedStack’s push Method

BoundedStack’s push Method

```
/*@ requires size < elems.length1;
@ assignable elems[size], size;
@ ensures size == \old(size+1);
@ ensures elems[size1] == x;
@ ensures_redundantly
@ (\forall int i; 0 <= i && i < size1;
@ elems[i] == \old(elems[i]));
@*/
public void push(Object x) {
elems[size] = x;
size++;
}
```

BoundedStack’s pop Method

BoundedStack’s pop Method

```
/*@ requires 0 < size;
@ assignable size, elems[size1];
@ ensures size == \old(size1);
@ ensures_redundantly
@ elems[size] == null
@ && (\forall int i; 0 <= i && i < size1;
@ elems[i] == \old(elems[i]));
@*/
public void pop() {
size;
elems[size] = null;
}
```

BoundedStack’s top Method

BoundedStack’s top Method

```
/*@ requires 0 < size;
@ assignable \nothing;
@ ensures \result == elems[size1];
@*/
public /*@ pure @*/ Object top() {
return elems[size1];
}
}
```