Java PathFinder

http://d3s.mff.cuni.cz

Pavel Parízek

Department of Distributed and Dependable Systems

CHARLES UNIVERSITY IN PRAGUE
faculty of mathematics and physics
Java PathFinder (JPF)

- Verification framework for Java programs
  - Explicit state space traversal (with POR)
  - Highly customizable and extensible (API)

- Open source since April 2005
  - Maintainers: NASA Ames Research Center

- WWW: http://babelfish.arc.nasa.gov/trac/jpf
What JPF really is ...

- Special JVM
  - Execution choices
  - Backtracking
  - State matching

- State space exploration
  - assertions, deadlocks, races, ...
General usage pattern

System under Test (Java bytecode) → JPF → report

JPF Configuration (properties to verify)

Picture taken from JPF wiki (http://babelfish.arc.nasa.gov/trac/jpf/wiki)
Architecture

Picture taken from JPF wiki (http://babelfish.arc.nasa.gov/trac/jpf/wiki)
Program state space in JPF

- States
  - Full snapshot of JVM
    - Dynamic heap
    - Thread stacks
    - Program counters
    - Static data (classes)
    - Locks and monitors
Program state space in JPF

- Transitions
  - Non-empty sequences of bytecode instructions
  - Terminates when JPF makes a new choice
Program state space in JPF

- Choices
  - Thread scheduling
  - Data (boolean, int)
On-the-fly state space construction

public Producer extends Thread {
    void run() {
        while (true) {
            d.buf = i;
            i++;
            d.count++;
        }
    }
}

public Consumer extends Thread {
    void run() {
        while (true) {
            k = d.buf;
            print(k);
        }
    }
}

public static void main(...) {
    Data d = new Data();
    new Producer(d).start();
    new Consumer(d).start();
}
On-the-fly state space construction

```java
public Producer extends Thread {
    void run() {
        while (true) {
            d.buf = i;
            i++;
            d.count++;
        }
    }
}

class Consumer extends Thread {
    void run() {
        while (true) {
            k = d.buf;
            print(k);
        }
    }
}

public static void main(...) {
    Data d = new Data();
    new Producer(d).start();
    new Consumer(d).start();
}
```
On-the-fly state space construction

public Producer extends Thread {
    void run() {
        while (true) {
            d.buf = i;
            i++;
            d.count++;
        }
    }
}

public Consumer extends Thread {
    void run() {
        while (true) {
            k = d.buf;
            print(k);
        }
    }
}

public static void main(...) {
    Data d = new Data();
    new Producer(d).start();
    new Consumer(d).start();
}
Properties

• Built-in
  - Deadlock freedom
  - Race conditions
  - Uncaught exceptions
  - Assertions
Features

- Partial order reduction
- Class loading symmetry
- Heap symmetry
- Selected heuristics
Running JPF
Running JPF

- Download JPF and unpack somewhere
  - [http://d3s.mff.cuni.cz/teaching/program_analysis_verification/files/JPF.zip](http://d3s.mff.cuni.cz/teaching/program_analysis_verification/files/JPF.zip)

- Example: Dining Philosophers
  - **Command:** `java -jar build\RunJPF.jar src\examples\DiningPhil.jpf`

- Output: application, error info, statistics
**Error info**

- Full error trace (counterexample)
- Snapshot of the error state
- Message from the property checker

**Command:**

```
java -jar build\RunJPF.jar +report.console.property_violation =trace,error,snapshot src\examples\DiningPhil.jpf
```
Running JPF

- Examples
  - BoundedBuffer
  - Crossing
  - oldclassic
  - Racer
JPF API

- Listeners
  - Inspecting current program state
- Custom properties
- Search driver

- Advanced
  - Instruction factory
  - Scheduler factory
Listeners

- Observer design pattern
- Notified about specific events
  - JVM: bytecode instruction executed, new heap object allocated, start of a new thread
  - State space traversal: new state, backtrack, finish
- Inspecting current program state
  - heap objects, local variables, thread call stacks, ...
Listeners

- SearchListener
- VMLListener
- ListenerAdapter

Examples (source code)
- JPF/src/main/gov/nasa/jpf/listener
Custom properties

- Property
- GenericProperty

- PropertyListenerAdapter
  - Common practice: decide property status based on listener notifications (and program state)

- Examples (source code)
  - JPF/src/main/gov/nasa/jpf/vm
Registering listeners and properties

```java
listener=<class name 1>,...,<class N>
search.listener=...

search.properties=...
```
Listeners: tracking bytecode instructions

- ExecTracker
- ObjectTracker
Listeners: inspecting program state

- CallMonitor
- ObjectTracker
Task 1

- Write your own listener
  - After every field write instruction, print the field name and new value
  - Before every method call (invoke), print values of all parameters supplied by the caller

- Use existing classes as a basic template
  - ListenerAdapter, VMLListener, CallMonitor, ObjectTracker
  - src/main/gov/nasa/jpf/listener/*
  - src/main/gov/nasa/jpf/jvm/bytecode/*

- Ask questions !!
Configuration properties

- File `jpf.properties`
JPF wiki

- [http://babelfish.arc.nasa.gov/trac/jpf/](http://babelfish.arc.nasa.gov/trac/jpf/)
  - User guide
    - [http://babelfish.arc.nasa.gov/trac/jpf/wiki/user/start](http://babelfish.arc.nasa.gov/trac/jpf/wiki/user=start)
  - Internals (developer guide)
    - [http://babelfish.arc.nasa.gov/trac/jpf/wiki/devel/start](http://babelfish.arc.nasa.gov/trac/jpf/wiki/devel/start)
JPF source code tree

- `src/main/gov/nasa/jpf`
  - the “main” class (JPF), interfaces
  - `vm`: virtual machine, choices, built-in properties
  - `jvm`: Java bytecode specific, instructions, class file
  - `search`: search driver, heuristics
  - `util`: custom data structures, utility classes
  - `report`: reporting system (console, XML)
  - `listener`: various listeners
JPF and native methods
JPF and native methods

- Support for all Java bytecode instructions
  - but some library methods are native
    - file I/O, GUI, networking, ...

- Problem
  - JPF cannot determine how execution of a native method changes the program state

- Solution: Model-Java Interface (MJI)
Model-Java Interface (MJI)

- Executing native methods in the underlying JVM
- Similar mechanism to Java-Native Interface (JNI)
- Custom versions of some Java library classes
  - Object, Thread, Class, java.util.concurrent.*, ...

Diagram:

- Model layer
  - "Model Java Interface" (MJI)
  - Modeled classes
  - JPF (Java application)
- Java layer
  - Library classes
  - Native libraries
- Native layer
  - Host JVM
  - Native libraries
  - Platform OS
Environment construction
Environment construction

- Why: some programs do not contain "main"
  - libraries, components, plug-ins

- Problem: JPF accepts only complete programs

- Solution: create artificial environment
  - Program with multiple threads and data choices
    - Also called “test driver”
Program: `java.util.HashMap`

```java
public class PutTh extends Thread {
    Map m;

    public void run() {
        m.put("1", "abc");
        m.put("2", "def");
    }
}

public class GetTh extends Thread {
    Map m;

    public void run() {
        m.get("1");
        m.get("0");
    }
}

public static void main(...) {
    Map m = new HashMap();
    Thread th1 = new PutTh(m);
    Thread th2 = new GetTh(m);

    th1.start();
    th2.start();

    th1.join();
    th2.join();
}
```
Environment construction – challenges

- **Coverage**
  - Should trigger all (most) execution paths, thread interleavings, and error states

- **Approach**
  - Different method call sequences
  - Many combinations of parameter values
  - Several concurrent threads

- **State explosion**
  - Use the least possible number of concurrent threads (2)
  - Reasonable number of parameter values (domain size)
Using the Verify class

- JPF-aware test drivers (environments)
  - Checking program behavior for different inputs

- Data choice
  ```java
  import gov.nasa.jpf.vm.Verify
  if (Verify.getBoolean())
  int x = Verify.getInt(0, 10)
  ```

- Search pruning
  ```java
  Verify.ignoreIf(cond)
  ```
Task 2

- Write reasonable environment for
  - java.util.LinkedList
  - java.util.concurrent.Semaphore

- Run JPF on the complete program
  - Enable search for data race conditions
    - Use: gov.nasa.jpf.listener.PreciseRaceDetector

- Try different workloads (threads, input data)
Time for questions about JPF

- Architecture
- Implementation
- How something works
- Public API
- Output

- Play with JPF (look into source code, try examples)
- Explore wiki: [http://babelfish.arc.nasa.gov/trac/jpf](http://babelfish.arc.nasa.gov/trac/jpf)
- Ask questions