

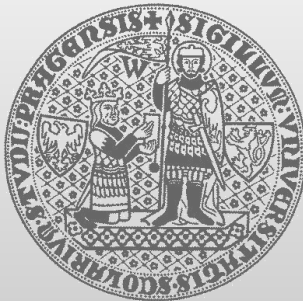
Java PathFinder

<http://d3s.mff.cuni.cz>

Department of
Distributed and
Dependable
Systems



Pavel Parízek



CHARLES UNIVERSITY IN PRAGUE

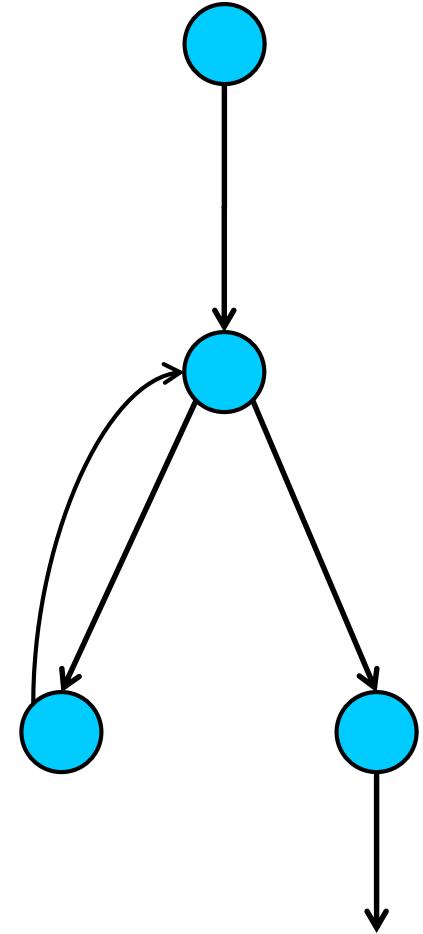
faculty of mathematics and physics

Java Pathfinder (JPF)

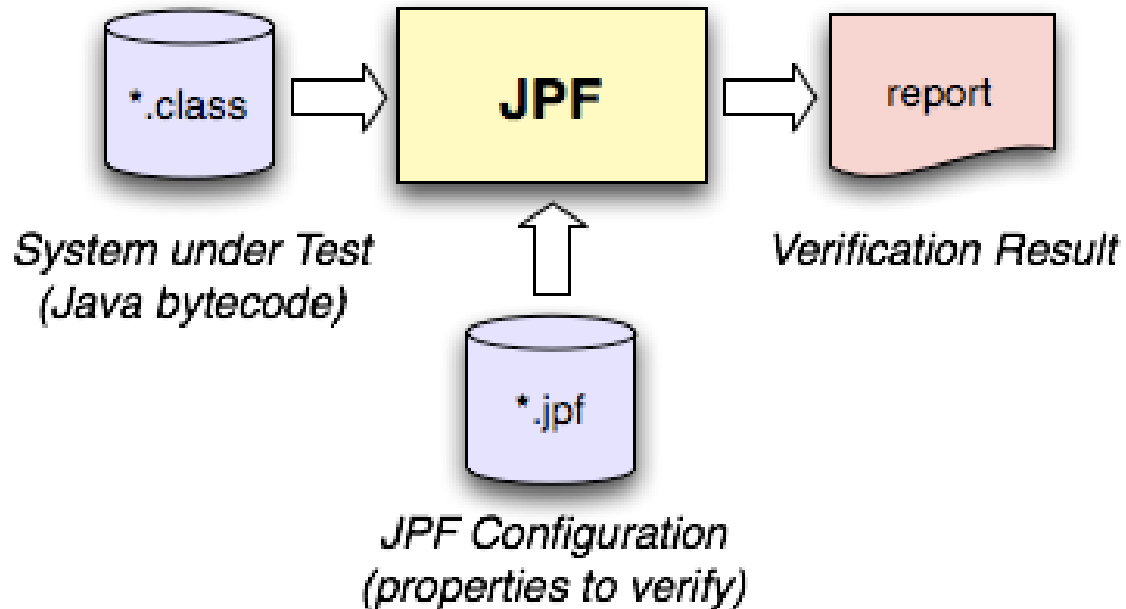
- Verification framework for Java programs
 - Explicit state space traversal (with POR)
 - Highly customizable and extensible (API)
- Open source since April 2005
 - Maintainers: NASA Ames Research Center
- Available on GitHub since 2018
- WWW: <https://github.com/javapathfinder/jpf-core>

What JPF really is ...

- Special JVM
 - Execution choices
 - Backtracking
 - State matching
- State space exploration
 - assertions, deadlocks, races, ...

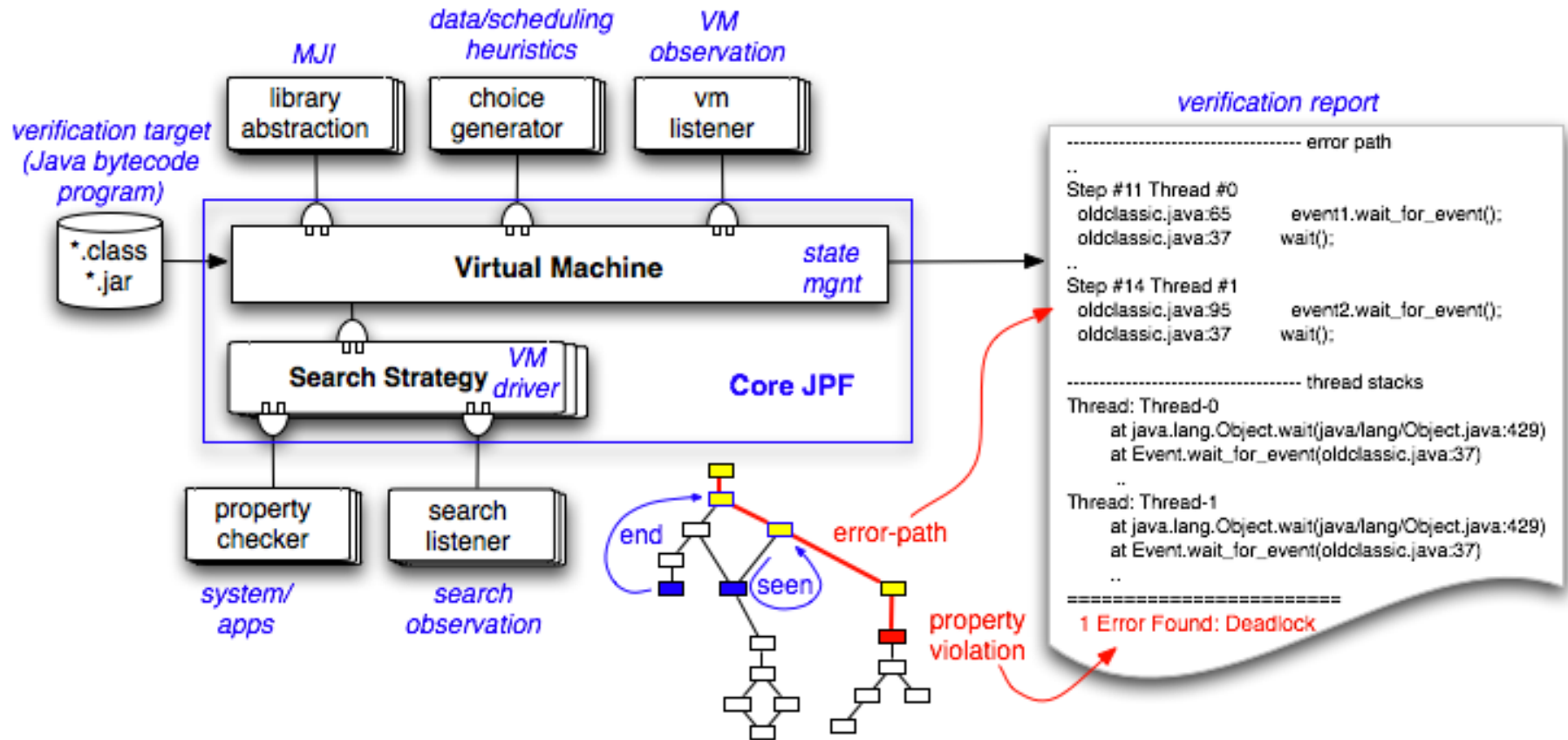


General usage pattern



Picture taken from JPF wiki (<https://github.com/javapathfinder/jpf-core/wiki>)

Architecture



Picture taken from JPF wiki (<https://github.com/javapathfinder/jpf-core/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

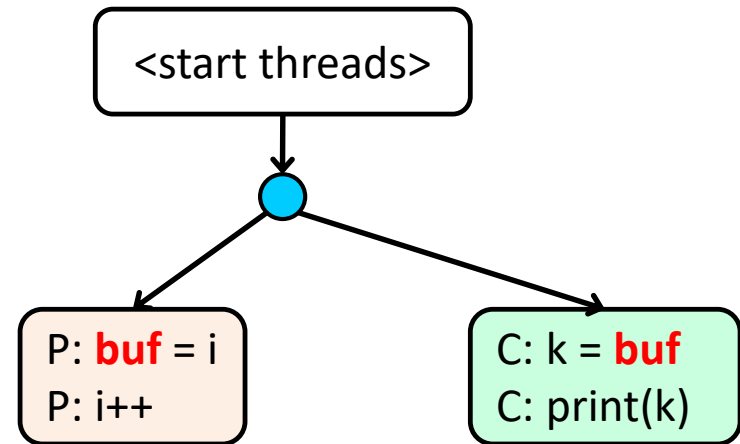
- Choices
 - Thread scheduling
 - Data (boolean, int)

On-the-fly state space construction

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

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

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

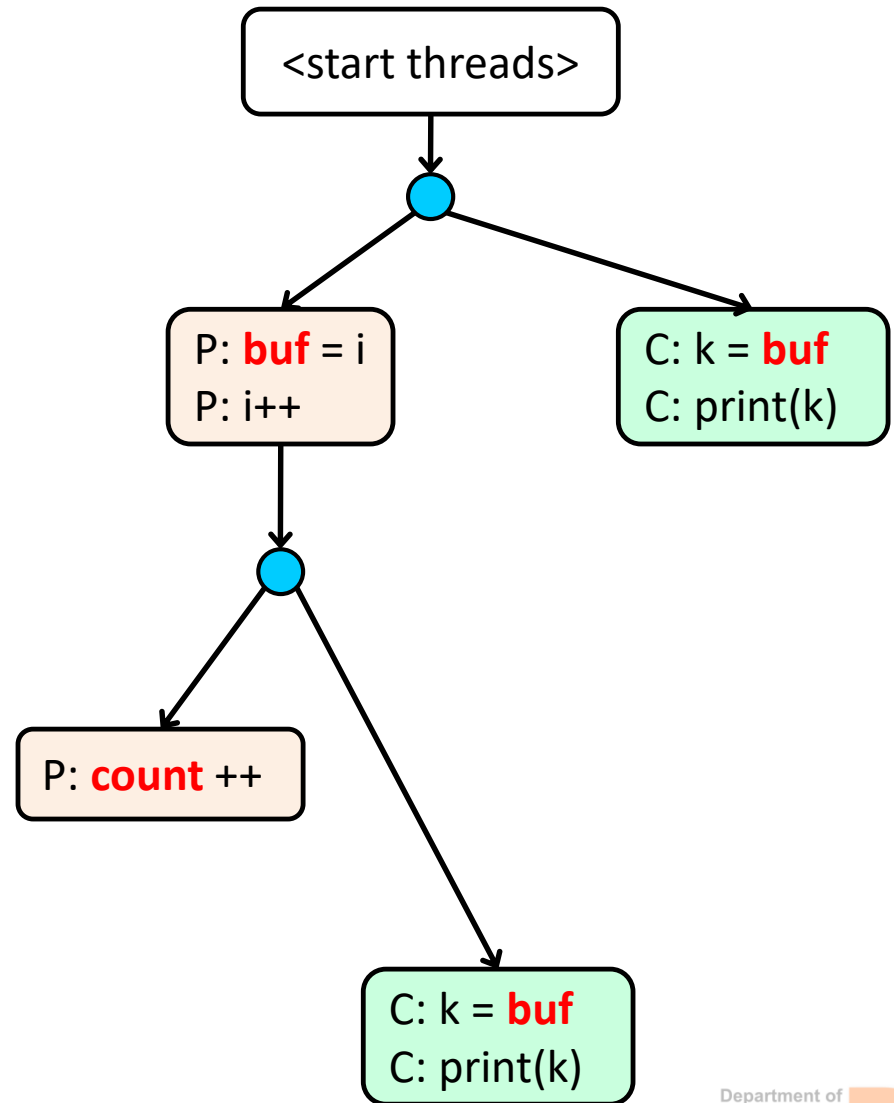


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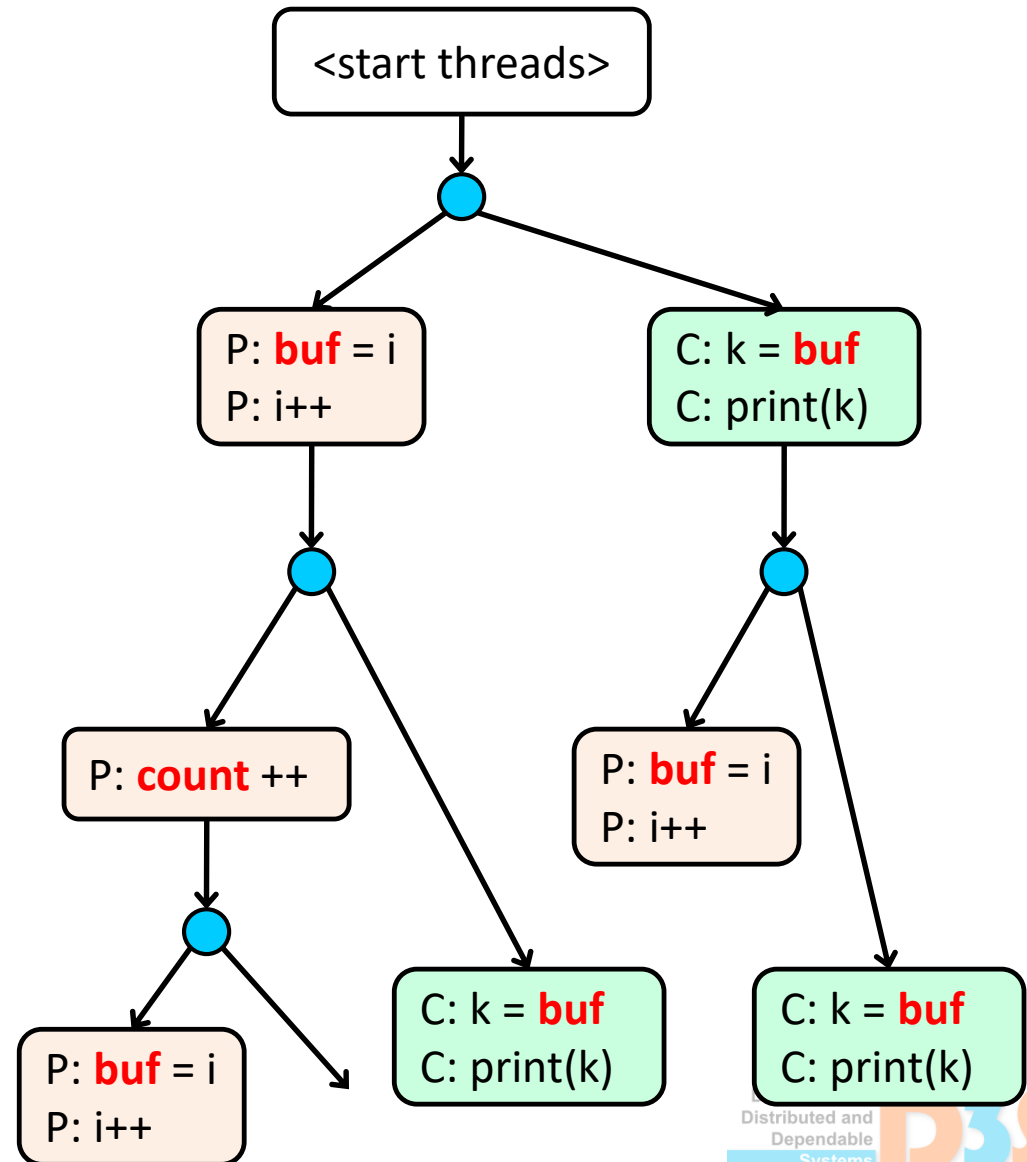


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Properties

- 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
- Example: Dining Philosophers
 - Command: `java -jar build\RunJPF.jar src\examples\DiningPhil.jpjf`
- 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 (bytecode interpreter)
 - Scheduler (sync policy, sharedness policy)

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
- VMListener

- 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

```
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, VMListener, CallMonitor, ObjectTracker
 - `src/main/gov/nasa/jpf/listener/*`
 - `src/main/gov/nasa/jpf/jvm/bytecode/*`
- Ask questions !!

Configuration properties

- File `jpf.properties`



- Main page
 - <https://github.com/javapathfinder/jpf-core/wiki>
- User guide
 - <https://github.com/javapathfinder/jpf-core/wiki/How-to-use-JPF>
- Internals (developer guide)
 - <https://github.com/javapathfinder/jpf-core/wiki/Developer-guide>

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

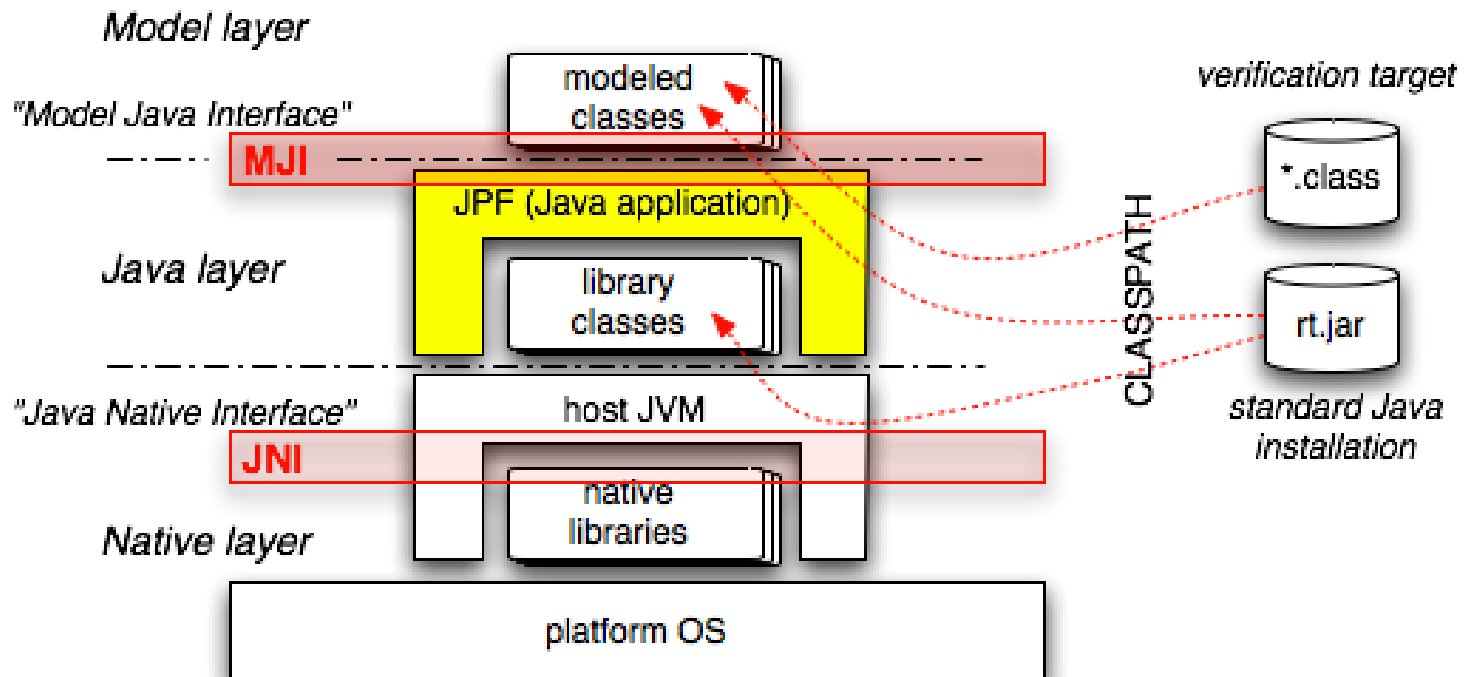


JPF and native methods

- 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.*, ...



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”

Example

- Program: `java.util.HashMap`

```
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

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

- Search pruning

```
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
 - <https://github.com/javapathfinder/jpf-core/wiki>
- Ask questions