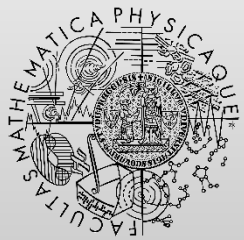
Java PathFinder

http://d3s.mff.cuni.cz

Pavel Parízek



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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

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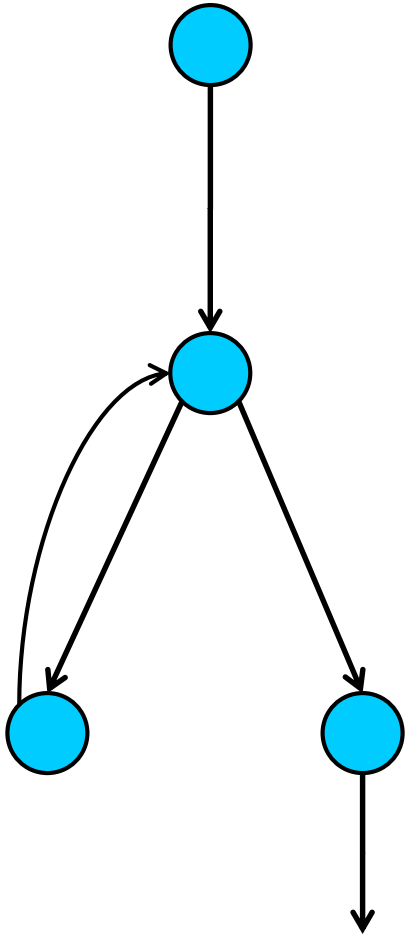
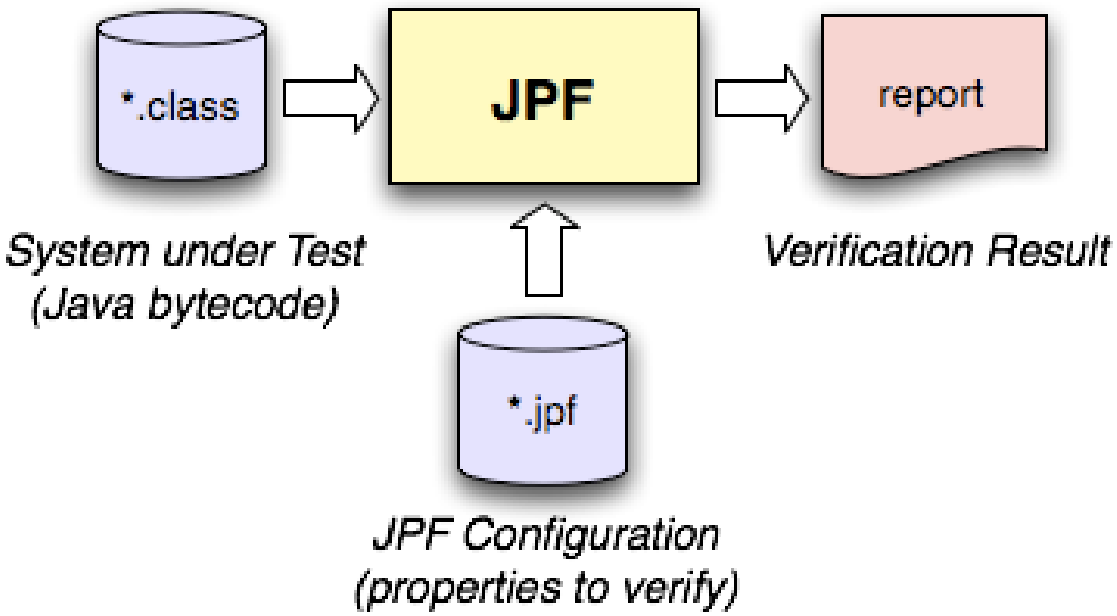
What JPF really is ...

- Special JVM
  - Execution choices
  - Backtracking
  - State matching



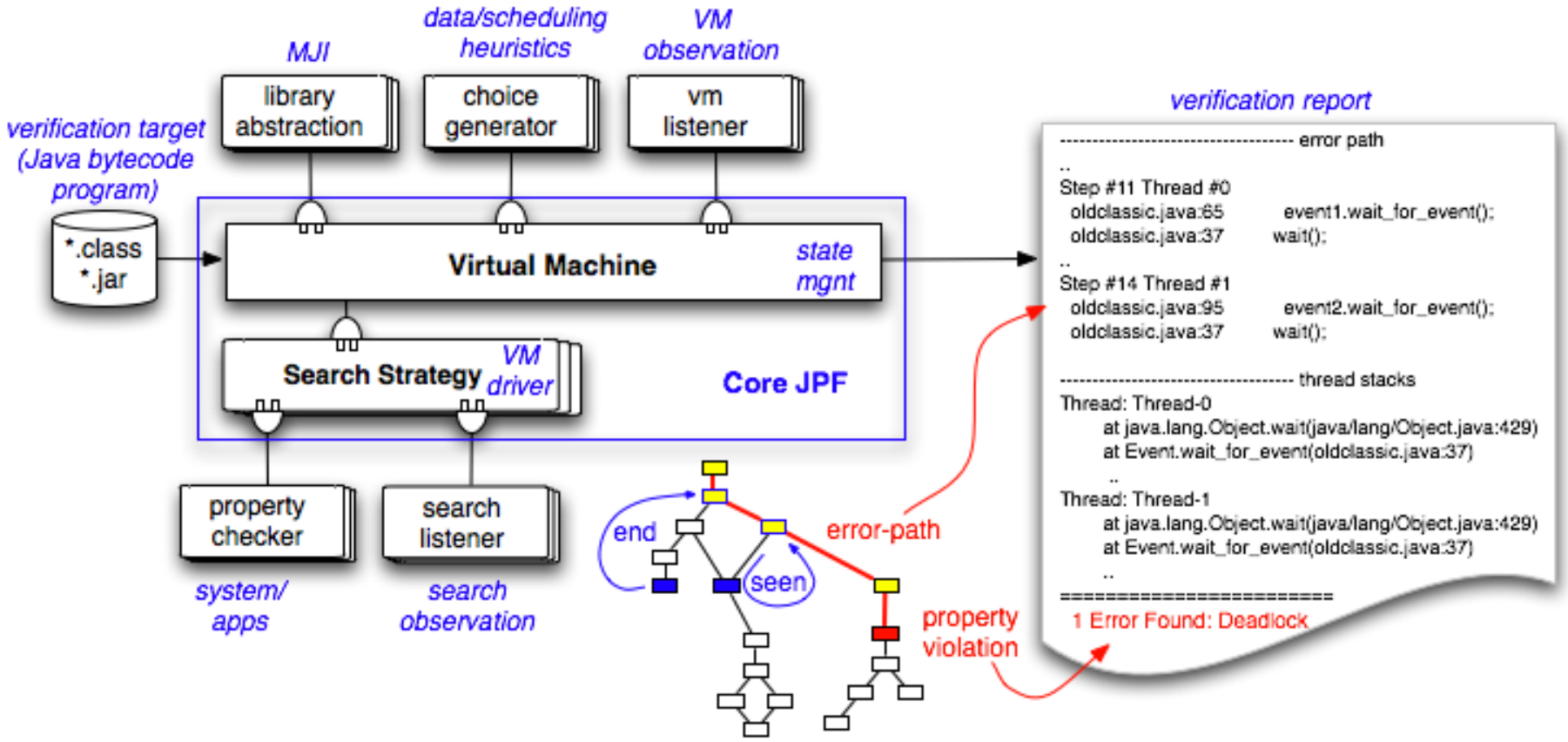
- State space exploration
  - assertions, deadlocks, races, ...

General usage pattern



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

Architecture



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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();
}
```

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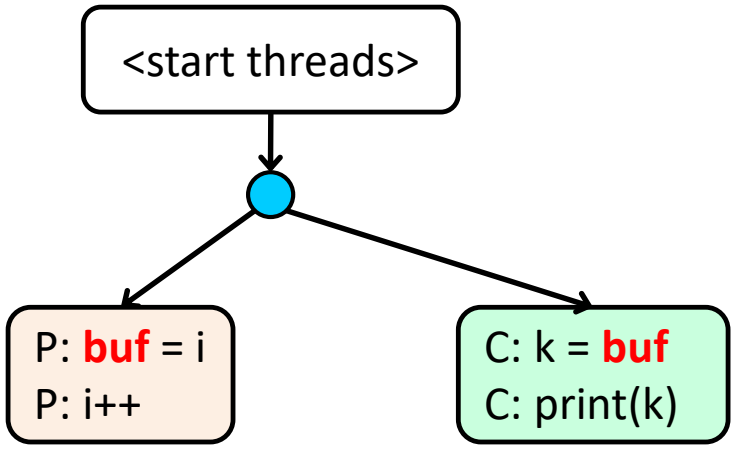

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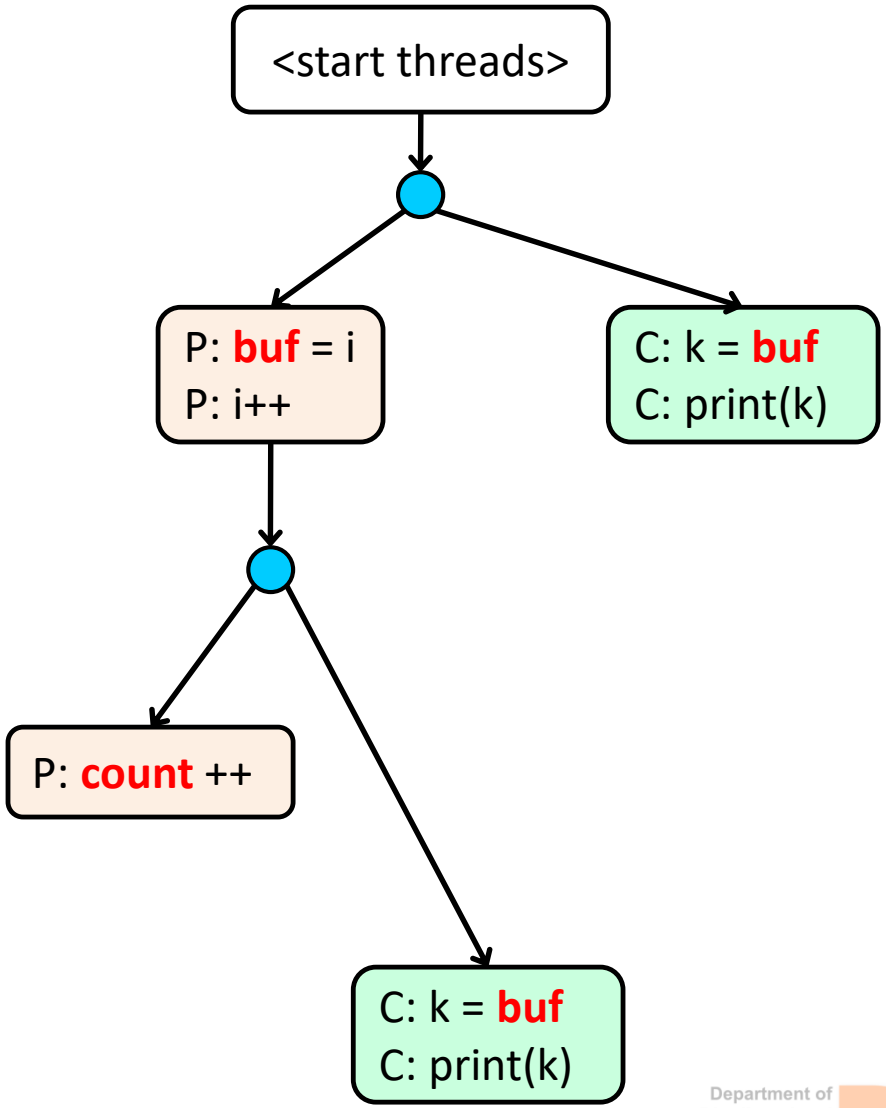

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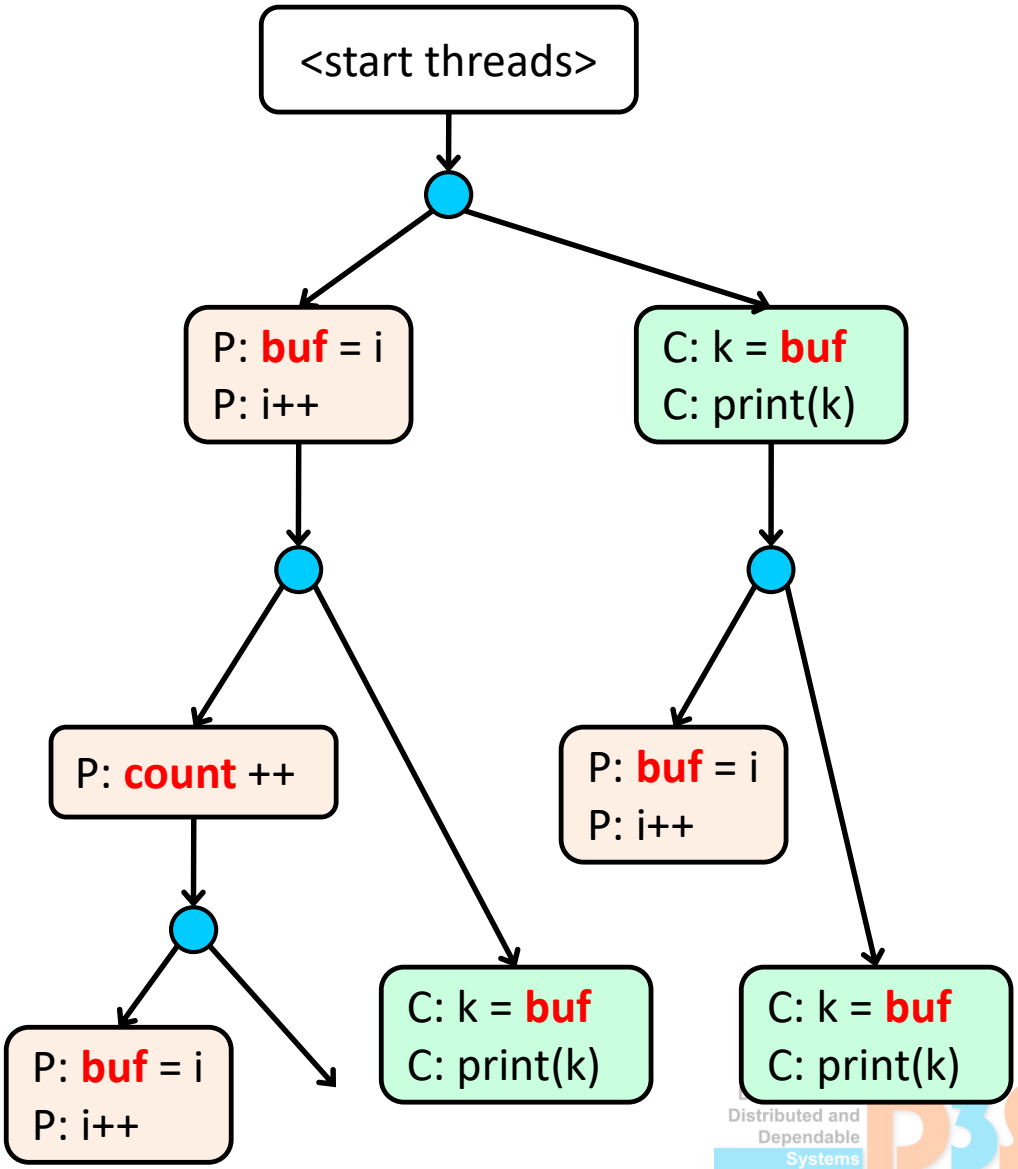

Properties

- 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/files/teaching/nswi132/files/JPF.zip
  - Current stable version runs well on Java 11

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

- Output: application, error info, statistics

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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

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 !!

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Configuration properties

- File `jpf.properties`

JPF wiki

- 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

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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

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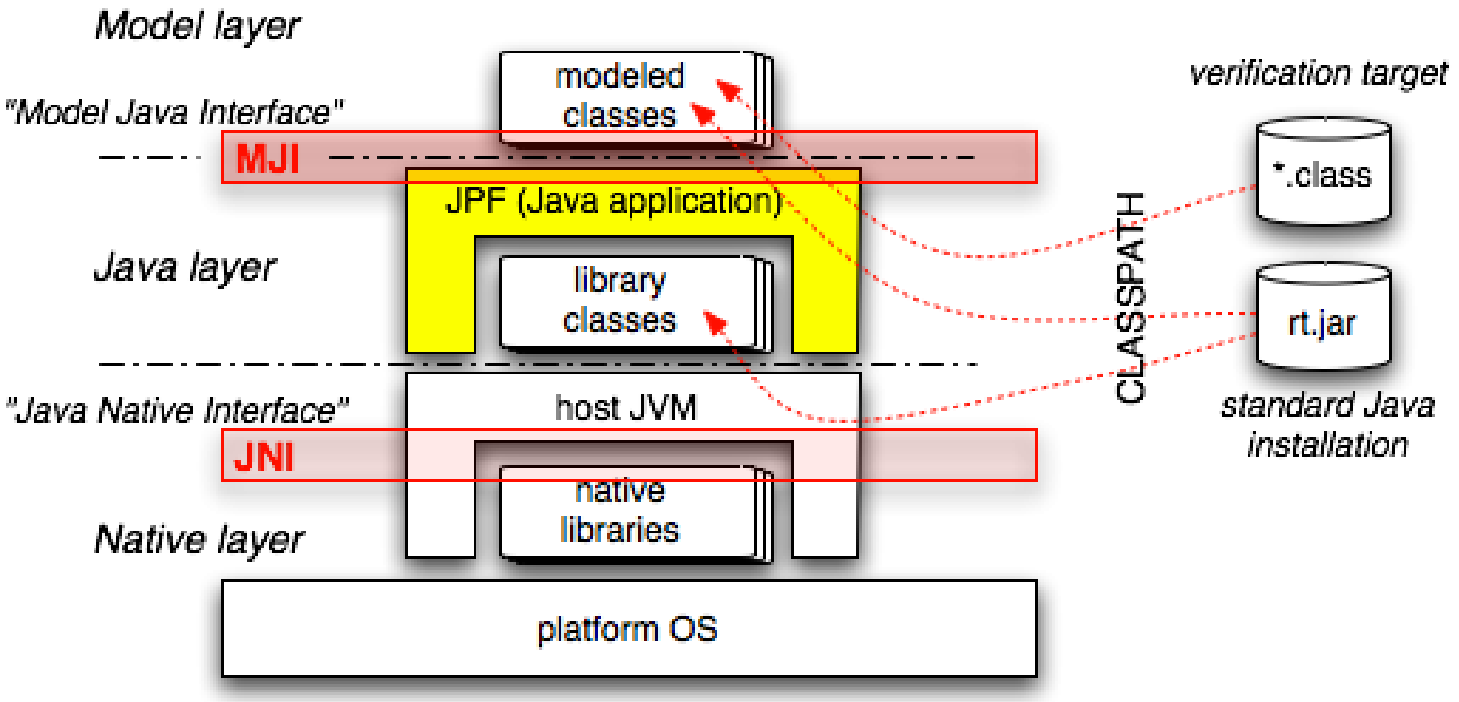
JPF and native methods

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)
```

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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

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