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A JIT Compiler for Android's Dalvik VM

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Overview

- View live session notes and ask questions on Google Wave:
  - http://bit.ly/bIzjnF
- Dalvik Environment
- Trace vs. Method Granularity JITs
- Dalvik JIT 1.0
- Future directions for the JIT
- Performance Case Studies
- Profiling JIT'd code
- Built-in Self-Verification Mode

Dalvik Execution Environment

- Virtual Machine for Android Apps
  - See 2008 Google IO talk
    - http://www.youtube.com/watch?v=ptjedOZEXPM
- Very compact representation
- Emphasis on code/data sharing to reduce memory usage
- Process container sandboxes for security

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Dalvik Interpreter

- Dalvik programs consist of byte code, processed by a host-specific interpreter
  - Highly-tuned, very fast interpreter (2x similar)
  - Typically less than 1/3rd of time spent in the interpreter
  - OS and performance-critical library code natively compiled
  - Good enough for most applications
- Performance a problem for compute-intensive applications
  - Partial solution was the release of the Android Native Development Kit, which allows Dalvik applications to call out to statically-compiled methods
- Other part of the solution is a Just-In-Time Compiler
  - Translates byte code to optimized native code at run time

A JIT for Dalvik - but what flavor of JIT?

- Surprisingly wide variety of JIT styles
  - **When** to compile
    - install time, launch time, method invoke time, instruction fetch time
  - **What** to compile
    - whole program, shared library, page, method, trace, single instruction
- Each combination has strengths & weaknesses - key for us was to meet the needs of a mobile, battery-powered Android device
  - Minimal additional memory usage
  - Coexist with Dalvik's container-based security model
  - Quick delivery of performance boost
  - Smooth transition between interpretation & compiled code

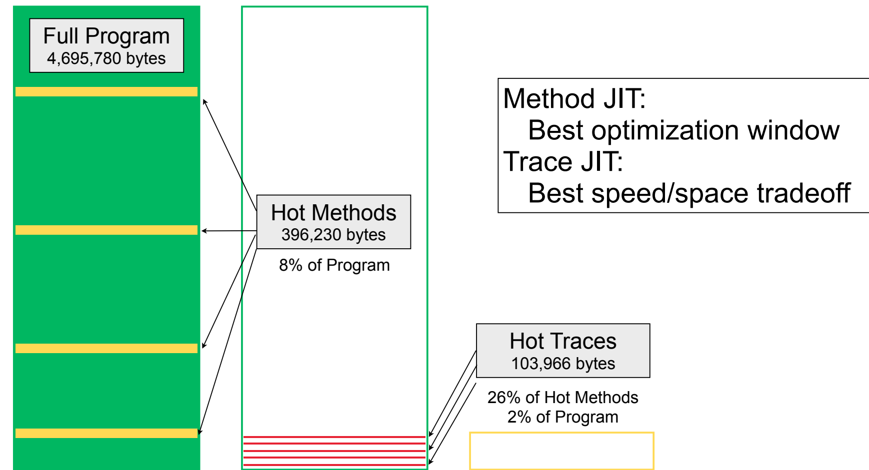
Method vs. Trace Granularity

- Method-granularity JIT
  - Most common model for server JITs
  - Interprets with profiling to detect hot methods
  - Compile & optimize method-sized chunks
  - Strengths
    - Larger optimization window
    - Machine state sync with interpreter only at method call boundaries
  - Weaknesses
    - Cold code within hot methods gets compiled
    - Much higher memory usage during compilation & optimization
    - Longer delay between the point at which a method goes hot and the point that a compiled and optimized method delivers benefits

Method vs. Trace Granularity

- Trace-granularity JIT
  - Most common model for low-level code migration systems
  - Interprets with profiling to identify hot execution paths
  - Compiled fragments chained together in translation cache
  - Strengths
    - Only hottest of hot code is compiled, minimizing memory usage
    - Tight integration with interpreter allows focus on common cases
    - Very rapid return of performance boost once hotness detected
  - Weaknesses
    - Smaller optimization window limits peak gain
    - More frequent state synchronization with interpreter
    - Difficult to share translation cache across processes

Hot vs. Cold Code: system_server example



Method JIT:
  Best optimization window
Trace JIT:
  Best speed/space tradeoff

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The Decision: Start with a Trace JIT

- Minimizing memory usage critical for mobile devices
- Important to deliver performance boost quickly
  - User might give up on new app if we wait too long to JIT
- Leave open the possibility of supplementing with method-based JIT
  - The two styles can co-exist
  - A mobile device looks more like a server when it's plugged in
  - Best of both worlds
    - Trace JIT when running on battery
    - Method JIT in background while charging

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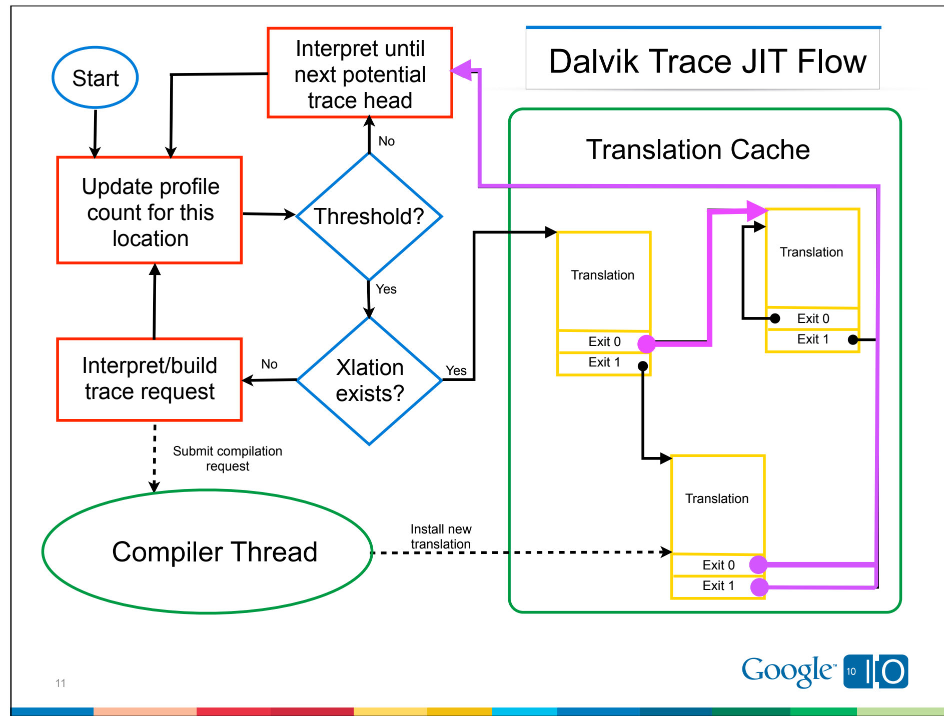
Dalvik Trace JIT Flow
Start
Interpret until next potential trace head
Update profile count for this location
Threshold?
No
Yes
Interpret/build trace request
No
Xlation exists?
Yes
Submit compilation request
Compiler Thread
Install new translation
Translation Cache
Translation
Exit 0
Exit 1
Translation
Exit 0
Exit 1
Translation
Exit 0
Exit 1
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Dalvik JIT v1.0 Overview

- Tight integration with interpreter
  - Useful to think of the JIT as an extension of the interpreter
- Interpreter profiles and triggers trace selection mode when a potential trace head goes hot
- Trace request is built during interpretation
  - Allows access to actual run-time values
  - Ensures that trace only includes byte codes that have successfully executed at least once (useful for some optimizations)
- Trace requests handed off to compiler thread, which compiles and optimizes into native code
- Compiled traces chained together in translation cache

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Dalvik JIT v1.0 Features

- Per-process translation caches (sharing only within security sandboxes)
- Simple traces - generally 1 to 2 basic blocks long
- Local optimizations
  - Register promotion
  - Load/store elimination
  - Redundant null-check elimination
  - Heuristic scheduling
- Loop optimizations
  - Simple loop detection
  - Invariant code motion
  - Induction variable optimization

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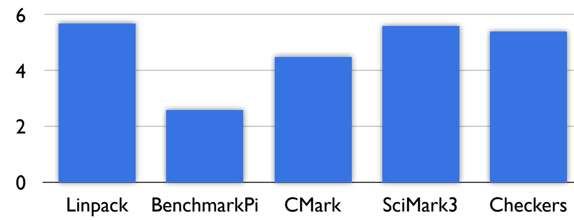
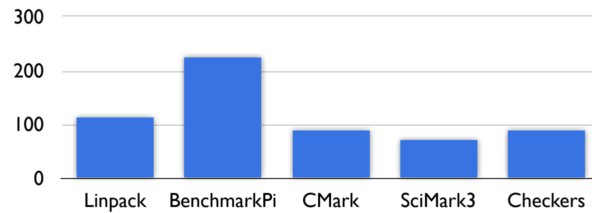
CPU-Intensive Benchmark Results

Speedup relative to Dalvik Interpreter on Nexus One



JIT Total Memory Usage (in kBytes)



- Linpack, BenchmarkPI, CaffeineMark & Checkers from the Android Market
- Scimark 3 run from command-line shell
- Measurements taken on Nexus One running pre-release Froyo build in airplane mode

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Future Directions

- Method in-lining
- Trace extension
- Persistent profile information
- Off-line trace coalescing
- Off-line method translation
- Tuning, tuning and more tuning

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Solving Performance and Correctness Issues

- How much boost will an app get from the JIT?
  - JIT can only remove cycles from the interpreter
  - OProfile can provide the insight to breakdown the workload
- How resource-friendly/optimizing is the JIT?
  - Again, OProfile can provide some high-level information
  - Use a special Dalvik build to analyze code quality
- How to debug the JIT?
  - Code generation vs optimization bugs
  - Self-verification against the interpreter

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Case Study: RoboDefense

Lots of actions

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Case Study: RoboDefense

Performance gain from Dalvik capped at 4.34%

Samples	%	Module
15965	**73.98**	**libskia.so**
2662	12.33	no-vmlinux
1038	4.81	libcutils.so
937	**4.34**	**libdvm.so**
308	1.42	libc.so
297	1.37	libGLESv2_adreno200.so

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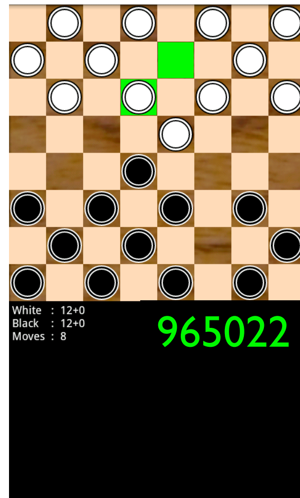
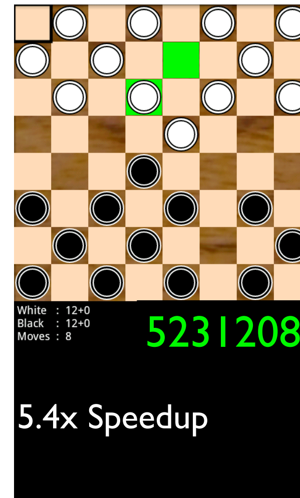
Case Study: Checkers

JIT <3 “Brain and Puzzle”





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Case Study: Checkers

Use OProfile to explain the speedup

Samples	%	Module
975	**93.57**	**dalvik-jit-code-cache**
30	2.88	libdvm.so
28	2.69	no-vmlinux
4	0.38	libc.so
3	0.09	libGLESv2_adreno200.so

96.45% (975 + 30 samples)

97% (dalvik-jit-code-cache) / **3%** (libdvm.so)

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Solving Performance and Correctness Issues
Part 2/3

- How much boost will an app get from the JIT?
- **How resource-friendly/optimizing is the JIT?**
- How to debug the JIT?

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Peek into the Code Cache Land

kill -12 <pid>

- Example from system_server (20 minutes after boot)
  - 9898 compilations using 796264 bytes
    - **80** bytes / compilation
  - Code size stats: 103966/396230 (trace/method Dalvik)
    - **796264 / 103966 = 7.7x** code bloat from Dalvik to native
  - Total compilation time: 6024 ms
    - Average unit compilation time: **609** µs

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JIT Profiling

Set “dalvik.vm.jit.profile = true” in /data/local.prop

count	%	offset (# insn), line	method signature
15368	**1.15**	**0x0(+2), 283**	**Ljava/util/HashMap;size;()I**
13259	1.00	0x18(+2), 858	Lcom/android/internal/os/ BatteryStatsImpl;readKernelWakelockStats;()Ljava/util/Map;
13259	1.00	0x22(+2), 857	Lcom/android/internal/os/ BatteryStatsImpl;readKernelWakelockStats;()Ljava/util/Map;
11842	0.89	0x5(+2), 183	Ljava/util/HashSet;size;()I
11827	0.89	0x0(+2), 183	Ljava/util/HashSet;size;()I
11605	0.87	0x30(+3), 892	Lcom/android/internal/os/BatteryStatsImpl;parseProcWakelocks; ([BI)Ljava/util/Map;

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Solving Performance and Correctness Issues

Part 3/3

- How much boost will an app get from the JIT?
- How resource-friendly/optimizing is the JIT?
- **How to debug the JIT?**

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Guess What's Wrong Here

A codegen bug is deliberately injected to the JIT

```
• E/AndroidRuntime(   84): *** FATAL EXCEPTION IN SYSTEM PROCESS:
  android.server.ServerThread
E/AndroidRuntime(   84): java.lang.RuntimeException: Binary XML file line #28: You
must supply a layout_width attribute.
```

```
E/AndroidRuntime(  187): *** FATAL EXCEPTION IN SYSTEM PROCESS:
WindowManager
E/AndroidRuntime(  187): java.lang.ArrayIndexOutOfBoundsException
```

```
E/AndroidRuntime(  435): *** FATAL EXCEPTION IN SYSTEM PROCESS:
android.server.ServerThread
E/AndroidRuntime(  435): java.lang.StackOverflowError
E/AndroidRuntime(  435):        at java.util.Hashtable.get(Hashtable.java:267)
E/AndroidRuntime(  435):        at
java.util.PropertyResourceBundle.handleGetObject(PropertyResourceBundle.java:120)
                       :
```


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Debugging and Verification Tools

	Byte code binary search	Call graph filtering	Self-verification w/ the interpreter
Code generation	✓	✓	✓
Optimization		✓	✓

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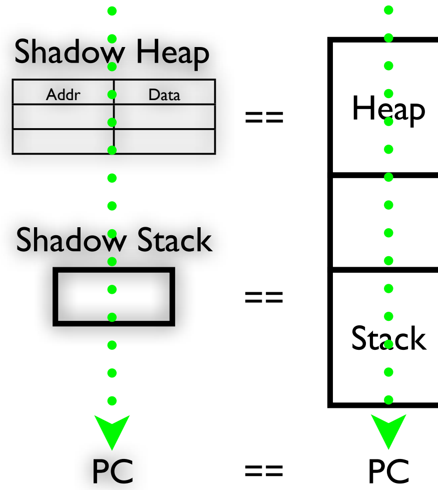
Bugs == Incorrect Machine States

Heap, stack, and control-flow



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Step-by-Step Debugging under Self-Verification

Divergence detected

```
~~~ DbgIntp(8): REGISTERS DIVERGENCE!
********** SHADOW STATE DUMP **********
CurrentPC: 0x42062d24, Offset: 0x0012
Class: Ljava/lang/Character;
Method: toUpperCase
Dalvik PC: 0x42062d1c endPC: 0x42062d24
Interp FP: 0x41866a3c endFP: 0x41866a3c
Shadow FP: 0x22c330 endFP: 0x22c330
Frame1 Bytes: 8 Frame2 Local: 0 Bytes: 0
Trace length: 2 State: 0
```


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Step-by-Step Debugging under Self-Verification

Divergence details

```
********** SHADOW TRACE DUMP **********
0x42062d1c: (0x000e) const/16
0x42062d20: (0x0010) if-ge
*** Interp Registers:
(v0) 0x      b5 X
(v1) 0x      55
*** Shadow Registers:
(v0) 0x      b6 X
(v1) 0x      55
```


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Step-by-Step Debugging under Self-Verification

Replay the compilation with verbose dump

```
Compiler: Building trace for toUpperCase, offset 0xe
0x42062d1c: 0x0013 const/16 v0, #181
0x42062d20: 0x0035 if-ge v1, v0, #4

TRACEINFO (141): 0x42062d00 Ljava/lang/Character;toUpperCase

-------- dalvik offset: 0x000e @ const/16 v0, #181
0x2 (0002): ldr     r1, [r5, #4]
0x4 (0004): mov     r0, #182
-------- dalvik offset: 0x0010 @ if-ge v1, v0, #4
0x6 (0006): cmp     r1, r0
0x8 (0008): str     r0, [r5, #0]
0xa (000a): bge     0x00000014
```


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Summary

- A resource friendly JIT for Dalvik
  - Small memory footprint
- Significant speedup improvement delivered
  - 2x ~ 5x performance gain for computation intensive workloads
- More optimizations waiting in the pipeline
  - Enable more computation intensive apps
- Verification bot
  - Dynamic code review by the interpreter

Q&A

- http://bit.ly/bIzjnF

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