Linaro connect
Las Vegas 2016

ART JIT in Android N

Xueliang ZHONG
Linaro ART Team
linaro-art@linaro.org

ENGINEERS
AND DEVICES
WORKING
TOGETHER

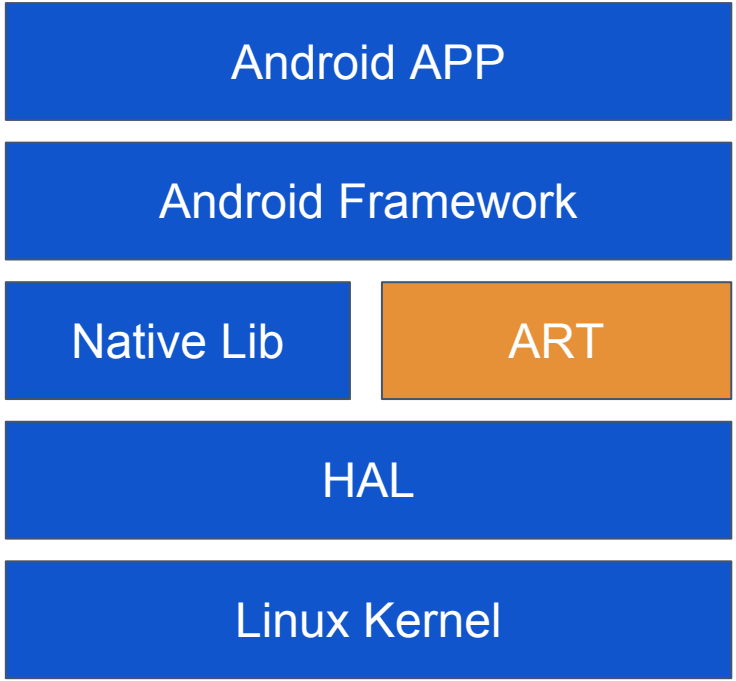
Outline

- Android Runtime (ART) and the new challenges
- ART Implementation in Android N
- Tooling
- Performance Data & Findings
- Q & A

ART

- Android Runtime (ART)

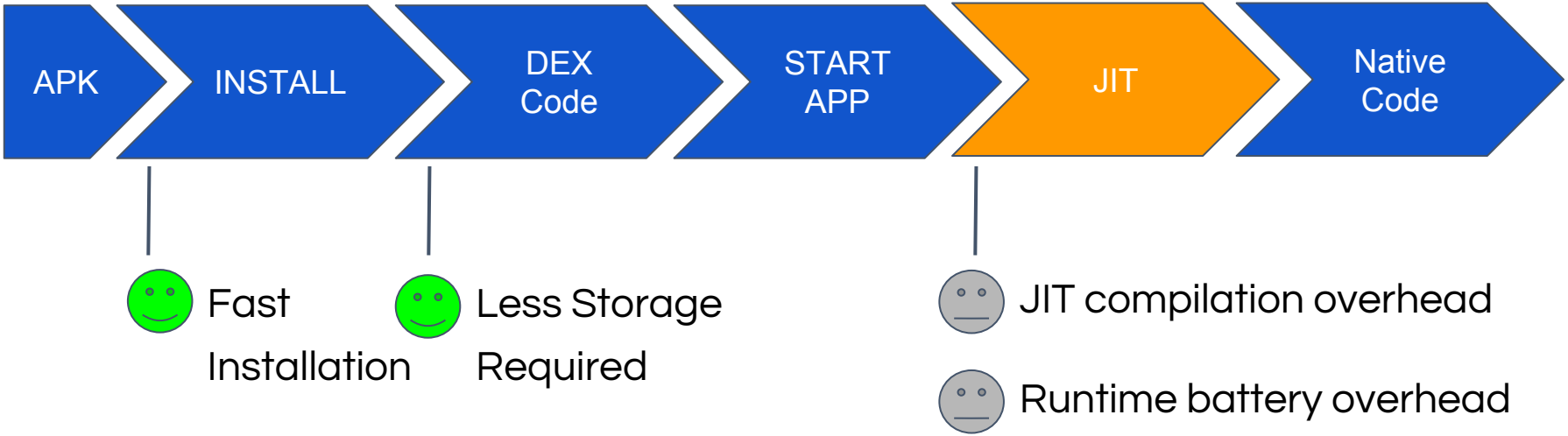
- Performance Requirements for ART:
  - Run APPs smoothly.
  - Fast APP startup.
  - Fast APP installation.
  - With minimal overhead.
    - CPU, memory, storage, power, ...



Android KitKat Just-In-Time (JIT) Solution

- **Dynamic** compilation

Android KitKat Just-In-Time (JIT) Solution



Android Marshmallow Ahead-Of-Time (AOT) Solution

- **Static** compilation

Android Marshmallow Ahead-Of-Time (AOT) Solution

Slow Installation

More Storage Required

Fast startup performance

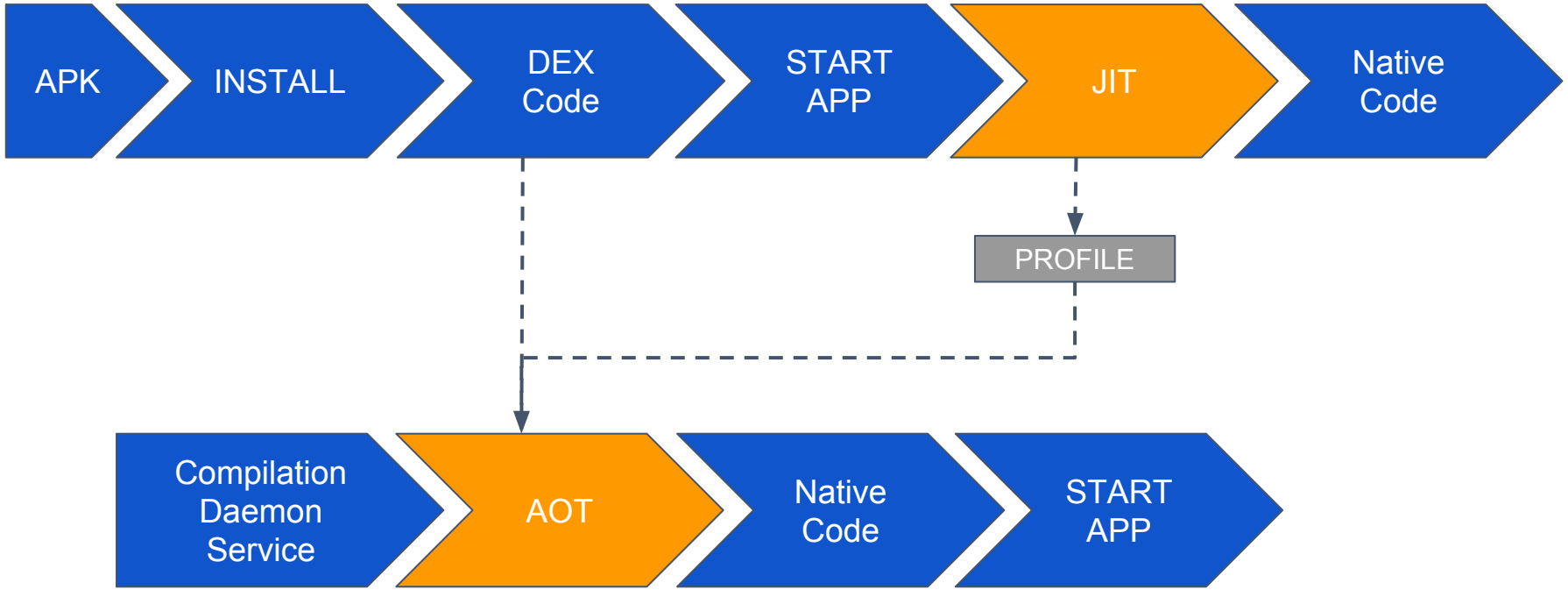
Fast runtime performance

Less runtime battery consumption

More Challenges for AOT Nowadays

- System Update Time
- Storage Consumption
- Dynamic APK

ART Implementation in Android N

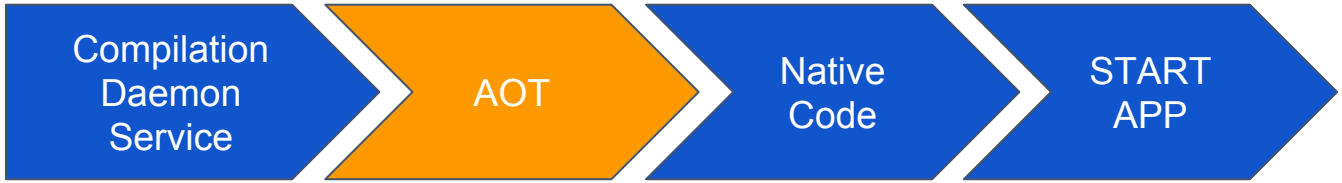


ART Implementation in Android N

- JIT Phase
  - Fast installation
  - Fast system update time (OTA)

ART Implementation in Android N

- Profile Guided AOT:
  - Fast startup and runtime performance
  - Lower overheads: CPU, storage, power ...



ART JIT - Implementation Overview

- JIT Runtime
- JIT Compiler
- Generates Profile File

ART JIT - Implementation Overview

- Interpreter
  - Computed-goto based
  - Opcode handling in ARM assembly
- Profiling & Triggering JIT Compilation
  - Based on execution count and heuristics
  - ‘hotness_count’
- JIT Code Cache
  - Manages JITed Code
  - Allocating ‘ProfilingInfo’ for hot methods

- **JIT Runtime**
- JIT Compiler
- Generates Profile File

ART JIT - Implementation Overview

- Method granularity compilation
- Background compilation.
  - Avoid blocking APP thread (e.g. UI thread)
- Based on ART optimizing compiler.
  - Same compiler used for AOT compilation.
- JIT compilation enhancements in optimizing compiler

- JIT Runtime
- **JIT Compiler**
- Generates Profile File

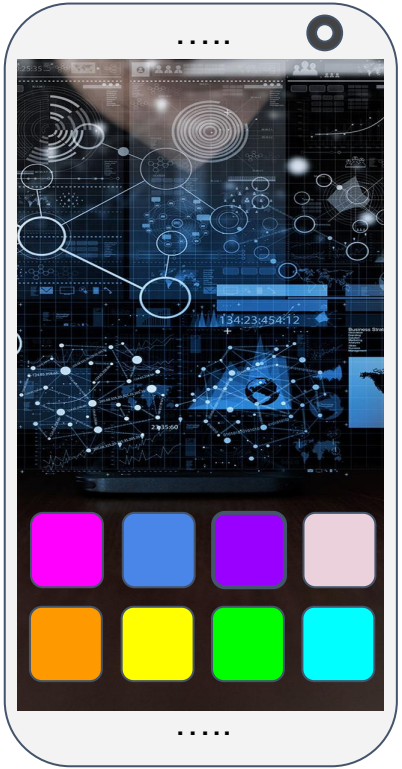
ART JIT - Implementation Overview

- ProfileSaver thread
  - Reads 'ProfilingInfo' about hot methods
  - Writes such info to disk
- Minimize overhead
  - Wakeup frequency
  - Minimize things to write

- JIT Runtime
- JIT Compiler
- **Generates Profile File**

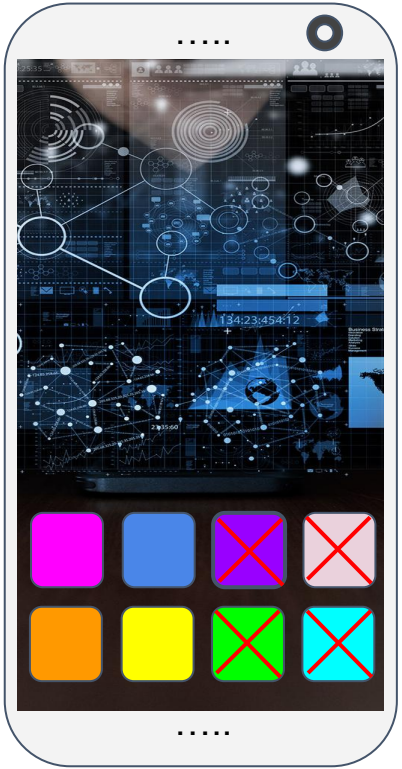
ART Hybrid Mode

- Idea of Hybrid Mode (JIT + AOT)



ART Hybrid Mode

- Idea of Hybrid Mode (JIT + AOT)
  - **Some users only use part of the APP. Only these frequently used features (and code behind them) are worth compiling into native code.**



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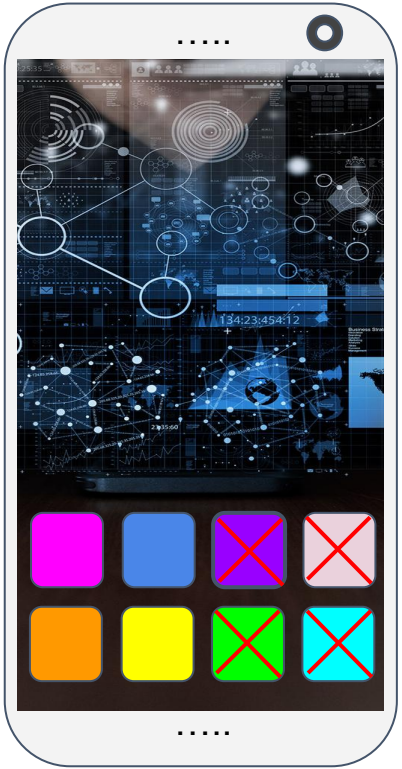
  - **Use JIT phase to find out the frequently used code.**



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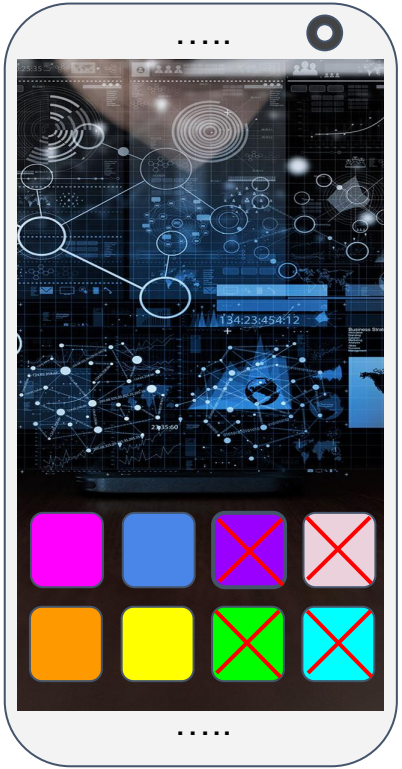
  - **Use AOT compilation & optimization to speed up frequent use cases.**



ART Hybrid Mode

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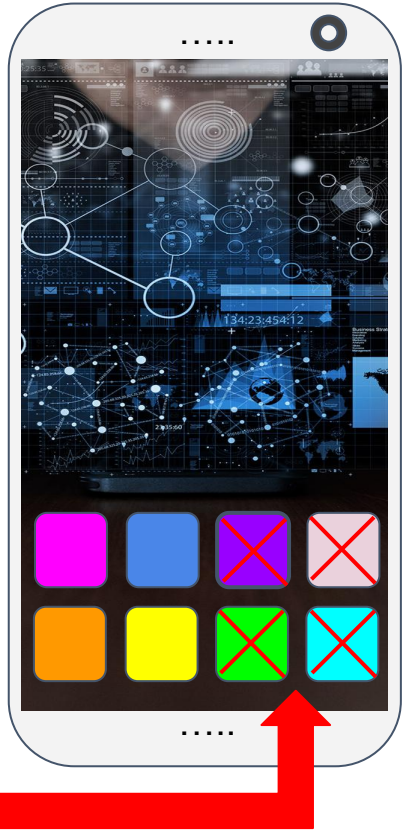
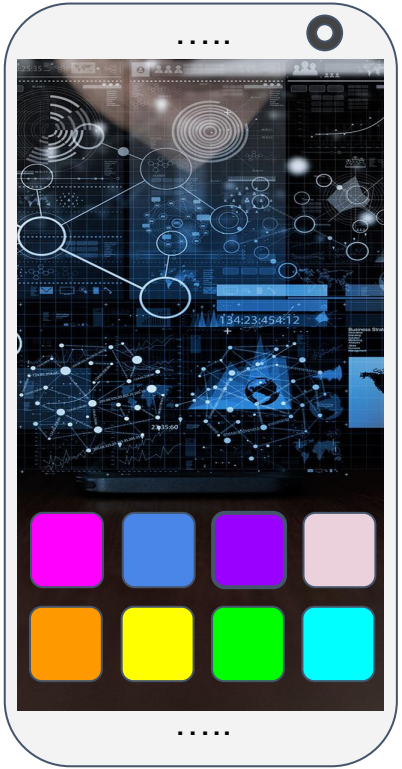
  - Some users only use part of the APP. Only frequently used features (and code behind them) are worth compiling into native code.
  - Use JIT phase to find out the frequently used code.
  - Use AOT compilation & optimization to speed up frequent use cases.
  - **Avoid paying overheads (compilation, storage, etc) to those less used codes.**

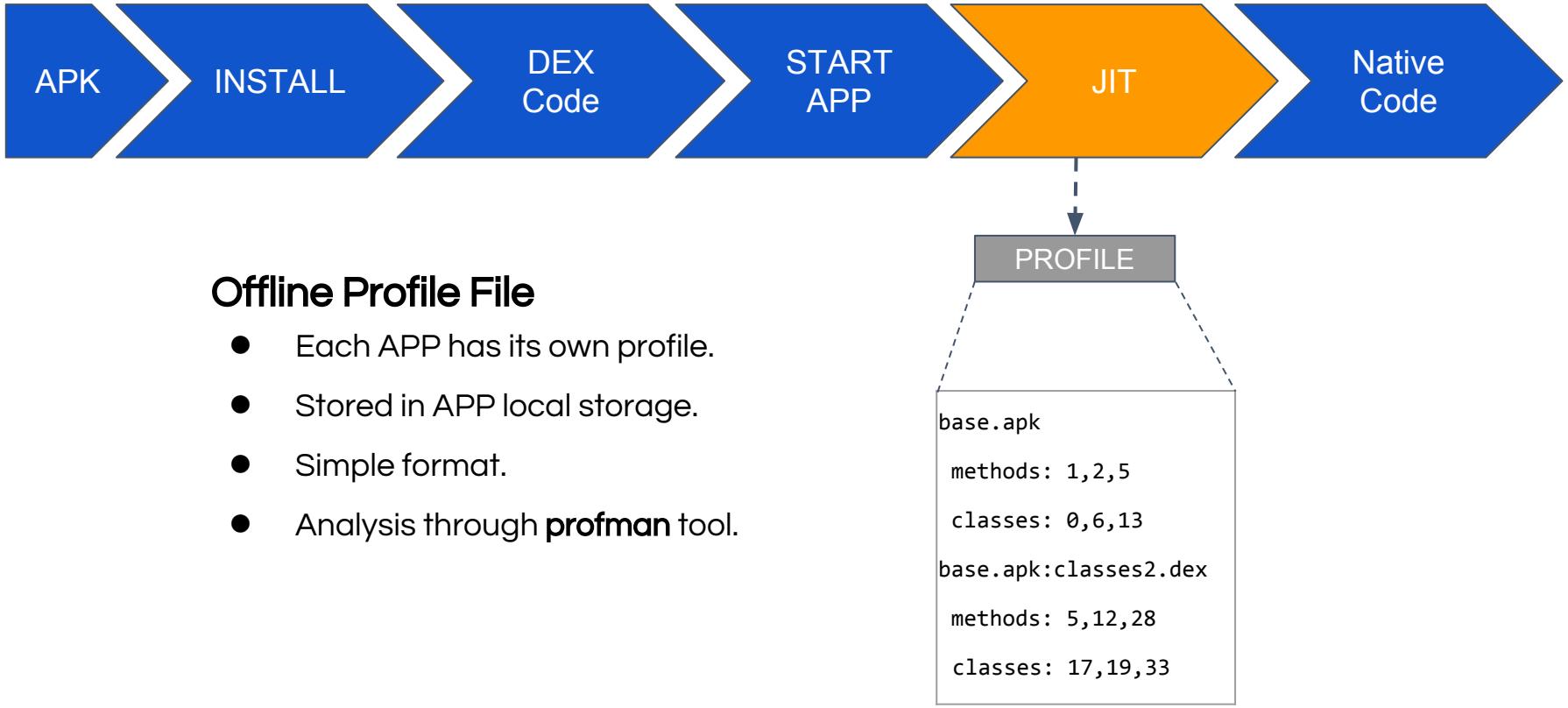


ART Hybrid Mode - Overview

- Implementation
  - Generate Offline Profile During JIT
  - Offline Profile File Format
  - Enhanced AOT Compiler (dex2oat)
  - Compilation Daemon Service



ART Hybrid Mode

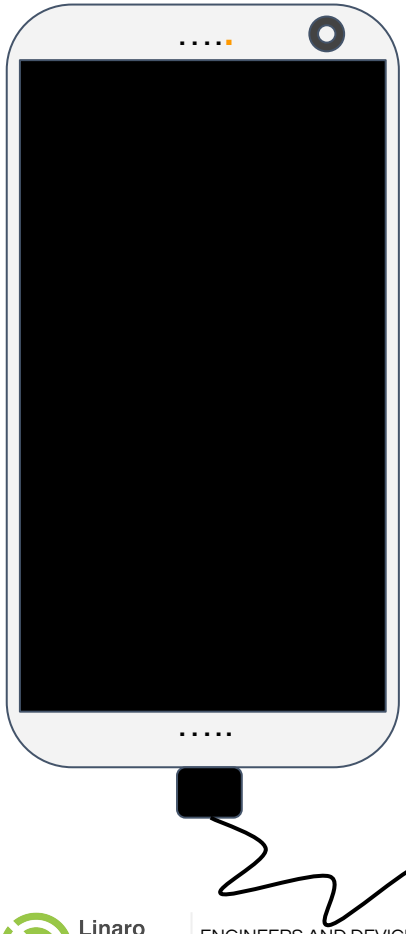


Offline Profile File

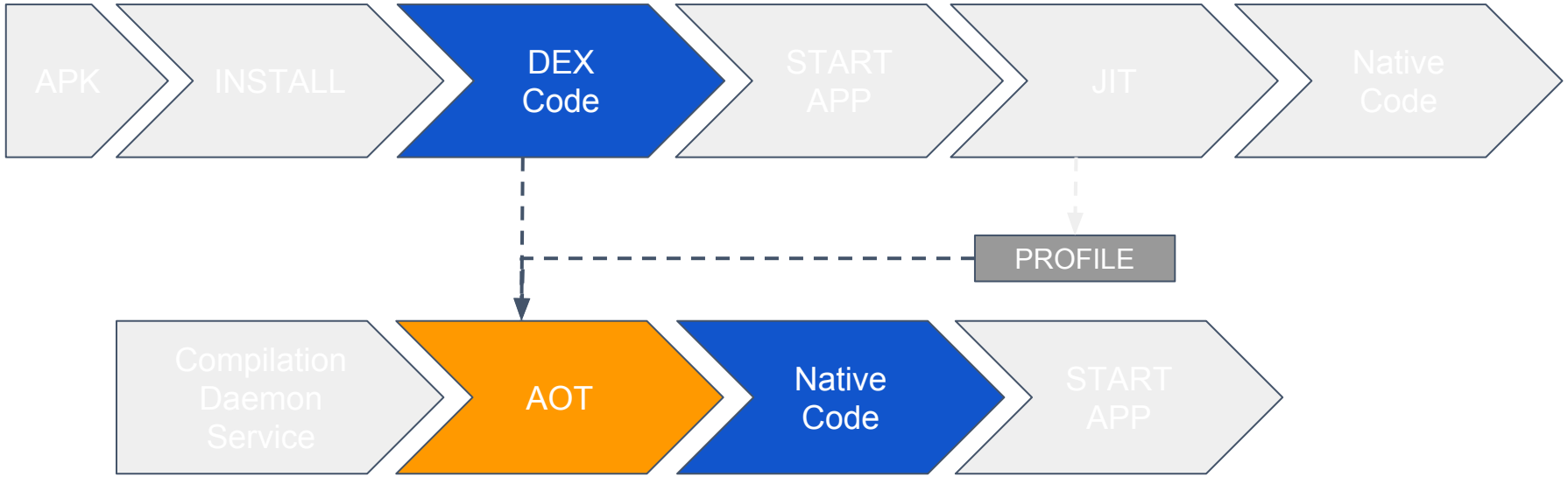
- Each APP has its own profile.
- Stored in APP local storage.
- Simple format.
- Analysis through **profman** tool.

ART Hybrid Mode

- Compilation Daemon
  - Triggers AOT when the device is **charging** and **idle**.
  - ‘BackgroundDexOptService’
  - frameworks/base/services/core/java/com/android/server/pm/



ART Hybrid Mode



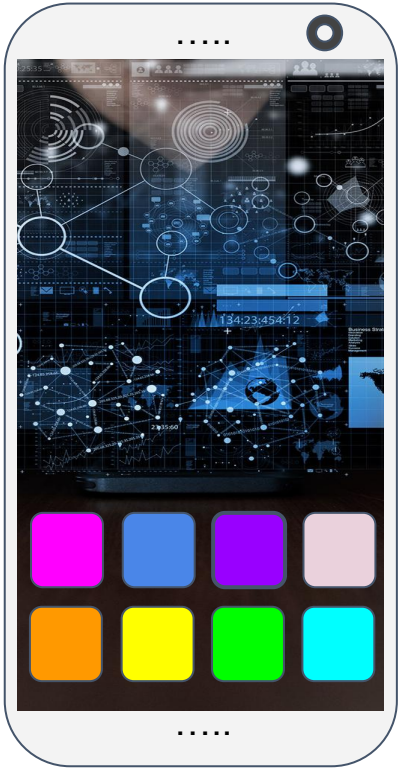
Profile Guided AOT

- dex2oat enhanced to accept profile
- selective compilation based on profile

```
dex2oat32 I compiler_driver.cc Skipped  method:void MyClass.<init>()
dex2oat32 I compiler_driver.cc Compiled method:int MyClass.foo(int)
dex2oat32 I compiler_driver.cc Compiled method:void MyClass.main()
dex2oat32 I compiler_driver.cc Skipped  method:boolean MyClass.verify()
dex2oat32 I compiler_driver.cc Skipped  method:void Class2.<init>()
```

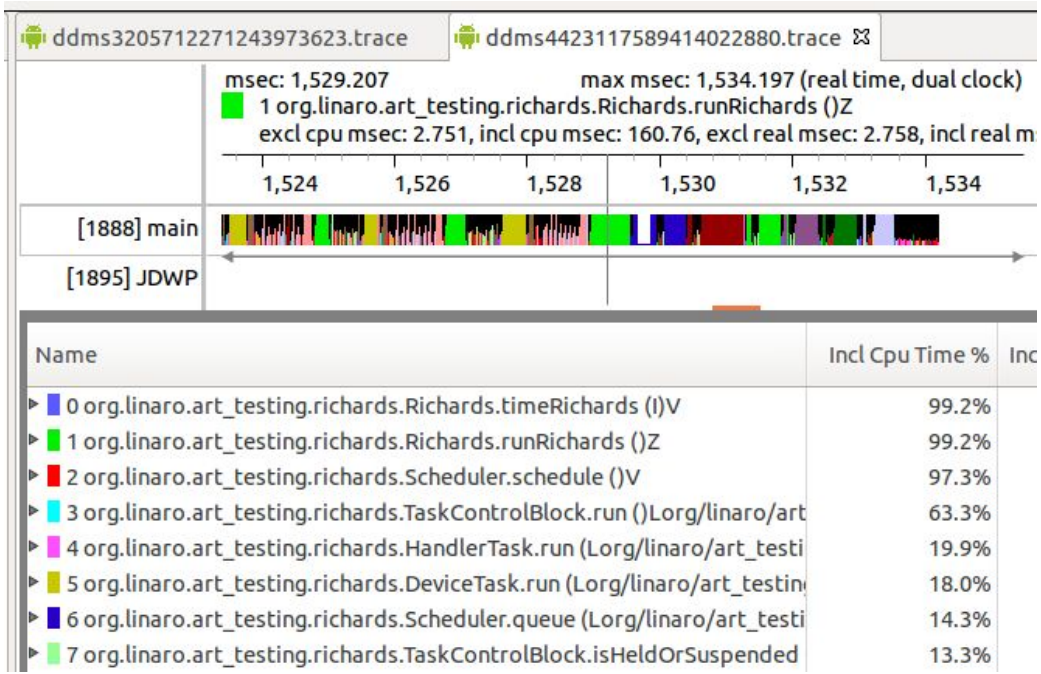
ART Hybrid Mode

- Run in Hybrid Mode
  - All previous ‘hot’ methods are AOT compiled
  - JIT compiler is still loaded in memory
    - For unexplored features/codes.
    - May generate new profiles.



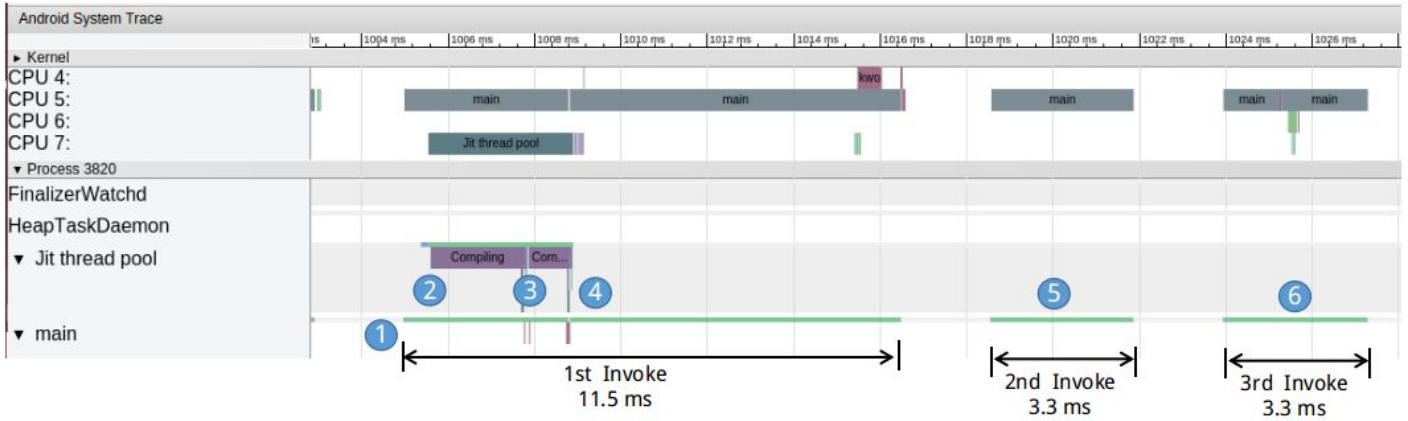
Tools

- TraceView (Android Studio / Android SDK)



Tools

- Systrace (Android Studio / Android SDK)
  - Enable 'dalvik' trace
  - Analyze JIT behaviors: JIT code cache, ProfilerSaver, GC, etc.
  - Helps to measure:
    i. Invoke Time (1, 5, 6)
    ii. JIT compilation time for each method (2, 3)
    iii. JITed code execution (4)



Tools

- JIT Compiler Analysis
  - CFG dump

```
dalvikvm -Xusejit:true -Xcompiler-option --dump-cfg=jit.cfg -cp Main.dex Main
```

    - CFG file analysis: IRHydra2 or c1visualizer

  - Profiling JITed code
    - Support generating **`/tmp/perf-PID-maps`** for method level profiling with **perf**.
    - Profile AOT compiled code is prefered, for instruction level profiling.

  - Other useful JIT statistics & logs:
    - `-verbose:compiler, -verbose:jit`
    - `-XX:DumpJITInfoOnShutdown`

Tools

- Profile Guided AOT Analysis - **profman**

profman --profile-file=<filename> **--dump-only**
This command can dump the contents in the given prof file.

profman --generate-test-profile=<filename>
This command can generate a random profile file for testing.

runtime/jit/offline_profiling_info.cc

```
// Debug flag to ignore checksums when testing.
// Used to facilitate testing across a large number of apps.
static constexpr bool kDebugIgnoreChecksum = true;
```

compiler/driver/compiler_driver.cc

```
// Print additional info during profile guided compilation.
static constexpr bool kDebugProfileGuidedCompilation = true;
```

Performance & Findings

- A Popular News Reader APP

	APP **Installation** Time
Full AOT Approach	88.7 sec
Hybrid Mode	11.4 sec

	APP **Startup** Time
Full AOT Approach	2.4 sec
Hybrid Mode (JIT)	2.9 sec

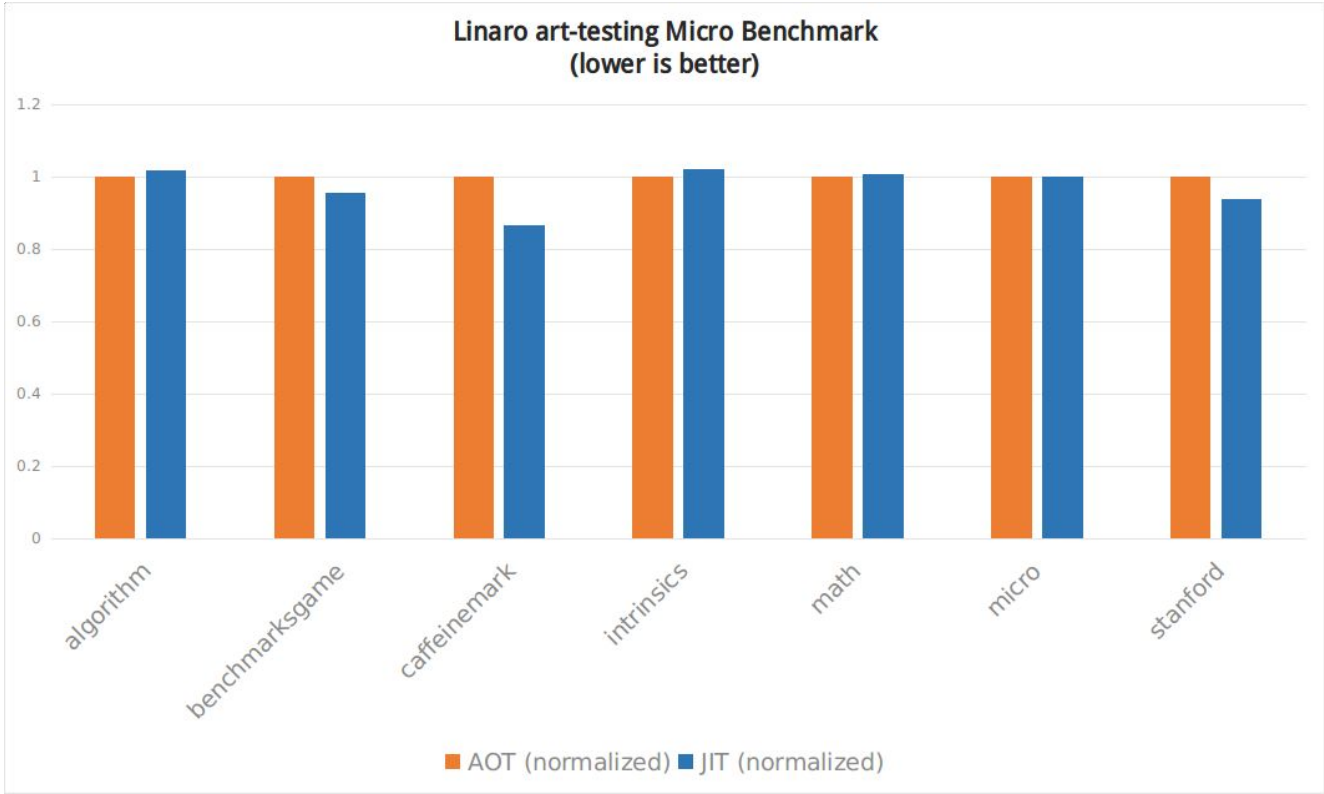
Performance & Findings

- A Popular News Reader APP

	.oat File Size in APP Local Storage
Full AOT Approach	97 MB
Hybrid Mode	42 MB (.prof file size 0.03MB)

Performance & Findings

- Micro Benchmark Performance, AOT vs. JIT



More Talks & Resources

- Linaro-ART Team:
  - VIXL: A Programmatic Assembler and Disassembler for AArch32
  - Android Runtime Performance Analysis

- The Evolution of ART - Google I/O 2016
  - https://www.youtube.com/watch?v=fwMM6g7wpQ8

- Implementing ART Just-In-Time (JIT) Compiler
  - http://source.android.com/devices/tech/dalvik/jit-compiler.html

Thank You

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For further information: www.linaro.org

LAS16 keynotes and videos on: connect.linaro.org

Backup

Performance & Findings - Example

- Micro Benchmarking – Running Unexpected Modes

```
void runAlgorithm(int iterations) {
 for(i=0; i<iterations; i++) {
   // long operations …
 }
}

void main() {
 int iterations = 20000;
 int before = time();
 runAlgorithm(iterations);
 int after = time();
 // …
}
```

Performance & Findings - Example

- JIT's Advantage over AOT – Inlining

```
public class MyClass {
  public /*private*/ /*final*/ /*static*/ int arithmeticSeries(int i)
  {
      if(i == 0)
        return 0;
      else
        return i + arithmeticSeries(i - 1);   // invoke-virtual
  }
}
```

ART JIT - Workflow