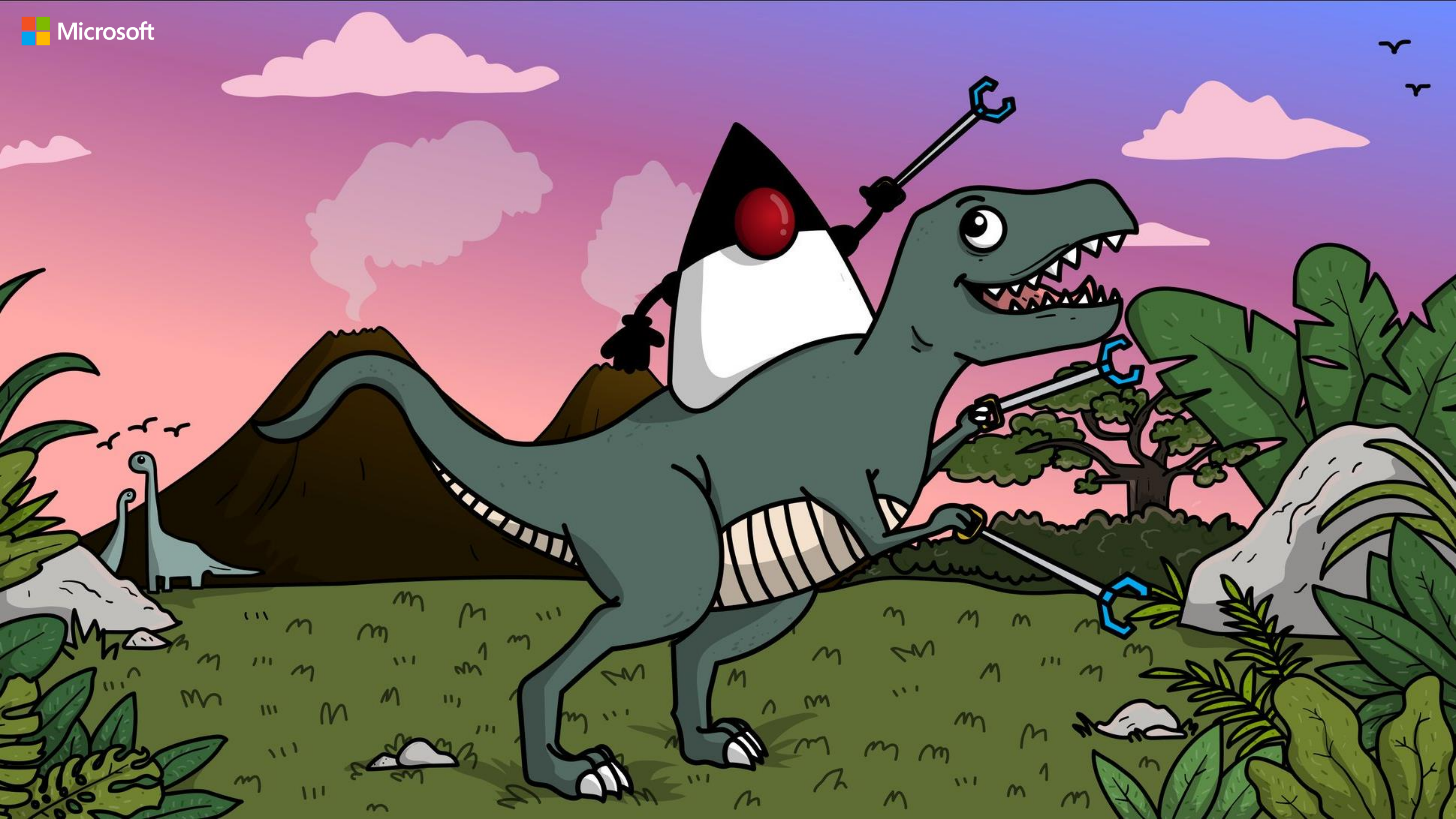

Microsoft

How to: make things start faster

Ludovic Henry

Java Engineering Group - Microsoft

About me

- Microsoft
- Empowering every Java developer to achieve more!
- Focus on VM Engineering

About you

- **Who develops with the JDK daily?**
  - Which languages?
- **What kind of workload**
  - Web services?
  - Big Data?
  - Desktop application?
  - Other?
- **Which metrics are your primary focus**
  - Throughput?
  - Latency?
  - Footprint?
  - **Startup?** 🡐 *Focus for this talk*

Agenda

Aside: The Importance of Methodology

Managing State

AOT Compilation and Beyond

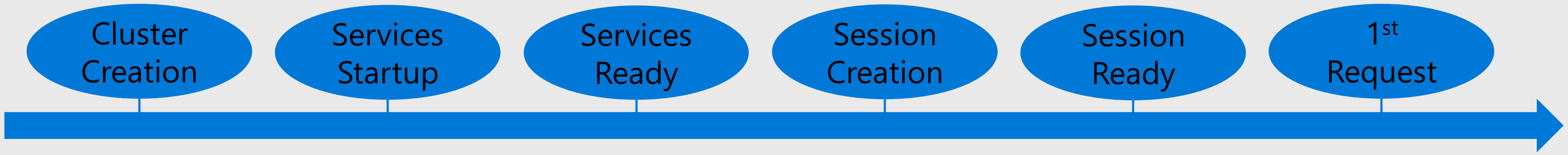
**If you have any questions,
please interrupt me at any time!**

Aside: the Importance of Methodology

The Project

- **Objective: make the product more responsive**

- **Key Result: reduce time from *Cluster Creation* to *Session Ready***



- **Context:**
  - Distributed Services (3+ machines)
  - Mostly Java processes (15+)
  - Many processes per machine (5+)

Given that context, what would you do?

What we did: followed a Methodology

Methodology

- **Java Performance Diagnostic Model (jPDM)**
  - [Using jPDM, a performance diagnostic model [Jfokus 2017, Kirk Pepperdine]]
- **Identify the bottlenecks**
  - `vmstat`
  - GC logs

```
$> vmstat 1
procs -----------memory------------- --swap-- -----io---- ---system-- ------cpu------
 r  b    swpd     free   buff    cache    si     so     bi     bo    in     cs   us sy id wa  st
11  3       0 16045660   9876   147268     0      0   3284    196   384   1088    4 19 73  4   0
 1  6       0 15932628  11024   235400     0      0  70736    640  1465   7377    7 12 11 70   0
 9  4       0 15850204  11736   305340     0      0  67780    508  1089   5284    5  6 26 63   0
17  1       0 15773448  13064   358904     0      0  46256   2692  2749  13125   33 16 26 24   0
 2  1       0 15697464  14432   405832     0      0  28952   3460  3476  16288   44 30 10 15   0
 1  2       0 15670680  15156   420480     0      0   9572   1780  2515   6868   28 12 36 24   0
14  1       0 15653340  15596   432096     0      0   7252   2048  2590   7254   23  9 43 25   0
 2  1       0 15628064  16096   443696     0      0   8312   2200  3452  11927   13 13 52 22   0
 1  1       0 15621172  16232   452180     0      0   8448    304   909   3315   12  4 65 19   0
 0  2       0 15612448  16340   456656     0      0   4408    360   460   2115    3  2 72 24   0      ← Launch
14  5       0 15428116  19472   509436     0      0  30024   4088  3027  14965   46 23  8 22   0
 8  4       0 15361456  20492   547724     0      0  37496   1336  2411   8830   29  9  8 54   0      ← main()
 0  7       0 15239784  20768   578928     0      0  26160   1388  2547   8426   49  9  6 36   0
 1  5       0 15154380  20876   603288     0      0  22548    872  1903   5944   27  5 12 56   0
 0  5       0 15194716  20972   621432     0      0  18128    984  2037   6548   12  6 23 60   0
 8  0       0 15114384  21020   637204     0      0  15360    408  1050   3690   21  3 19 58   0
 0  5       0 15086716  21276   649100     0      0  10716    812  1599   7093   45  6 12 37   0
 4  3       0 15000088  21392   661688     0      0  10788    768  2407   7380   34  7 17 41   0
 0  4       0 14967924  21480   669056     0      0   7000    452  1130   3815   19  2 25 53   0
 1  4       0 14915884  21512   679332     0      0   9480    188  1109   3969   43  3 16 38   0      ← Ready
```

Solution

- **Prefetch files to filesystem cache**
  - mmap + mlock from another process launched at boot

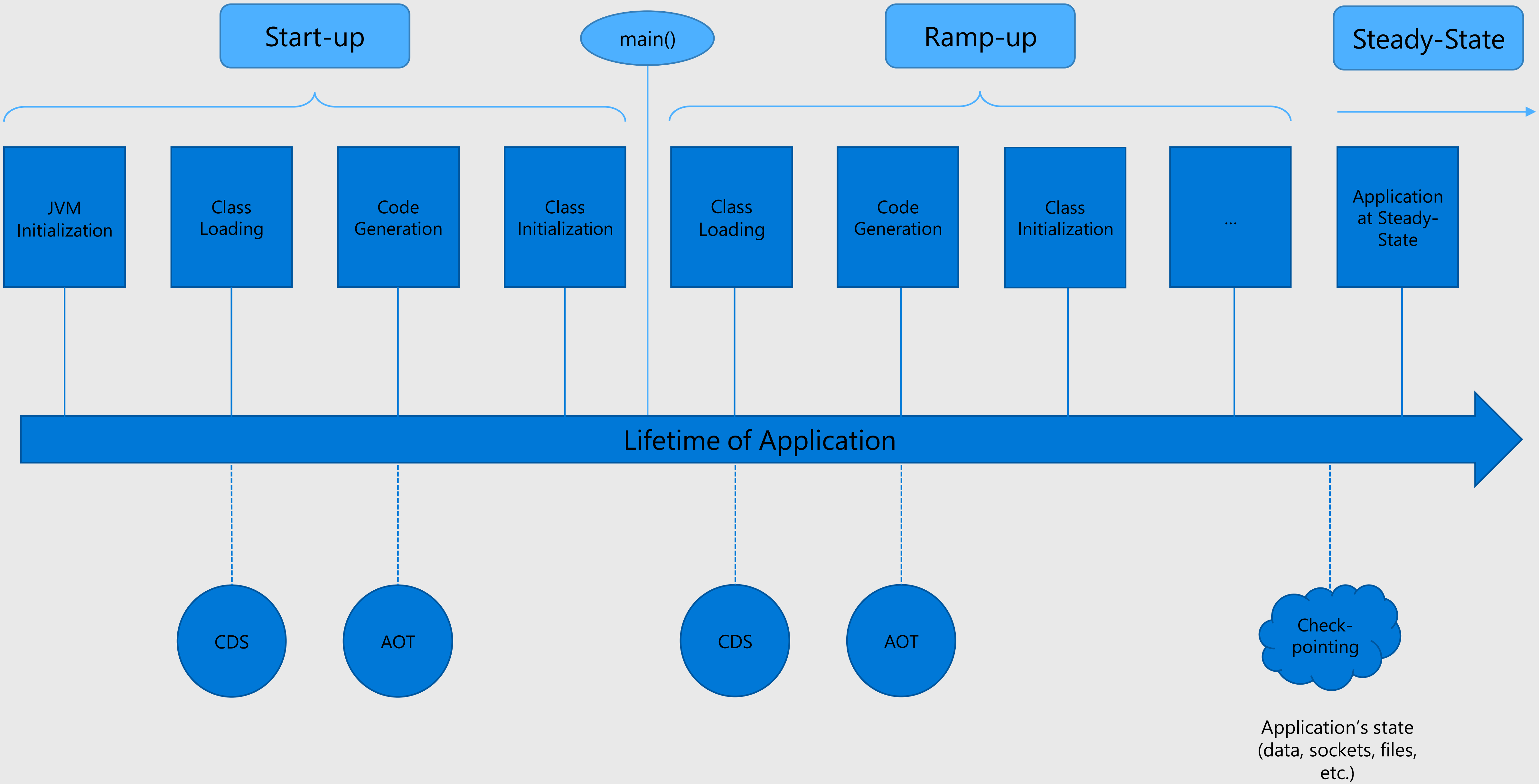
- **Results**
  - Avg: 51s to 43s ➔ 15% faster
  - 95p: 61s to 49s ➔ 20% faster

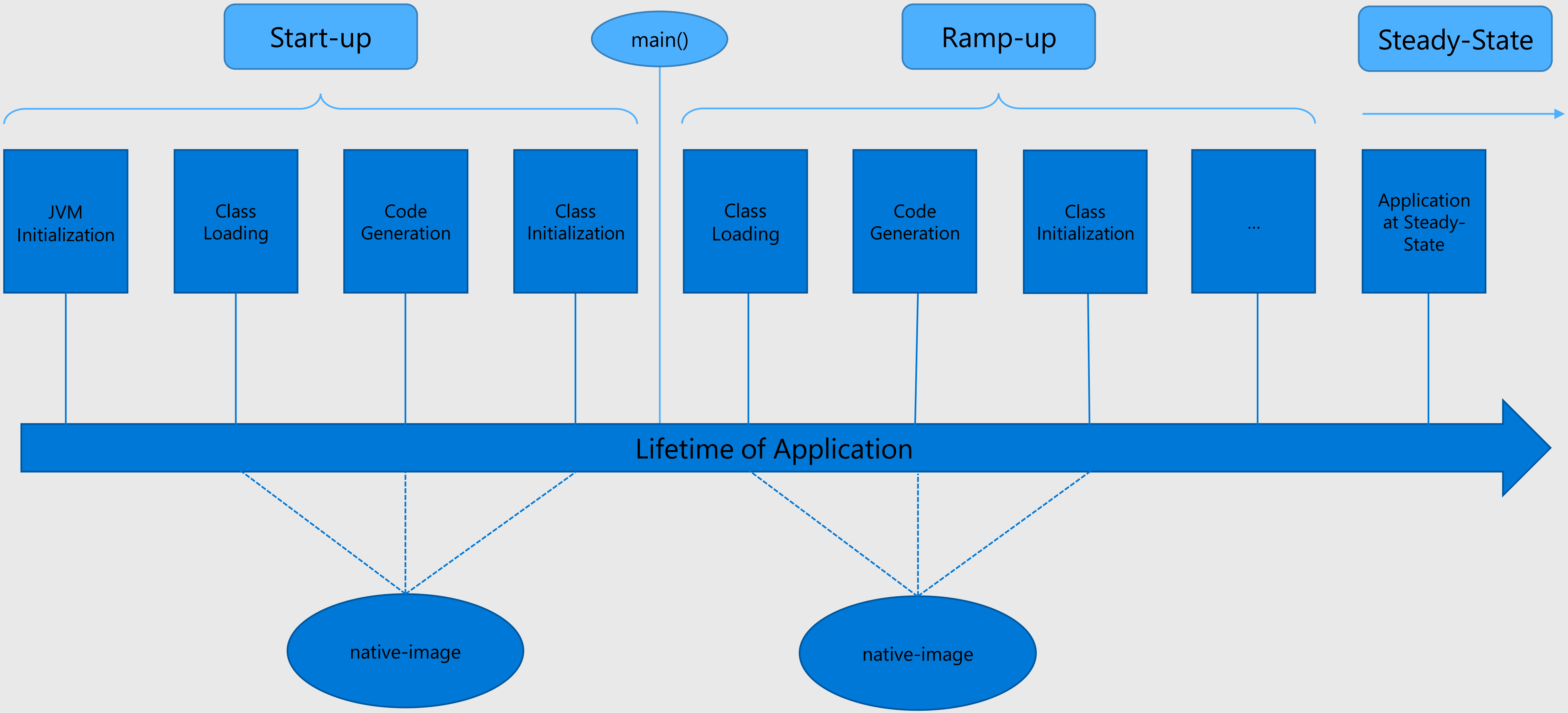
```
$> vmstat 1
procs -----------memory------------- --swap-- -----io---- ---system-- ------cpu------
 r  b   swpd   free   buff   cache    si    so    bi    bo   in    cs   us sy id wa st
 8 11      0 16042280  10444  153436   0     0  3456   218  394  1089   4 21 70  4  0
 0  9      0 15936404  11128  234228   0     0 69508   532 1149  5870   6 12  5 77  0
 0  4      0 15844404  11536  307684   0     0 69084   760 1917  6875   4  9 18 69  0
 0  5      0 15769280  12384  378260   0     0 69452   600 1270  4007   9  5 32 54  0
 0  5      0 15691104  12772  448248   0     0 69328   688  875  3335   7  4 37 52  0
 0  3      0 15612672  13700  518440   0     0 69604   708  718  2365   6  4 43 47  0
15  9      0 15483816  14112  606592   0     0 69496  1100 1832  8286  31 26 18 24  0
 2  5      0 15427128  14428  675460   0     0 68344  1288 2038  7367  31 17 11 41  0
 0  3      0 15324972  14884  751408   0     0 68984  1232 1350  4248  20  9 28 42  0
 0  3      0 15269128  15104  821236   0     0 69200   988 1303  3811   8  3 38 50  0
 1  3      0 15204932  15400  886728   0     0 64024  1372 1972  5628  19 10 26 45  0
 1  2      0 15156048  16244  903088   0     0  7572  4696 5054 20494  32 33 25 11  0
 2  0      0 15171516  16484  905324   0     0  1652  1500 2206  6039  15  8 69  7  0
 1  0      0 15171980  16516  904796   0     0     0    84  238  1089   0  1 99  0  0
 3  0      0 15146488  16584  911560   0     0  3160   316  815  3028  12  4 81  3  0    ← Launch
10  4      0 14990868  19740  945696   0     0 11804  5324 2614 18250  66 25  7  2  0
 8  3      0 14853528  20612  976652   0     0 23616  1660 1284 10272  84 13  0  3  0
10  4      0 14748248  20972  997824   0     0 16432  2040 2373 23566  79 18  1  3  0    ← main()
13  3      0 14707516  21076 1021824   0     0 21884   848 2643 32709  85 12  1  2  0
 5  4      0 14675788  21224 1038060   0     0 13904  1480 11513 51637 73 15  4  9  0
 5  3      0 14625984  21332 1055720   0     0 13004   888 22791 70219 52 18  9 21  0
 2  3      0 14601044  21436 1065760   0     0  7152   732 7463 23289  40  8 18 34  0    ← Ready
```

Managing State

What State?

- In the OS
  - Filesystem Cache
  - File Descriptors (e.g. files, sockets, devices)
- In the JVM
  - Metadata
  - Code
- In the Application
  - Data


Start-up
main()
Ramp-up
Steady-State
JVM Initialization
Class Loading
Code Generation
Class Initialization
Class Loading
Code Generation
Class Initialization
...
Application at Steady-State
Lifetime of Application
CDS
AOT
CDS
AOT
Check-pointing
Application's state (data, sockets, files, etc.)



Start-up
main()
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Class Initialization
...
Application at Steady-State
Lifetime of Application
native-image
native-image

`native-image` / SubstrateVM

- AOT Initialization
  - Heap Snapshotting
  - Class Initialization
- AOT Compilation

AOT Compilation and Beyond

In HotSpot, not `native-image` / SubstrateVM

`jaotc`

- AOT Compiler in HotSpot
- Available in Java 9+
- Based on Graal JIT compiler
- https://docs.oracle.com/en/java/javase/13/docs/specs/man/jaotc.html
  - `--class-name` / `--jar` / `--module` / `--directory`
  - `--compile-command`
  - `--compile-for-tiered`
  - `-J`*flag*

Tradeoffs

Position Independent Code (PIC)

- Foundational concept of Shared Libraries

  https://www.technovelty.org/linux/plt-and-got-the-key-to-code-sharing-and-dynamic-libraries.html

  What's going on here? What is happening is ***lazy binding*** *— by convention when the dynamic linker loads a library, it will put an identifier and resolution function into known places in the GOT. Therefore, what happens is roughly this:* ***on the first call of a function, it falls through to call the default stub, which loads the identifier and calls into the dynamic linker****, which at that point has enough information to figure out "hey, this libtest.so is trying to find the function foo". It will go ahead and find it, and* ***then patch the address into the GOT*** *such that the* ***next time the original PLT entry is called****, it will* ***load the actual address of the function****, rather than the lookup stub. Ingenious!*

- AOT requires indirect access to symbols, JIT doesn't

Tradeoffs

Missed Optimizations: dead-code elimination

```
final static boolean shouldExplode =
      rand.nextBoolean(); // hopefully not!

static void tryExplode()
{
    if (shouldExplode)
    {
        explode();
    }
}
```

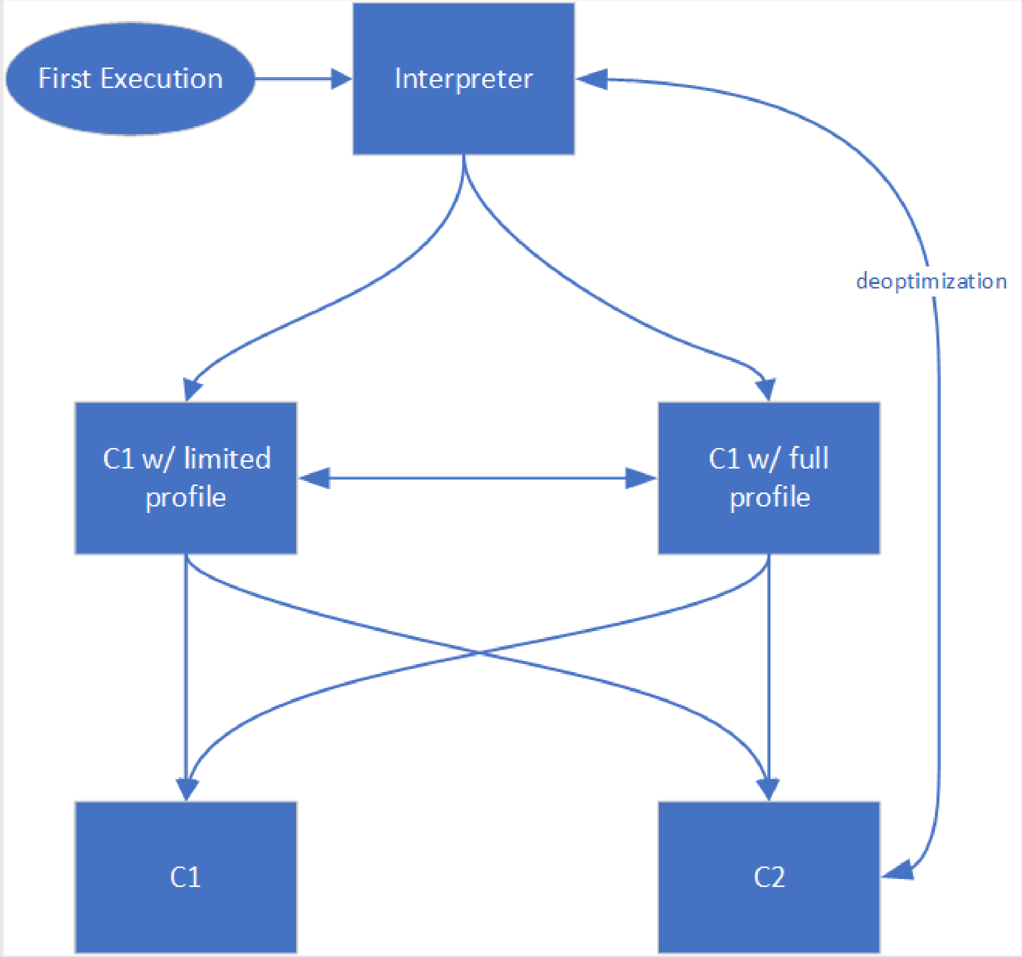
Tradeoffs

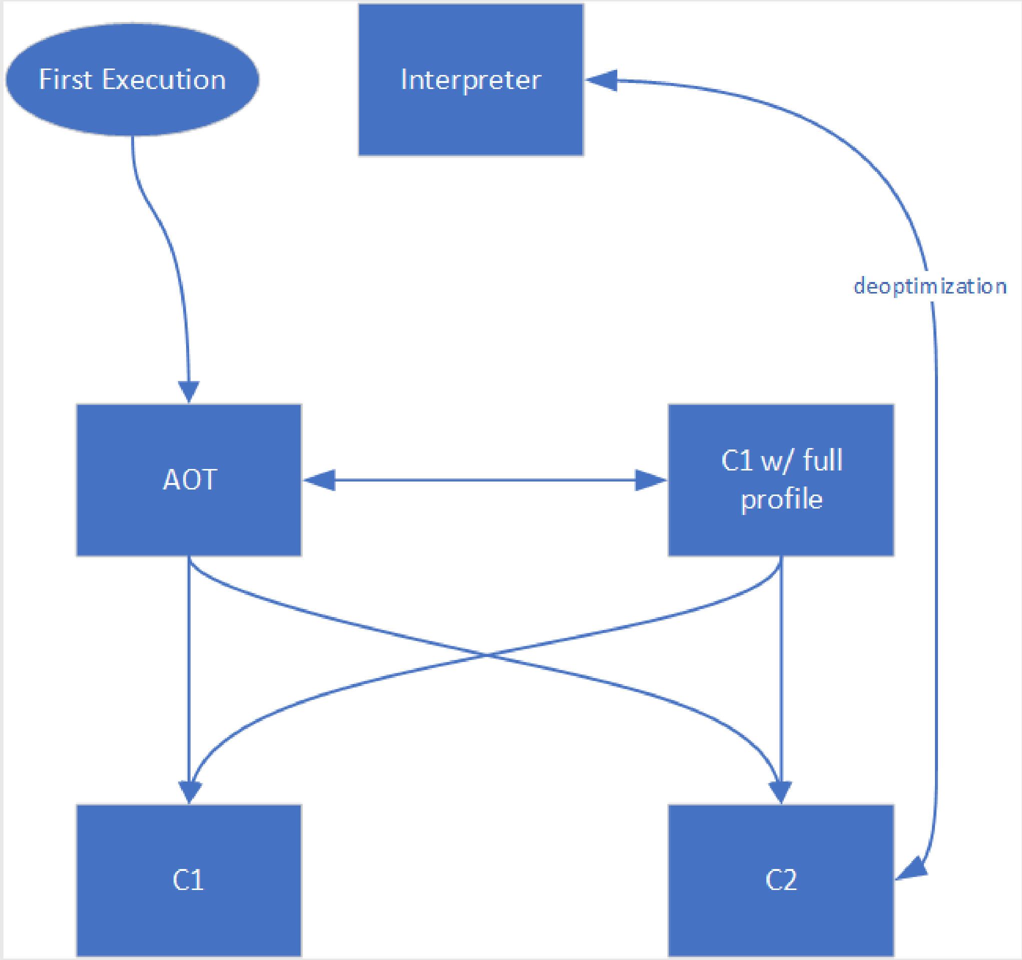
Missed Optimizations: lack of Profiling Data

- It doesn’t know what types are used at call sites
  - Inlining

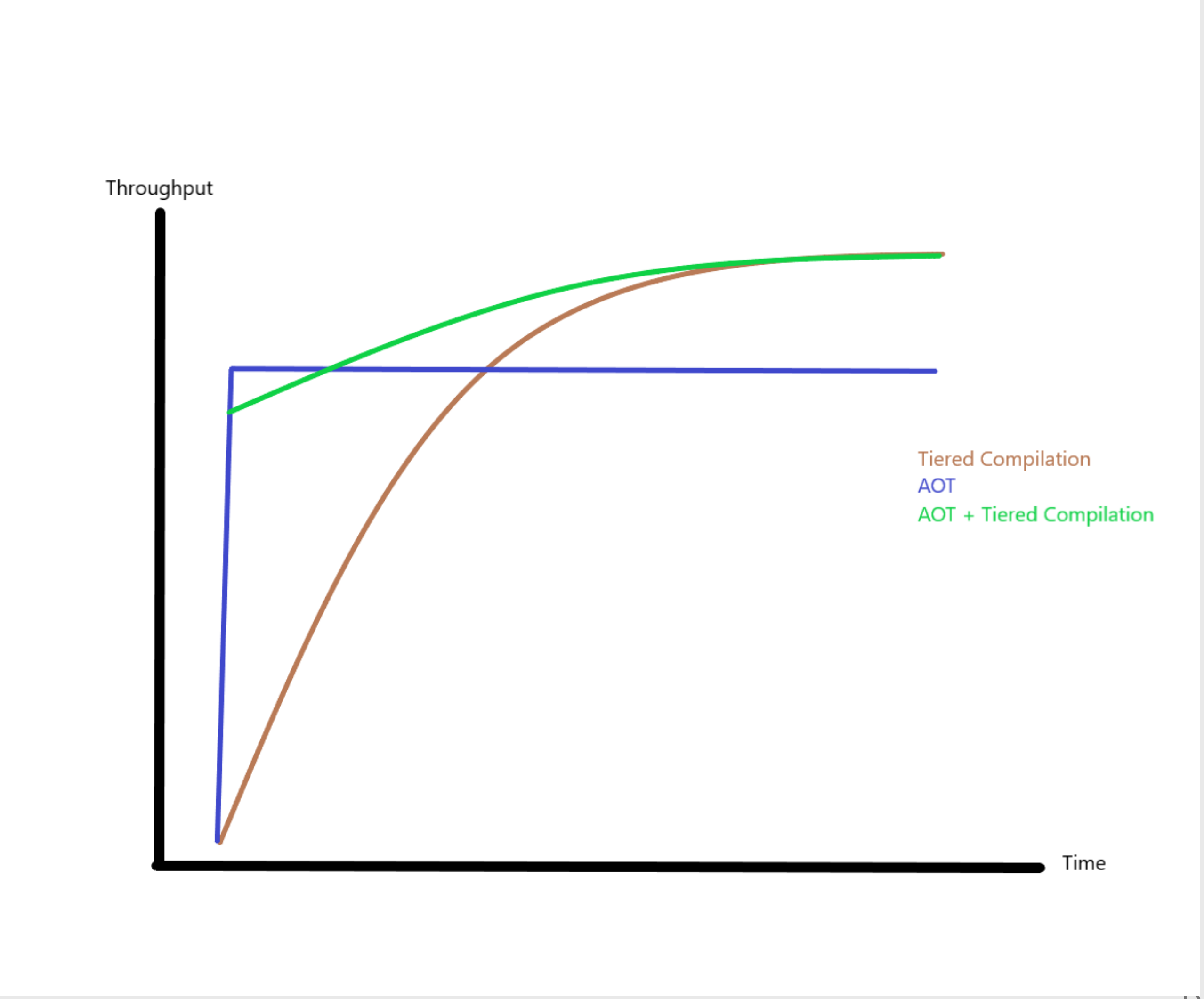
- It doesn’t know which code is cold/warm/hot
  - Basic Block Ordering
  - Register Allocation

Integration to Tiered Compilation Pipeline





Integration to Tiered Compilation Pipeline



Demo

https://github.com/luhenry/demo/tree/master/java-aot

Class Data Sharing

- JDK 5: Class-Data Sharing
- JDK 10: Application Class-Data Sharing
- JDK 12: Default Class-Data Sharing Archives
- JDK 13: Dynamic Class-Data Sharing

Demo

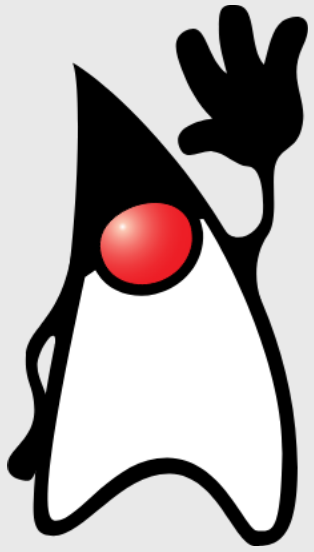
https://github.com/luhenry/demo/tree/master/java-cds

What's missing in HotSpot?

- **Better integration between components: `jlink`, `jaotc`, CDS**
  - Lots to learn from `native-image` / SubstrateVM
    - AOT Initialization beyond `string` in CDS

- **Better integration to Tiered Compilation pipeline**
  - Integrate at Tier-3 (C1 w/ full profile)
    - No need for Interpreter
    - Deoptimization from C2 to AOT
    - Allows for JIT-less runtimes with JITaaS

Thank you!



luhenry@microsoft.com

java-performance@microsoft.com

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Java Engineering Group - Microsoft