What does the JVM do with my code?

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Language Translator

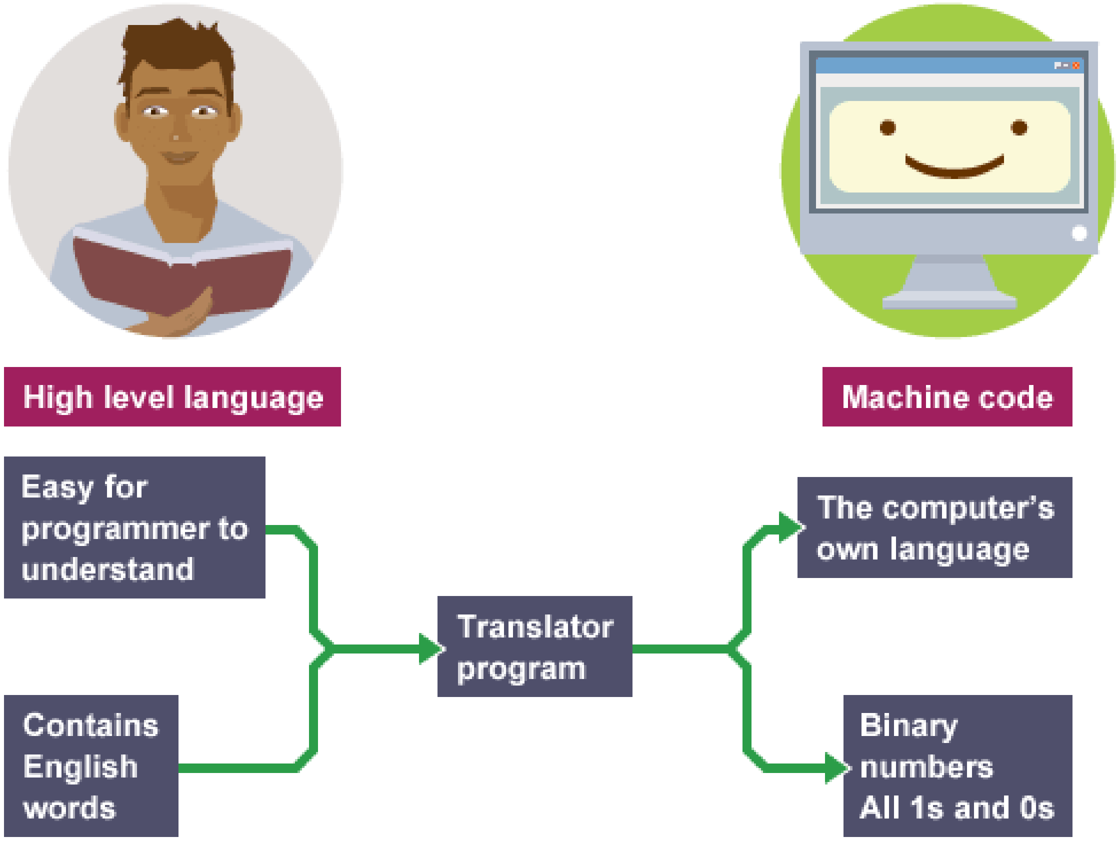


Image source: http://www.bbc.co.uk/education/guides/zgmpr82/revision

Compiler vs Interpreter

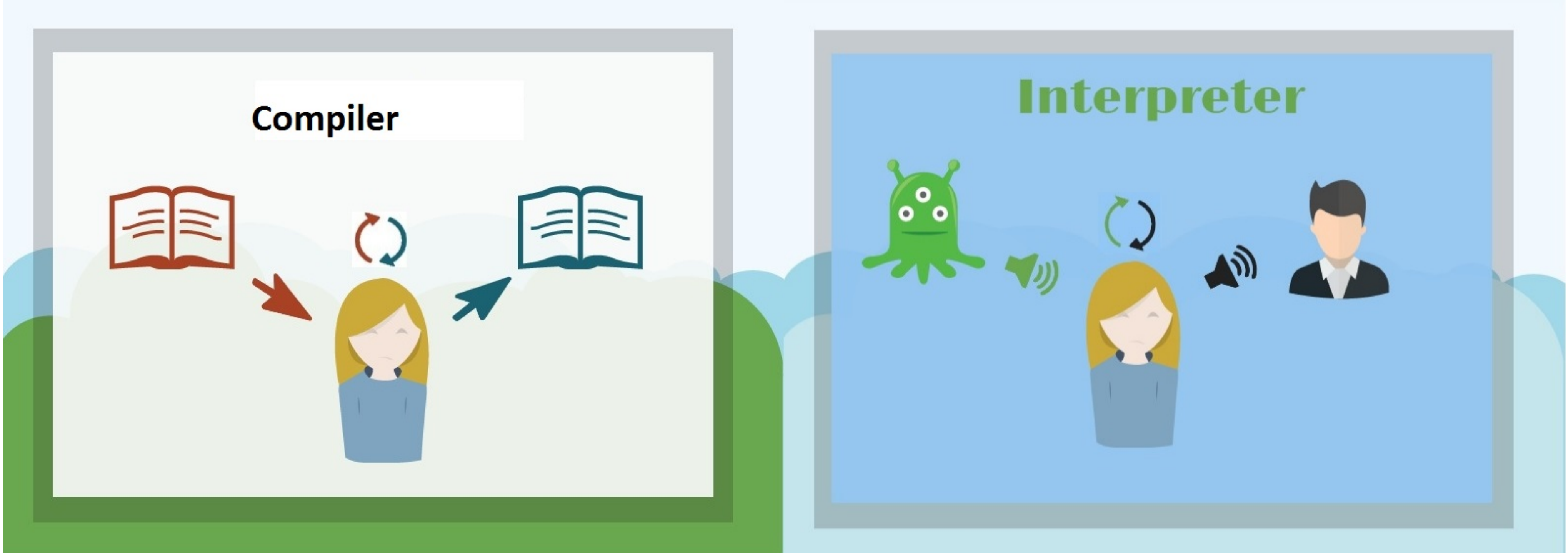


Image source: https://stackoverflow.com/a/31551282

Compiler vs Interpreter

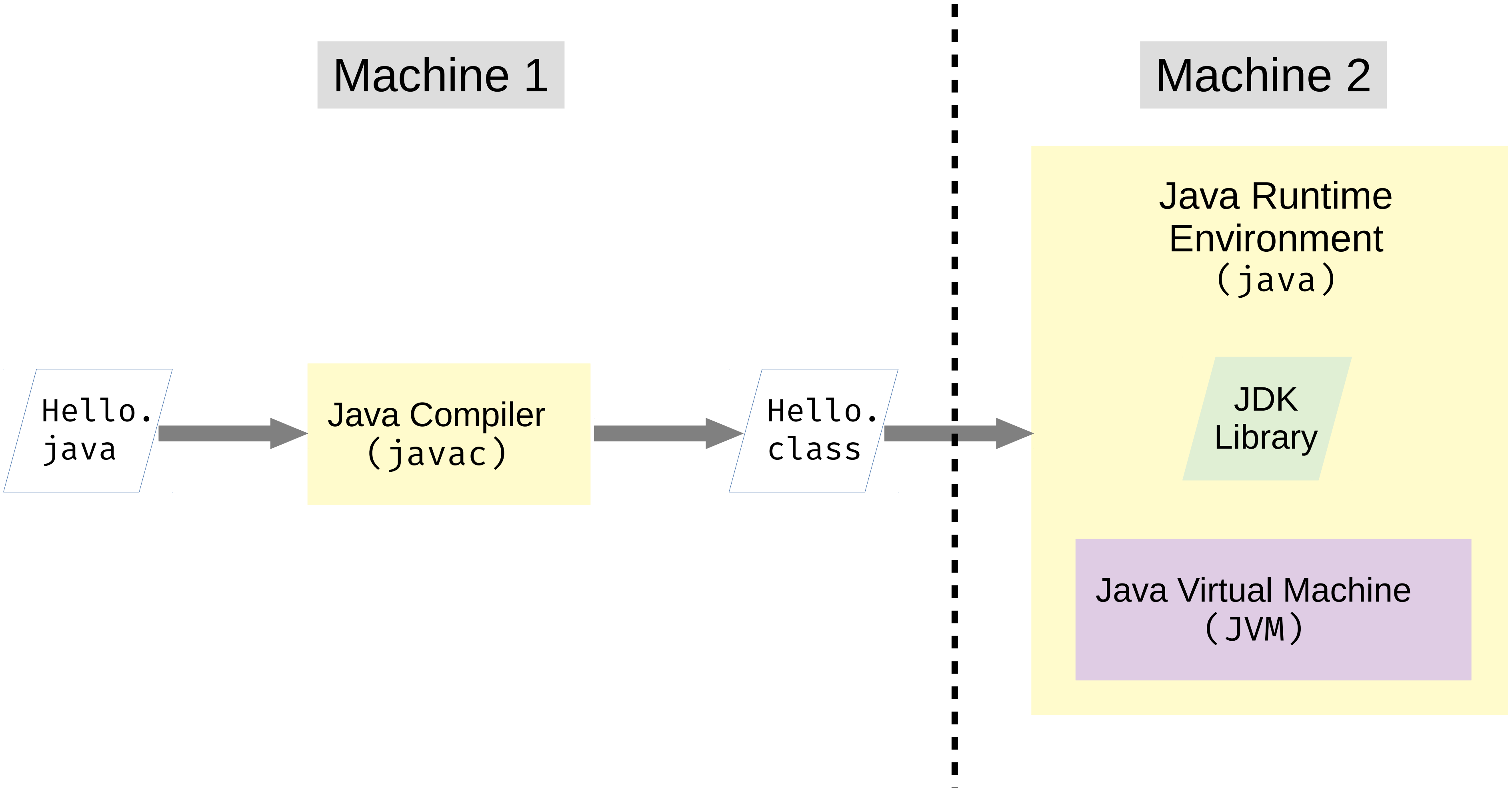
	A COMPILER	AN INTERPRETER
Input	... takes an entire program as its input.	... takes a single line of code, or instruction, as its input.
Output	... generates intermediate object code.	... does not generate any intermediate object code.
Speed	... executes faster.	... executes slower.
Memory	... requires more memory in order to create object code.	... requires less memory (doesn't create object code).
Workload	... doesn't need to compile every single time, just once.	... has to convert high-level languages to low-level programs at execution.
Errors	... displays errors once the entire program is checked.	... displays errors when each instruction is run.

Image source: https://www.upwork.com

Outline

- Basics
- The Java way
- HotSpot under the hood
- Playing around

The Java Compilation+Execution Model



A Bit of Bytecode

```
int a = 10;
int b = 20;
int c = a + b;
```

```
 0: bipush        10
 2: istore_1
 3: bipush        20
 5: istore_2
 6: iload_1
 7: iload_2
 8: iadd
 9: istore_3
10: return
```

Bytecode indices

`javap -c` *`class_name`*

What does the JVM do with my code?

- Basics
- The Java way
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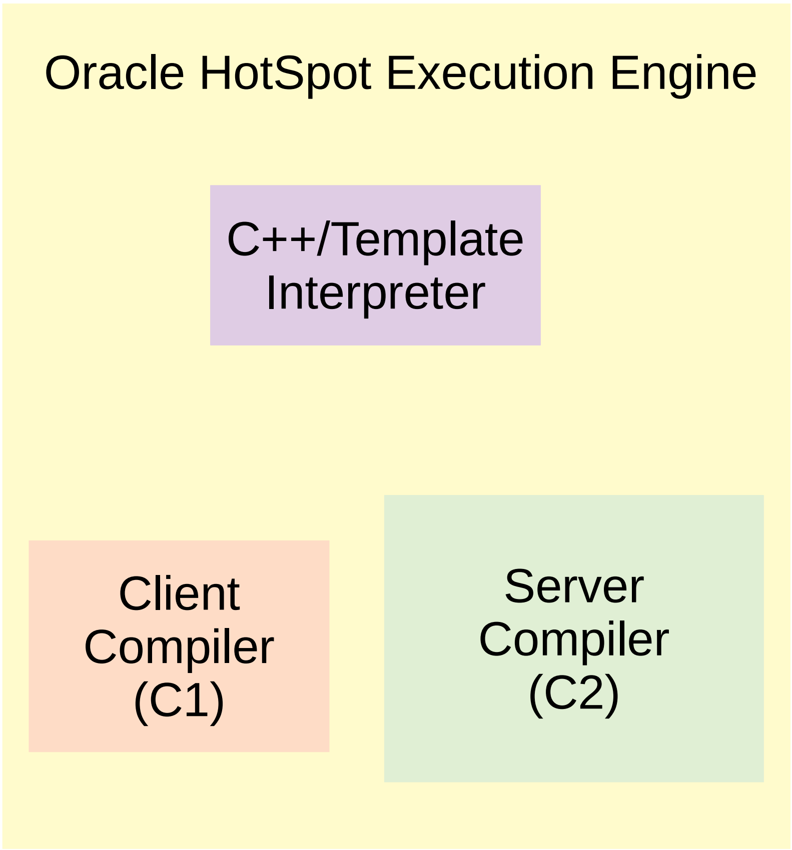
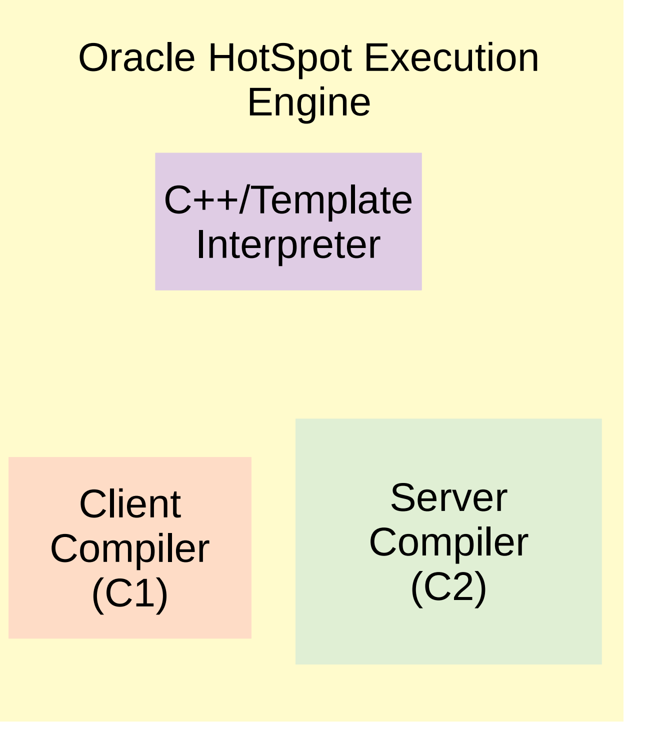
Is Java Bytecode interpreted or compiled?

Java Bytecode is interpreted as well as compiled!!



The "HotSpot" JVM

- HotSpot uses *tiered* compilation with profiling
  - Starts off with interpreter
  - Hot spots get compiled as they get executed
    - Method entry-points changed dynamically
    - Loops replaced *on-the-stack*
- Interpreters:
  - C++ interpreter (deprecated)
  - Template interpreter
- Just-In-Time (JIT) Compilers:
  - C1 (aka *client*)
  - C2 (aka *server*)



The C++ Interpreter

- Simple switch-case

```
switch (bytecode) {
    case nop        : break;
    case aconst_null: push(null); break;
    case iconst_1   : push(1); break;
    ...
}
```

- Disadvantage: Slow
  - Too many comparisons
  - No idea where to go for the next bytecode

The C1 Compiler

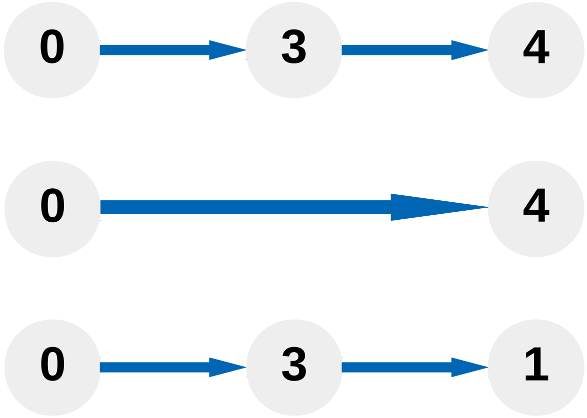
- Targets fast compilation
- Still performs several optimizations:
  - Method inlining
  - Dead code/path elimination
  - Heuristics for optimizing call sites
  - Constant folding
  - Peephole optimizations
  - Linear-scan register allocation, etc.
- Threshold: 1000 to 2000

The C2 Compiler

- Targets more-and-more optimization
- Performs expensive optimizations (*apart from the ones performed by C1*):
  - Escape analysis
  - Null-check elimination
  - Loop unrolling/unswitching
  - Branch prediction
  - Graph-coloring based register allocation, etc.
- Threshold: 10000 to 15000

Compilation Levels

- 0 – Interpreter
- 1 – Pure C1
- 2 – C1 with invocation and backedge counting
- 3 – C1 with full profiling
- 4 – C2 (full optimization)



Deoptimization

- Optimistic optimizations:
  - Branch prediction
  - Implicit null checks
  - Morphism
- When an assumption fails, the compiled method may be invalidated, and the execution falls back to the interpreter
- Consistency maintained using *safepoints*
- Method states: `in use, not entrant, zombie, unloaded`

Deoptimization is costly; happens lesser the better

HotSpot in Action

GIF source: https://plus.google.com/115554596490492757072

When Theory becomes Practice

- Basics
- The Java way
- HotSpot under the hood
- Playing around

"It was here when Harris decided to 'tweak' things a bit..."

Some Useful Flags

- Compilation details: `-XX:+PrintCompilation`
- Dump assembly: `-XX:+PrintInterpreter`
- Interpreter-only mode: `-Xint`
- Compiler-only mode: `-Xcomp`
- Disable levels 1, 2, and 3: `-XX:-TieredCompilation`
- Stop compilation at level n: `-XX:TieredStopAtLevel=n`

Some key learnings

- Java programs are not inherently slow.
- Compiler analyses/optimizations tremendously affect the program performance.
- Java programs are interpreted *as well as* compiled.
- Trust the JVM, and help it.
- Keep experimenting.

Pointers for the enthusiast

- *https://www.cubrid.org/blog/understanding-jvm-internals*
- *https://www.artima.com/insidejvm/ed2/jvmP.html*
- *https://declara.com/content/3gBB6Jge*
- *https://www.infoq.com/presentations/hotspot-memory-data-structures*
- *http://www.progdoc.de/papers/Jax2012/jax2012.html*
- *https://www.ibm.com/developerworks/library/j-jtp12214/index.html*

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