Polyglot Native: Scala, Kotlin, and Other JVM-Based Languages with Instant Startup and low Footprint

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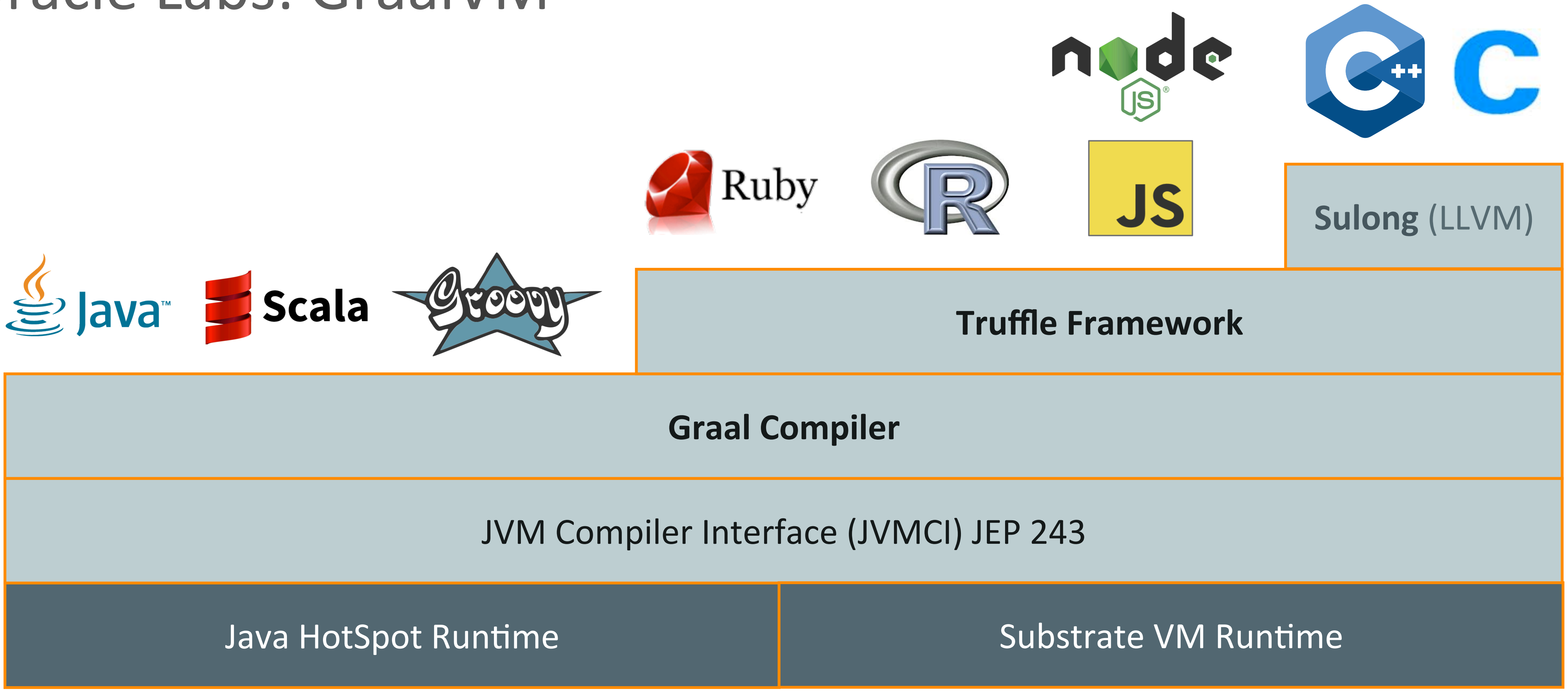
Safe Harbor Statement

Oracle Labs: GraalVM



Sulong (LLVM)

Truffle Framework

Graal Compiler

JVM Compiler Interface (JVMCI) JEP 243

Java HotSpot Runtime

Substrate VM Runtime

Managed Runtimes: Slow Startup and High Footprint

- Slow startup and high footprint
  - Class loading
  - Bytecode interpretation or baseline compilation
  - Just-in-time compilation

Program	Time	Instructions
“Hello, World!” in C	0.005s	154,127
“Hello, World!” in Java	0.109s	162,673,275
“Hello, World!” in JS on the JVM	1.268s	3,272,118,178

Complexity of JNI

JVM

Process Boundary

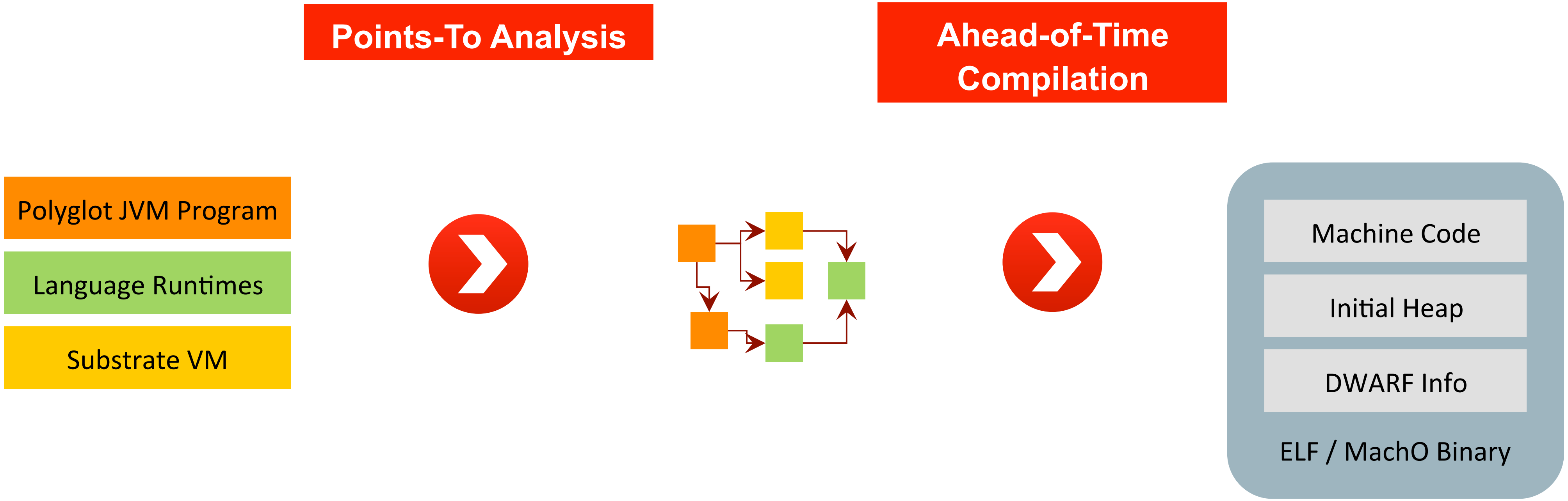
Native Code

Java AOT (JEP 235) and Project Panama

- Java AOT addresses startup performance on the JVM
  - Ahead-of-time compiles Java bytecode
  - Code is JIT compiled with profiling information
  - Ahead-of-time compiled code contains additional instructions for profiling

- Project Panama
  - Makes it faster and easier to call native code from Java
  - Allows changes the Java object layout for native code
  - JVM still can not be easily embedded in native projects

Polyglot Native: Execution Model



Points-To Analysis

Ahead-of-Time Compilation

Polyglot JVM Program

Language Runtimes

Substrate VM

Machine Code

Initial Heap

DWARF Info

ELF / MachO Binary

All classes from
the user application,
all language runtimes,
and Substrate VM

Reachable methods,
fields, and classes

Application running
without dependency on JDK
and without Java class loading

The Substrate VM is …

… an **embeddable** VM

for, and written in, a **subset of Java**

optimized to **execute Truffle** languages

ahead-of-time compiled using Graal

integrating with **native development tools.**

Substrate VM Building Blocks

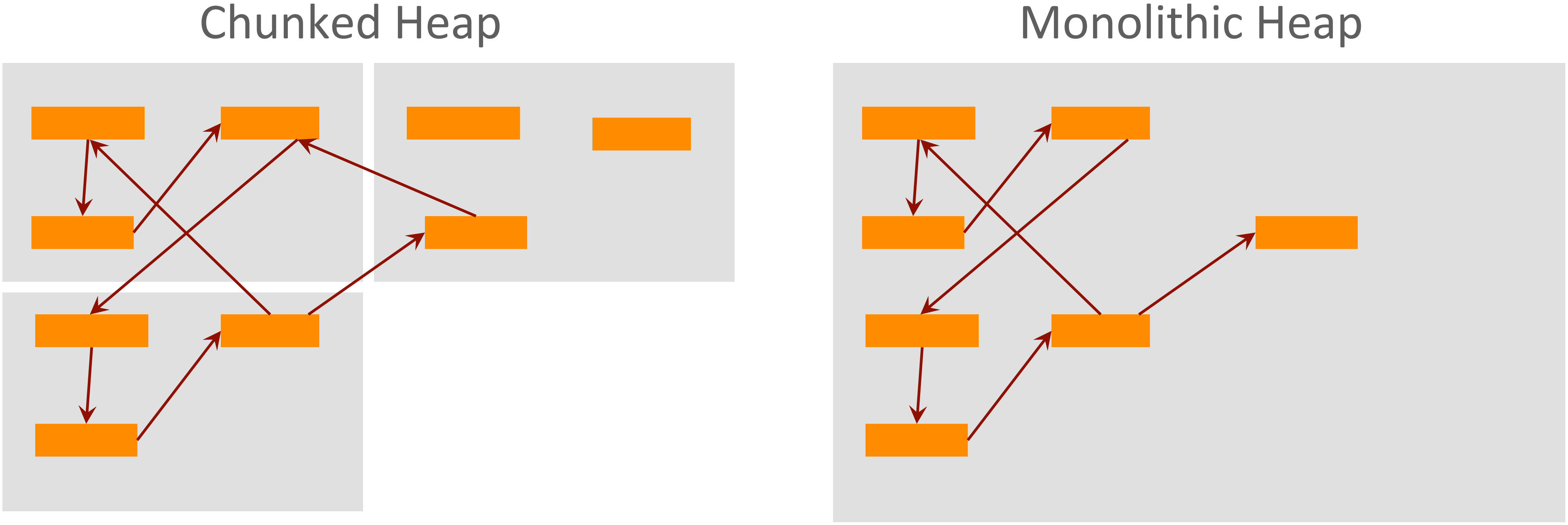
- Reduced runtime system, all written in Java
  - Stack walking, exception handling, garbage collector, deoptimization
  - Graal for ahead-of-time compilation and dynamic compilation

- Points-to analysis
  - Closed-world assumption: no dynamic class loading, no reflection
  - Using Graal for bytecode parsing
  - Fixed-point iteration: propagate type states through methods

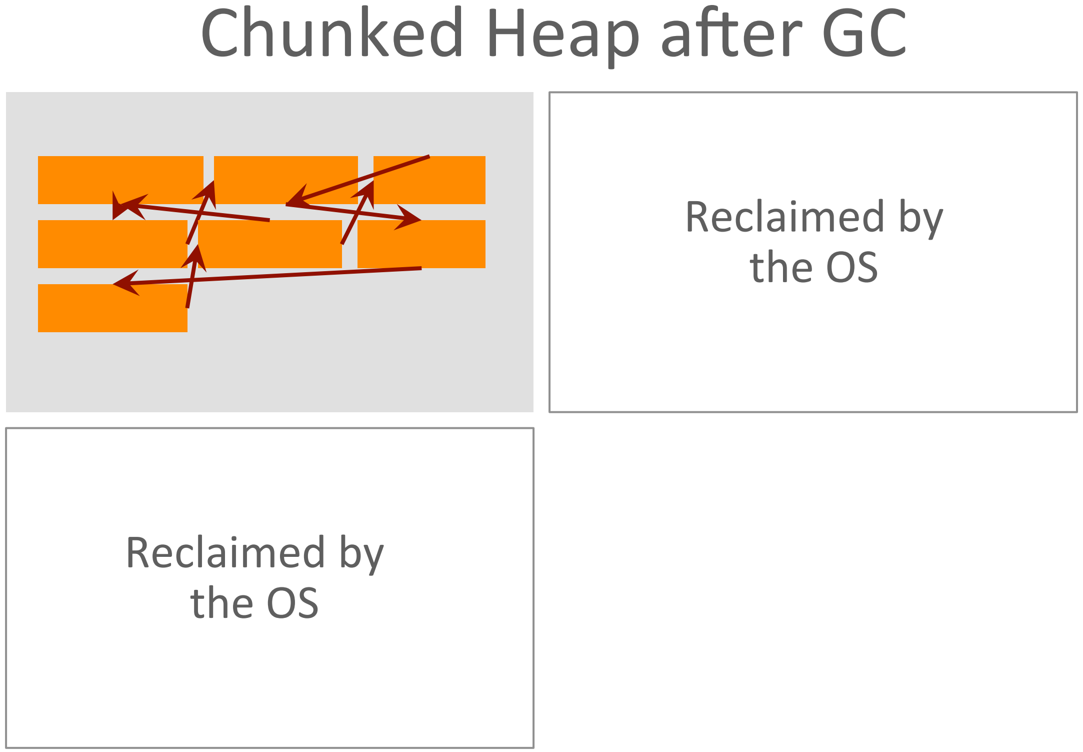
- SystemJava for integration with C code
  - Machine-word sized value, represented as Java interface, but unboxed by compiler
  - Import of C functions and C structs to Java

- Substitutions for JDK methods that use unsupported features
  - JNI code replaced with SystemJava code that directly calls to C library

Chunked Heap for Low Footprint



Chunked Heap for Low Footprint


Chunked Heap after GC

Reclaimed by
the OS

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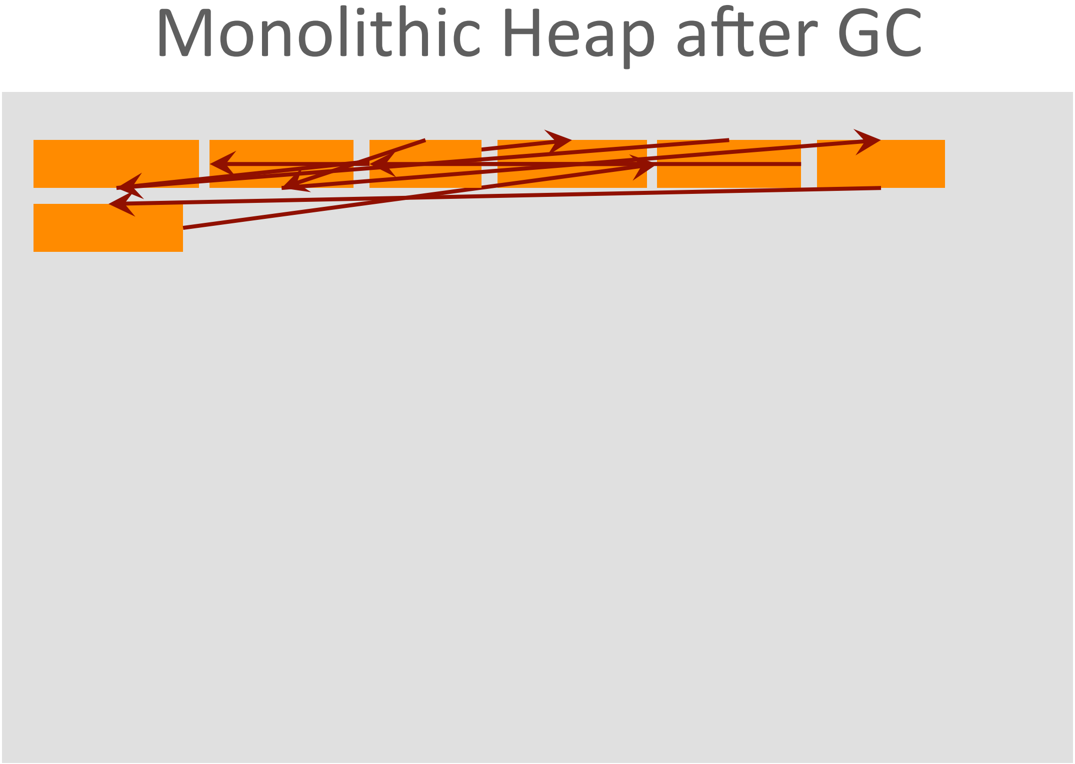
Monolithic Heap after GC

Polyglot Native: Execution Model

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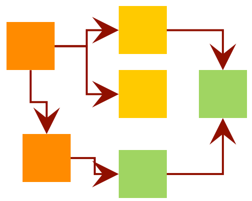

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Points-To Analysis

Graal as a Static Analysis Framework

- Graal and the hosting Java VM provide
  - Class loading (parse the class file)
  - Access the bytecodes of a method
  - Access to the Java type hierarchy, type checks
  - Build a high-level IR graph in SSA form
  - Linking / method resolution of method calls

- Static points-to analysis and compilation use same intermediate representation
  - Simplifies applying the analysis results for optimizations

- Goals of points-to analysis
  - Identify all methods reachable from a root method
  - Identify the types assigned to each field
  - Identify all instantiated types
- Fixed point iteration of type flows: Types are propagated from sources (allocations) to usages

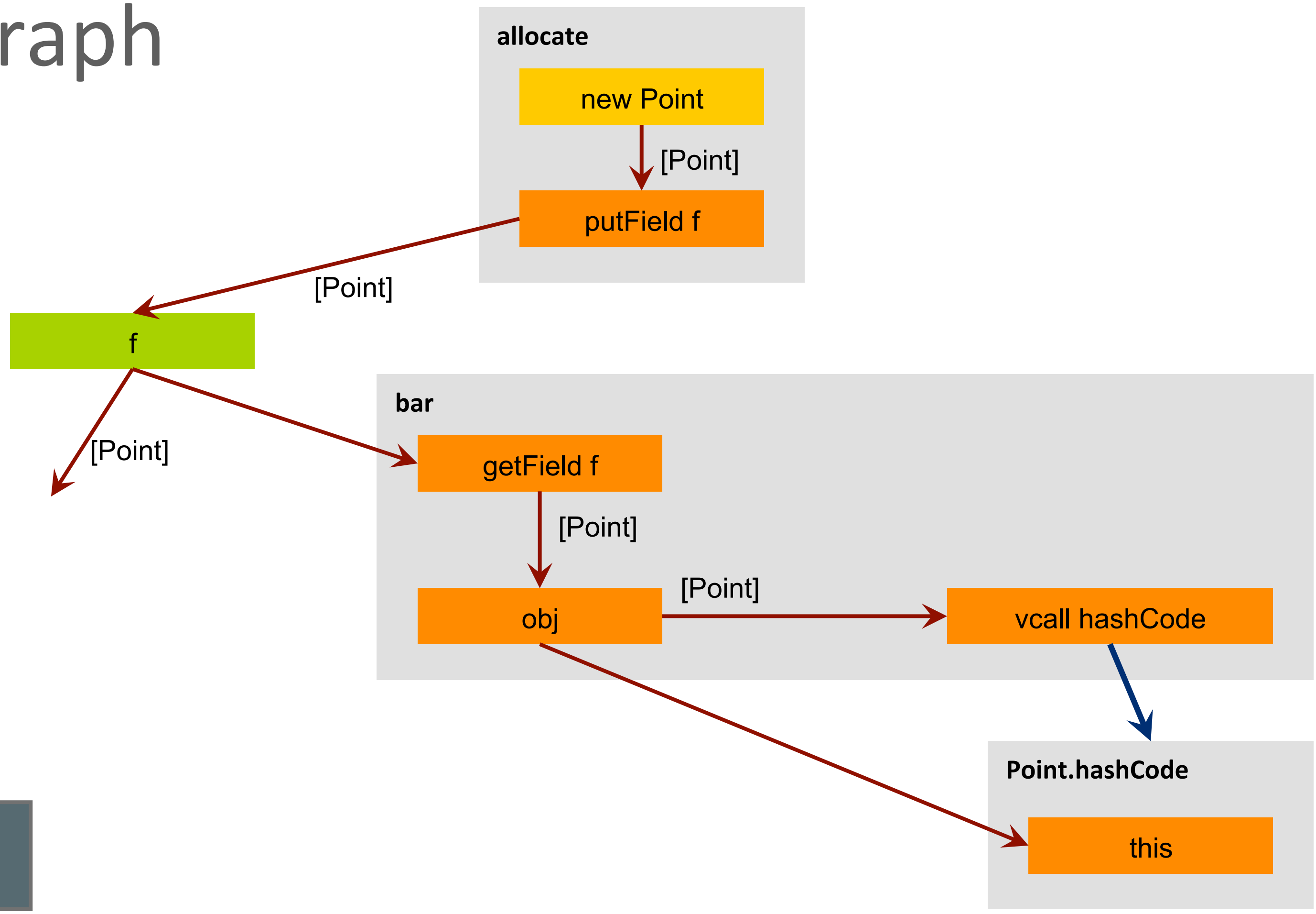
Example Type Flow Graph

```
Object f;

void foo() {
  allocate();
  bar();
}

Object allocate() {
  f = new Point()
}

int bar() {
  return f.hashCode();
}
```



Analysis is context insensitive:
One type state per field

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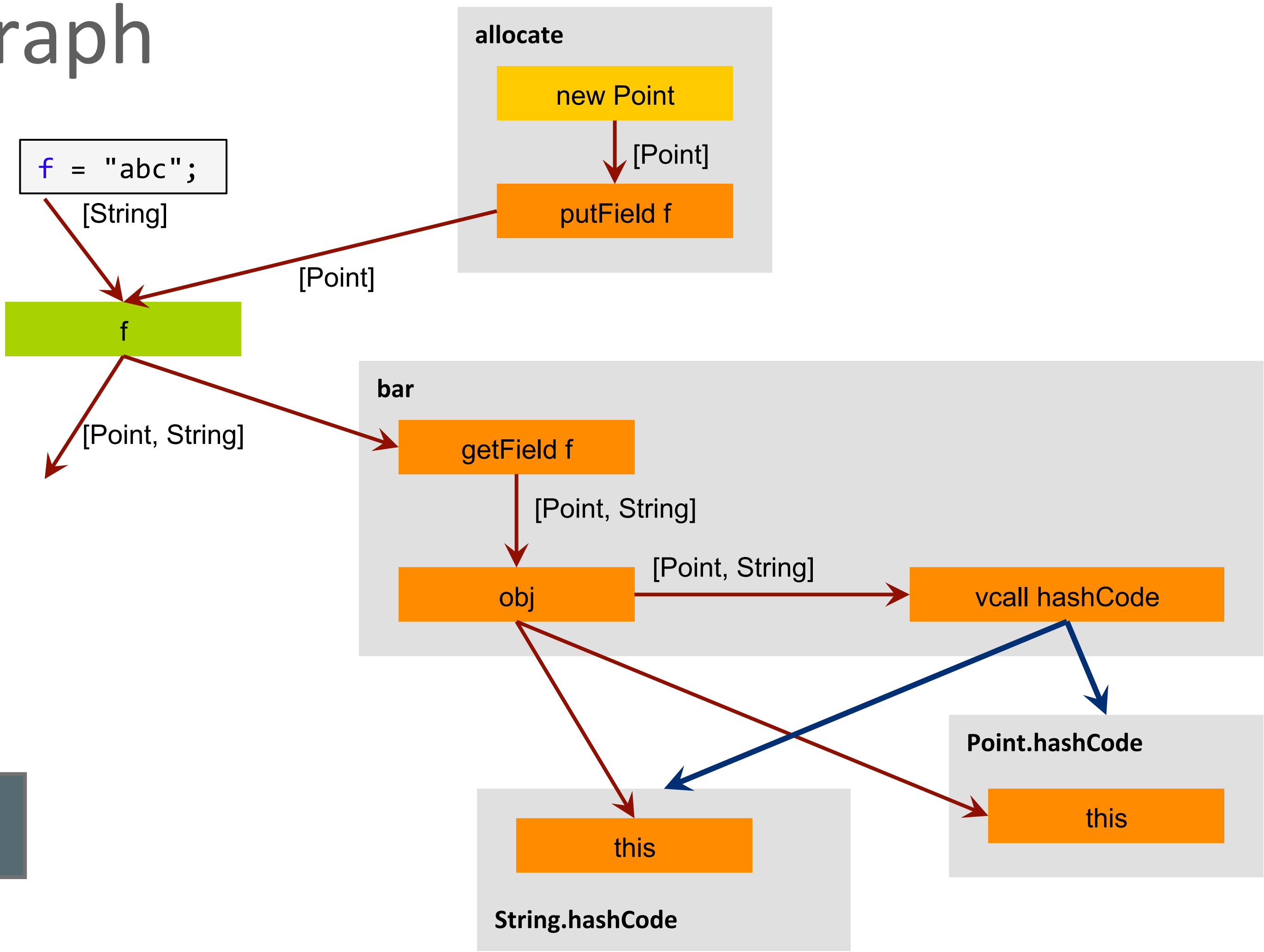

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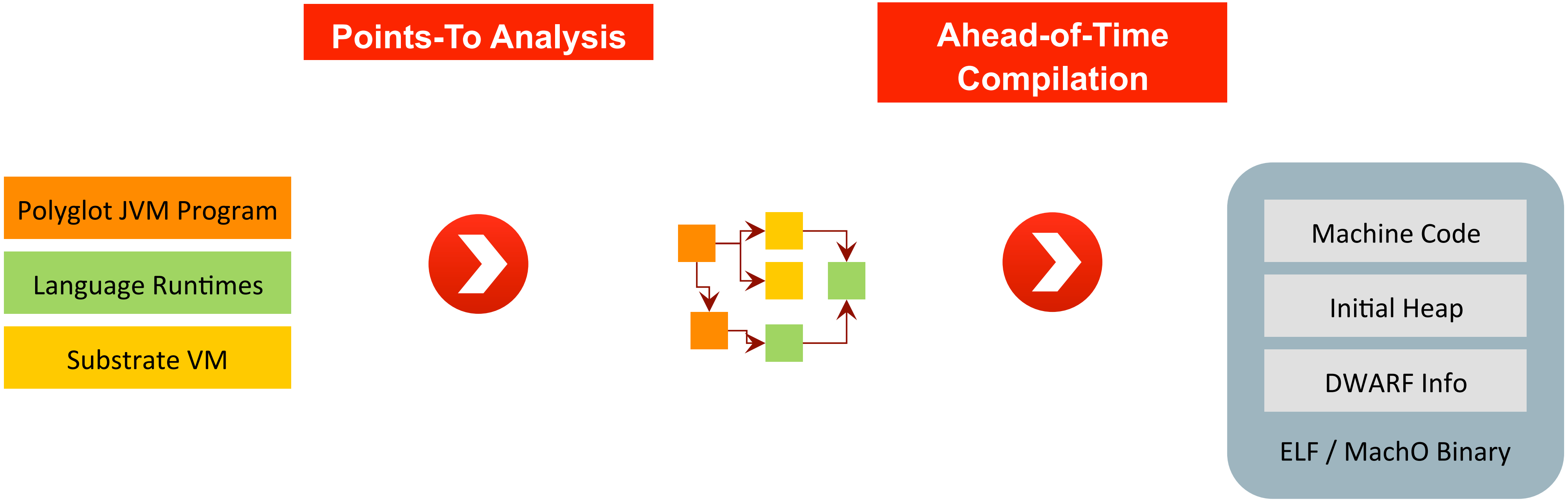

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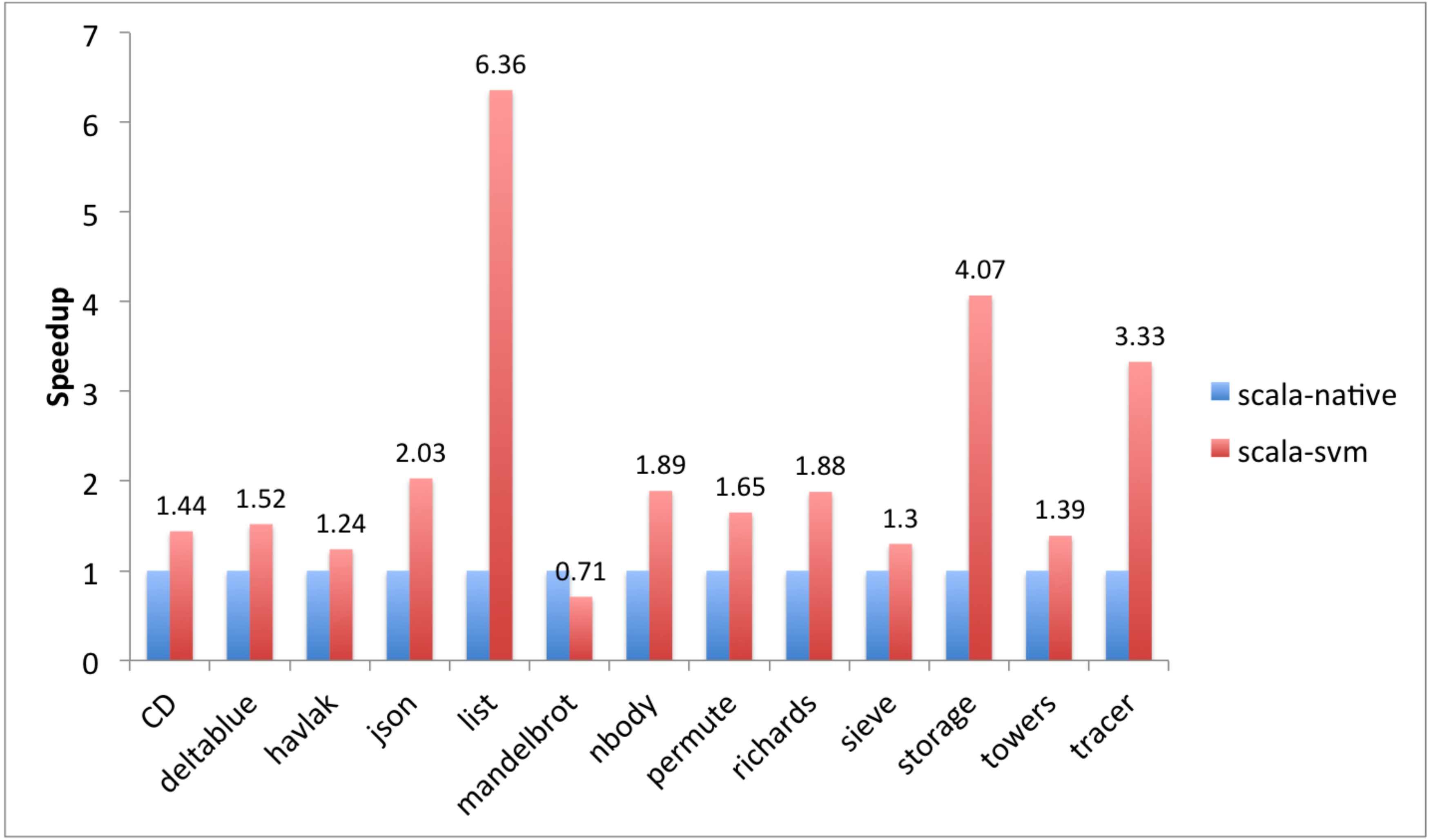
Polyglot Native Startup

- Slow startup and high footprint
  - Class loading
  - Bytecode interpretation
  - Just-in-time compilation
  - Monolithic heap

Program	Time	Instructions
“Hello, World!” in C	0.005s	154,127
“Hello, World!” in PN	0.006s	232,122
“Hello, World!” in JS with PN	0.028s	915,461

Demo: Instant Startup of JVM Code

Benchmarks: Scala Native vs SystemJava



SystemJava

SystemJava

- Legacy C code integration
  - Need a convenient way to access preexisting C functions and structures

- Legacy Java code integration
  - Leverage preexisting Java libraries
  - Example: JDK class library

- Call Java from C code
  - Entry points into JVM code

SystemJava vs. JNI

- Java Native Interface (JNI)
  - Write custom C code to integrate existing C code with Java
  - C code knows about Java types
  - Java objects passed to C code using handles

- SystemJava
  - Write custom Java code to integrate existing C code with Java
  - Java code knows about C types

Word Type for Low-Level Memory Access

- Requirements
  - Support raw memory access and pointer arithmetic
  - No extension of the Java programming language
  - Pointer type modeled as a class to prevent mixing with, e.g., `long`
  - Transparent bit width (32 bit or 64 bit) in code using it

- Base interface `Word`
  - Looks like an object to the Java IDE, but is a primitive value at run time
  - Graal does the transformation

- Subclasses for type safety
  - `Pointer`: C equivalent `void*`
  - `Unsigned`: C equivalent `size_t`
  - `Signed`: C equivalent `ssize_t`

```
public static Unsigned strlen(CharPointer str) {
  Unsigned n = Word.zero();
  while (str.read(n) != 0) {
    n = n.add(1);
  }
  return n;
}
```

Java Annotations for C Interoperability

```
@CFunction static native int clock_gettime(int clock_id, timespec tp);
```

```
int clock_gettime(clockid_t __clock_id, struct timespec *__tp)
```

```
@CConstant static native int CLOCK_MONOTONIC();
```

```
#define CLOCK_MONOTONIC 1
```

```
@CStruct interface timespec extends PointerBase {
  @CField long tv_sec();
  @CField long tv_nsec();
}
```

```
struct timespec {
  __time_t tv_sec;
  __syscall_slong_t tv_nsec;
};
```

```
@CPointerTo(nameOfCType="int") interface CIntPointer extends PointerBase {
  int read();
  void write(int value);
}
```

```
int* pint;
```

```
@CPointerTo(CIntPointer.class) interface CIntPointerPointer ...
```

```
int** ppint;
```

```
@CContext(PosixDirectives.class)
```

```
#include <time.h>
```

```
@CLibrary("rt")
```

```
-lrt
```

Implementation of `System.nanoTime()` using SystemJava:

```
static long nanoTime() {
  timespec tp = StackValue.get(SizeOf.get(timespec.class));
  clock_gettime(CLOCK_MONOTONIC(), tp);
  return tp.tv_sec() * 1_000_000_000L + tp.tv_nsec();
}
```

SystemJava from JVM Languages

- SystemJava extracts semantics from bytecode
- For all static JVM languages:
  - Function calls are propagated
  - Java annotations are propagated to bytecode
- Possible extension to language idiomatic interface
  - In Scala *sizeOf[CCharPointer]* would be preferred to *SizeOf.get(CCharPointer.class)*

SystemJava	SystemScala	SystemKotlin
SizeOf.get(CCharPointer.class)	SizeOf.get(classOf[CCharPointer])	SizeOf.get(CCharPointer::class)
StackAlloc.get(…)	StackAlloc.get(…)	StackAlloc.get(…)
@CStruct interface AStruct {…}	@CStruct trait AStruct {…}	@CStruct interface AStruct {…}

Managed Objects in Native Code

- Managed objects are different than native objects
  - in layout, as every object has a header
  - memory location, they can, at any time, be moved by the garbage collector

- To avoid these issues, when passing objects to native code
  - use handles when native code only holds a reference
  - pin objects and ignore their header when native code reads the object

Demo: Sentiment Analysis of Tweets

Limitations

- Java reflection can not be fully supported
  - Dynamic class loading is not possible
- Currently not implemented
  - Reflective access to Java fields, methods, and types

Take Polyglot Native for a Spin

- Download GraalVM

  http://www.oracle.com/technetwork/oracle-labs/program-languages/downloads/index.html

- The Tweet Sentiment Analysis Demo

  https://github.com/vjovanov/polyglot-native-demo

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