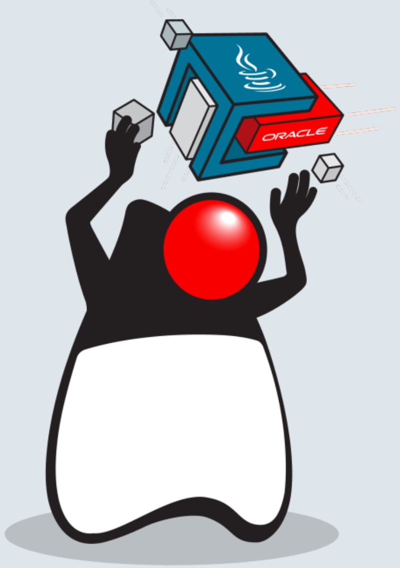
Project Panama

Status update

March, 2019



A rising tide

GPUs and deep learning

- Linear algebra computations critical for machine learning
  - E.g. matrix multiplications (dot products) and additions
- Matrix computations are *embarrassingly parallel*!
  - GPUs provide acceleration for common computations (e.g. cuBLAS)
- Deep learning frameworks support GPUs as execution backend of choice
  - Theano, Tensorflow, Spark, Torch, …
- But wait, all these frameworks rely on **native** libraries!

Going native

- Sometimes you just have to “go native”
  - Off-CPU computing (Cuda, OpenCL)
  - Deep learning (Blas, cuBlas, cuDNN, Tensorflow, …)
  - Graphics processing (OpenGL, Vulkan, DirectX)
  - Others (OpenSSL, SQLite, V8, ...)
- Languages/platforms must **lower** the *activation energy* required to do so!

Java Native Interface

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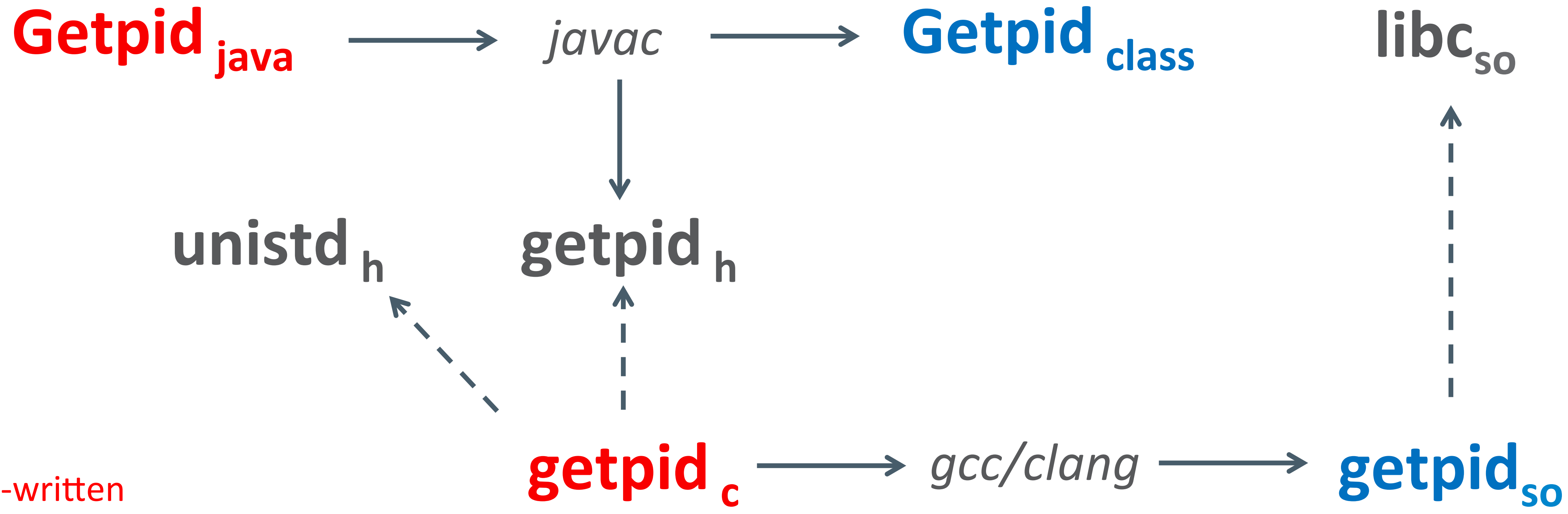
Getpid in JNI

```
//Getpid.java
public class Getpid {
   native int getpid();
}

//Client.java
class Client {
   public static void main(String[] args) {
      new Getpid().getpid();
   }
}
```

Getpid in JNI

Workflow



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Getpid in JNI

Gluing all the framents

```
//Getpid.java
public class Getpid {

  static {
    System.loadLibrary("getpid");
  }

  native int getpid();
}

//Client.java
class Client {
   public static void main(String[] args) {
      new Getpid().getpid();
   }
}
```

```
//getpid.h
#include <jni.h>
#include <stdlib.h>

#ifndef _Included_GetPid
#define _Included_GetPid
#ifdef __cplusplus
extern "C" {
#endif
/*
 * Class:     GetPid
 * Method:    getpid
 * Signature: ()I
 */
JNIEXPORT jint JNICALL Java_GetPid_getpid
  (JNIEnv *, jobject);

#ifdef __cplusplus
}
#endif
#endif
```

```
//getpid.c
#include <unistd.h>
#include "GetPid.h"

JNIEXPORT jint JNICALL Java_GetPid_getpid
  (JNIEnv *env, jobject recv) {
   return getpid();
}
```

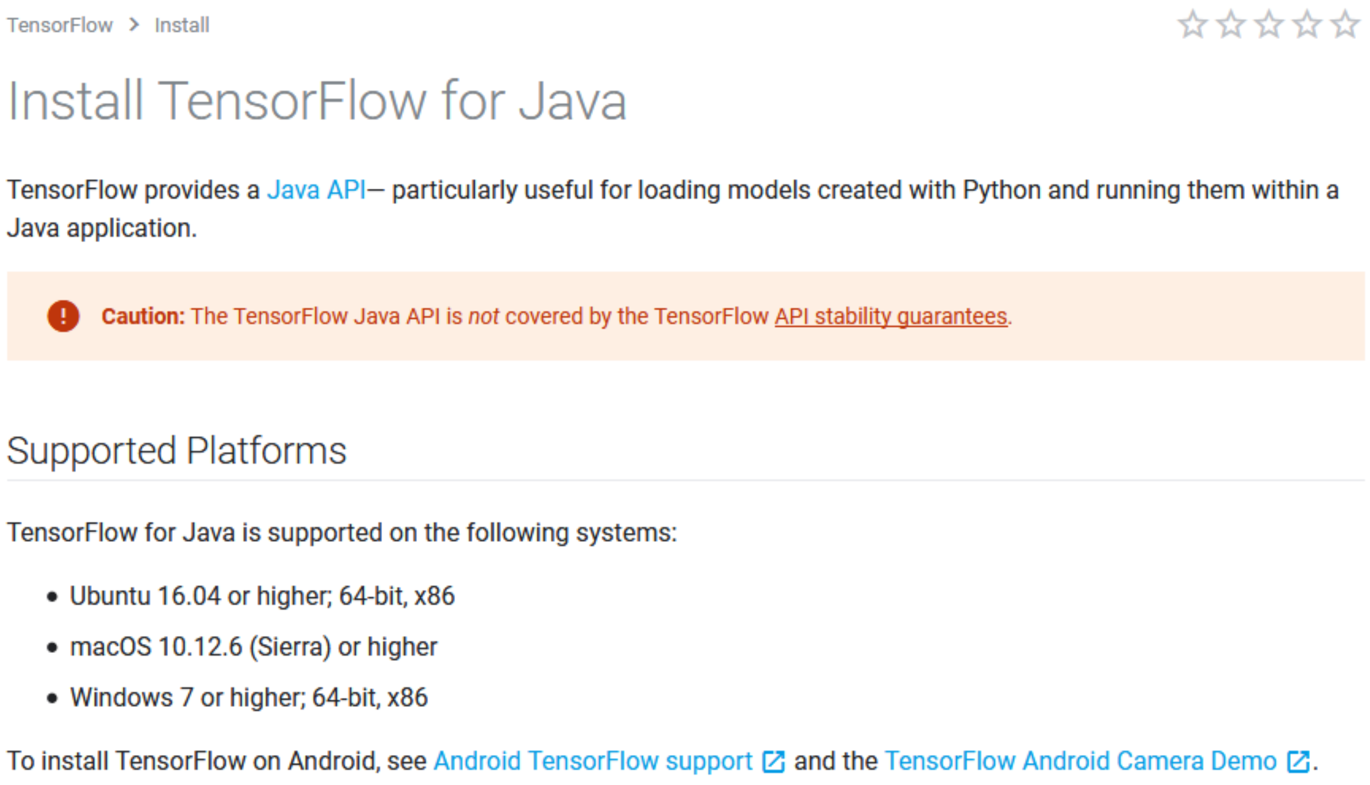
Java Native Interface

Works, but…

- Good: Rich, **bidirectional** interop between Java and native code
- Bad: No support for modelling **off-heap** data
  - DIY solutions: Unsafe, ByteBuffer, …
- Ugly: Convoluted workflow
  - (Java) users must know how to write (and build!) *native* code
- Result: writing native bindings in Java is **hard**!
  - Many things can go out of sync as native libraries are updated

When JNI fails

Java native bindings fall behind



TensorFlow > Install

☆☆☆☆☆

Install TensorFlow for Java

TensorFlow provides a Java API— particularly useful for loading models created with Python and running them within a Java application.

> **Caution:** The TensorFlow Java API is *not* covered by the TensorFlow API stability guarantees.

Supported Platforms

TensorFlow for Java is supported on the following systems:

- Ubuntu 16.04 or higher; 64-bit, x86
- macOS 10.12.6 (Sierra) or higher
- Windows 7 or higher; 64-bit, x86

To install TensorFlow on Android, see Android TensorFlow support and the TensorFlow Android Camera Demo.

Enter Panama

The vision

> ***“If non-Java programmers find some library useful and easy to access, it should be similarly accessible to Java programmers”***

John Rose, JVM Architect

Panama

The approach

- Idea: model foreign libraries as ordinary Java interfaces
  - Foreign interfaces can be generated by tools
  - Implementations generated on-the-fly (*binding*)
- Rich API to model **off-heap** data
  - Layout, Pointer, Array, Scope, …
- Result: no more native methods!

Getpid in Panama

Library as interfaces

- Foreign functions are *just* methods calls on some *library* object

```
_lib.getpid();
```

Getpid in Panama

Library as interfaces

- Foreign functions are *just* methods calls on some *library* object
- Library objects are obtained by *binding* a library interface

```
var _lib = Libraries.bind(
                  MethodHandles.lookup(),
                  Getpid.class);
_lib.getpid();
```

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Getpid in Panama

Library as interfaces

```
@NativeHeader
interface Getpid {
    @NativeFunction(“()i32”)
    int getpid();
}


var _lib = Libraries.bind(
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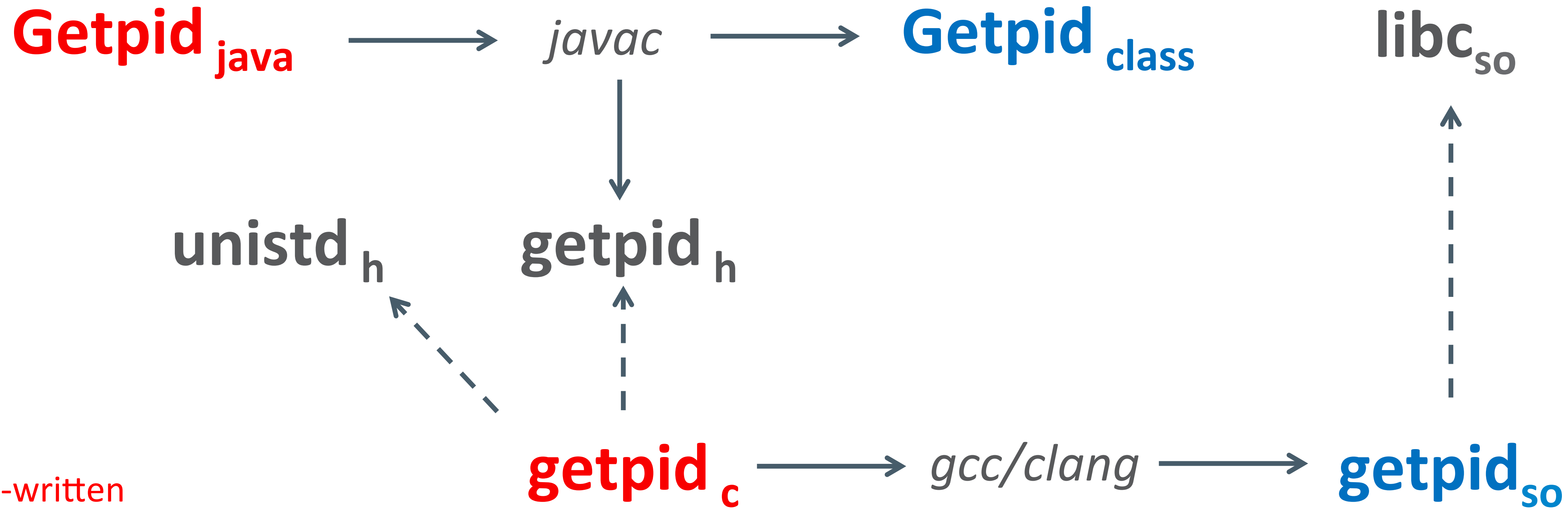
_lib.getpid();
```

- Foreign functions are *just* methods calls on some *library* object
- Library objects are obtained by *binding* a library interface
- Library interfaces contain *metadata*
  - – E.g. to describe native layouts

Getpid in JNI

Workflow



Getpid$_{java}$

javac

Getpid$_{class}$

libc$_{so}$

unistd$_{h}$

getpid$_{h}$

getpid$_{c}$

gcc/clang

getpid$_{so}$

user-written
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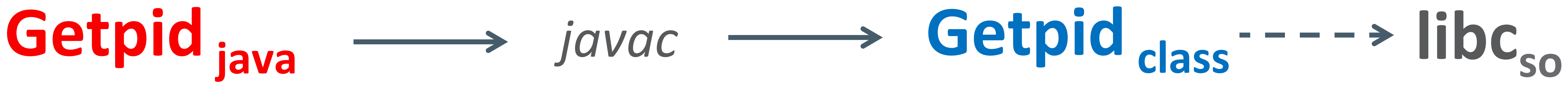
Getpid in Panama

Workflow



$\text{Getpid}_{\text{java}}$ → *javac* → $\text{Getpid}_{\text{class}}$ - - - -> libc_{so}

user-written
generated

Off-heap access

pointers and arrays

- Native pointers are modelled with generic class Pointer<X>
  - Pointer<X> = address + layout$_{\text{pointee}}$ + carrier$_X$
- Basic operations
  - Offset, cast, dereference (get/set), iteration
- Pointers lifecycle managed by Scope
  - Cannot dereference a pointer whose owning scope has been closed!
- Native arrays are modelled with generic class Array<X>
  - Array<X> = Pointer<X> + size

Off-heap access

Pointers and arrays

```
@NativeHeader
interface Strings {
    @NativeFunction(“u64:u8)i32”)
    int strlen(Pointer<Byte> buf);
}

…

var _lib = Libraries.bind(
                  MethodHandles.lookup(),
                  Strings.class);
try (var scope = Scope.newNativeScope()) {
   var strPtr = scope.allocateCString(“Hello”);
   _lib.strlen(strPtr);
}
```

Off-heap access

Pointers and arrays

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- Scope + try-with-resources
  - delimit code blocks which can safely access off-heap memory

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Off-heap access

Pointers and arrays

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```

- Scope + try-with-resources
  - delimit code blocks which can safely access off-heap memory
- Scope provides many useful allocation helpers
  - allocateCString, allocateArray, …

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Panama

Scorecard so far

- Panama interfaces to access foreign functions/data w/o native code!
- But, writing annotated interfaces is (still) relatively **hard** and **error prone**!
  - Interface metadata contains *platform-specific* layout descriptions
- Real world example (Tensorflow)
  - **161** functions, **23** structs, **50** constants, **2** callbacks
  - Total: **26** annotated interfaces!
- Can we do better?

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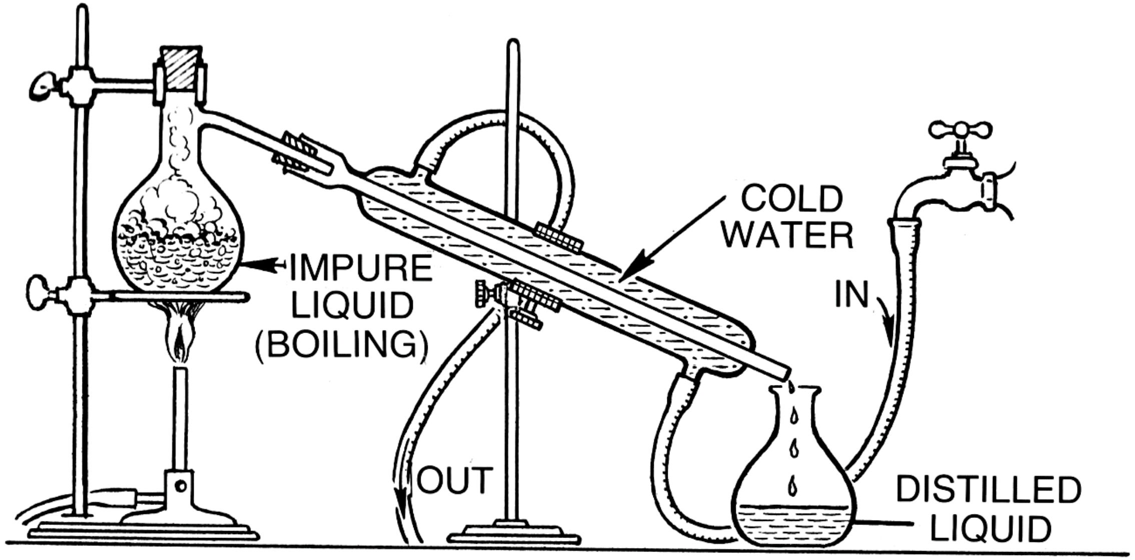
Jextract



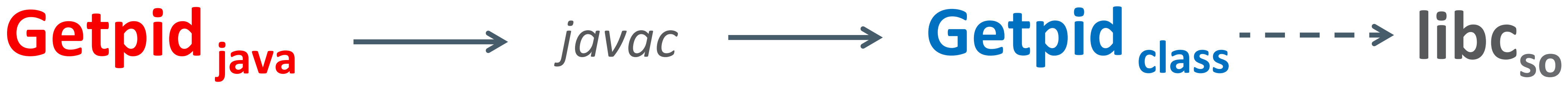
Jextract

Tools sweet tools

- Goal: auto-generate bundles of annotated interfaces from a C header file
  - The generated jar bundle contains headers, structs, callbacks interfaces
- Jextract parses headers (clang), infers layouts, picks Java carrier types
  - The generated bundle is *platform dependent*!
- Tested with many real world libraries
  - Tensorflow, BLAS/LAPACK, OpenCL, Clang, OpenGL, Sqlite, Python, …
  - http://hg.openjdk.java.net/panama/dev/raw-file/foreign/doc/panama_foreign.html

Getpid in Panama

Workflow

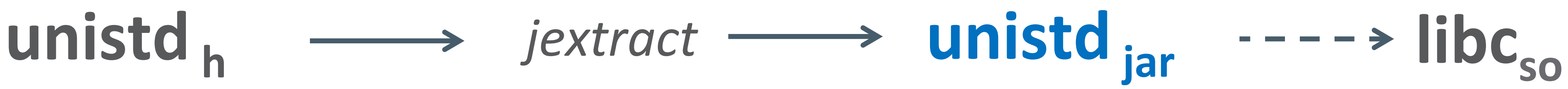


$\text{Getpid}_{\text{java}}$ → *javac* → $\text{Getpid}_{\text{class}}$ - - - - → libc_{so}

user-written
generated

Getpid in Panama

Workflow w/ jextract



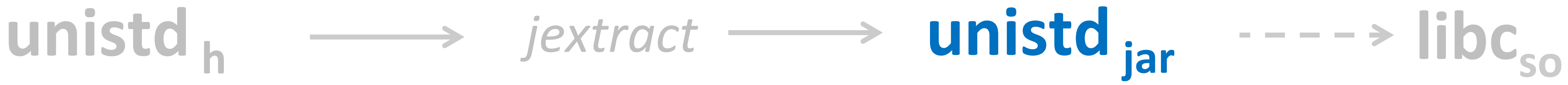
unistd_{h} → *jextract* → $\text{unistd}_{\text{jar}}$ - - - -> libc_{so}

user-written

generated

Getpid in Panama

Workflow w/ jextract

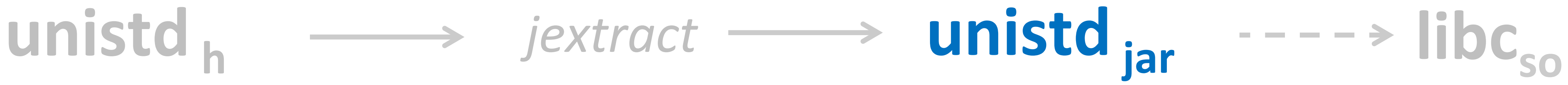


```
unistd.class
unistd$gid_t.class
unistd$intptr_t.class
unistd$off_t.class
unistd$pid_t.class
unistd$socklen_t.class
unistd$ssize_t.class
unistd$uid_t.class
unistd$useconds_t.class
```

user-written
generated

Getpid in Panama

Workflow w/ jextract



```
...
int getpid();
int getppid();
int getpgrp();
int  __getpgid(int);
int getpgid(int);
int setpgid(int, int);
int setpgrp();
...
```

```
unistd.class
unistd$gid_t.class
unistd$intptr_t.class
unistd$off_t.class
unistd$pid_t.class
unistd$socklen_t.class
unistd$ssize_t.class
unistd$uid_t.class
unistd$useconds_t.class
```

user-written
generated

Getpid in Panama

```
@NativeHeader(declarations=
    “getpid=()i32”)
interface Getpid {
    int getpid();
}

…

var _lib = Libraries.bind(
                  MethodHandles.lookup(),
                  Getpid.class);
_lib.getpid();
```

Getpid in Panama

Closing the loop w/ jextract

```
import static stdlib.unistd_h.*;
…
getpid();
```

Performances

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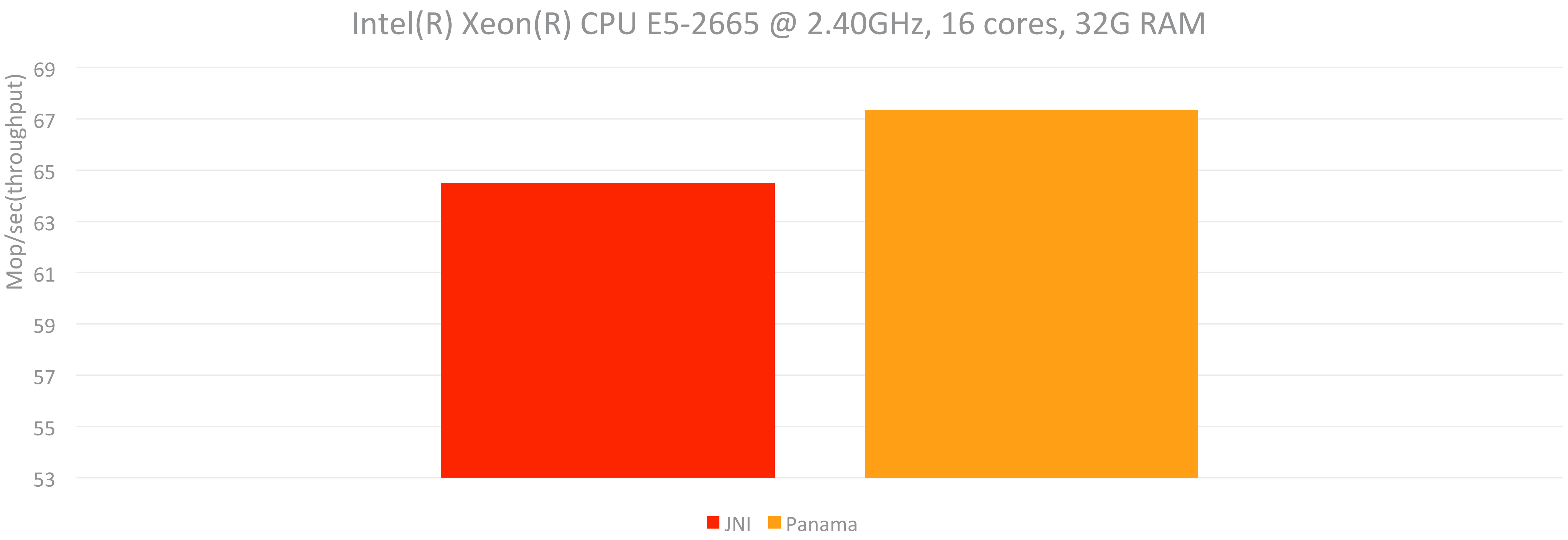
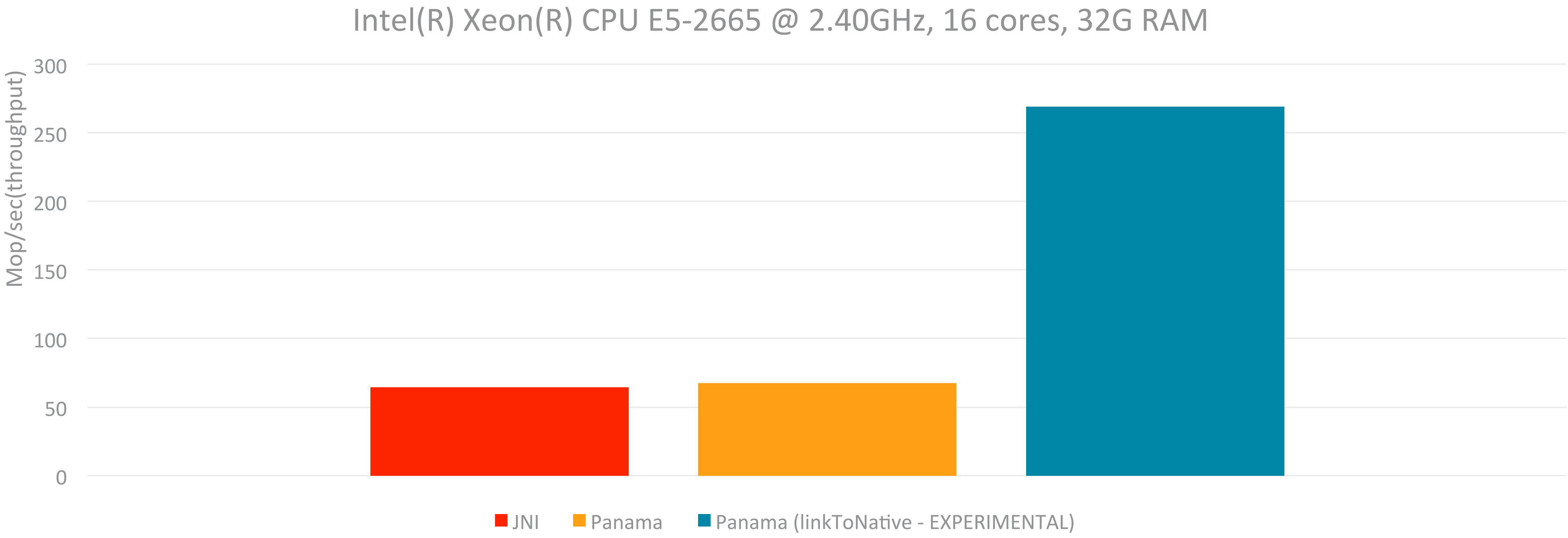
Performances

Getpid



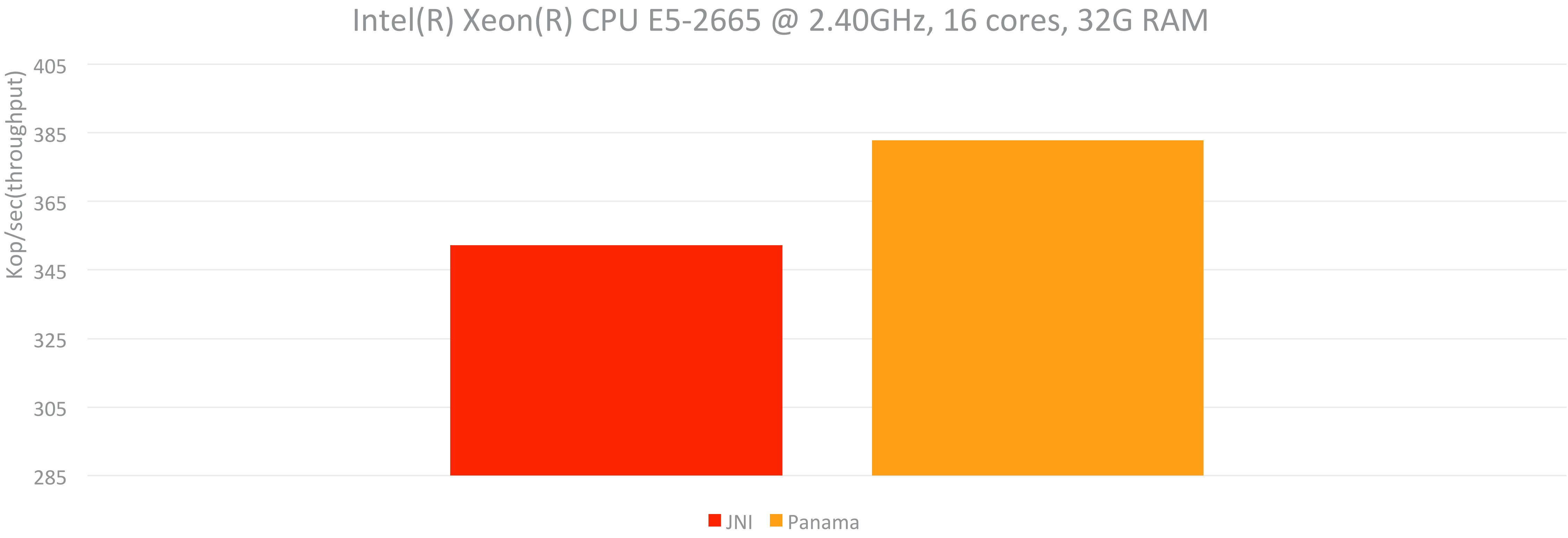
Performances

getpid reloaded (don’t try this at home… yet!)



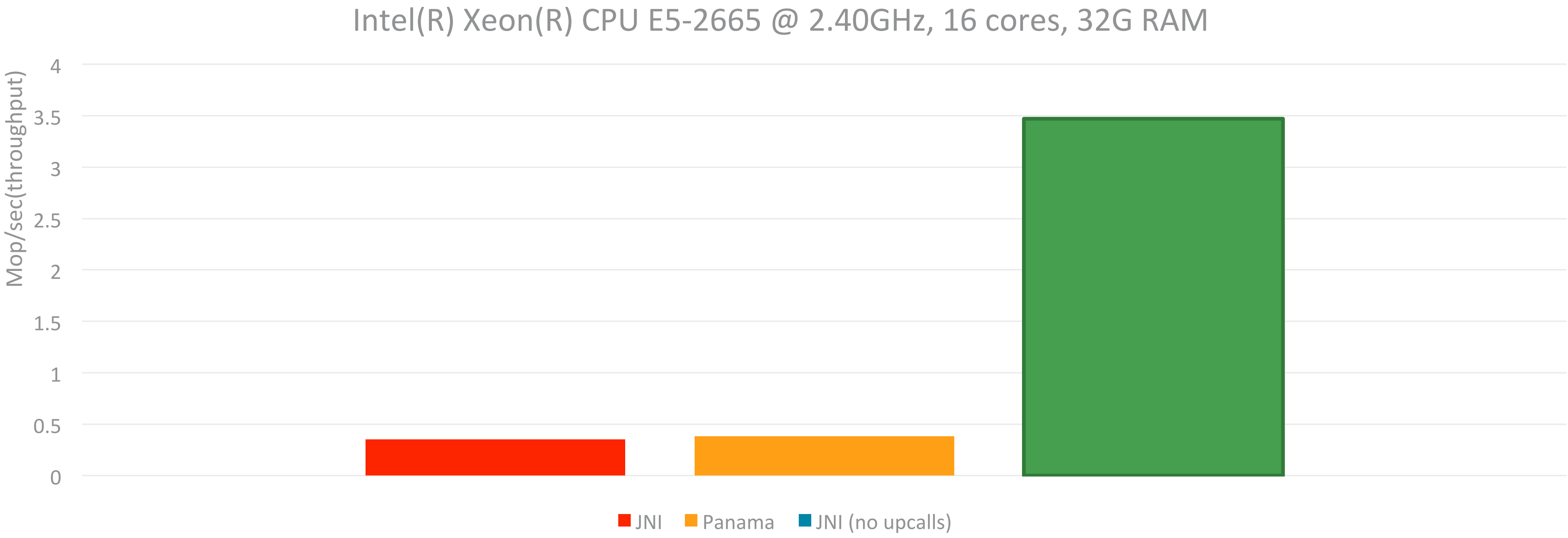
Performances

qsort



Performances

qsort reloaded (upcalls are still expensive)



Panama

Scorecard

- Ease of use: from header files to native bundles with jextract
- Rich API provides seamless integration with native code
  - much of the JNI boilerplate can now be expressed *in Java!*
- A safer alternative to JNI
  - Scope API manages resource lifecycles (pointers, structs, callbacks, …)
- Room for performance improvement is huge
  - Reduce latency of native calls, hoist native transitions out of loops, ...
- Not just for C!

Panama status

- Early access binaries (macOS/Linux/Windows x64)
  - https://jdk.java.net/panama/
- Many community-extracted bindings
  - Vulkan, FFTW, Wayland, Cuda, …
- Community-led ARM port effort is in the works
- Extensive talks with Intel (Steve Dohrmann) to support NVM

Panama Roadmap

Version 2.0

- Step 1: Low-level, foreign data support
  - MemoryAddress, MemoryScope, Layout API, VarHandle changes
- Step 2: Low-level foreign function support
  - SystemABI, VM changes to support “native” method handles (aka LinkToNative)
- Step 3: High level C interop support
  - Pointer<X>, Array<X>, Struct<X>, binder, jextract tool