Write Once, Run Anywhere... Well, What About Heterogeneous Hardware?

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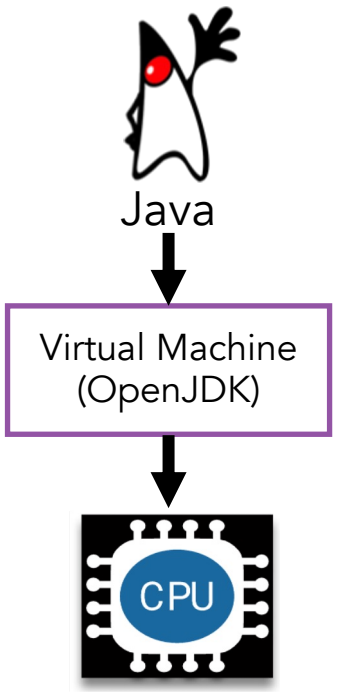
Friends of OpenJDK devroom
Sunday 5th February 2023

Write Once, Run Anywhere

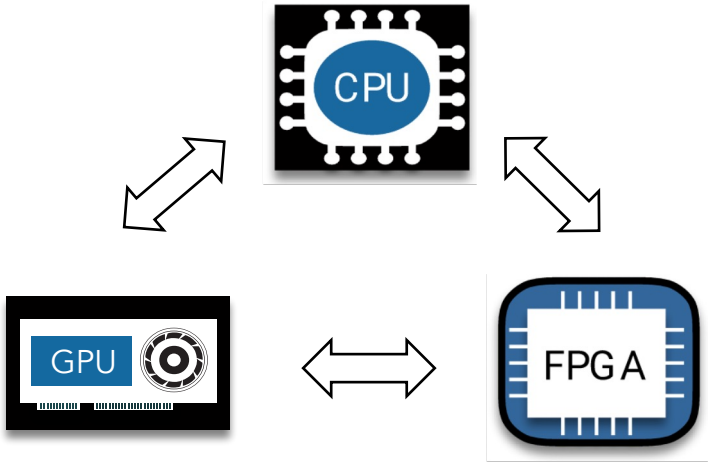


Abstraction

Portability (across different CPUs)

? Portability on heterogeneous hardware

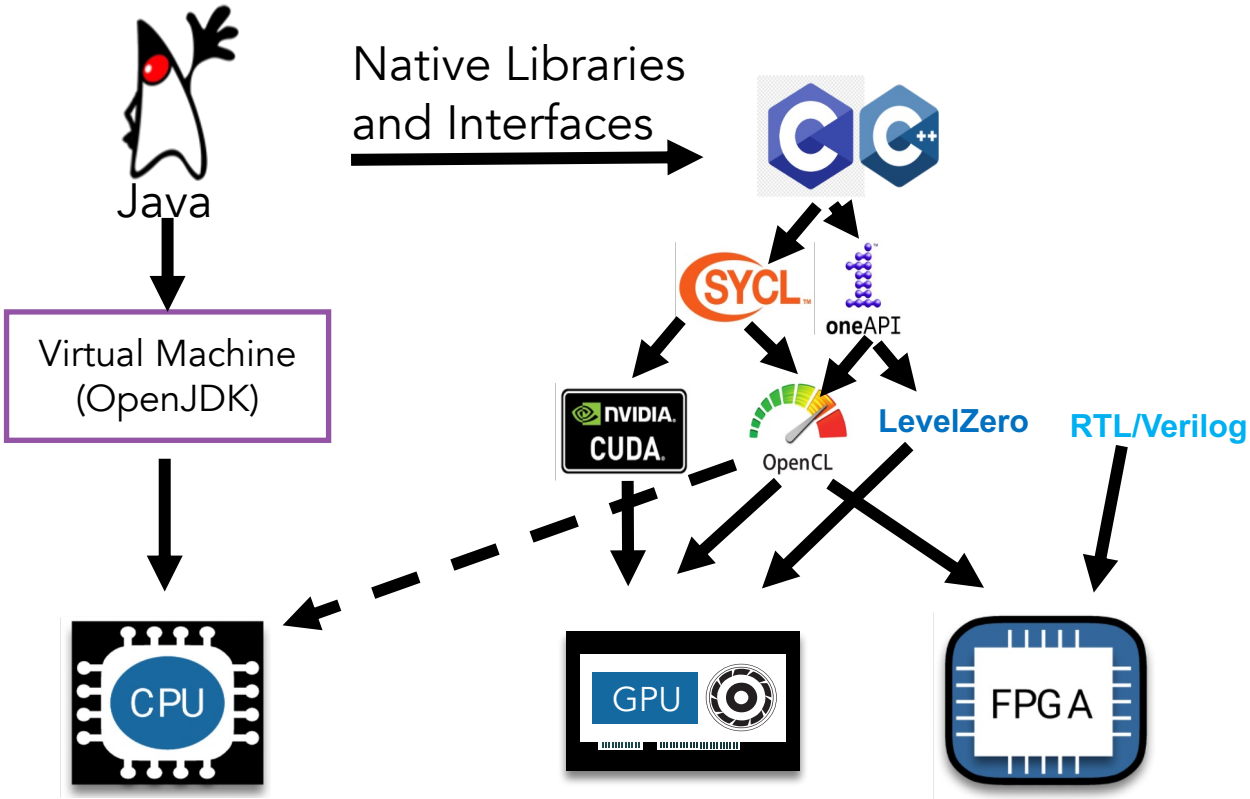
Hardware is evolving



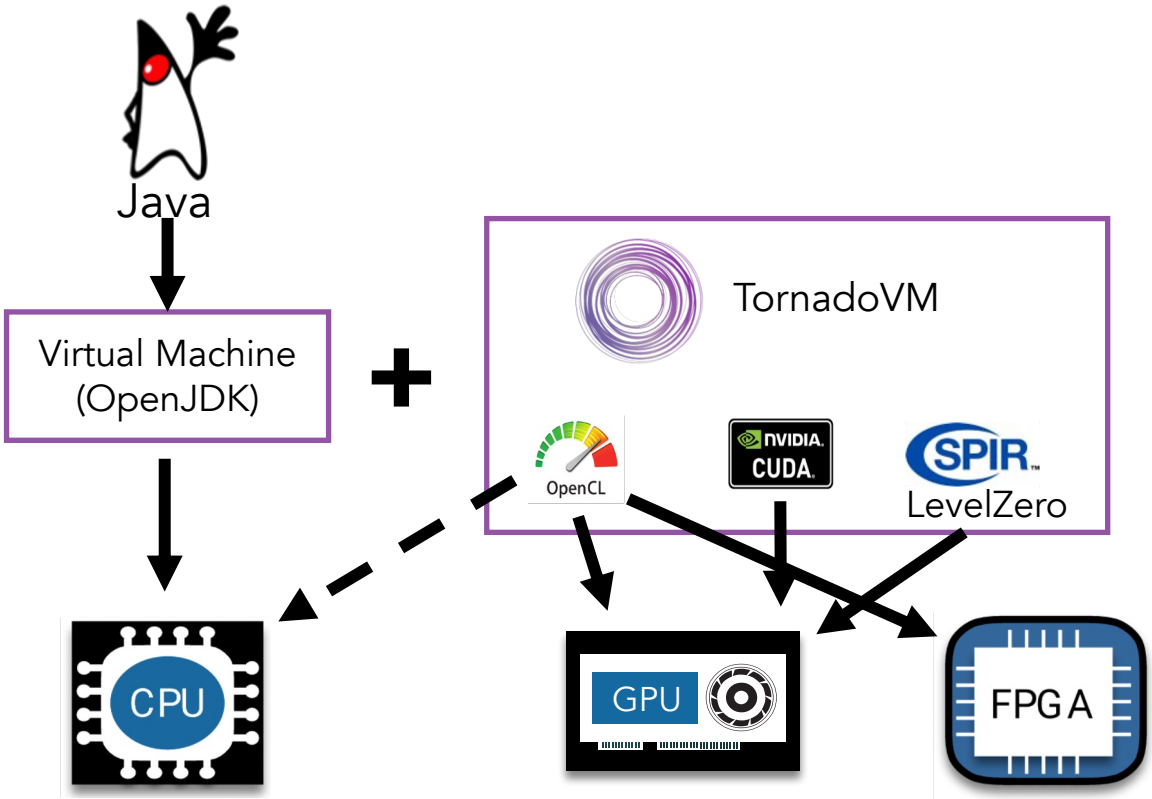
Pros: ☻
- Higher Performance
- Better Resource Utilization - Cost
- Energy Efficiency

Cons:☹
- Challenges in programming

Programming Heterogeneous Hardware



Programming Heterogeneous Hardware



https://tornadovm.org

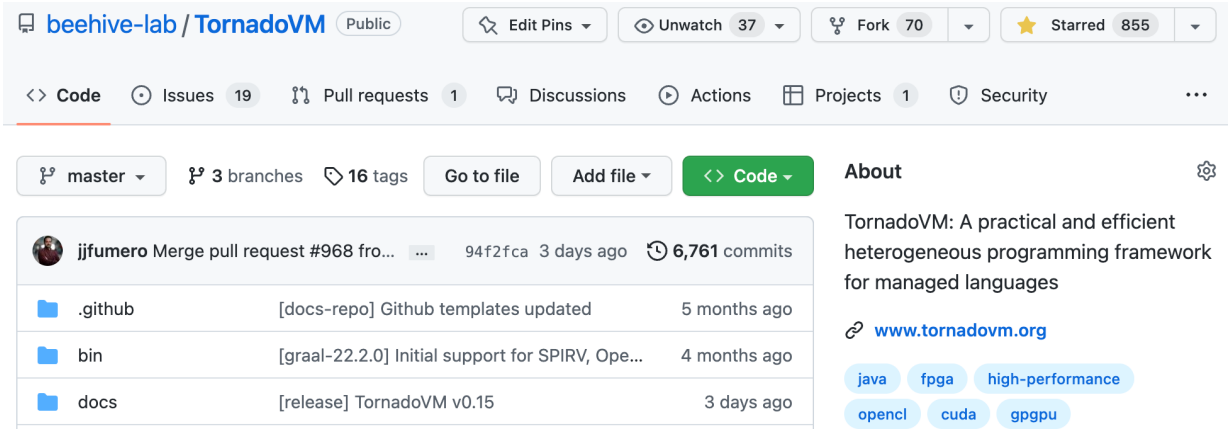
@tornadovm

A JVM plugin that accelerates Java methods on heterogeneous hardware!

Features:

- Lightweight API
- Platform agnostic
- Automatic code specialization

TornadoVM in GitHub & DockerHub!



https://github.com/beehive-lab/TornadoVM

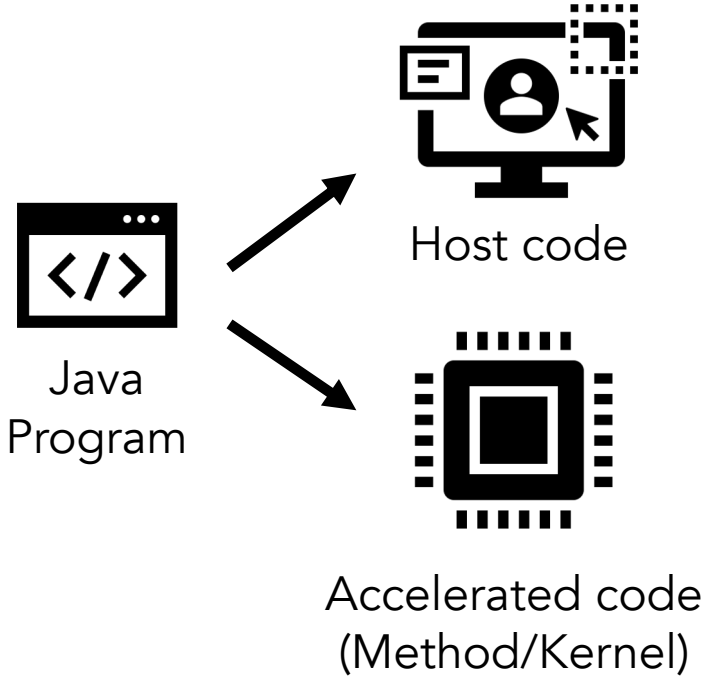

```
$ docker pull beehivelab/tornado-gpu

# And RUN !
$ ./run_nvidia.sh javac.py YouApp.java
$ ./run_nvidia.sh tornado YourApp
```

https://github.com/beehive-lab/docker-tornado

TornadoVM API

TornadoVM Programming Model



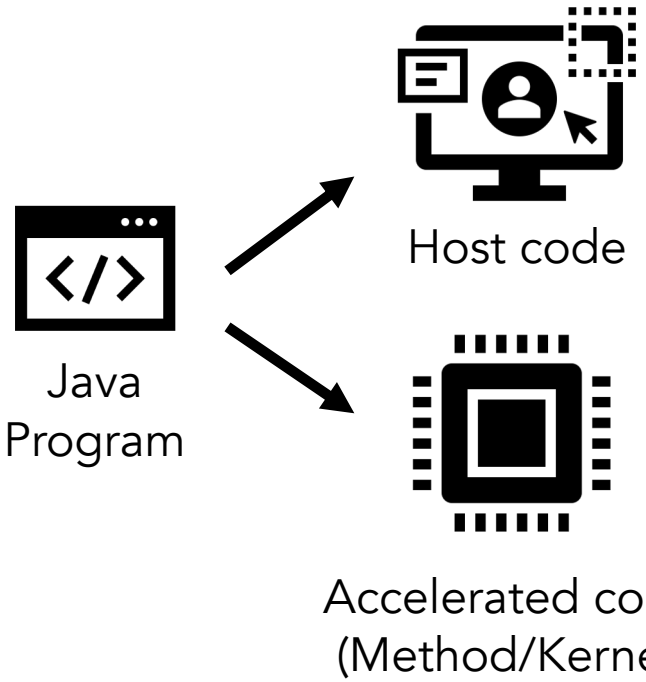
Execution Model

Trasfer Data to Device

Processing

Transfer Data to Host

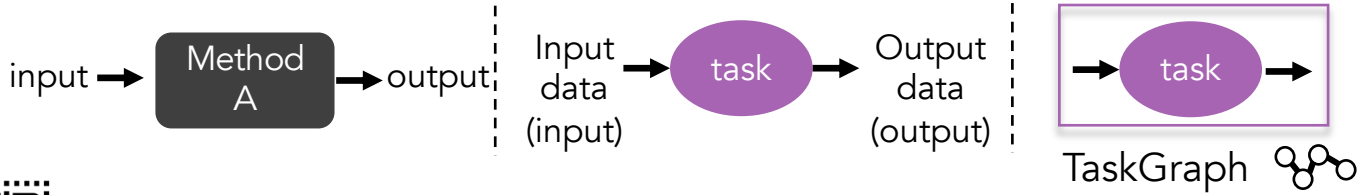
TornadoVM API

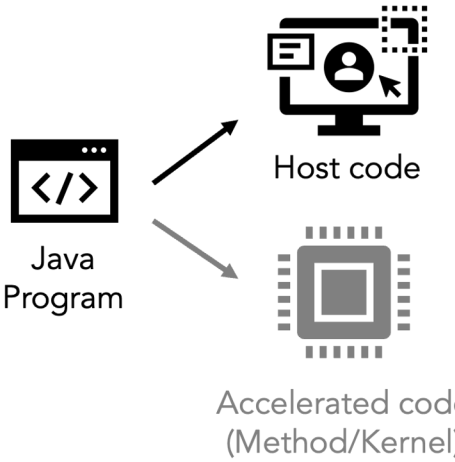


`TaskGraph`,
`TornadoExecutionPlan`

`@Parallel`,
`@Reduce` ,
`KernelContext`

TornadoVM TaskGraph (What to run?)



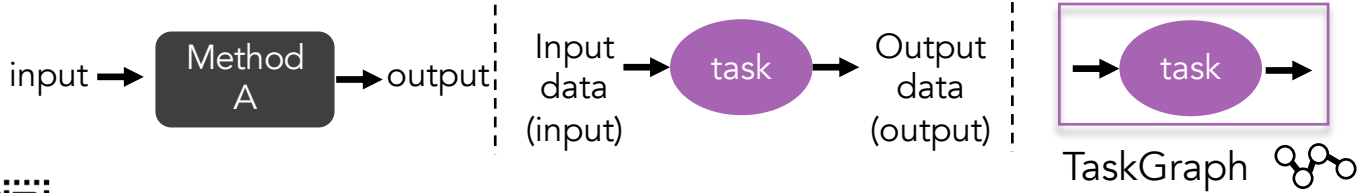


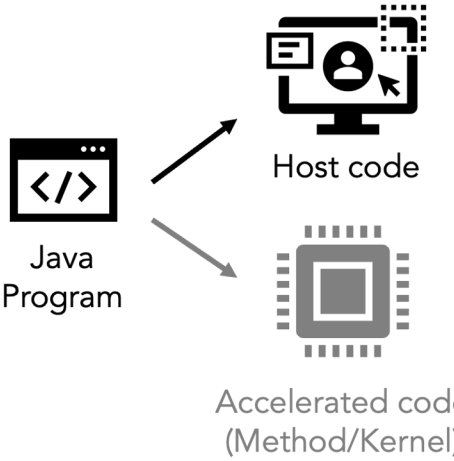
How often to transfer the data?
(first execution, always, last execution)

```
TaskGraph taskGraph = new TaskGraph("tg")
        .transferToDevice(DataTransferMode.FIRST_EXECUTION, input)
        .task("methodA", Class::MethodA, input, output, ...)
        .transferToHost(DataTransferMode.EVERY_EXECUTION, output);
```

The TaskGraph at this stage is **mutable**!

TornadoVM Immutable TaskGraph





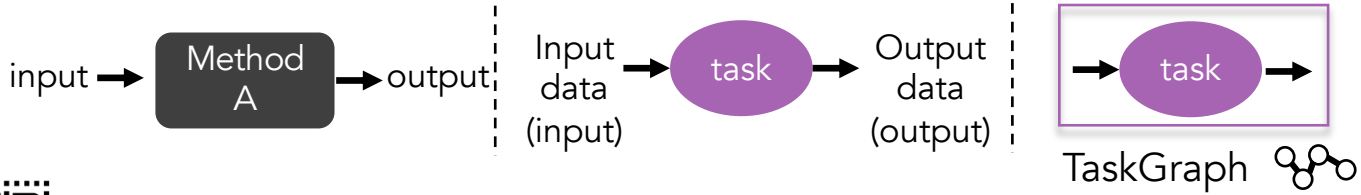
How to preserve the shape of a TaskGraph?


```
ImmutableTaskGraph immutableTaskGraph = taskGraph.snapshot();
```

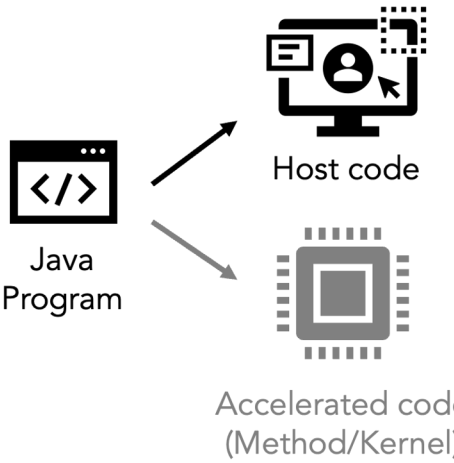
Mutable TaskGraph
- Can be modified

Immutable TaskGraph
- Cannot be modified

TornadoVM Execution Plan (How to run?)



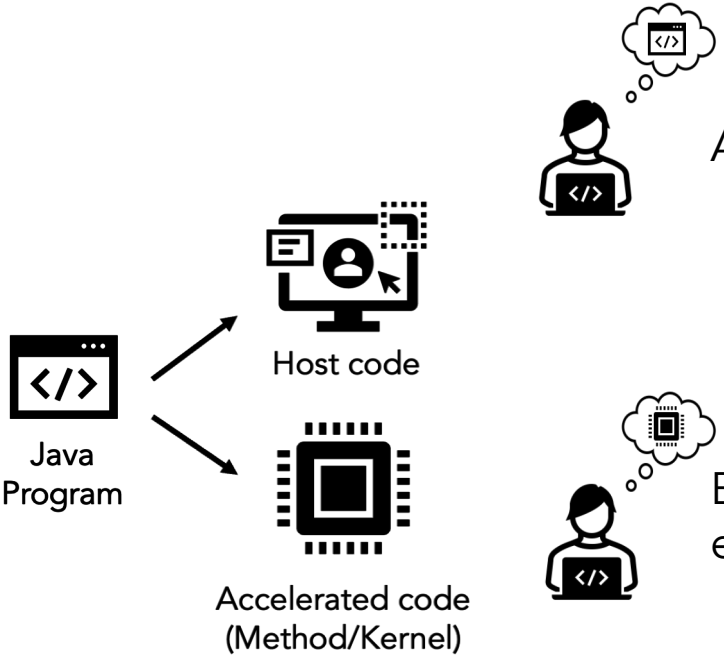
How to execute an **immutable** TaskGraph?



TornadoExecutionPlan

```
TornadoExecutionPlan executionPlan =
                    new TornadoExecutionPlan(immutableTaskGraph).build();
executionPlan.execute();
executionPlan.withDynamicReconfiguration(Policy.PERFORMANCE,
DRMode.PARALLEL);
```

TornadoVM - Expressing Parallelism



A) Loop Parallel API for Java programmers

Annotate for loops using *@Parallel*

B) Kernel API for programmers with OpenCL/CUDA expertise, or not (e.g. porting existing kernels)

Customize methods using the KernelContext object

For more info:
https://tornadovm.readthedocs.io/en/latest/programming.html

Example of Matrix Multiplication in Java

```java
private static void matrixMultiplication(final float[] A, final float[] B, final float[] C, final int size) {
    for (int i = 0; i < size; i++) {
        for (int j = 0; j < size; j++) {
            float sum = 0.0f;
            for (int k = 0; k < size; k++) {
                sum += A[(i * size) + k] * B[(k * size) + j];
            }
            C[(i * size) + j] = sum;
        }
    }
}
```

Accelerated Code

```java
public static void main(String[] args){
    int size = 512;

    float[] matrixA = new float[size * size];
    float[] matrixB = new float[size * size];
    float[] matrixC = new float[size * size];
    float[] resultSeq = new float[size * size];

    Random r = new Random();
    IntStream.range(0, size * size).parallel().forEach(idx -> {
        matrixA[idx] = r.nextFloat();
        matrixB[idx] = r.nextFloat();
    });

    // Run matrixMultiplication on Java sequentially
    matrixMultiplication(matrixA, matrixB, resultSeq, size);
}
```

Host Code

Utilize the Loop Parallel API

```
private static void matrixMultiplication(final float[] A, final float[] B, final float[] C, final int size) {
    for (int i = 0; i < size; i++) {
        for (int j = 0; j < size; j++) {
            float sum = 0.0f;
            for (int k = 0; k < size; k++) {
                sum += A[(i * size) + k] * B[(k * size) + j];
            }
            C[(i * size) + j] = sum;
        }
    }
}
```

```
private static void matrixMultiplication(final float[] A, final float[] B, final float[] C, final int size) {
    for (@Parallel int i = 0; i < size; i++) {
        for (@Parallel int j = 0; j < size; j++) {
            float sum = 0.0f;
            for (int k = 0; k < size; k++) {
                sum += A[(i * size) + k] * B[(k * size) + j];
            }
            C[(i * size) + j] = sum;
        }
    }
}
```

Utilize the Kernel API

```
private static void matrixMultiplication(final float[] A, final float[] B, final float[] C, final int size) {
    for (@Parallel int i = 0; i < size; i++) {
        for (@Parallel int j = 0; j < size; j++) {
            float sum = 0.0f;
            for (int k = 0; k < size; k++) {
                sum += A[(i * size) + k] * B[(k * size) + j];
            }
            C[(i * size) + j] = sum;
        }
    }
}
```

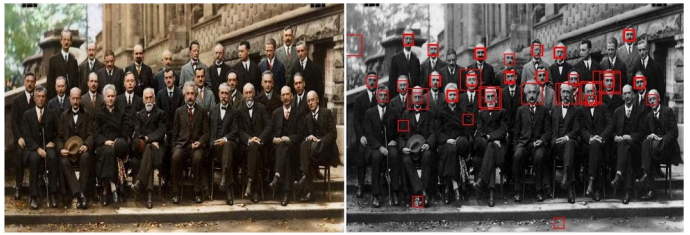
```
private static void matrixMultiplication(KernelContext context, final float[] A, final float[] B, final float[] C, final int size) {
    int globalRow = context.globalIdx;
    int globalCol = context.globalIdy;
    float sum = 0;

    for (int k = 0; k < size; k++) {
        sum += A[(k * size) + globalRow] * B[(globalCol * size) + k];
    }
    C[(globalCol * size) + globalRow] = sum;
}
```

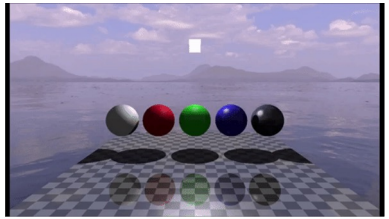
For more info, watch the FOSDEM'22 presentation:
https://www.youtube.com/watch?v=RD9W68rYS7I

Use Cases

COMPUTER VISION



FACE DETECTION



RAY TRACING

MACHINE LEARNING

https://www.tornadovm.org/use-cases

Acceleration as a Service…

Horizon 2020 ELEGANT

A software stack that unifies development for Big Data and IoT software ecosystems!

https://www.elegant-h2020.eu/

Acceleration as a Service for Java

```
private static void vectorAdd(int[] a, int[] b, int[] c,
                              int size) {
    for (@Parallel int i = 0; i < size; i++) {
        c[i] = a[i] + b[i];
    }
}
```

```
    "deviceInfo": {
      "deviceName": "Nvidia GPU",
      "doubleFPSupport": true,
      "maxWorkItemSizes": [16, 1, 1],
      "deviceAddressBits": 64,
      "deviceType": "CL_DEVICE_TYPE_GPU",
      "deviceExtensions": "cl_khr_int64_base_atomics",
      "availableProcessors": 2048
    }
```

Source code, hw characteristics

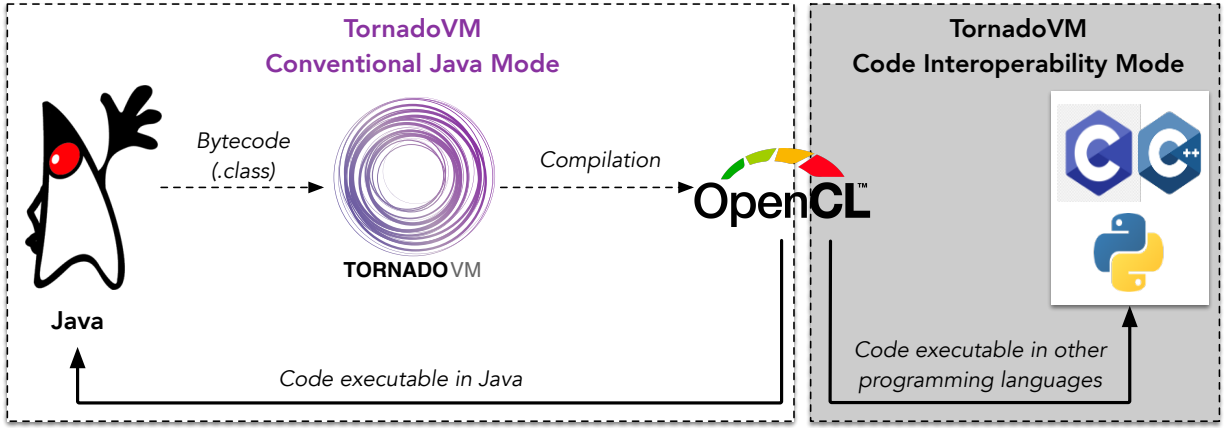
REST API

OpenCL kernel

```
__kernel void vectorAdd(__global uchar *a,
                        __global uchar *b,
                        __global uchar *c,
                        __private int size)
{
    // ...
    i_3  =  (ulong) size;
    for(;i_5 < i_3;) // Replacement of constant value
    {
        // BLOCK 2
        l_6  =  (long) i_5;
        l_7  =  l_6 << 2; ; // Header offset (24L) is skipped
        ul_8  =  ul_0 + l_7;
        i_9  =  *((__global int *) ul_8);
        ul_10  =  ul_1 + l_7;
        i_11  =  *((__global int *) ul_10);
        ul_12  =  ul_2 + l_7;
        i_13  =  i_9 + i_11;
        *((__global int *) ul_12)  =  i_13;
        i_14  =  get_global_size(0);
        i_15  =  i_14 + i_5;
        i_5  =  i_15;
    }  // B2
    // BLOCK 3
    return;
}  //  kernel
```

TornadoVM CIM Mode

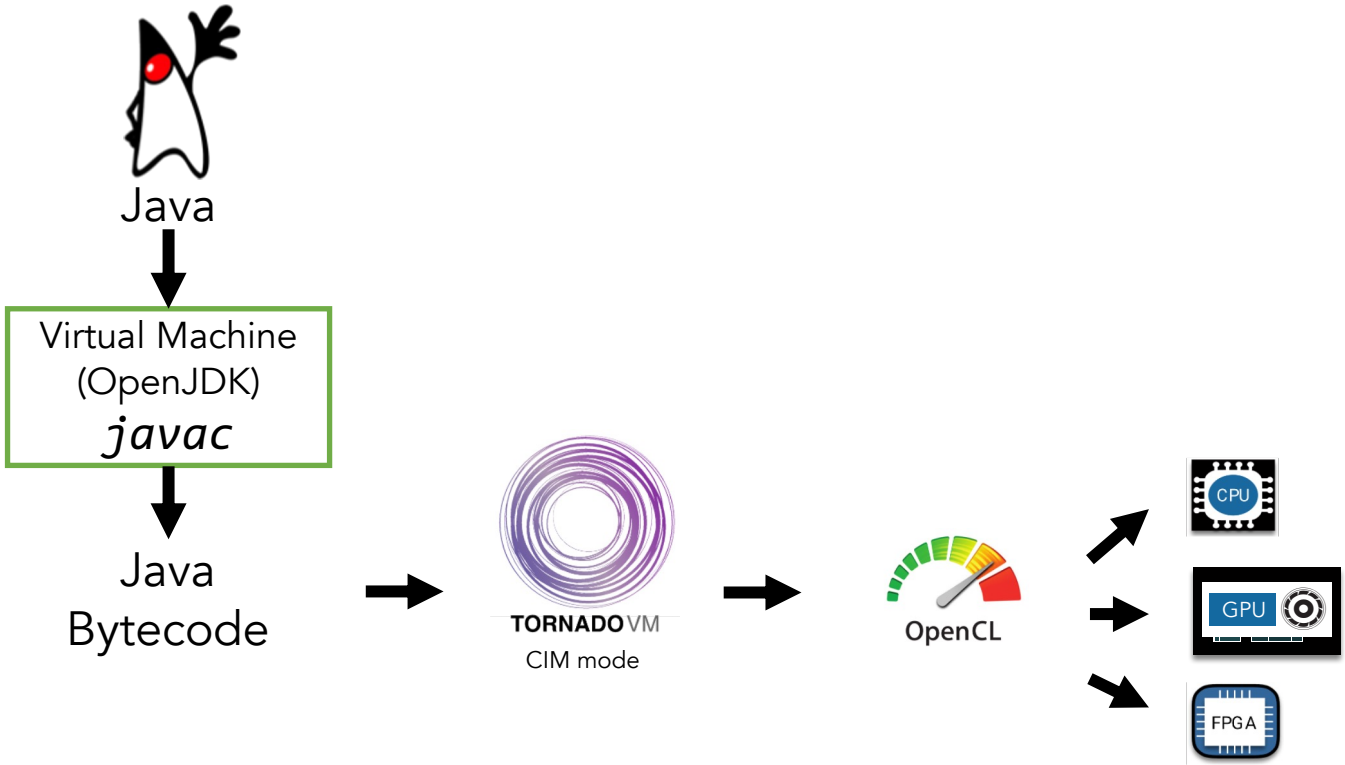
(Experimental – not upstream)



Java as prototyping language for parallel programming

Cross-language portability of the generated kernels

Write Once, Run Anywhere



Wrap Up

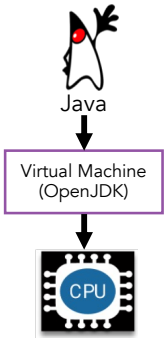
Can we help you?

 Glad to seek for synergies (acceleration of software).

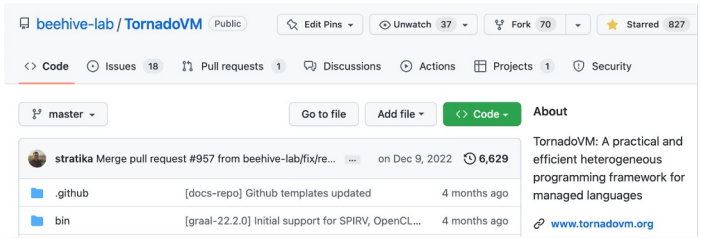
 https://tornadovm.org/contact/

Summary

Write Once, Run Anywhere



✓Abstraction
✓Portability (across different CPUs)
? Portability on heterogeneous hardware



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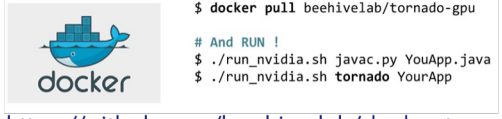

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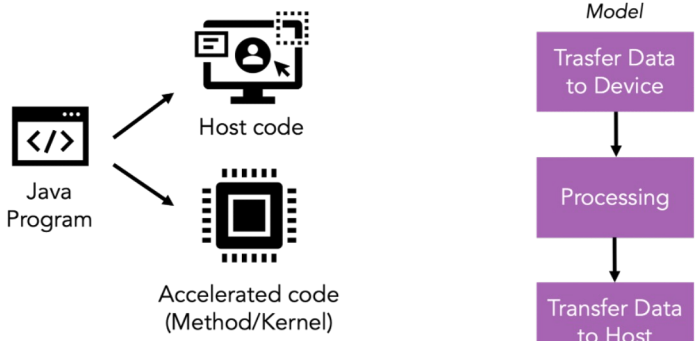
TORNADOVM

https://tornadovm.org
@tornadovm

TornadoVM Programming Model



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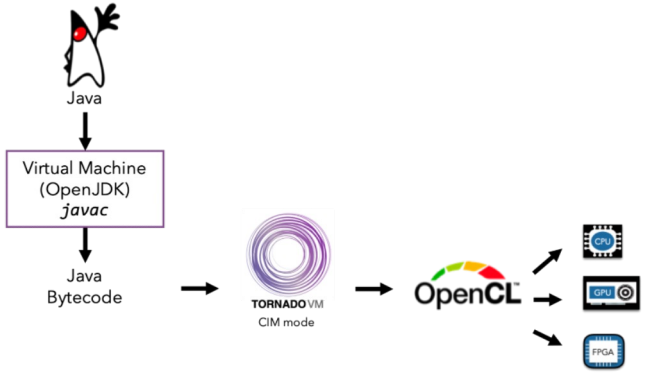

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ELEGANT

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UK Research and Innovation