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Tornado: Accelerating Java Applications Using GPGPUs

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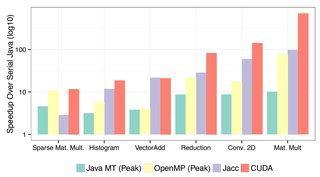
Introduction

- Tornado is a programming framework which allows developers to write complex heterogeneous applications in Java.
- It can be used to target OpenCL compatible devices.
- The dynamic compiler generates OpenCL C code directly from Java bytecode.
- Applications are programmed using a task-based programming model.
- Tasks can be assigned to execute on specific devices.
- It enables applications to schedule multiple-tasks across multiple-devices.

History - Java for Accelerators (JACC)

- Using Jacc [1] we demonstrated that it was possible to increase the performance of some Java benchmarks by an order of magnitude.



Programming Model

- Tornado uses a task-based programming model.
- Tasks can be executed serially or by using parallel threads.
- Parallelism is expressed using the `@Parallel` annotation within tasks.
- Tasks are assigned to execute on specific devices - either statically or dynamically.
- The dynamic compiler parallelises the code depending on the target device.
- Multiple tasks can be composed into a task-graph.
- Tasks are free to execute on different devices.

Creating A Task

```
public void add(
      @Read  final float[] a,
      @Read  final float[] b,
      @Write final float[] c)
  {
    for (@Parallel int i = 0; i < a.length; i++)
      c[i] = a[i] + b[i];
  }

Task addTask = createTask(VectorAddFloat.class, "add");
```

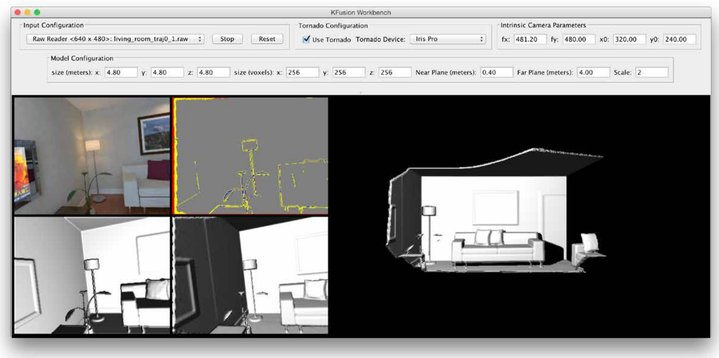
Executing A Task

```
// Invoke add with parameter a, b, c.
TaskInvocation add = addTask.invoke(a, b, c);

// Assign task to run on a GPGPU
add.mapTo(EXTERNAL_GPU);

// block until complete
add.execute();
```

Case Study: Kinect Fusion

- Our case study is an implementation of the Kinect Fusion application [4].
- KFusion is a computer vision application which reconstructs a 3D scene from a stream of RGB-D data.
- Ported KFusion into Java from the CUDA version of SLAMBENCH [3].
- The processing pipeline uses 12 unique tasks.
- To work in real-time the application needs to execute 20 tasks in 1/30th of a second.

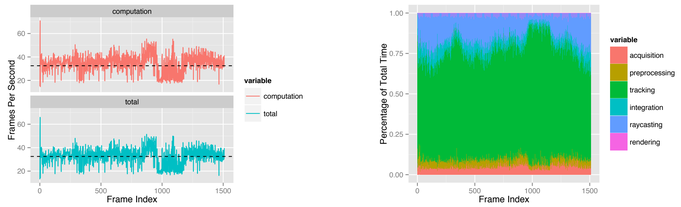
Kinect Fusion Java



Runtime and Language Support

- The Tornado runtime is able to automatically schedule data transfers between devices.
- By using task-graphs the runtime system can eliminate redundant data transfers.
- The runtime system is responsible for satisfying all inter-task data
- A library of common numerical functions has been developed.
- Support for short-vector types, e.g. float3, double4.

Kfusion Performance

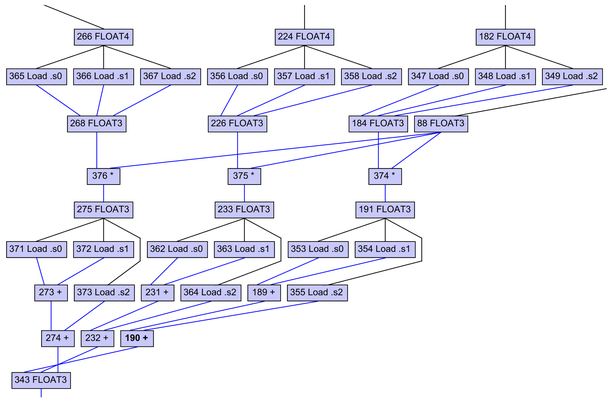


- Our serial Java implementation achieves between 0.2 and 1.2 FPS.
- Using Tornado we have achieved over 30 FPS.
- Frame rate is heavily on dependent performance of the tracking algorithm.
- Our Java implementation has been developed to produce bit-exact results when compared to SLAM BENCH implementations.

Kfusion Code

```
public void vertex2normal(@Write Image3 normals, @Read Image3 verticies) {
  for (@Parallel int y = 0; y < normals.Y(); y++)
    for (@Parallel int x = 0; x < normals.X(); x++) {

      final Float3 left = verticies.get(max(x - 1, 0), y);
      final Float3 right = verticies.get(min(x + 1, verticies.X() - 1), y);
      final Float3 up = verticies.get(x, max(y - 1, 0));
      final Float3 down = verticies.get(x, min(y + 1, verticies.Y() - 1));


      final Float3 dxv = sub(right, left);
      final Float3 dyv = sub(down, up);

      boolean invalidNormal = left.getZ() == 0 || right.getZ() == 0
            || up.getZ() == 0 || down.getZ() == 0;

      final Float3 normal = (invalidNormal) ?
        new Float3(INVALID,0f,0f)
        : normalise(cross(dyv,dxv));

      normals.set(x, y, normal);
    }
}
```

Dynamic Compiler



- The compiler is developed using GRAAL [2].
- It supports developer-driven parallelisation of tasks.
- It Support for vectorisation of memory accesses and arithmetic optimisations.
- Uses partial evaluation to eliminate all possible exception checks.

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