Automatic Parallelization for Graphic Processing Units

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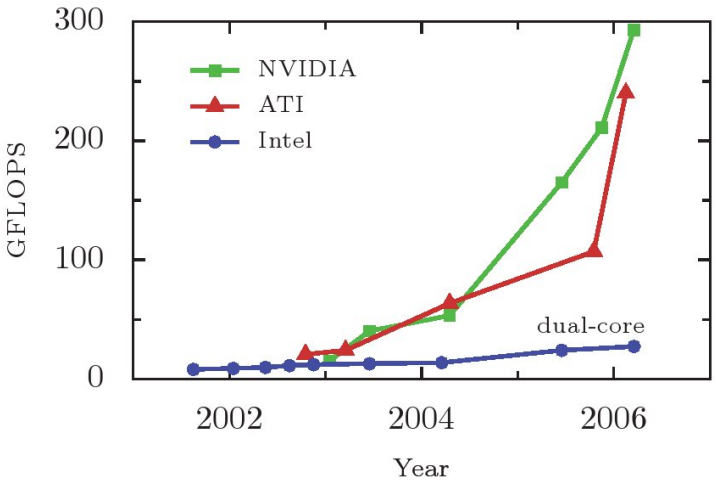
Overview / Motivation

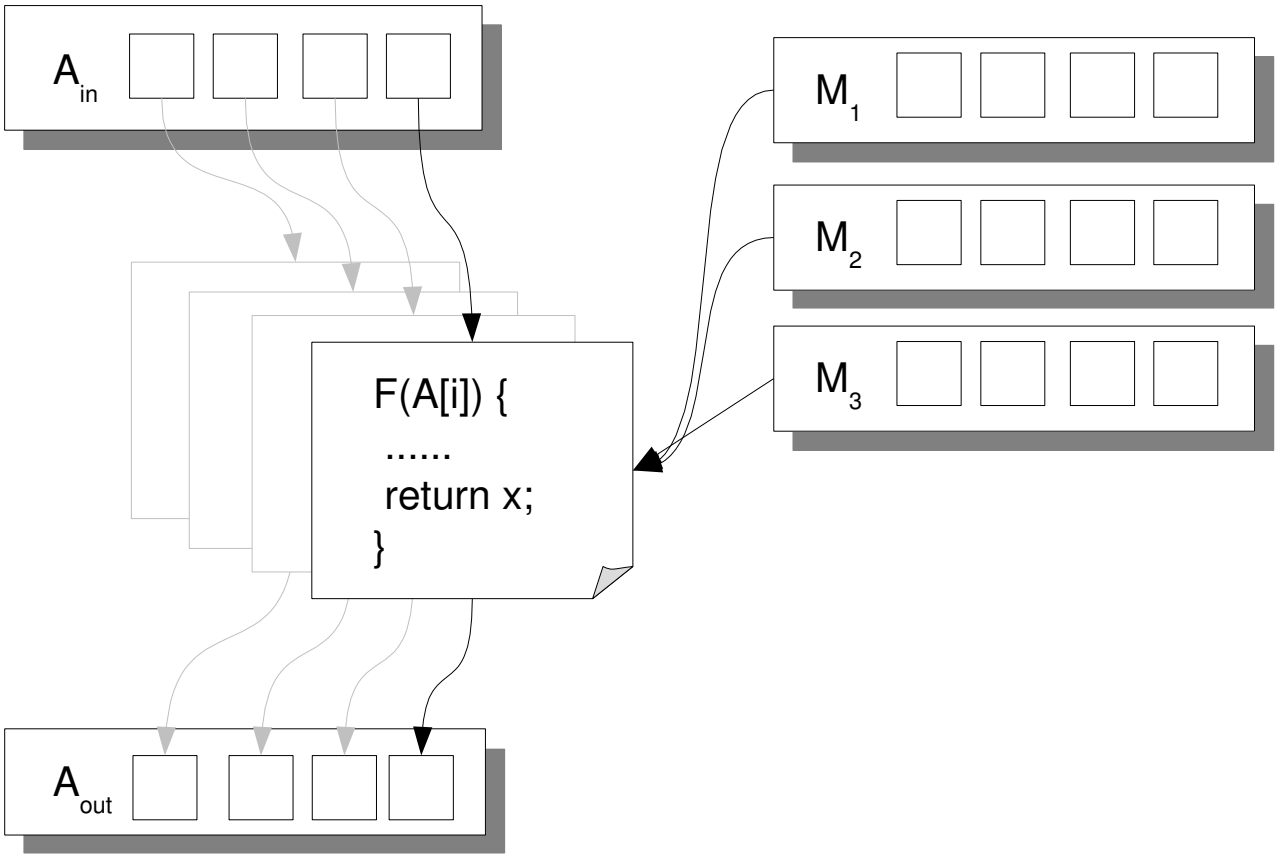


[1]

- Graphical Processing Units (GPUs)
- $50 to $500+ massively parallel devices specialized for large throughput
- Prototype JIT (JikesRVM) that utilizes GPUs for up to 5.4x speed ups

[1] Owens et al. A Survey of General-Purpose Computation on Graphics Hardware.

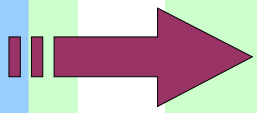
GPU SPMD Computing Model



- SPMD (Single Program Multi-Data) program model
- Gather (array reads from arbitrary index) is supported
- Scatter (array writes to arbitrary index) is NOT supported

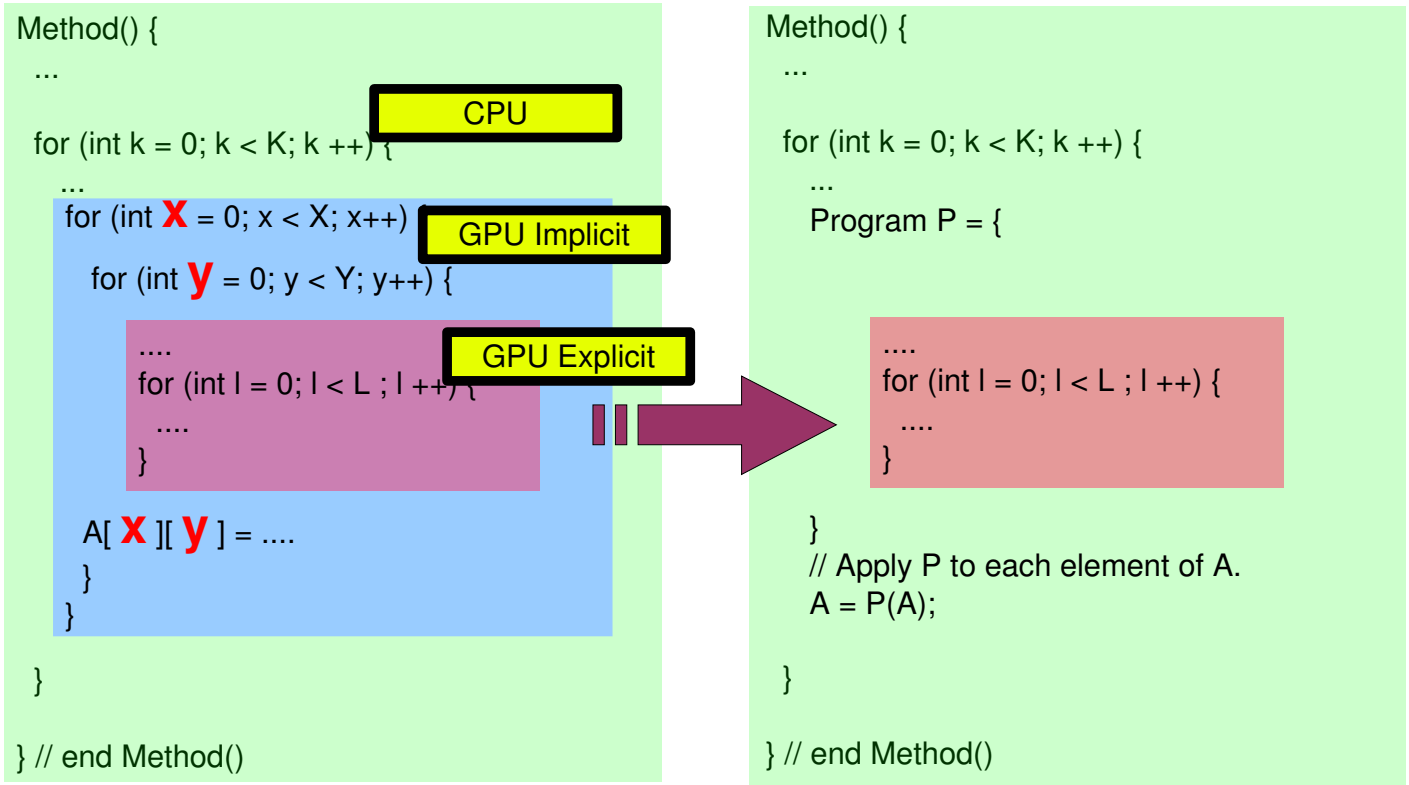
GPGPU Example

```
Method() {
  ...

  for (int k = 0; k < K; k ++) {
    ...
    for (int x = 0; x < X; x++) {
      for (int y = 0; y < Y; y++) {
        ....
        for (int l = 0; l < L ; l ++) {
          ....
        }
      A[ x ][ y ] = ....
      }
    }
  }

} // end Method()
```

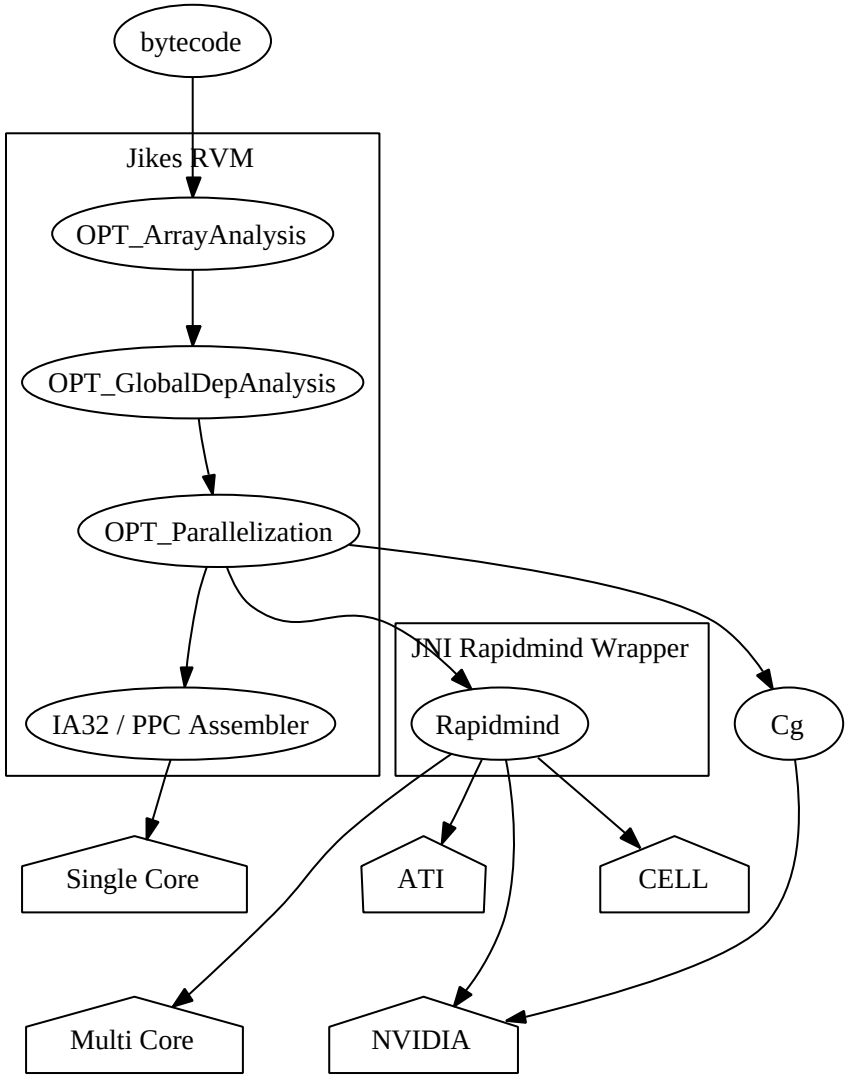


```
Method() {
  ...

  for (int k = 0; k < K; k ++) {
    ...
    Program P = {
      ....
      for (int l = 0; l < L ; l ++) {
        ....
      }
    }
    // Apply P to each element of A.
    A = P(A);

  }

} // end Method()
```

Loop Classification



Implementation Overview



Loop Classification: WriteIndices

Definition

Given a loop L in the loop nesting tree, WRITEINDICES(L) is defined as

- A vector of indices for all array writes in L's body
- $\top$, if there is more than one unique vector
- $\bot$, if there are no array writes

Loop Classification: TNLoops

Definition

For a loop L in the loop nesting tree, let TNLOOPS(L) be a list of all loops that are tightly nested within L.

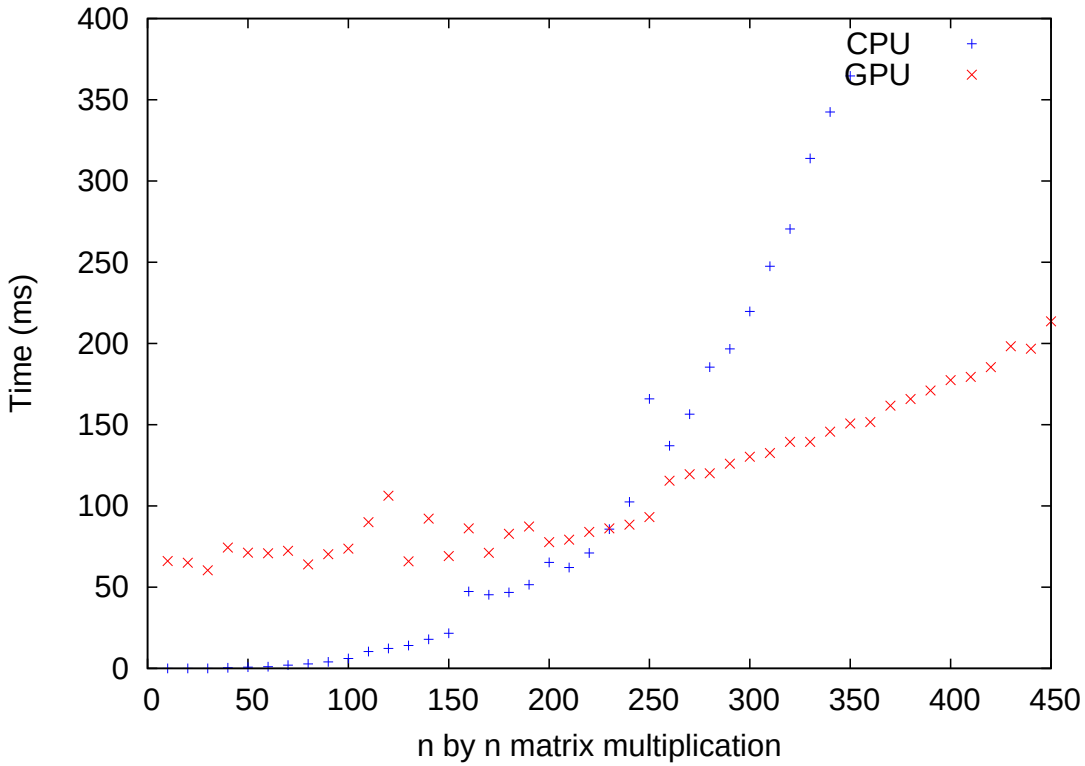
```
for (...){
  ......
    for (...) {
        for (...) {
            ....
            for (...) { }
        }
    }
}
```

Loop Classification: Algorithm

Algorithm PARALLELIZE(loop L):

1: **if** WRITEINDICES(L) $= (i_1, \ldots, i_n)$
and $\{i_1, \ldots, i_n\} \subseteq$ TNLOOPS(L)
and no dependencies are carried by loops $i_1, \ldots, i_n$
and TNLOOPS(L) can be interchanged so the outermost n loops are $i_1, \ldots, i_n$, in this order **then**
2: interchange TNLOOPS(L) in this way
3: generate GPU program for body of loop i_n
4: replace loop i_1 with code to execute GPU program
5: **else**
6: **for** each child loop L' of L in the loop nesting tree **do**
7: PARALLELIZE(L')

Data Transfer



- Transferring data to/from GPU is slow
- Too many combinations of CPUs and GPUs available on the market....

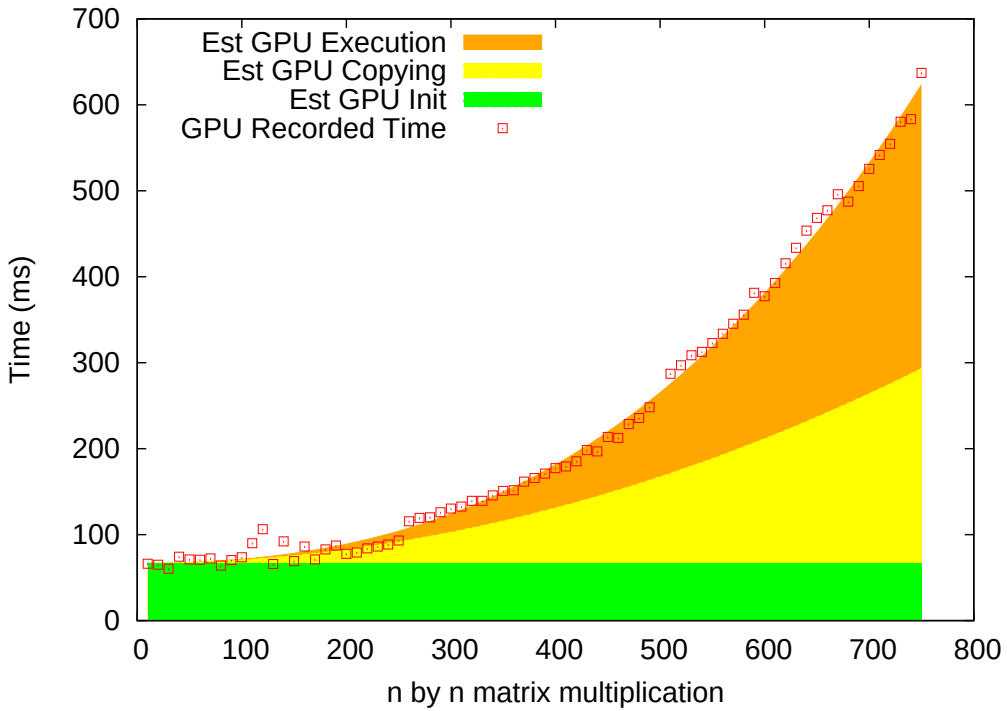
Cost Modeling

Definition

$$Cost_{cpu} = t_{cpu} \times insts_{cpu} \times A_{out}.size$$
$$Cost_{gpu} = t_{gpu} \times insts_{gpu} \times A_{out}.size + copy \times \sum_{A \in Ainout} A.size + init$$

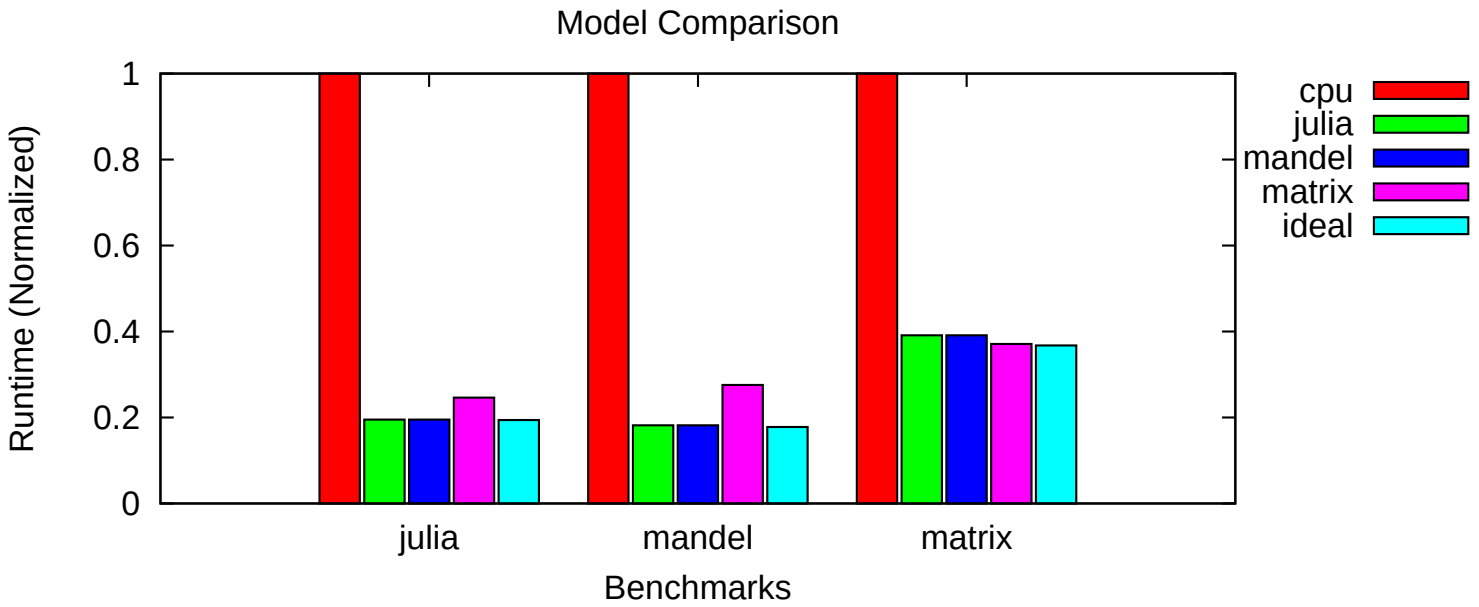
- t_{cpu}, t_{gpu}: Average time per CPU/GPU instruction (Installation)
- $insts_{cpu}$, $insts_{gpu}$: Estimate number CPU/GPU inside the loop (Compile time)
- $A_{out}.size$: Output array size (Runtime)
- $A.size$: Size of all the array that needs to be copied to/from the GPU (Runtime)
- $copy$: Average time for copying a single float to/from the GPU (Installation)
- $init$: Constant initialization factor (Installation)

Matrix Multiplication Example



- $t_{gpu} = 7.81 \times 10^{-8}$ ms / instruction
- $copy = 1.01 \times 10^{-4}$ ms / element
- $init = 66.57$ ms

Performance Evaluation



- Intel Pentium 4 CPU running at 3.0 GHz with 1 GB of Memory
- NVIDIA GeForce 7800 GPU with 256 MB of GPU memory
- Modified JikesRVM O2
- Rapidmind 2.0.0.6546

Other Issues

- Exceptions (ArrayIndexOutOfBoundsException ... etc..)
- No real multi-dimensional arrays in Java
- Intra-array aliasing
- Non-rectangular arrays
- Branching in bytecode

Conclusion

- Algorithm for detecting GPU executable loops
- Cost model that is close to ideal performance
- 5.4x speed up in one of the benchmarks

Future work

- Other backends (Cell, multi-core CPU)
- CUDA / newer generation of GPUs
- Model improvements
- Limit CPU-GPU texture transfer

Questions

- Email: acleung@plg.uwaterloo.ca
- Thank you!
- Questions and Answers