A Preliminary Study of Compiler Transformations for Graph Applications on the EMU System

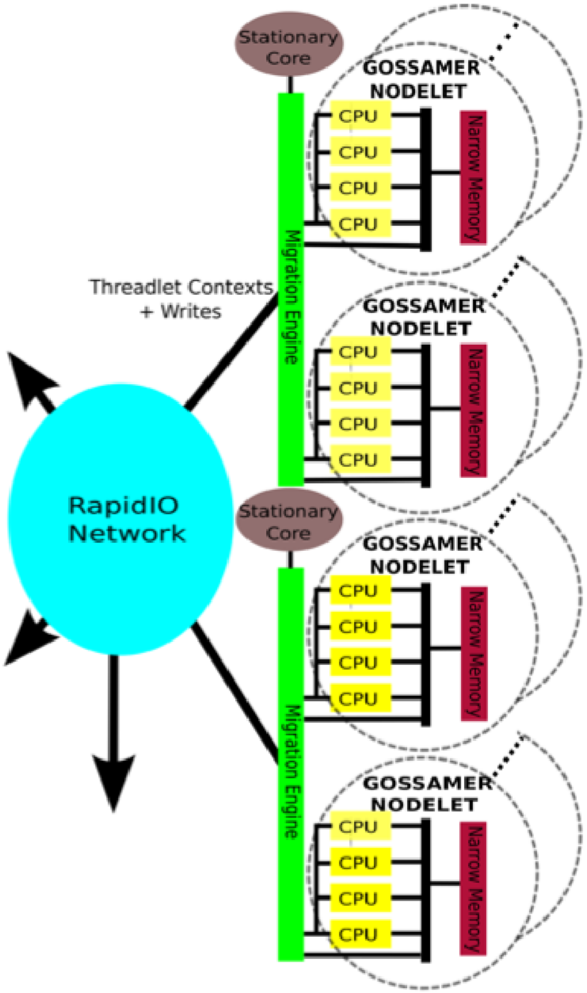
Prasanth Chatarasi, and Vivek Sarkar

Habanero Extreme Scale Software Research Project
Georgia Institute of Technology, Atlanta, USA

Introduction – Graph applications

- Increasing in importance for high-performance
  - With the advent of "big data"
- Random memory access patterns
  - Inefficient utilization of memory & cache in CPU and GPU's
- Growing interest to innovate architectures
  - To handle applications with weak-locality

EMU [Kogge et al. IA3'16]

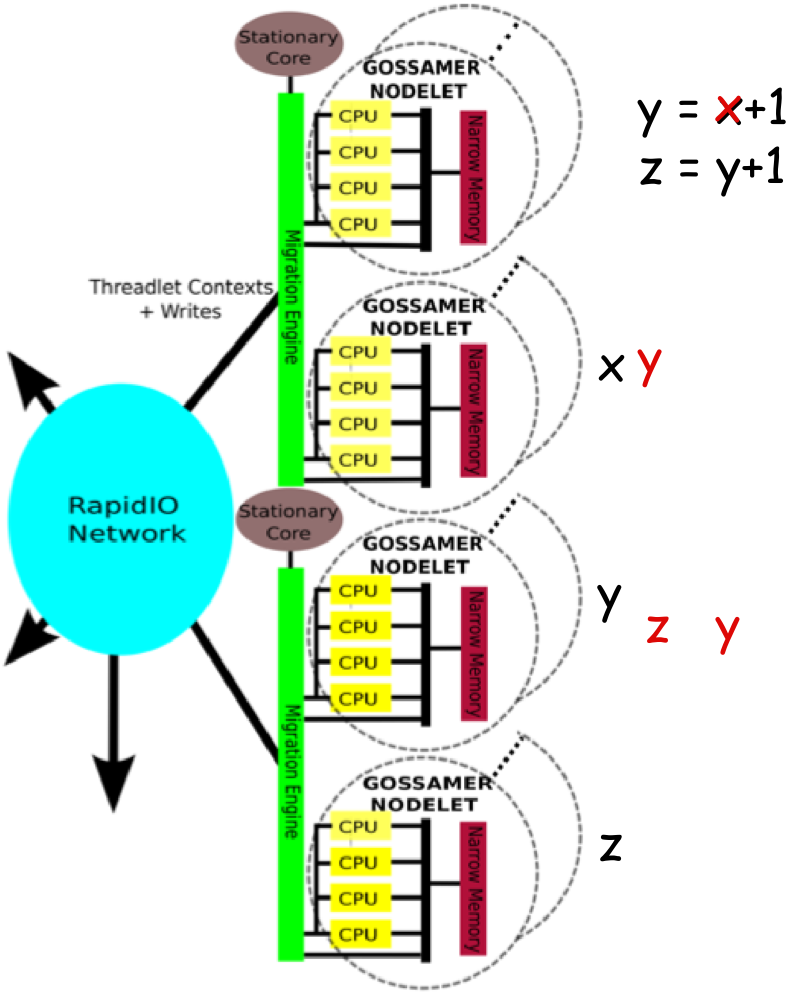


http://www.emutechnology.com/products/ #lightbox/0/

- A highly scalable near-memory multi-processor
  - 8 nodes → 8 nodelets/node → 4 cores/nodelet → 64 threads/core
  - Cilk programming model for expressing parallelism

A Comparison b/w EMU and Xeon on a pointer-chasing benchmark
-- Hein et al. [IPDPSW'18]

1) Key features – Thread migration



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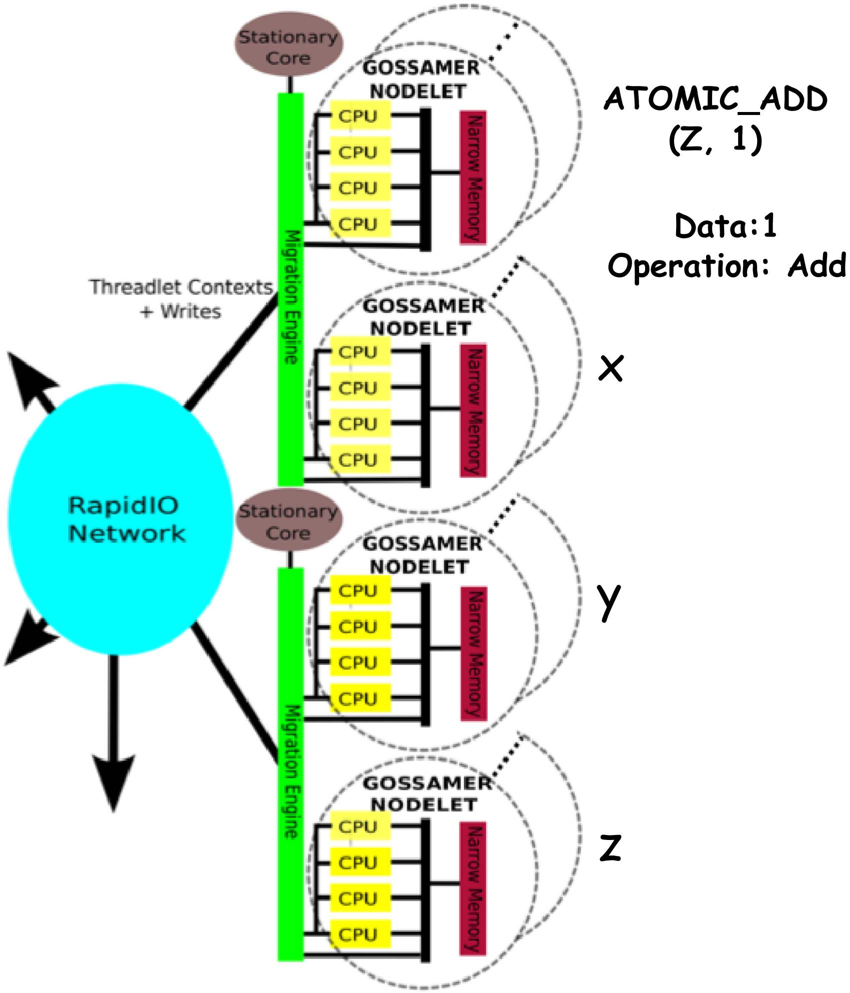
- Automatic thread migrations on an access to a non-local data
  - Computation moves instead of data
- Benefits of thread migration
  - Sparse matrix vector multiply
    - Kogge et al. [IA3'17]
  - BFS algorithm
    - Belviranli et al. [HPEC'18]

2) Key features – Remote atomic updates



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- Atomic updates that do NOT cause a thread migration
  - Sends a packet having data and operation to be performed
- Used when a thread doesn't need a return value of atomic operation
  - Otherwise, explicit FENCE required to block the thread

Challenges with the EMU system

- Overheads from thread migrations, thread creation and synchronization.

- We focus on exploring compiler transformations to reduce the overheads and improve performance
  - High-level compiler transformations
    - Node fusion and Edge flipping
  - Low-level compiler transformations
    - Use of remote atomic updates

Agenda

- Introduction
- Compiler transformations
- Evaluation
  - Conductance
  - Bellman-Ford's algorithm for single-source shortest path
  - Triangle counting
- Conclusions and future work

1) Node fusion

```
parallel-for(v ∈ vertices) {
  p1[v] = …
} // Implicit barrier

parallel-for(v ∈ vertices) {
  p2[v] = f(p1[v], …)
}
```

⟹

```
parallel-for(v ∈ vertices) {
  p1[v] = …
  p2[v] = f(p1[v], …)
}
```

- **Repeated migrations for**
  - Same property across parallel loops
  - Different properties of same vertex across parallel loops
    - Can be reduced with fusing parallel loops

      Can reduce thread creation and synchronization overhead

2) Edge flipping

```
for(t-loop) {
  parallel-for(v ∈ vertices)
    for(u ∈ incoming_neighbors(v))
      p1[v] = f(p1[u], …);
}
```

```
for(t-loop) {
  parallel-for(v ∈ vertices)
    cont = f(p1[v], …);
    for(u ∈ outgoing_neighbors(v))
      atomic_update(p1[u], cont);
}
```

- **Back and forth migrations**
  - From a vertex to each of its incoming neighbor vertices
    - Can be reduced by pushing vertex contribution to its outgoing neighbors

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Experimental setup

Table 1: Specifications of a single node of the Emu system.

	Emu system
Microarch	Emu1 Chick
Clock speed	150 MHz
#Nodelets	8
#Cores/Nodelet	1
#Threads/Core	64
Memorysize/Nodelet	8 GB
NCDRAM speed	1600MHz
Compiler toolchain	emusim.HW.x (18.08.1)

- Evaluation on a single node of the Emu system
  - Actual hardware on FPGA
- Two experimental variants
  - Original version of a graph algorithm
  - Transformed version after *manually* applying compiler transformations

Graph applications

- Graph applications
  - Conductance
  - Bellman-Ford's algorithm for single-source shortest path
  - Triangle counting
    - Developed using the MEATBEE framework

- Input data sets
  - RMAT graphs from scale of 6 to 14 as specified by Graph500
    - #vertices = 2^{scale}
    - #edges = 16 * #vertices

https://github.gatech.edu/ehein6/meatbee

1) Conductance algorithm

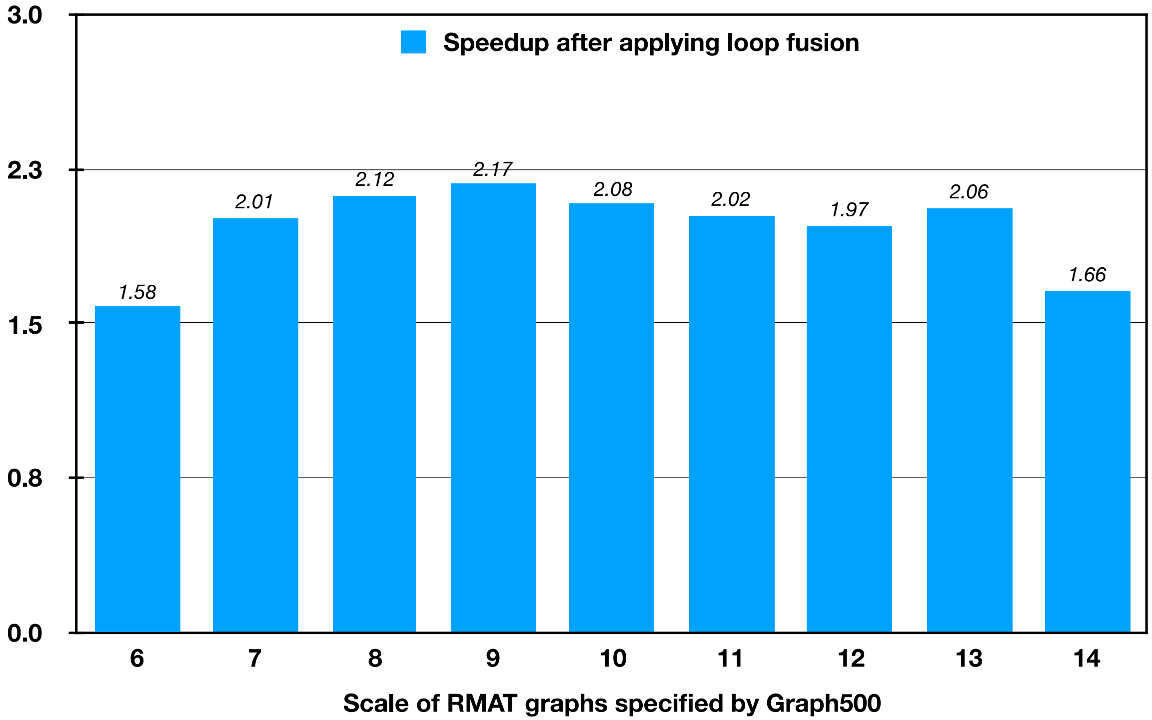
- **Computes a flow from a given partition of graph to others**

```
def CONDUCTANCE(V, id):
for each v ∈ V do in parallel with reduction
    if v.partition_id == id then
            ▷ Thread migration for v.partition_id value
        din+ = v.degree
for each v ∈ V do in parallel with reduction
    if v.partition_id != id then
        dout+ = v.degree
for each v ∈ V do in parallel with reduction
    if v.partition_id == id then
        for each nbr ∈ v.nbrs do
            if nbr.partition_id != id then
                dcross+ = 1
return dcross/((din < dout)?din : dout)
```

- **Repeated migrations to same nodelet for the same property from multiple parallel loops**

- **All the parallel loops can be fused to avoid the overheads**

Results after node fusion



- Speedups of up to 2.2x (geometric mean: 1.95x)
  - Also, a geometric mean reduction of 6.06% in thread migrations

2) Bellman-Ford's algorithm

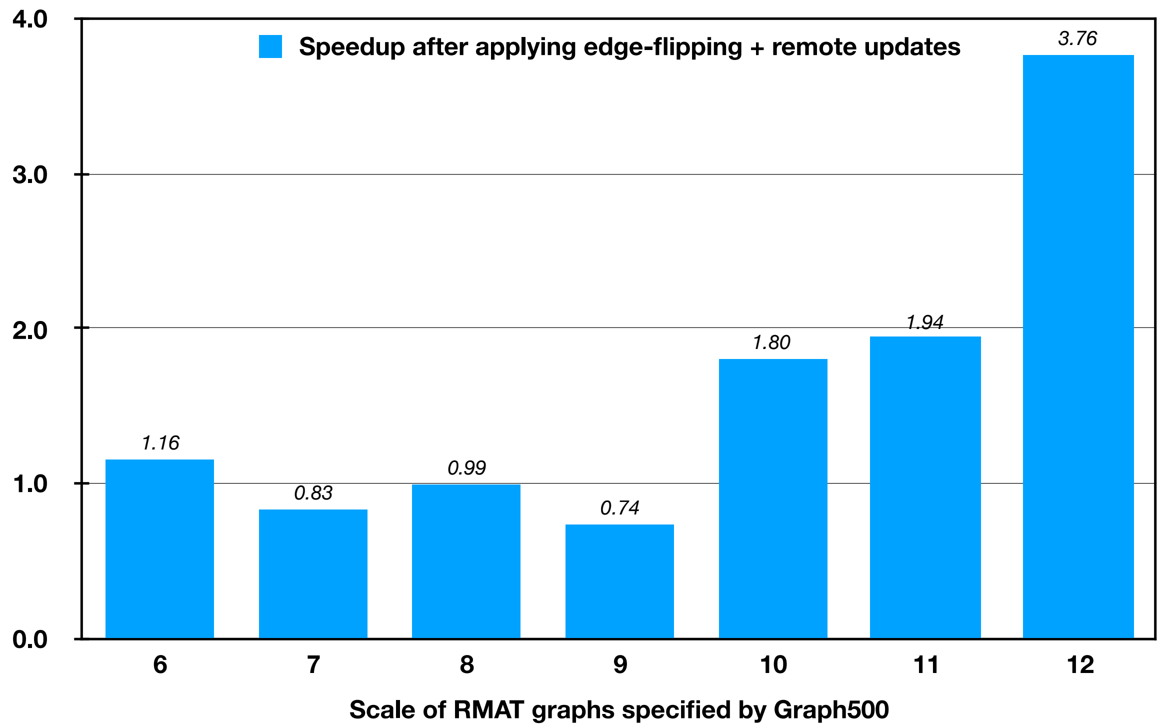
- **Compute shortest paths from a single source vertex to all the other vertices in a weighted directed graph**

```
for t ← 0 to |V| − 1 do
    for each v ∈ V do in parallel
        for each u ∈ incoming_neighbors(v) do
            temp = distance(u) + weight(u, v)
                            ▷ Migration for distance(u) value
            if distance(v) > temp then
                temp_distance(v) = temp
            end
        end
    endfor
```

Back and forth migration for every incoming neighbor

- **Edge flipping followed by remote updates can avoid back and forth migrations**

Results after Edge flipping + Remote updates



- **Speedups of up to 3.8x (geometric mean: 1.38x)**
  - Also, a geometric mean reduction of 36.39% in thread migrations

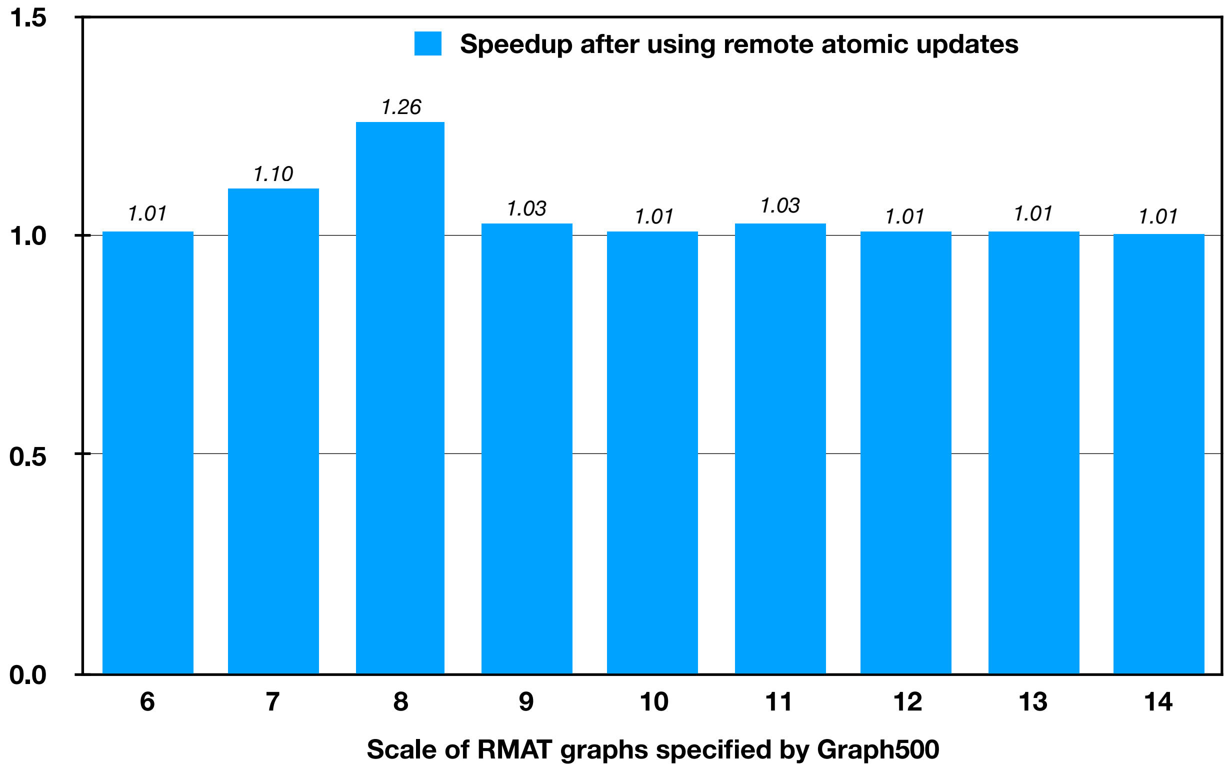
3) Triangle counting

- Computes the number of triangles in a given undirected graph
  - Also computes the number of triangles that each node belongs to

```
for each v ∈ V do in parallel
    for each u ∈ v.nbrs do
        if nbr1 > v then
            for each w ∈ v.nbrs do
                if w > u then
                    if edge_exists(u, w) then
                        tc_count ++; //Atomic
                        tc(v) ++; //Atomic
                        tc(u) ++; //Atomic
                        tc(w) ++; //Atomic
                            ▹ Above regular atomics can be
                        replaced by the remote updates.
```

- Regular atomic updates can be replaced with remote updates

Results after using Remote updates



- Speedups of up to 1.3x (geometric mean: 1.05x)
  - Also, a geometric mean reduction of 54.55% in thread migrations

Conclusions & Future work

- **EMU architecture is a potential choice for graph applications**
  - **But, a careful attention is required to make sure that overheads don't hurt the benefits**
  - **Evaluated compiler transformations for three graph applications**

Applications	Transformations
Conductance	Node fusion
Bellman-Ford's algorithm	Edge flipping + Remote updates
Triangle counting	Remote updates

- **Future work**
  - **Systematically explore & evaluate more compiler transformations**

Any questions?

Acknowledgements

- MCHPC'18 Program committee
- Eric Hein and Jeff Young
  - Getting setup with EMU machine and the MEATBEE framework
- CRNCH center at Georgia Tech
  - Rogues gallery

http://crnch.gatech.edu/rogues-emu