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An Evaluation of Parallelization Techniques for MRF Image Segmentation

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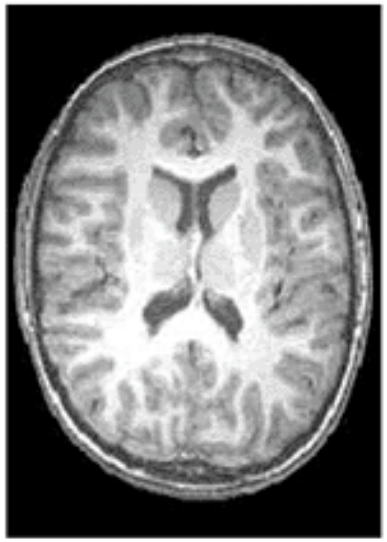
Motivation

- MRFs are of great interest to the medical image community
  - Captures spatial information
  - Many successful applications
- Problems:
  - Parameter selection
  - Computational complexity



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Motivation

- Solution: acceleration via parallelization
  - Mitigates computational complexity
  - Enables real-time interaction

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Evaluation

- Chose Belief Propagation (BP) MRF optimization
- Parallelize for multi-core processors
- Why not GPU?
  - Lack of global synchronization
  - Programming model can reduce productivity and performance

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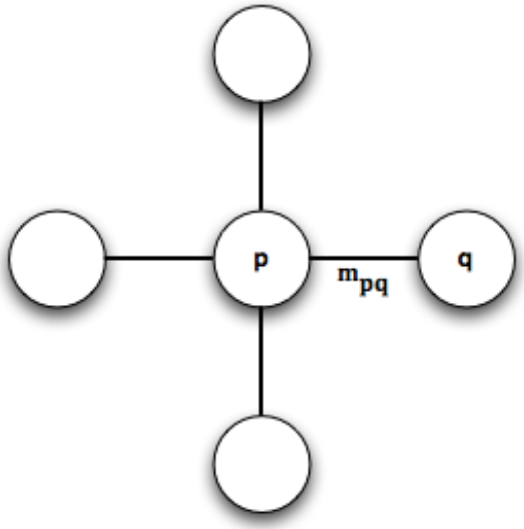
BP Overview

- Image represented as a graph
  - Nodes represent pixels
  - Edges defined by neighbourhood
- Nodes pass messages to their neighbours
  - Node p passes message m_{pq} to node q
- After T iterations, accumulated messages determine labeling



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BP Messages

- In iteration t, node p sends message m_{pq}^{t} to node q:

$$m_{pq}^{t}(f_q) = \min_{f_p}\left(V(f_p, f_q) + D_p(f_p) + \sum_{s \in N(p)\setminus q} m_{sp}^{t-1}(f_p) \right)$$

smoothness term

data term

received messages from t-1

- m_{pq}^{t} is a vector with size = number of labels

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BP Labelling

- After T iterations, a pixel's label b_q is calculated as:

$$b_q(f_q^*) = D_q(f_q^*) + \sum_{p \in N(q)} m_{pq}^t(f_q^*)$$

- Where f_q^* is the optimal label

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Parallelizing BP: Dependencies

- If two sections/blocks of code share heap data, **data dependency** exists
- In BP, neighbours will read/write shared memory to send messages
- There is also a dependency between iterations

Thread 0

```
msg[q][p] = calc(msg[p][q])
```

Thread 1

```
msg[p][q] = calc(msg[q][p])
```

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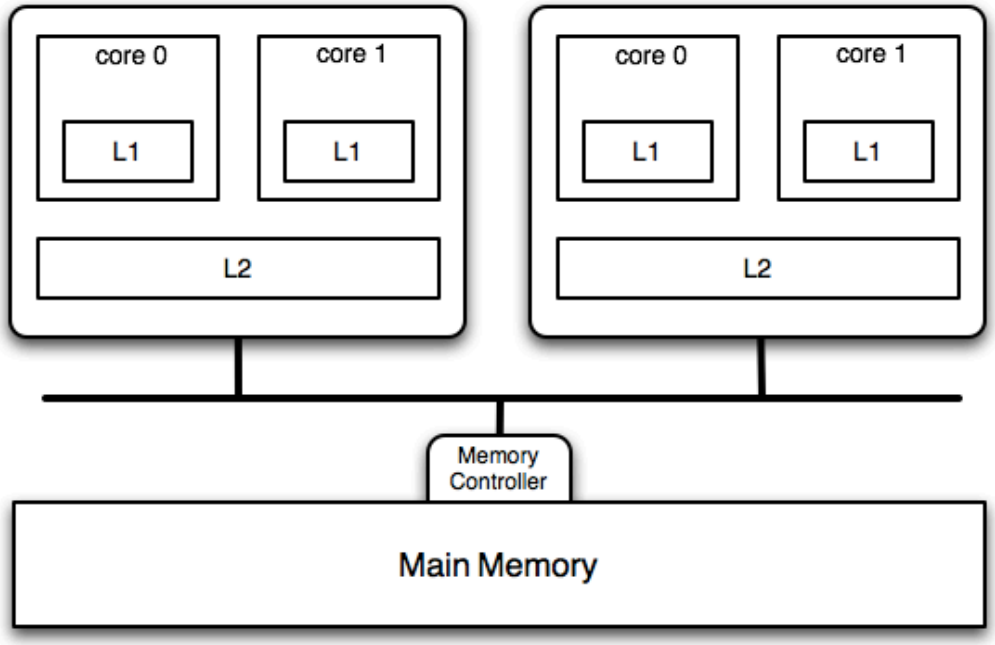
Parallelizing BP: Inter-processor communication

- Concurrent shared memory access means:
  - Inter-processor/inter-thread communication, and/or
  - Synchronization
- Communication increases latencies and contention



- Must carefully manage data and synchronization!

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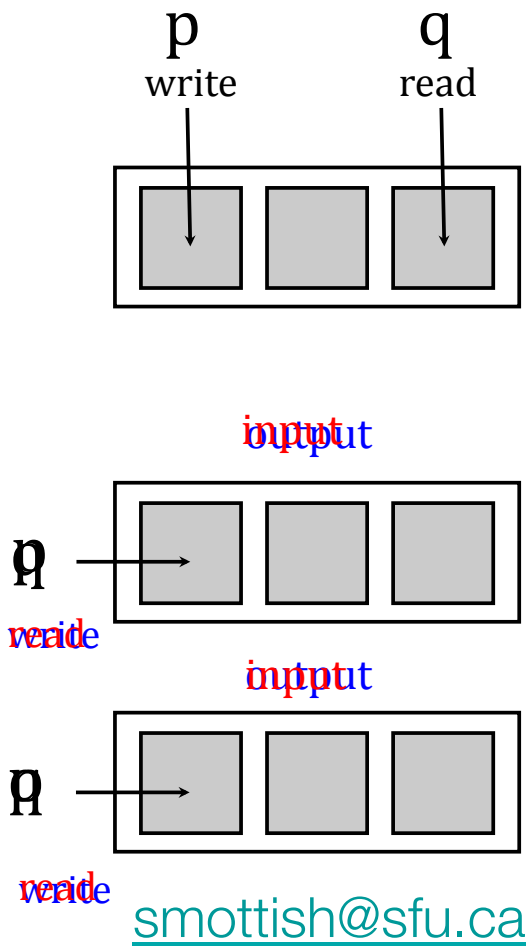
Implementation

- "Typical" implementation
  - Neighbours share a queue to send/receive messages
  - Problem: requires synchronization for each read/write!
- Double buffering
  - Separate read/write or input/output queues
  - Single synchronization step to "swap"



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Implementation

- In iteration t, synchronization required to guarantee that:
  - A node has received all its messages from t-1
  - A node only sends to neighbour if neighbour also in t

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Implementation: Partitioning

- Each thread works on an equal partition of nodes
- Each thread is bound to a core
- When message sent from node in partition X to node in partition Y, inter-thread/inter-core communication
- Assign “neighbouring partitions” to threads/cores on same chip

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Implementation: Message Passing

Algorithm 1: parallel message-passing routine executed by each thread

```
   Input: number of iterations T and a set of nodes N
 1 begin
 2     for t ← 1 to T do
 3         foreach p ∈ N do
 4             foreach q ∈ neighbours(p) do
 5                 message ← m^t_pq
 6                 while stateOf(q) ≠ RESET do
                       ▷loop until condition met i.e. spin
 7                 end
 8                 sendMsg(message)
 9             end
10             while stateOf(p) ≠ FULL do
                   ▷loop until condition met i.e. spin
11             end
12             swapBuffers(p)
13             stateOf(p) ← RESET
14         end
15     end
16 end
```

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Implementation: “lock-step”

Algorithm 2: parallel lock-step routine executed by each thread

```
   Input: number of iterations T and a set of nodes N
 1 begin
 2     for t ← 1 to T do
 3         foreach p ∈ N do
 4             foreach q ∈ neighbours(p) do
 5                 message ← m_pq^t
 6                 sendMsg(message)
 7             end
 8         end
 9         spinWait()
10         swapBuffers(p)
11         spinWait()
12     end
13 end
```

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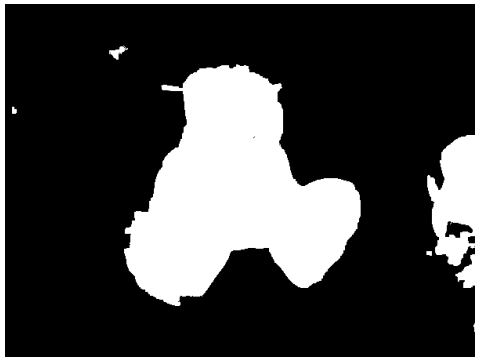
Experimental Setup

- Binary image segmentation
  - 600x450 greyscale image
  - 15 iterations



- Measure the time it takes for all threads to complete an iteration
- Run-time = sum of iteration times
- Averaged over 10 trials

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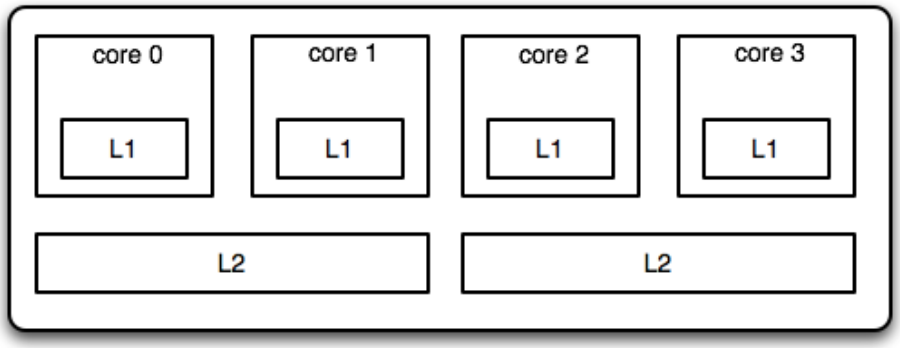
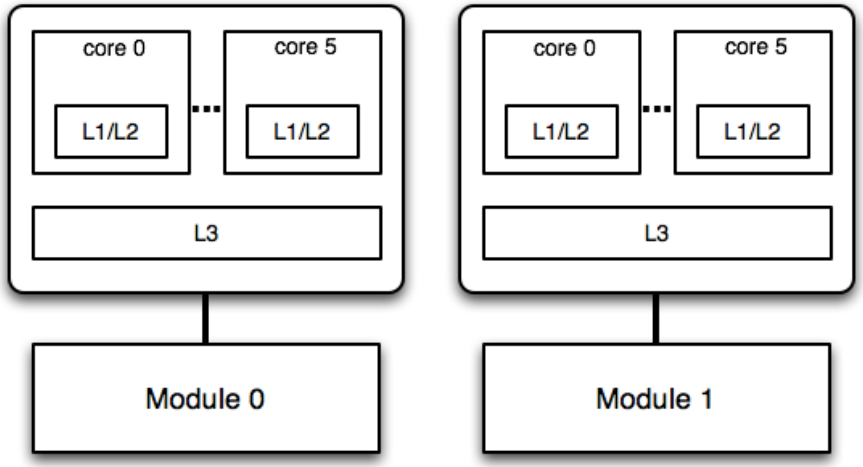
Experimental Setup: Machines

2x 4-core Intel Xeon E5405



4x 6-core AMD Opteron 2435



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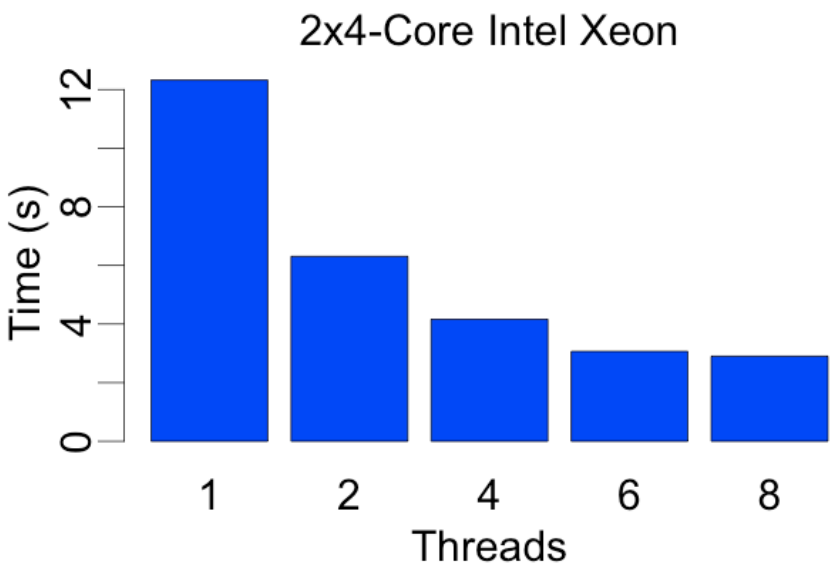
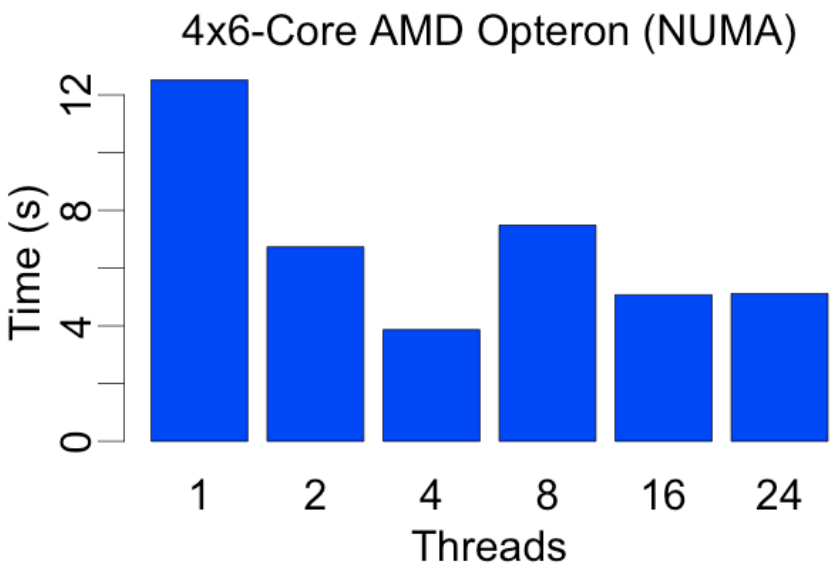
Results: “Message Passing”

- Run-times





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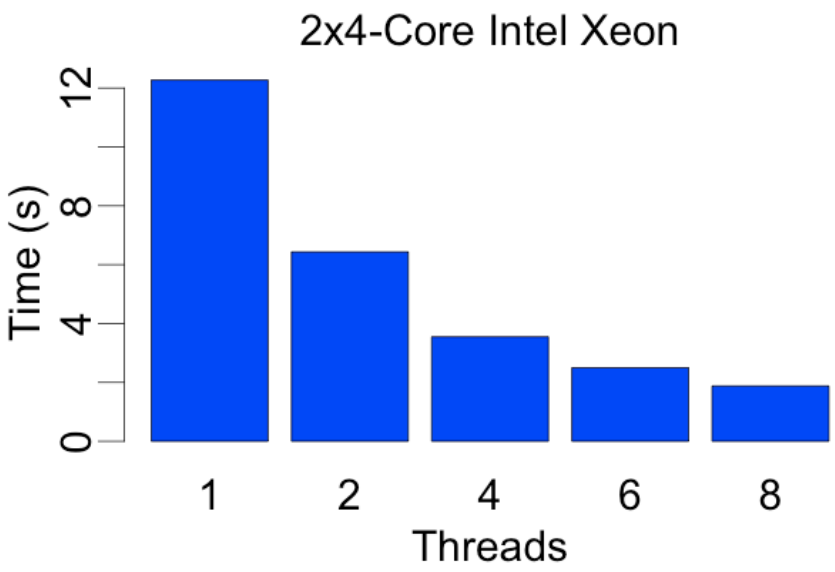
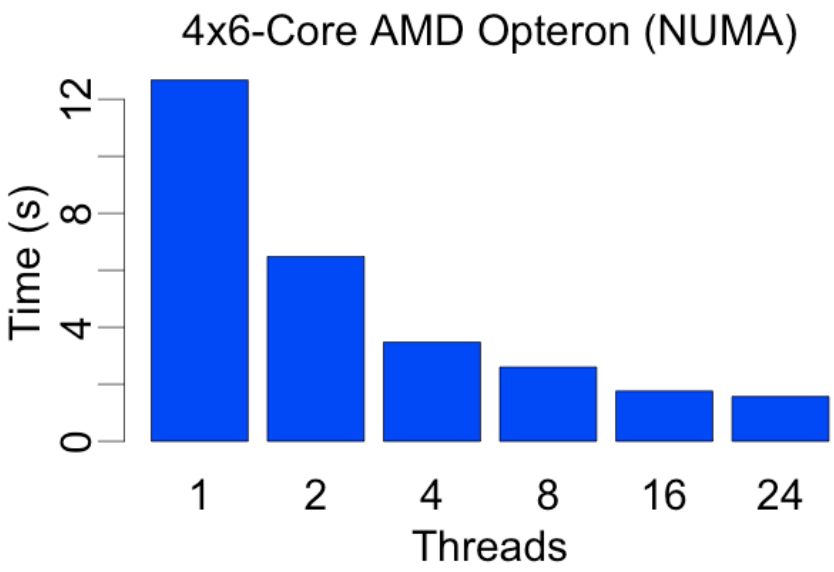
Results: “Lock-step”

- Run-times





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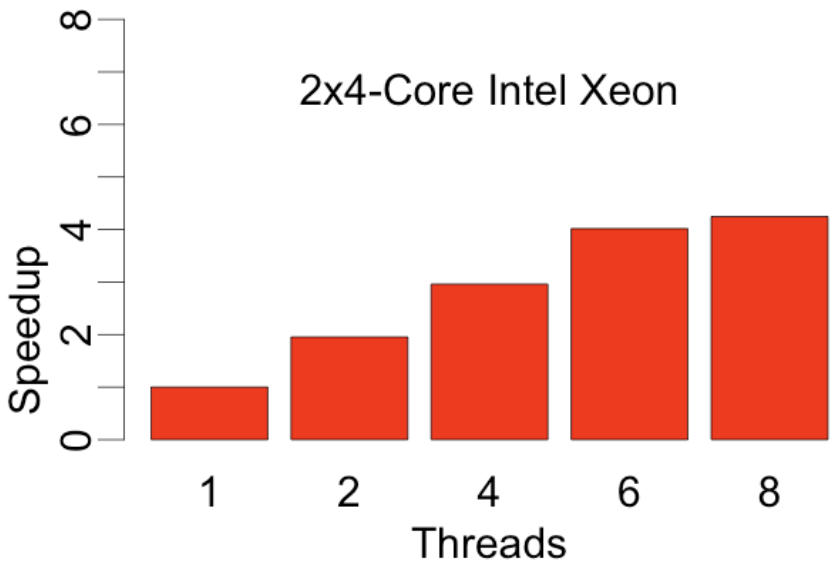
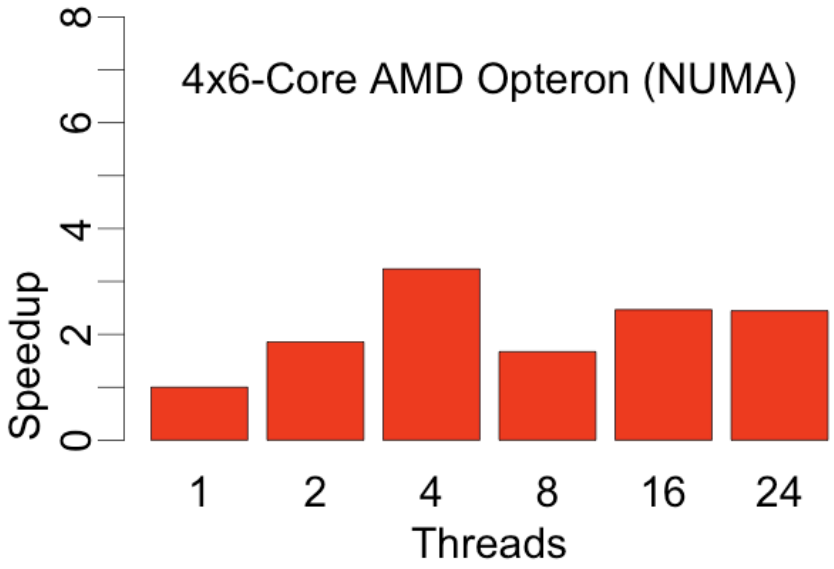
Results: “Message Passing”

- Speed-up





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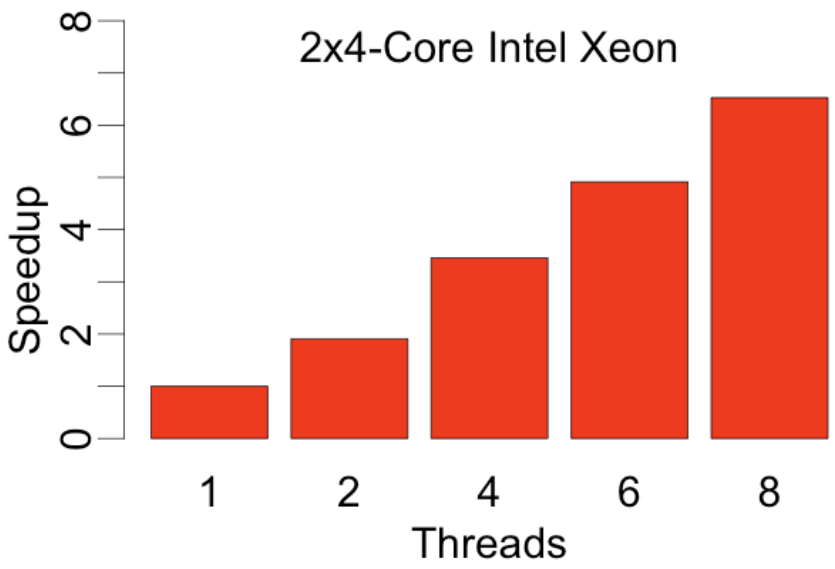
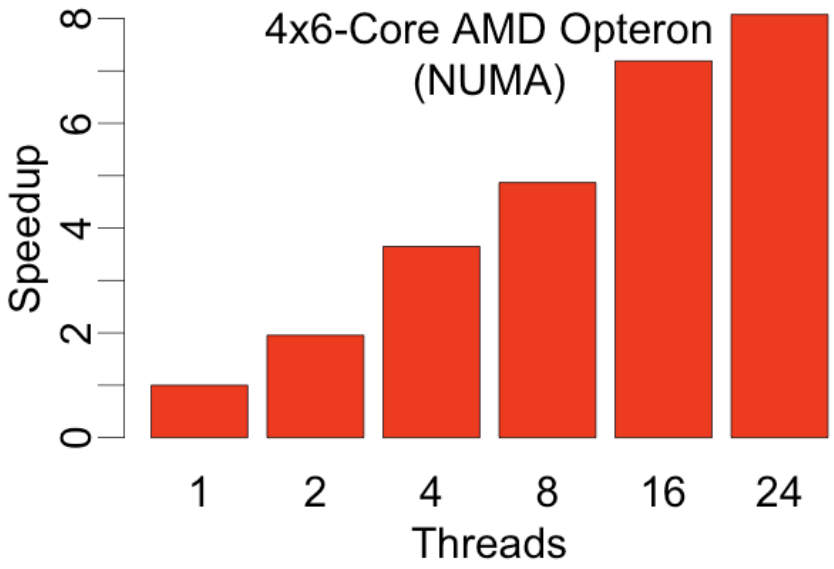
Results: “Lock-step”

- Speed-up





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Conclusion

- Achieved a maximum speedup of 8.08
- Managing data and inter-processor communication is crucial!
- Further optimization can be done to further reduce:
  - Memory latencies
  - Inter-processor communication
- Implement and compare a GPU version
- Hybrid CPU-GPU version

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