Detecting and Using Critical Paths at Runtime in Message Driven Parallel Programs

Isaac Dooley, Laxmikant V. Kale
Department of Computer Science
University of Illinois

idooley2@illinois.edu
kale@illinois.edu

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Motivation

- Critical paths historically have been used important in post-mortem (offline) parallel performance analysis.
- Can they be computed online in message driven parallel languages?
- Is critical path information useful in running parallel HPC programs?

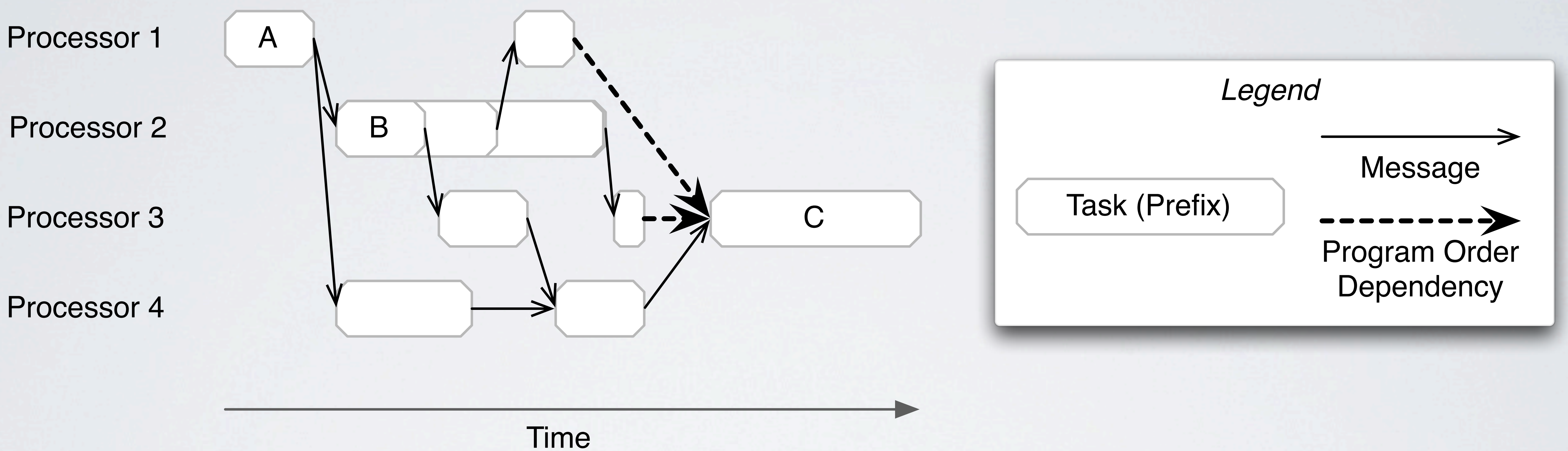
Critical Paths in Parallel Programs

- Existing algorithms for recording critical paths in a hybrid online/offline manner:
  - J Hollingsworth. *An online computation of critical path profiling.* In SPDT '96: Proceedings of the SIG-METRICS symposium on Parallel and distributed tools, pages 11–20, New York, NY, USA, 1996
  - J Hollingsworth. *Critical path profiling of message passing and shared-memory programs*. Parallel and Distributed Systems, IEEE Transactions on, 9(10):1029– 1040, Oct 1998
  - C Yang, B P Miller. *Path Analysis for the Execution of Parallel and Distributed Programs.* IEEE Transactions on Parallel and Distributed Systems, pages 1029 - 1040, Oct 1998
  - M Schulz. *Extracting critical path graphs from MPI applications*. Cluster Computing, 2005, pages 1 – 10, Sep 2005
  - For guiding expert post-mortem performance analysis
  - For visualizing parallel program execution to gain understanding

Critical Paths in Message Driven Parallel Programs

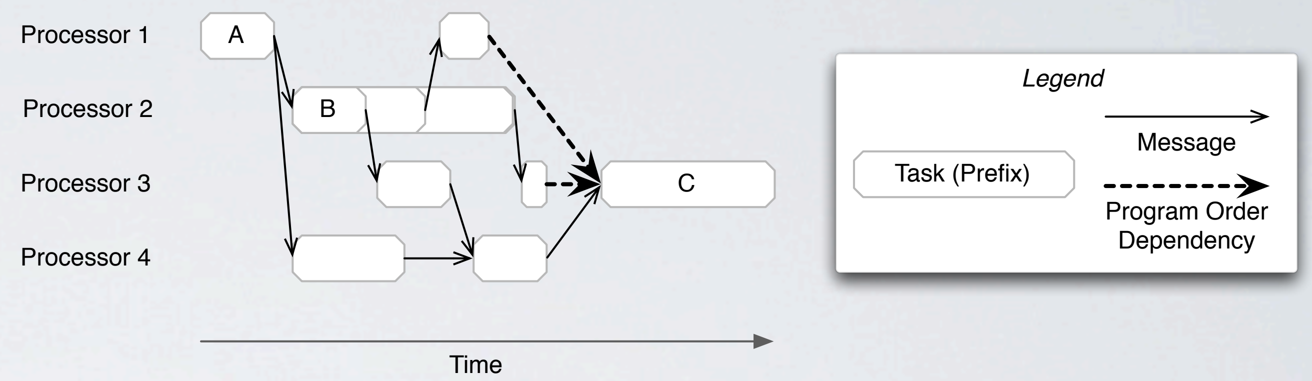
- Message Driven Execution (as implemented in Charm++):
  - Tasks invoke methods asynchronously
  - An asynchronous method invocation results in:
    - New local task in queue, or
    - Message sent to remote processor, resulting in new task

Example
Program Activity Graph



- Critical path profiles represent a path through the Program Activity Graph (PAG) composed of computation and messages.

Program Activity Graph



- The PAG can be recorded as a program runs in a distributed graph

- Path weights include computation time, but not message send time

Processor 1

	Task Prefix Index	In-Edge (processor, Index)
A	1	initial
	2	(2,2)

Processor 2

	Task Prefix Index	In-Edge (processor, Index)
B	1	(1,1)
	2	(1,1)
	3	(1,1)

Processor 3

	Task Prefix Index	In-Edge (processor, Index)
	1	(2,1)
	2	(2,3)
C	3	(1,2) or (3,2) or (4,2)

Processor 4

Task Prefix Index	In-Edge (processor, Index)
1	(1,1)
2	(3,1) or (4,1)

Finding Critical Paths

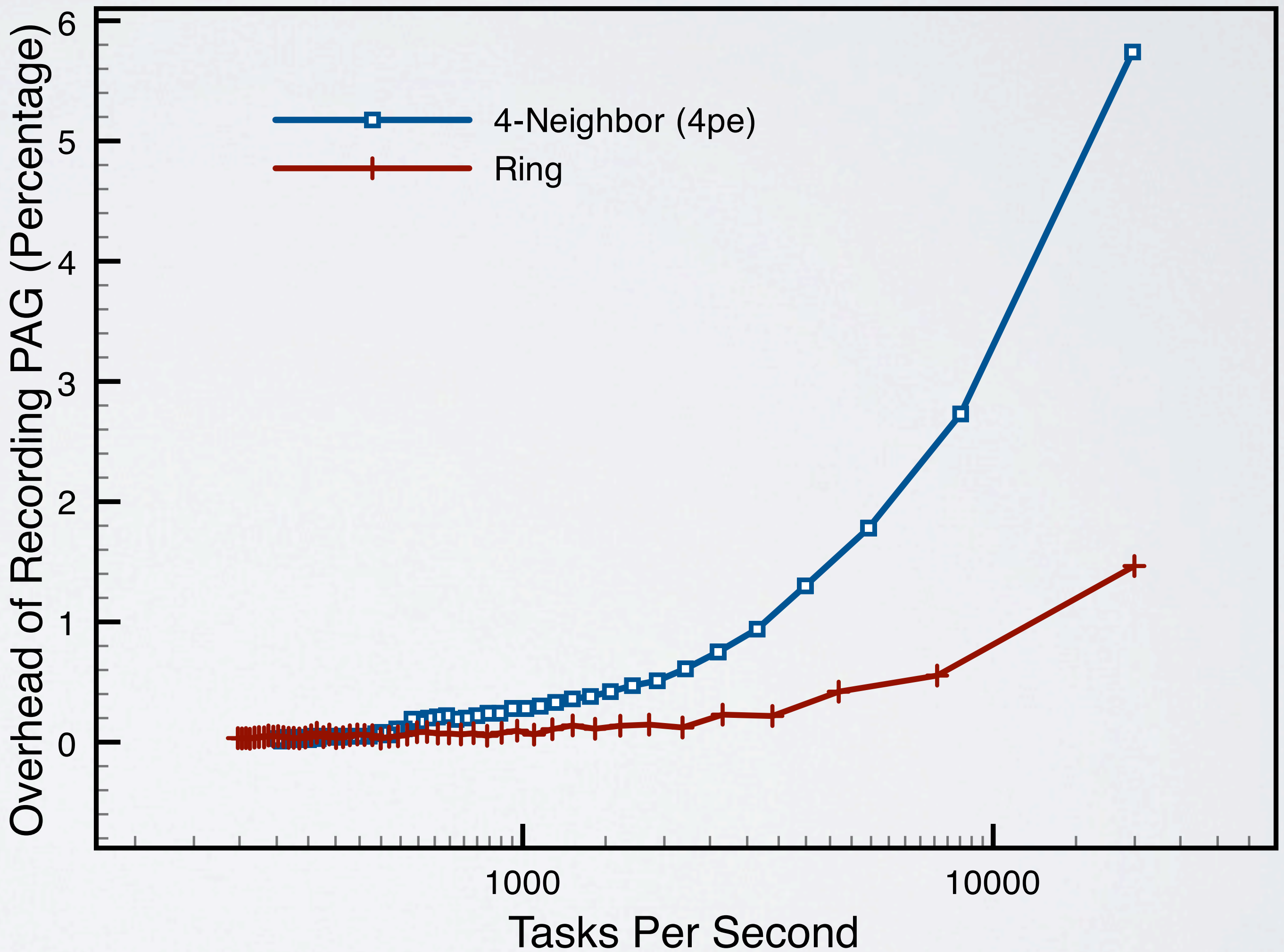
- Record PAG as program runs
  - Augment each message with:
    - an identifier
    - path length
  - Record maximal incoming path for each task in a table
    - Requires compiler support or code modifications
- Retrieve Critical Path for any task with a backwards traversal

Implementation

- Implemented in the Charm++ runtime system.
- Supports multiple languages:
  - Charm++
  - Structured Dagger
  - Charisma
- Trickiness is in how multiple incoming dependencies are captured.
  - Reductions
  - User maintains knowledge of dependencies satisfied by earlier tasks
  - Language specific dependency mechanisms

Costs of Recording Critical Paths

- Cost of extra 8 bytes in message
- Cost of adding table entries for each task execution
    - Microbenchmarks:



- Cost of backwards traversal retrieval: Application Dependent

Use: Automatic Task Priorities

- Automatically Tuning Task Priorities:
  - OpenAtom Application
  - Record critical path for 20 iterations, then switch to new priorities based on observed critical path.
  - **10.2% speedup** when prioritizing critical path task types

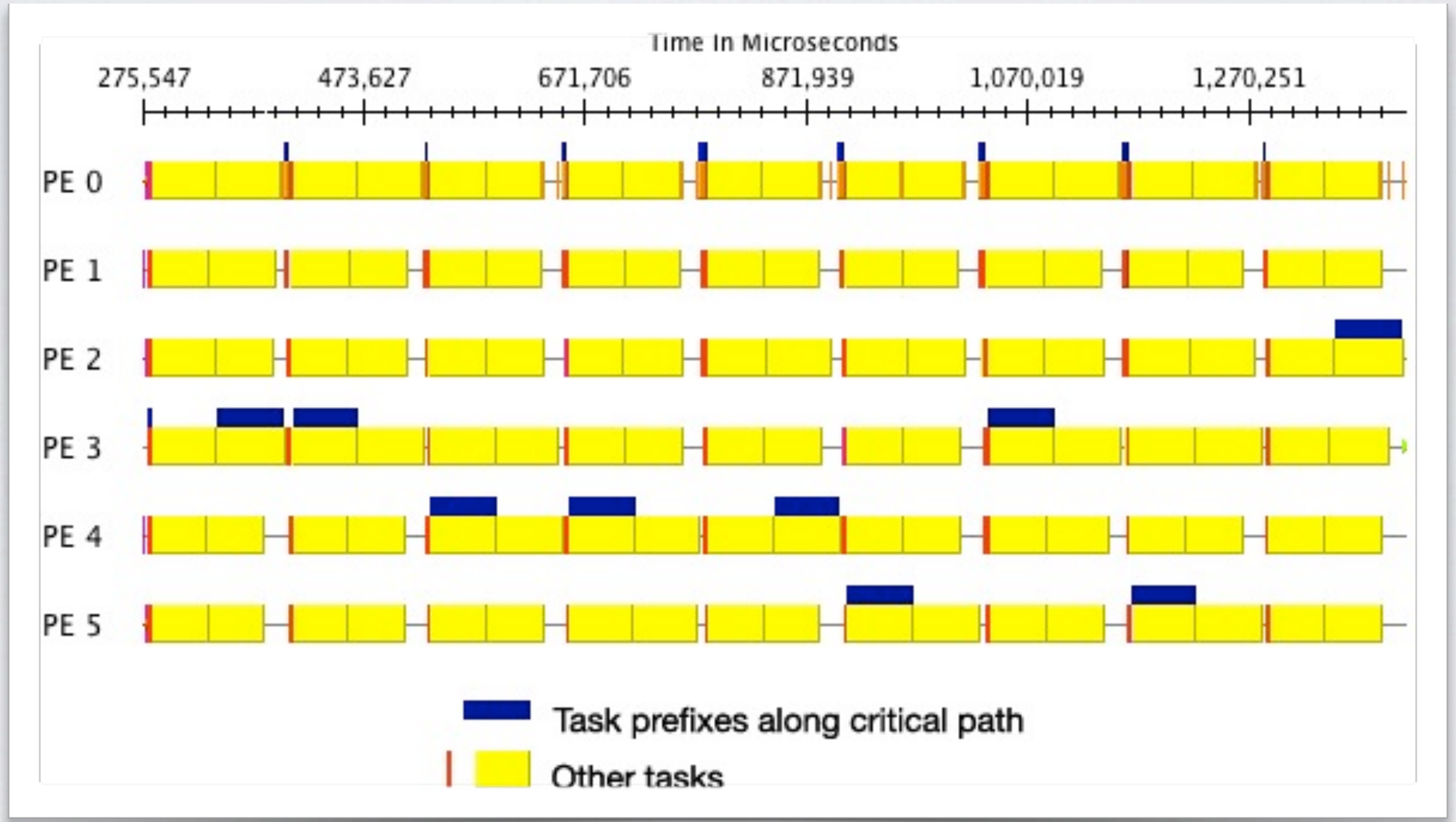
Uses: Phase Detection

- Critical path is retrieved
- Frequently repeated subpaths are extracted
- Cheap!

a b b b b b b c d e f g g g g g h i j b b b b b k l m n o p o p q r b b b b s t i u v w b b b b x x y v w b b b b
b A A x y v w b b b b x x x y v w b b b b b x x x y v w b b b b b x x x a b b b b b b c d e f g g g g g h i j b
b b b b b k l m n o p o p q r b b b b s t i u v w b b b b b A A x y v w b b b b b A A x y v w b b b b b A A x
y v w b b b b b x x x y v w b b b b b x x x **a b b b b b b c d e f g g g g g h i j b b b b b k l m n o p o p q r**
b b b b s t i u v w b b b b x x y v w b b b A A x y v w b b b b x x x y v w b b b b A x x y w b b b A A x a b
b b b b b c d e f g g g h i j b b b k l m n o p o p q r b b b b s t i u v w b b b b b A x x y v w b b b b b A x x
y v w b b b b b x x x y v w b b b b x x x y w b b b b x x A **a b b b b b b c d e f g g g g g h i j b b b b b k l**
m n o p o p q r b b b b s t i u v w b b b b x x y v w b b b b x x x y v w b b b b x x x y v w b b b b x x x y v
w b b b b b x x x **a b b b b b b c d e f g g g g g h i j b b b b b k l m n o p o p q r b b b b s t i u v w b b b b**

Uses: Performance Analysis

- Visualization:



Uses: Filter Performance Data

- Reducing volume of performance analysis data
  - Filter out processors not on critical path
  - Performance analyst only needs to manipulate & view fewer files

Conclusion

- Our Contribution:

  Critical paths can be recorded and used in message driven parallel programs at runtime for tuning message priorities.

Thanks & Questions

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Handling Multiple Input Dependencies