High-Performance Filter-Stream Frameworks for Hierarchical, Heterogeneous, Distributed Supercomputers

Timothy D. R. Hartley, Department of Electrical and Computer Engineering, The Ohio State University

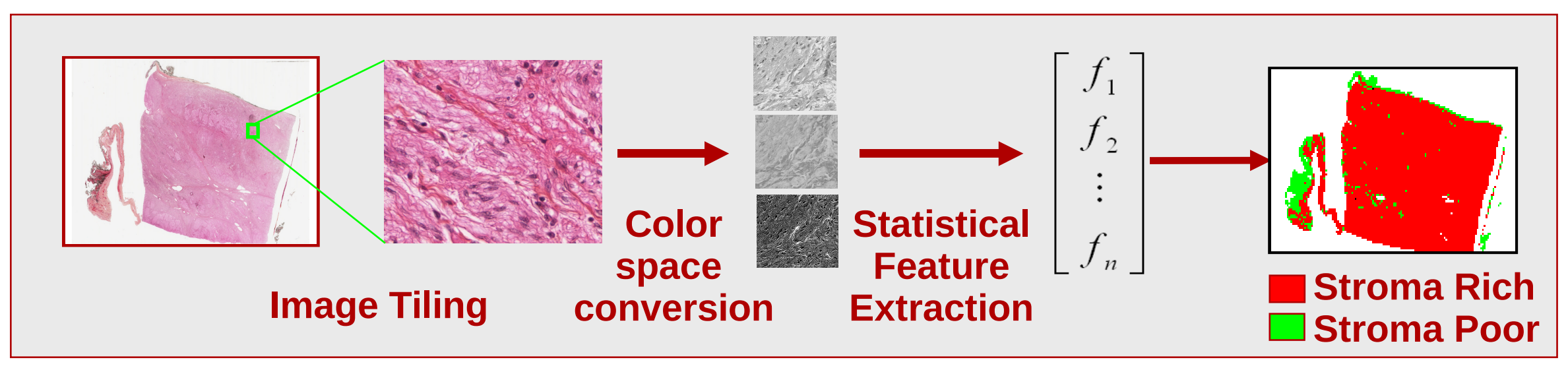
Advisor: Umit V. Catalyurek, Departments of Biomedical Informatics
and Electrical and Computer Engineering, The Ohio State University

Motivation: Multi-grain Software and Hardware

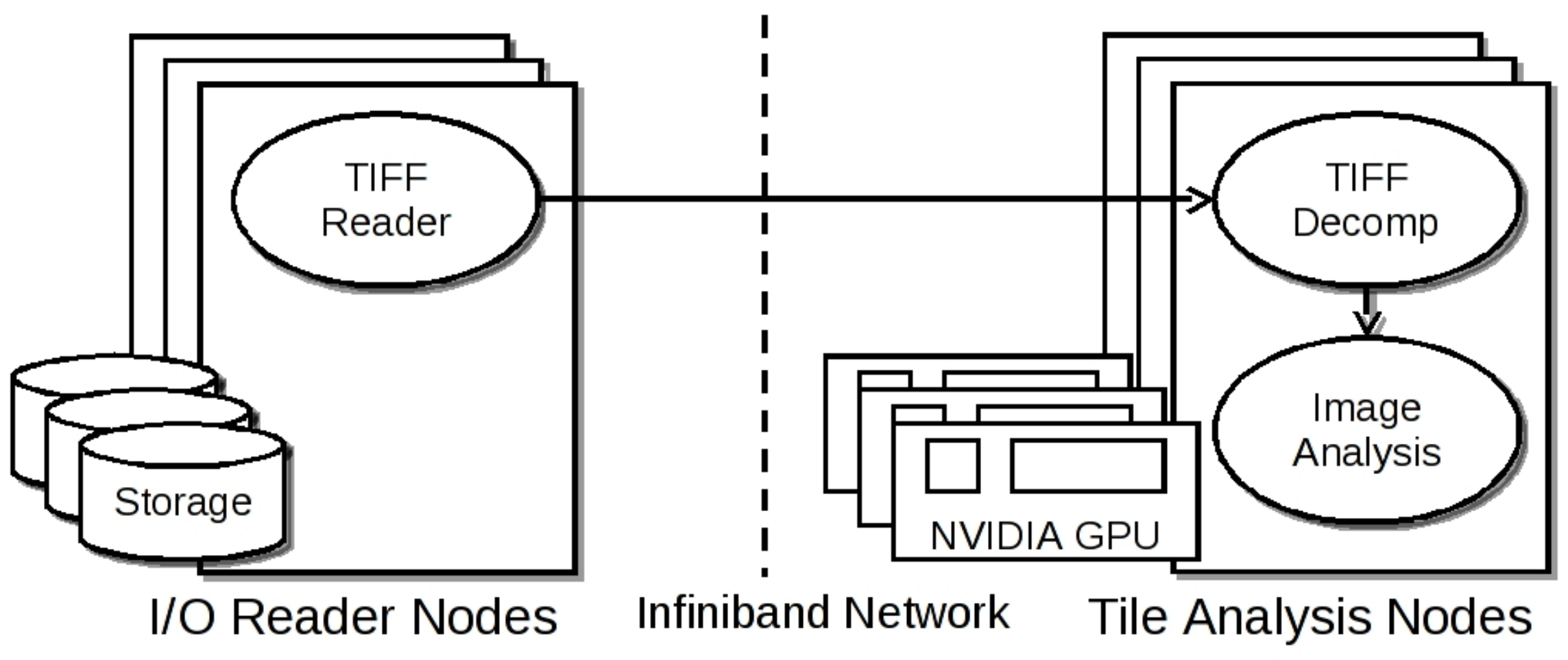
- Complex, large-scale parallel applications have inherent granularity
- Large, distributed cluster supercomputers have inherent granularity
  - Modern multicore processors such as chip multiprocessors (CMPs)
    - Accelerators
      - GPUs
      - Cell Broadband Engine
  - Hierarchy due to mixed node types, mixed processor types
- Difficult application to hardware mapping
  - Current programming systems flatten hierarchy
  - Incomplete handling of multiple levels of granularity
  - Trial-and-error optimization of important application parameters
- Filter-stream programming framework excellent for multi-grain
  - Component-based, for best task compartmentalization
  - Data-driven, for easy application development
  - Ensures efficient application/hardware granularities

Coarse-grain Development with GPUs

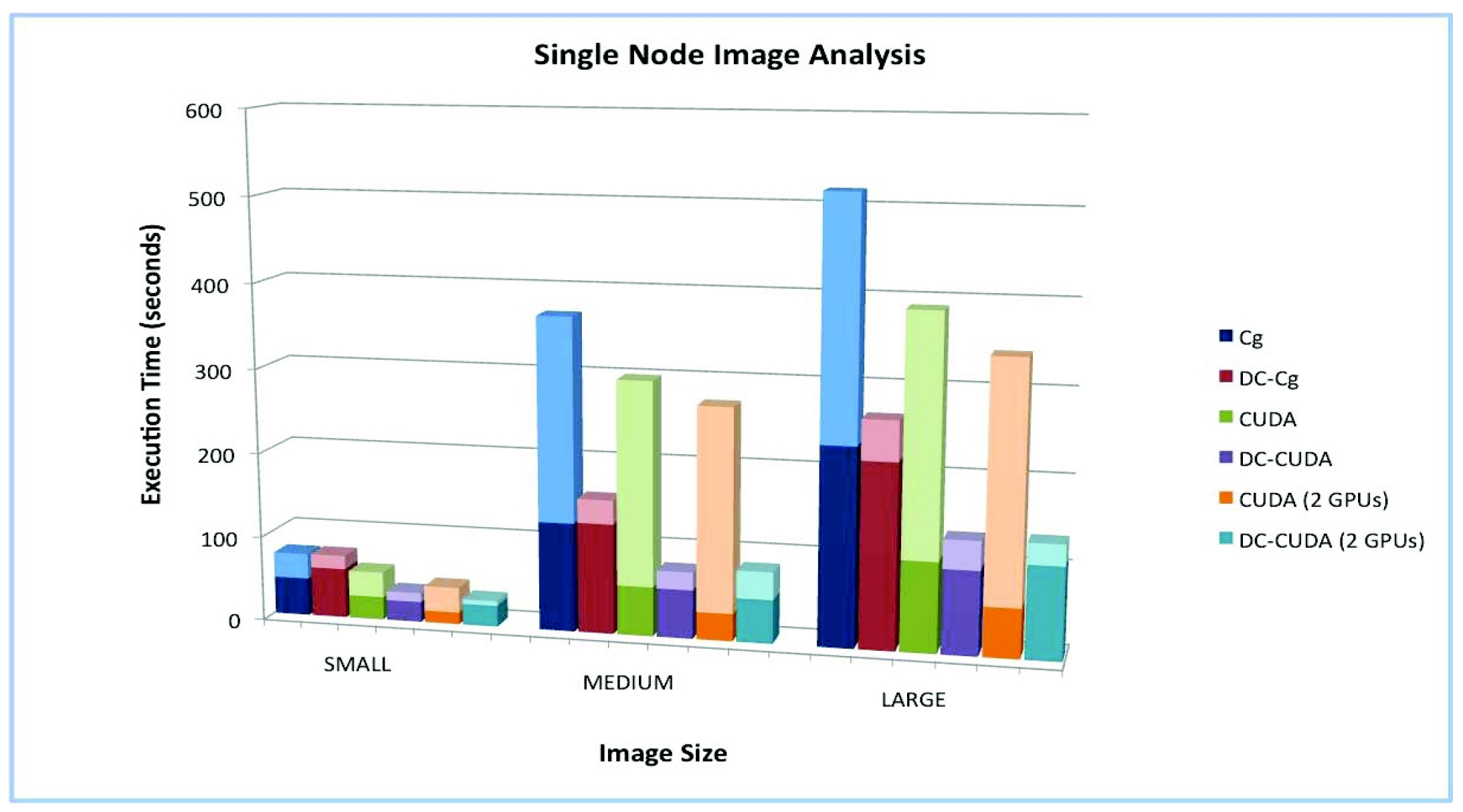
- Coarse-grain CMP/GPU cluster utilized for biomedical image analysis
  - Neuroblastoma a childhood cancer
  - Prognosis based partially on digitized microscope tissue slides analysis
  - Computerized prognosis system needs to analyze up to 30 GB images



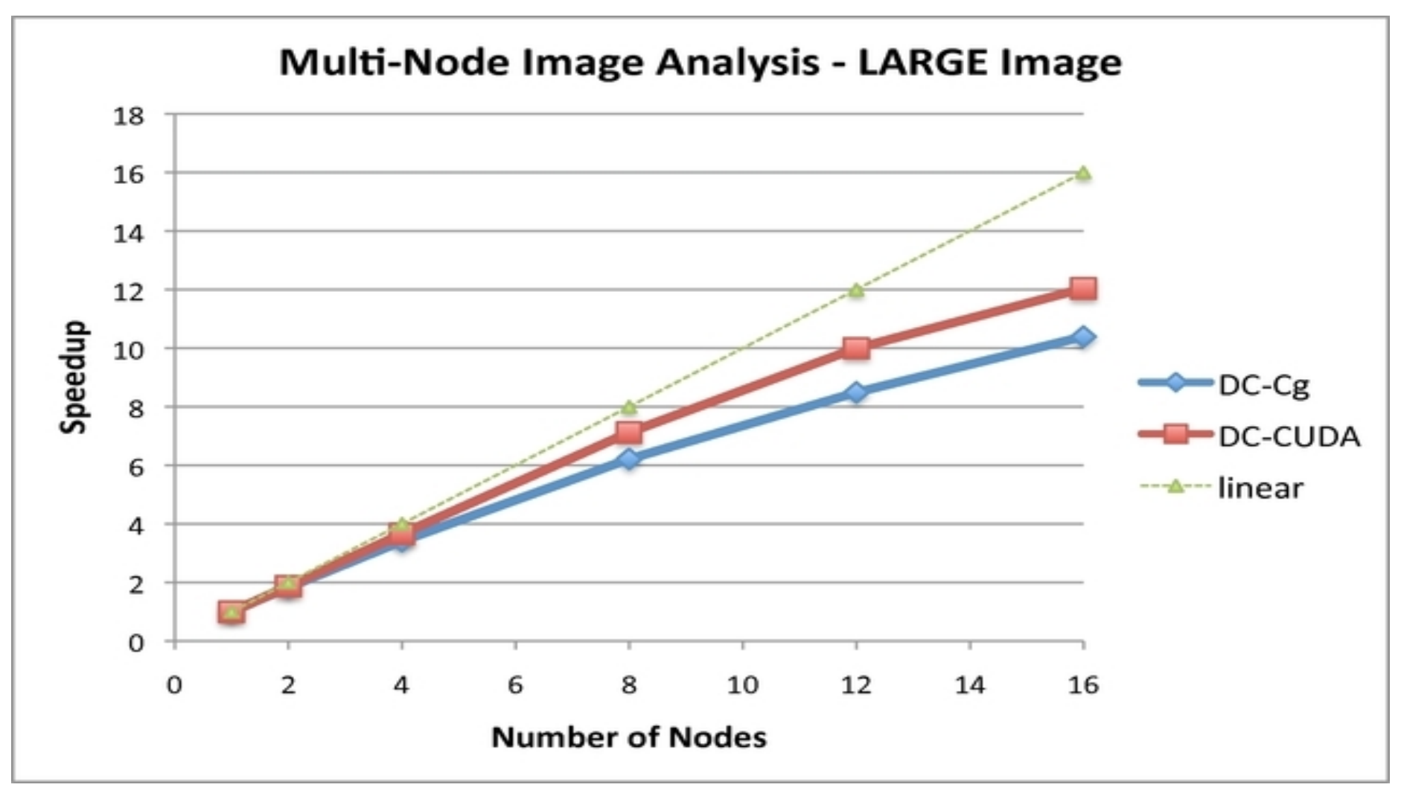
Coarse-grain Biomedical Application Results



- Processing nodes consist of:
  - Dual-socket 2.4GHz dual-core AMD Opteron
  - 2 NVIDIA Quadro 5600 GPUs

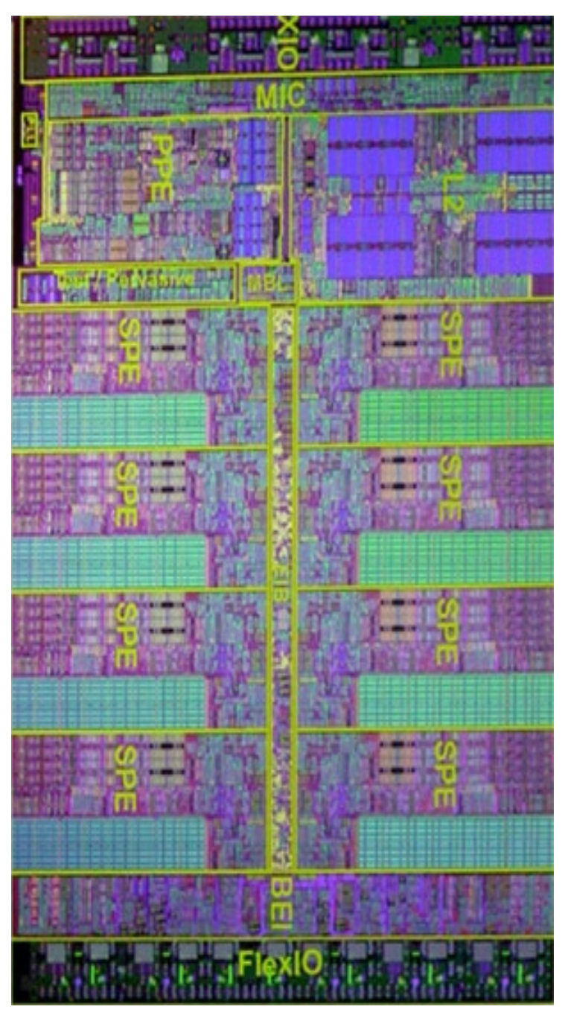


- 46.5x speedup 1 GPU vs sequential C++`
- Dual GPU time under one minute for largest image (excluding overheads)



- 926x speedup 16-node GPU vs 1-node C++
- LARGE image (109,110 x 80,828 pixels) analyzed in under 12 seconds

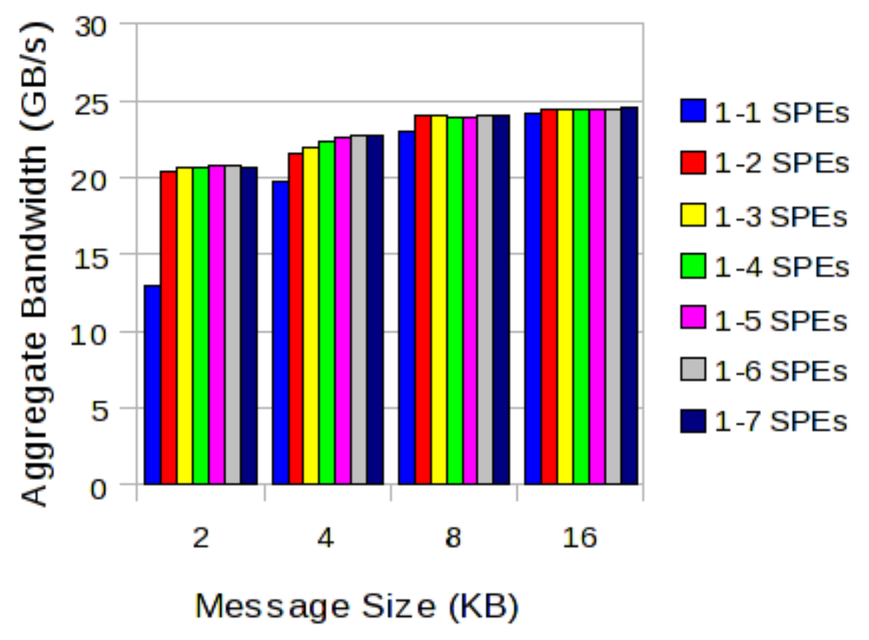
Fine-grain Filter-stream Framework for the Cell Broadband Engine



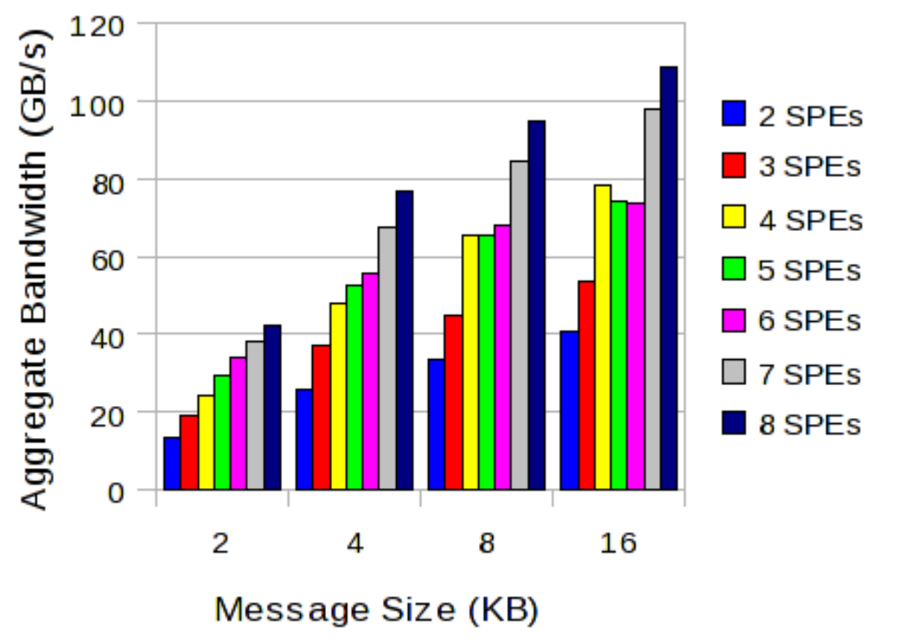
- Cell Intercore Messaging Library
  - High performance messaging library
  - Two-sided communication semantics
  - Maintains most of Cell's bandwidth
- DataCutter-Lite
- Fine-grain component-based filter-stream framework
  - Event-based filter-stream programming
  - Automatic multi-buffering of data
  - Simple multi-threaded, heterogeneous application development

Cell Broadband Engine Intercore Messaging Library (CIML)

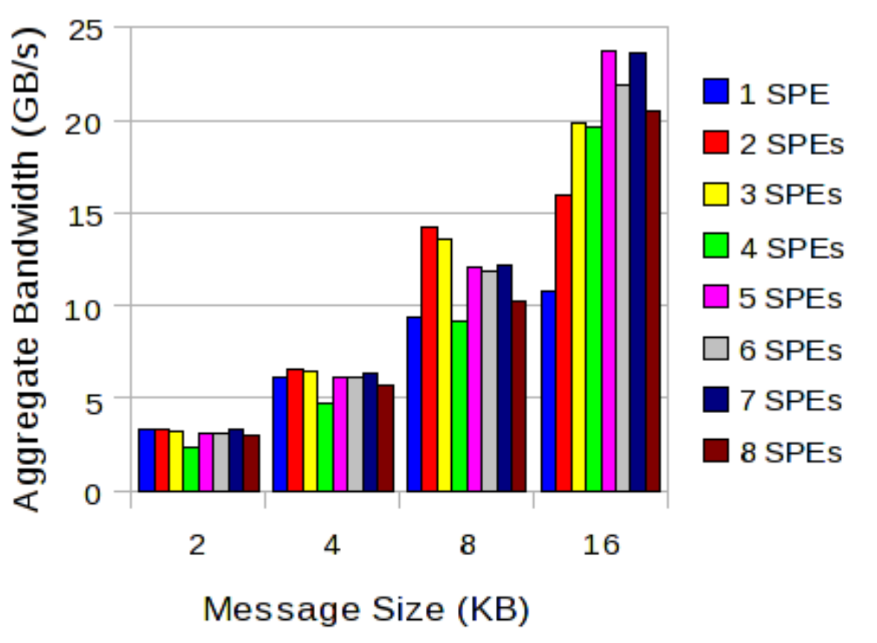
CIML SPE-SPE Communication



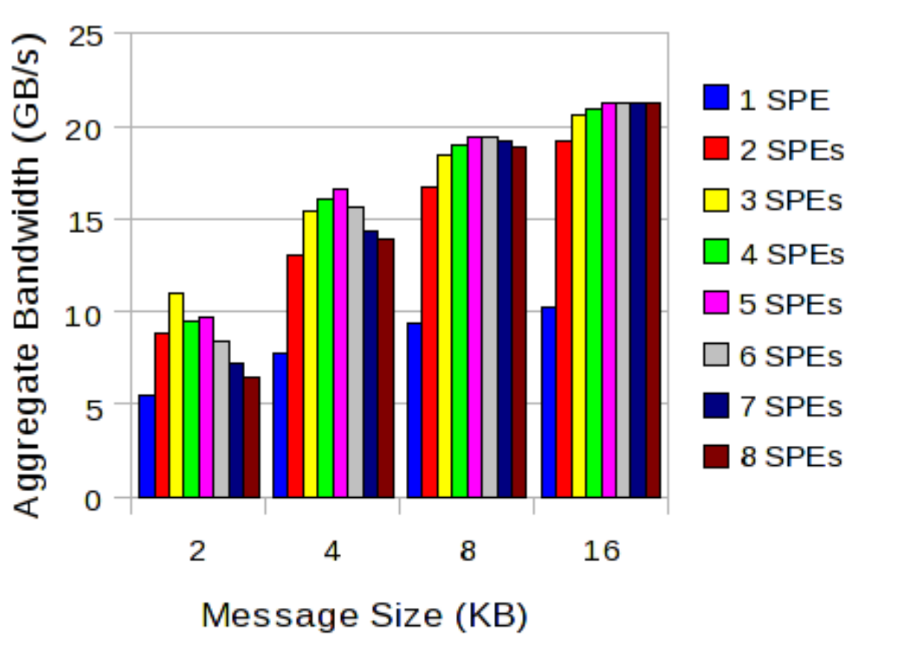
CIML SPE-SPE Ring Communication



CIML SPE-PPE Communication

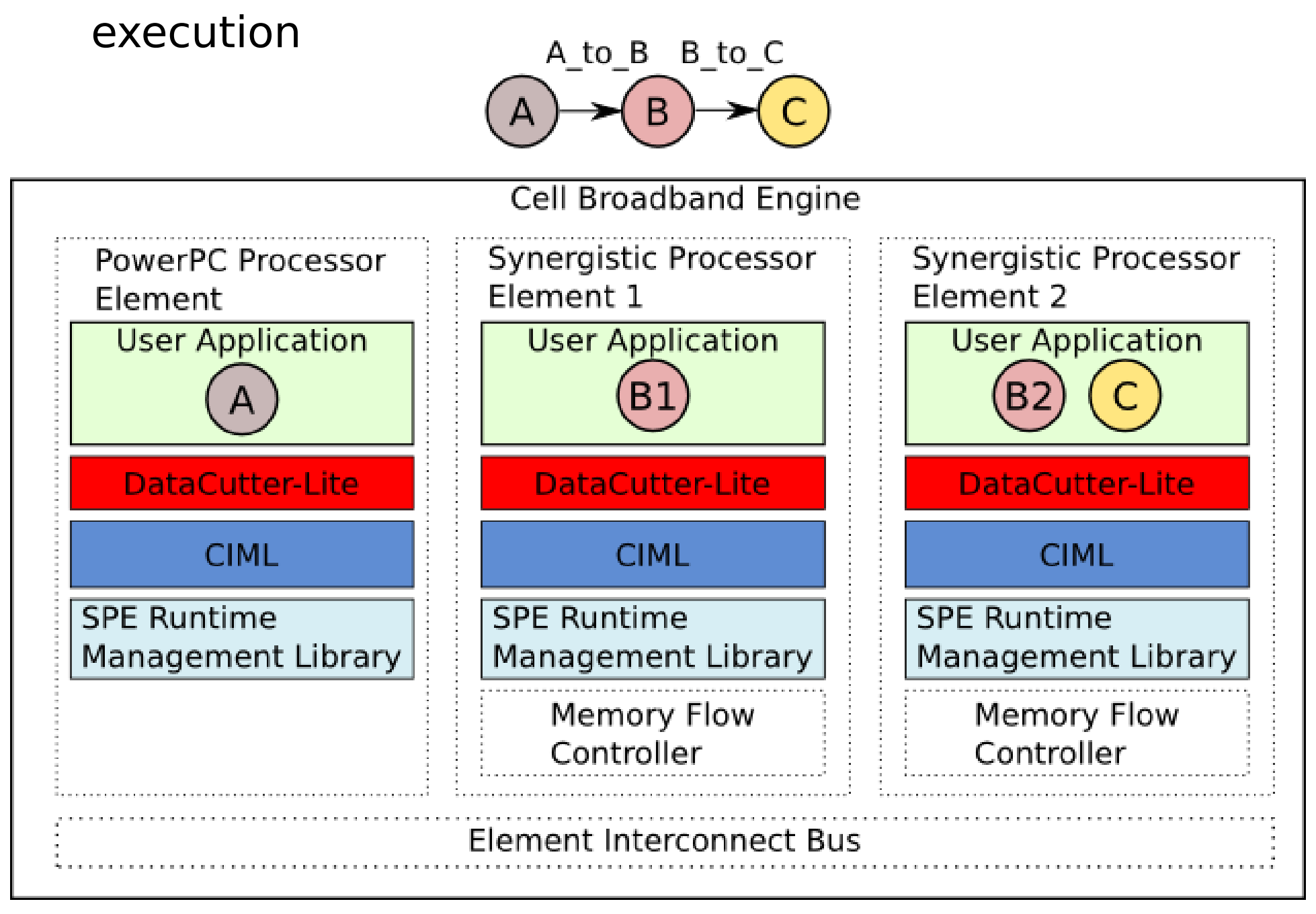


CIML PPE-SPE Communication

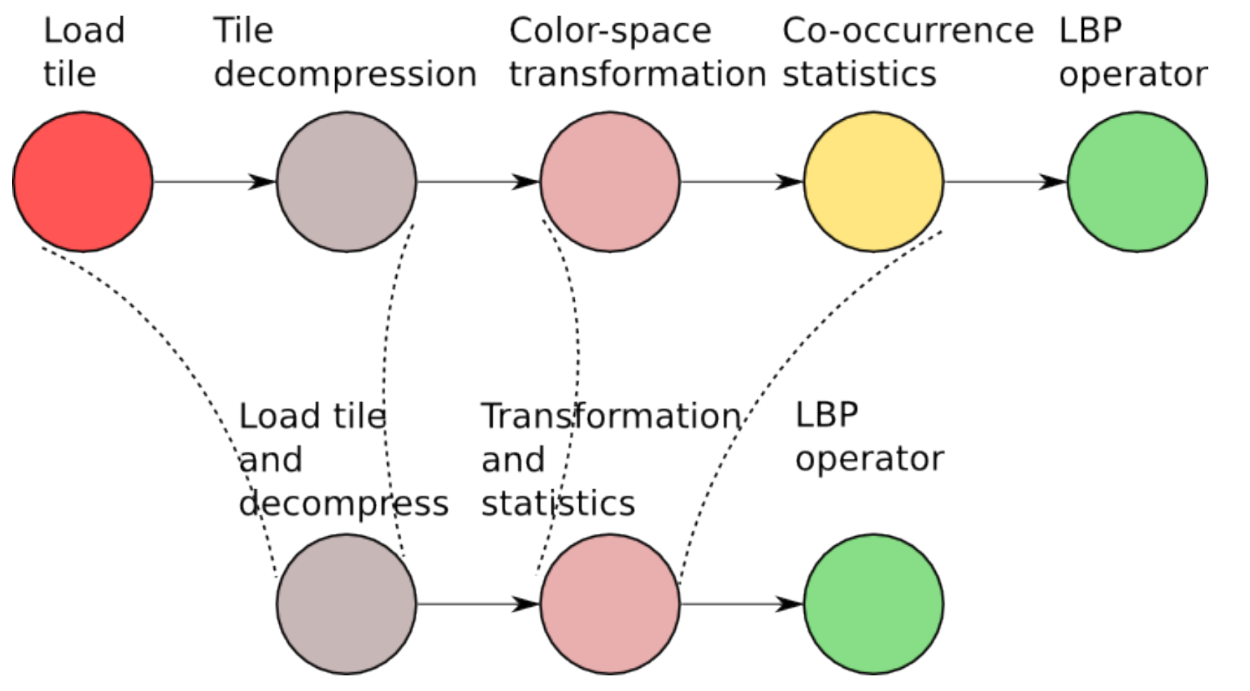


DataCutter-Lite: Fine-grain Filter-stream Programming Framework and Runtime Engine

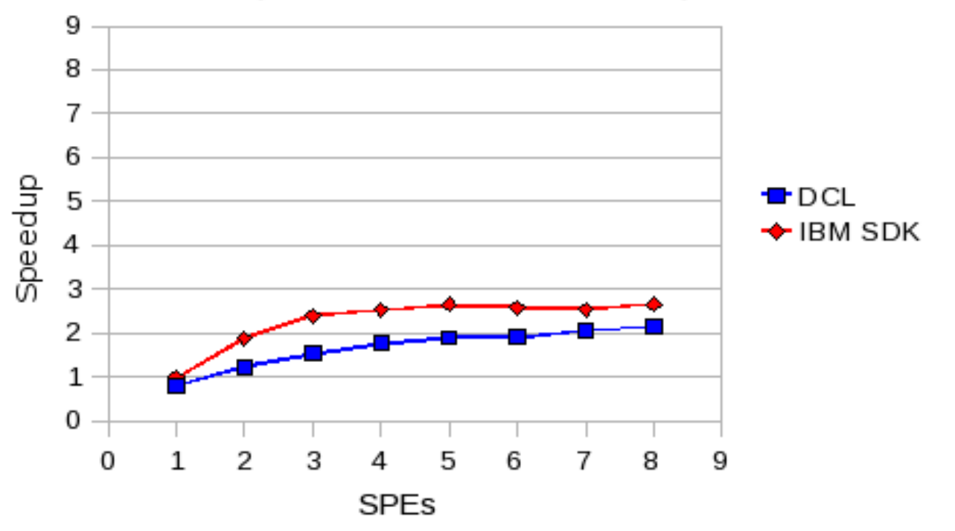
- Component-based, filter-stream programming framework
  - Define computation as task-graph
  - Tasks are *filters*, which are functions which compute
  - Data flows along *streams* to/from filters along pre-defined paths
  - Automatic multi-buffer of data
  - Automatic PPE-SPE, inter-SPE communication
- DCL is event-based
  - Arrival of stream *buffer* (quantum of data) triggers filter execution



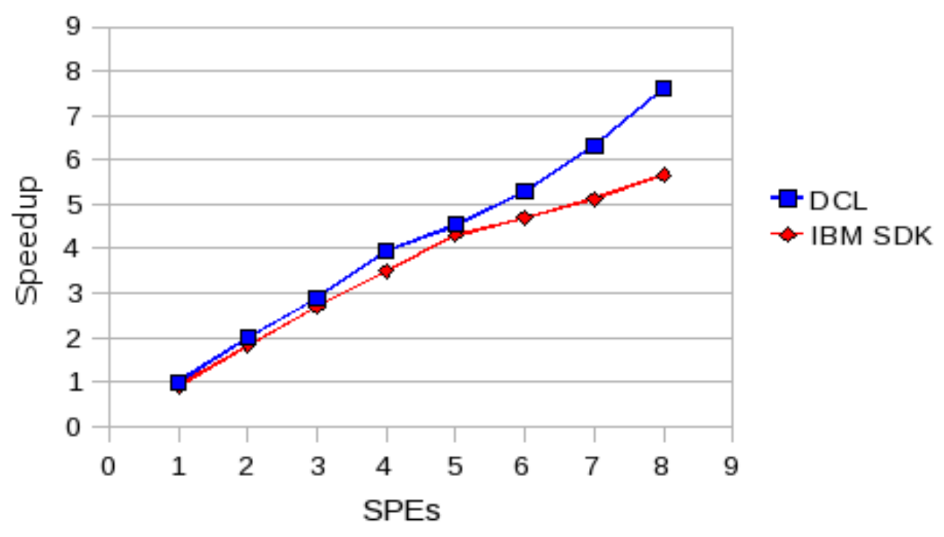
Fine-grain Biomedical Application Results



Biomedical Application performance (overheads included)

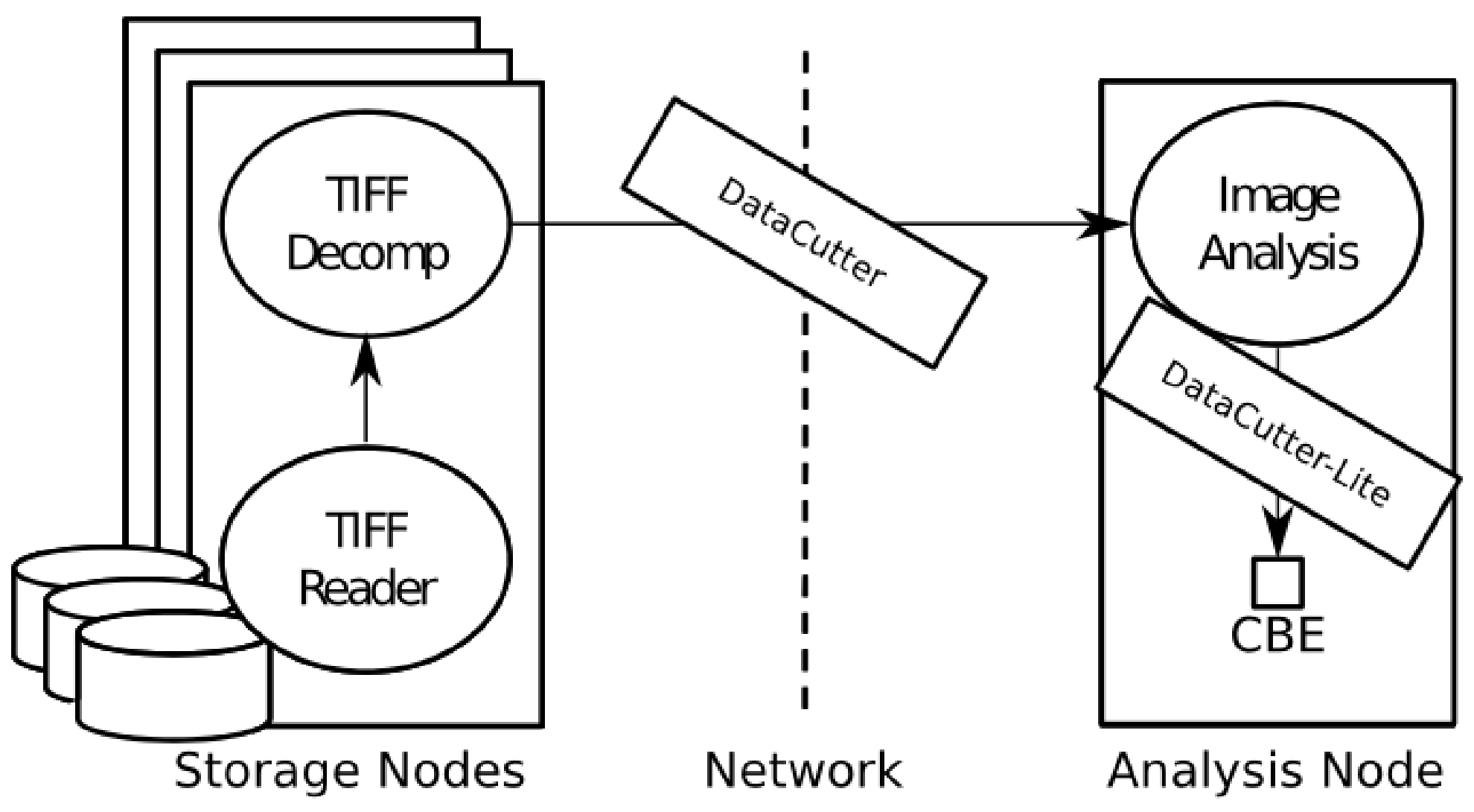


Biomedical Application performance (overheads excluded)

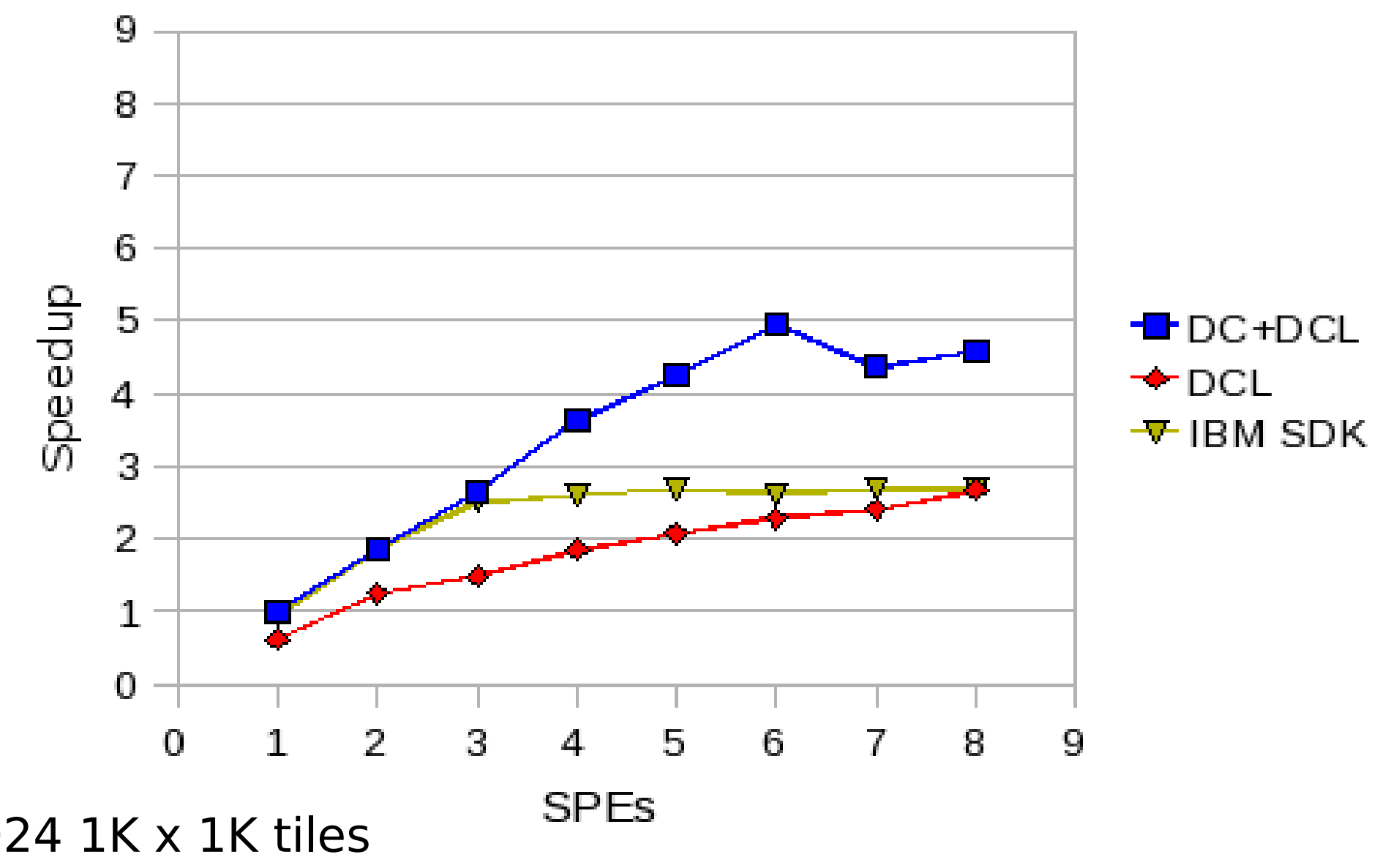


- Compared against custom IBM SDK version
- 32 1Kx1K image tiles
- Overheads included: DCL takes 23-57% longer
- Overheads excluded: SDK takes 5-26% longer

Multi-grain Biomedical Application Results

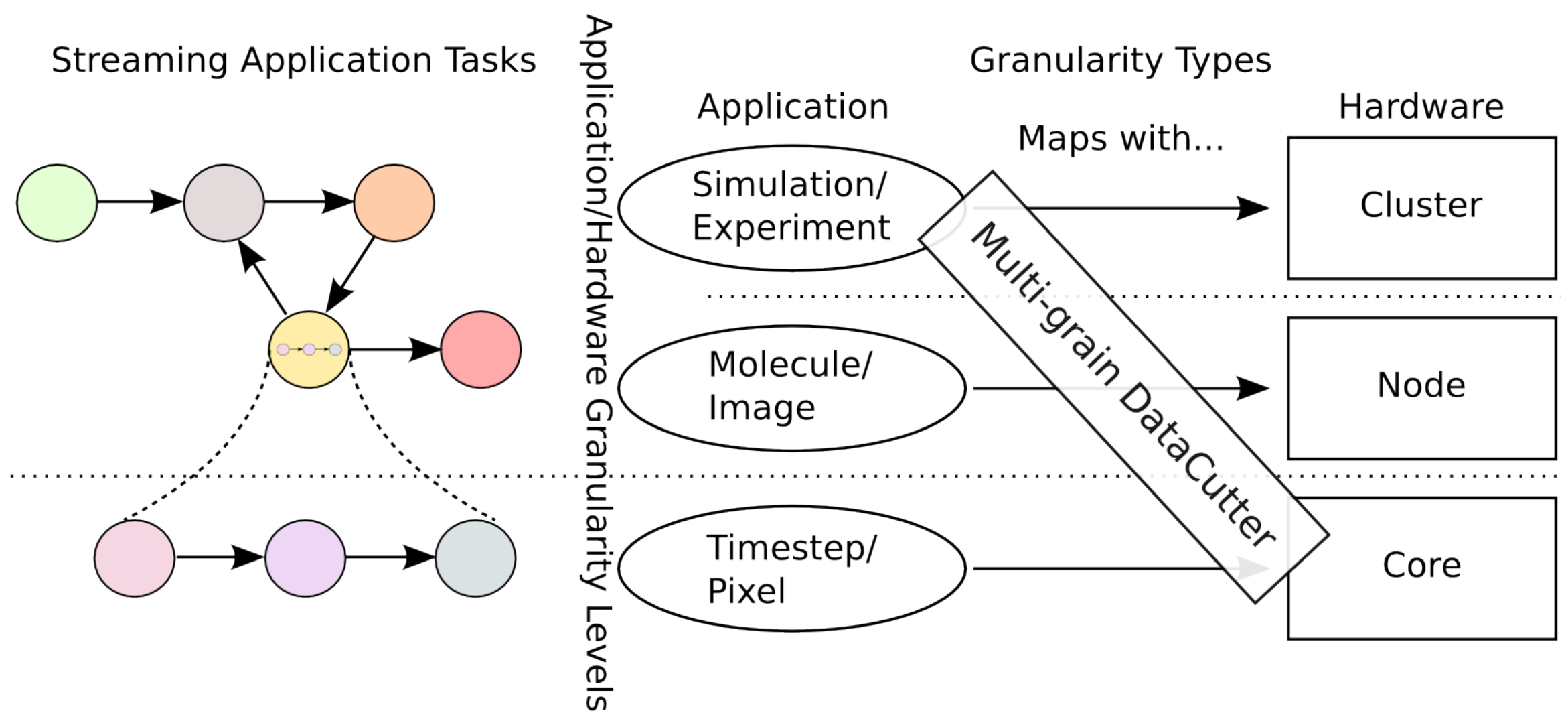


Biomedical Application performance



- 1024 1K x 1K tiles
- DataCutter+DataCutter-Lite (DC+DCL) has 42% shorter execution time

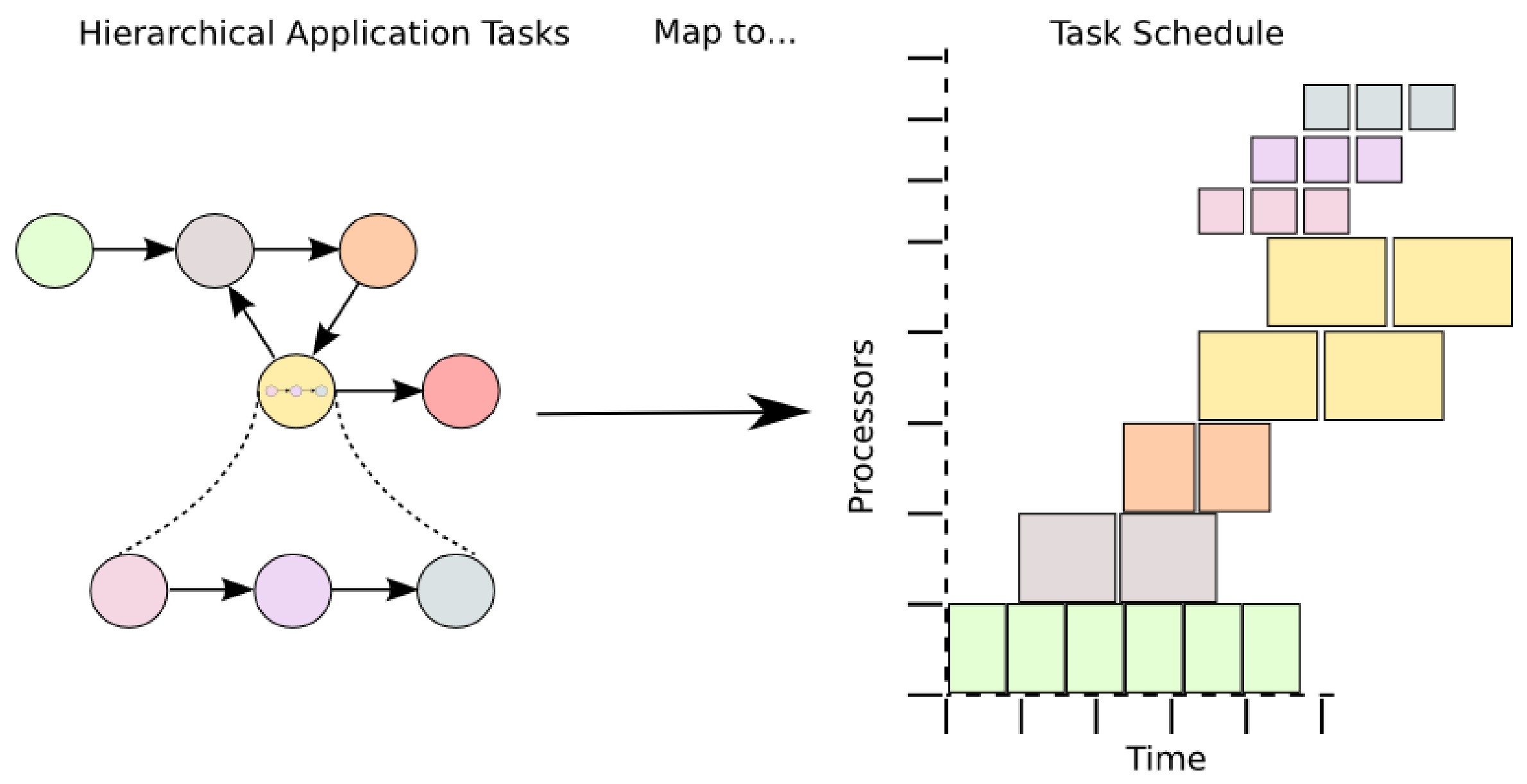
Future Work: Filter-stream Runtime Systems



- Extend filter-stream programming framework to other fine-grain multicore processors
  - Chip Multiprocessors (CMPs)
  - Graphics Processing Units (GPUs)
  - Runtime engine support needed for multiple different architectures
- Create multi-grain runtime engine for programming distributed, hierarchical systems containing multiple processor architectures
  - Develop optimizations targeted to most efficiently use:
    - Multiple processor types
    - On-chip networks
    - Intra-node networks
- Hierarchical, multi-grain application/hardware mapping:

Future Work : Filter-stream Task Scheduling

- Heterogeneity and hierarchy make scheduling problem difficult
  - Algorithms needed to deal with task scheduling at all hardware and software granularity levels
  - Inter-node, fine-grain tasks affect node performance, network performance, etc.
  - Intra-node, coarse-grain tasks affect data availability, network endpoint contention, etc.
  - Small memories of Cell, deep-cache hierarchy CMPs introduce new scheduling constraints
- Heart of future runtime systems, programming frameworks will be intelligent task scheduling
  - Optimize:
    - Execution time (makespan)
    - Resource utilization



This work was supported in part by the U.S. Department of Energy SciDAC Grant DE-FC02-06ER2775; by the U.S. National Science Foundation under Grants CNS-0643969, CCF-0342615, CNS-0426241, and CNS-0403342; by Ohio Supercomputing Center Grant PAS0052; by AFRL/DAGSI Ohio Student-Faculty Research Fellowship RY6-OSU-08-3.

Biomedical Informatics

http://bmi.osu.edu