Supporting Software

Compilers and Autotuners
Virtual Machines
Middleware
Operating Systems

Challenges and Directions

- System software
  - Compilers
  - Middleware, libraries
  - Operating systems
- Main directions
  - Compilers vs autotuners
  - Monolithic OS vs virtual machines + libraries

Compiler Challenges

- Hard to add new optimizations to handle data/task parallelism to traditional compilers
  - Functional correctness of the code is the main concern
  - Difficult to verify optimizations against all possible cases
- For instance, Streamit is a new compiler and has been verified only on a limited set of test cases
- Autotuners?

Autotuners

- *Search-based* optimization
  - Optimize a set of library kernels by generating many variants and benchmarking each variant by running on the target platform
  - Search process tries many or all optimizations (takes hours but run only once)
- Applying autotuners to parallelism?
  - Search space is too large
  - Possible solution: decouple the search for good data layout and communication patterns from good kernels

Parallelizing compilers

- Examples
  - Streamit (streaming applications)
  - OpeMP (general purpose)
- StreamIt on the IBM cell
  - Push/pop and work are implemented using hw FIFOs managed by DMA
  - A runtime environment implement the work construct through creation and destruction of threads on the SPE engines
  - Load and remove code/data on the private memories of the SPEs

Streamit Compiler

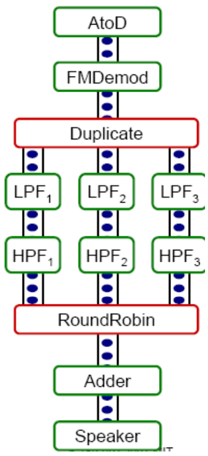
- Main idea: parellelizing compilers such as OpenMP or HPF expose the programmer to details of parallelism, which lead to the following problems
- Granularity decisions:
  - f too small, lots of synchronization and thread creation
  - if too large, bad locality
- Load balancing decisions
  - Create balanced parallel sections (not data-parallel)
- Locality decisions
  - Sharing and communication structure
- Synchronization decisions
  - barriers, atomicity, critical sections, order, flushing
- For mass adoption, we need a better paradigm:
  - Where the parallelism is natural
  - Exposes the necessary information to the compiler

Unburden the Programmer

- Move these decisions to compiler
  - Granularity
  - Load Balancing
  - Locality
  - Synchronization
- Exploit StreamIt language features
- NB: optimization based on static TG analysis
  - No profiling
  - No real-time requirements

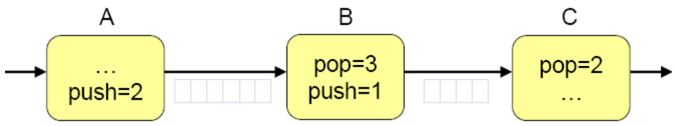
Properties of Stream Programs

- Regular and repeating computation
- Synchronous Data Flow
- Independent actors with explicit communication
- Data items have short lifetimes
- Benefits:
  - Naturally parallel
  - Expose dependencies to compiler
  - Enable powerful transformations



Steady State Schedule

- All data pop/push rates are constant
- Can find a Steady-State Schedule
  - # of items in the buffers are the same before and after executing the schedule
  - There exist a unique minimum steady state schedule
- Schedule = { }



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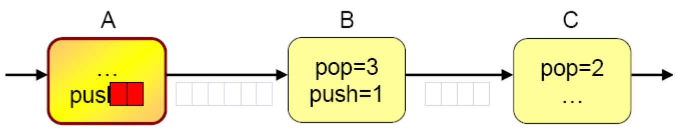

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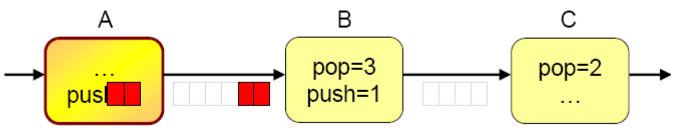

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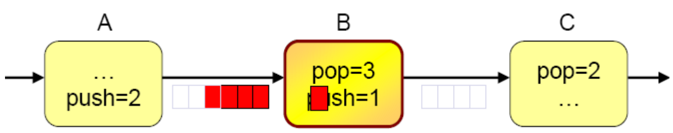

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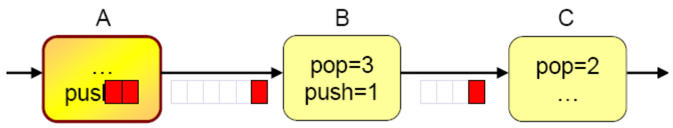

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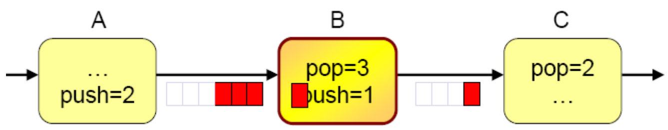

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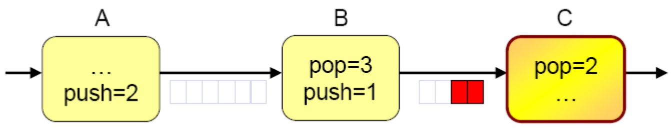
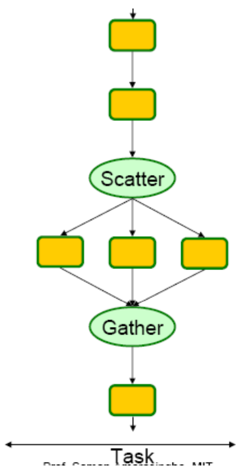


Types of Parallelism in Streamit



- Task Parallelism
  - Parallelism explicit in algorithm
  - Between filters *without producer/consumer* relationship

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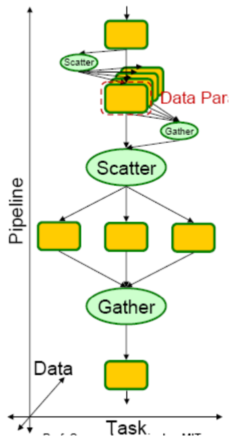
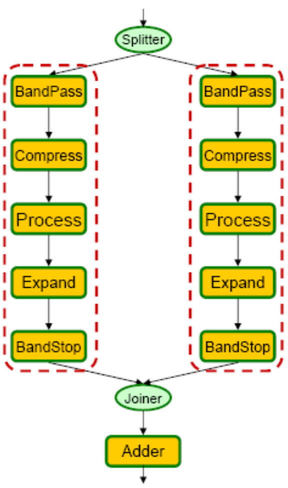


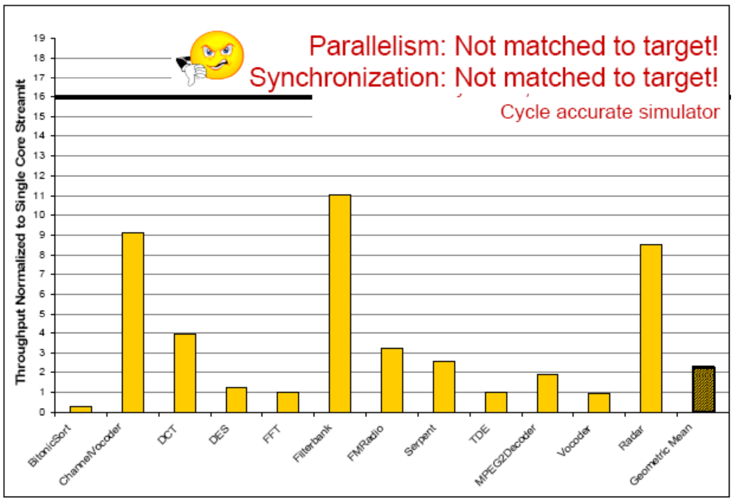
- Task Parallelism
  - Parallelism explicit in algorithm
  - Between filters *without producer/consumer* relationship
- Data Parallelism
  - Between iterations of a *stateless filter*
  - Place within scatter/gather pair *(fission)*
  - Can't parallelize filters with state
- Pipeline Parallelism
  - Between producers and consumers
  - *Stateful filters can be parallelized*

Baseline 1: Task Parallelism

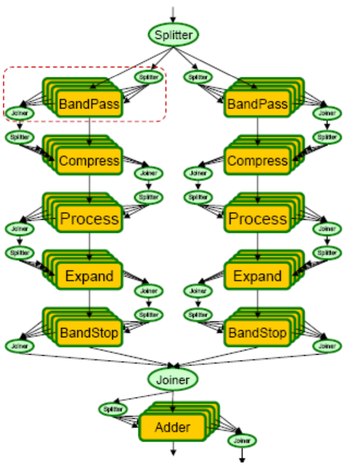


- Inherent task parallelism between two processing pipelines
- Task Parallel Model:
  - Only parallelize explicit task parallelism
  - Fork/join parallelism
- Execute this on a 2 core machine ~2x speedup over single core
- What about 4, 16, 1024, … cores?

Evaluation: Task Parallelism

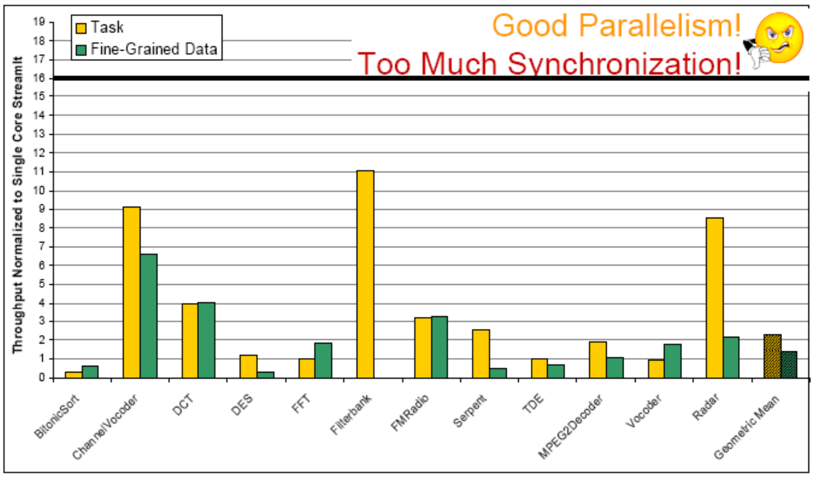


Baseline 1: Fine-Grained Data Parallelism

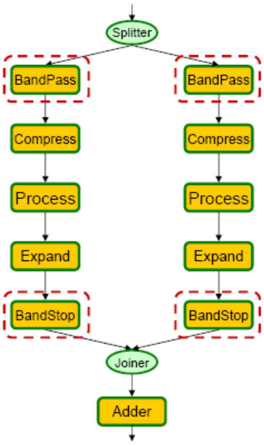


- Each of the filters in the example are stateless
- Fine-grained Data Parallel Model:
  - *Fiss each stateless filter N ways (N is number of cores)*
  - Remove scatter/gather if possible
- We can introduce data parallelism
  - Example: 4 cores
- Each fission group occupies entire machine

Evaluation: Fine Grained Data Parallelism

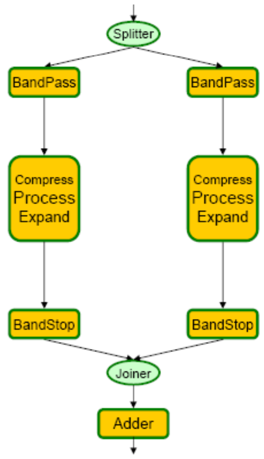


Baseline 3: Hardware Pipeline Parallelism



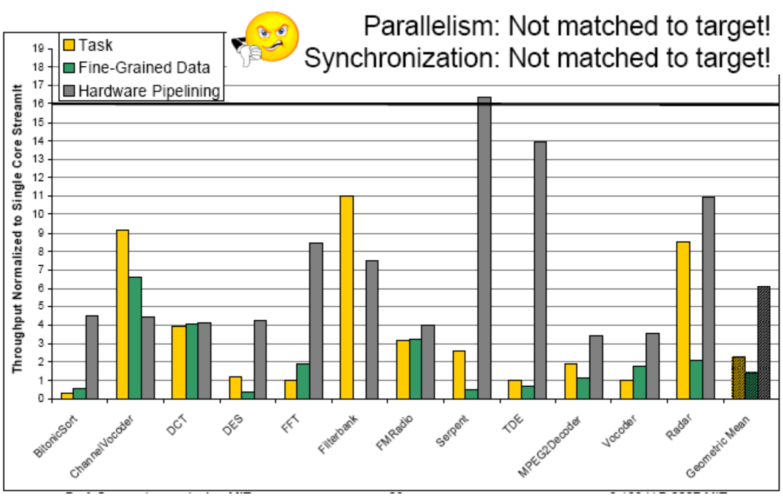
- The BandPass and BandStop filters contain all the work
- Hardware Pipelining
  - Use a greedy algorithm to fuse adjacent filters
  - Want # filters <= # cores
- Example: 8 Cores

Baseline 3: Hardware Pipeline Parallelism

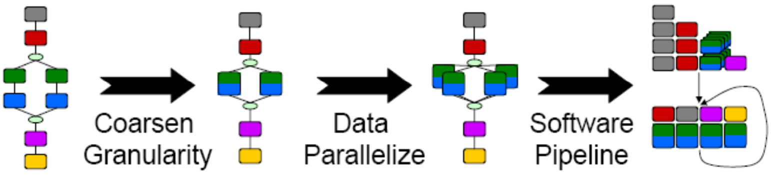


- Resultant stream graph is mapped to hardware
  - One filter per core
- What about 4, 16, 1024, cores?
  - Performance dependent on fusing to a load-balanced stream graph

Evaluation: Hardware Pipeline Parallelism



Streamit Compiler



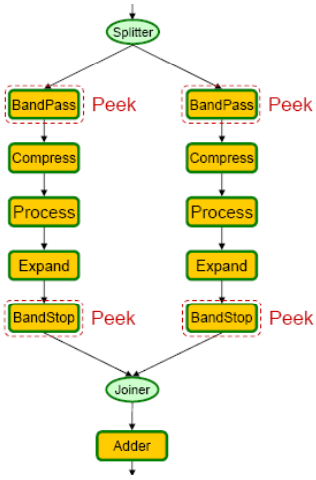
1. Coarsen: Fuse stateless sections of the graph
2. Data Parallelize: parallelize stateless filters
3. Software Pipeline: parallelize stateful filters

- Compile to a 16 core architecture
  - 11.2x mean throughput speedup over single core

Notes

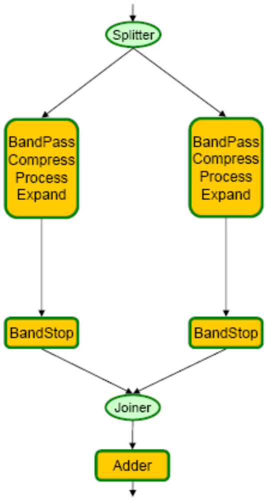
- When # tasks > # proc a schedule must be defined within each core
- StreamIt on IBM Cell architecture
  - A runtime environment handles thread creation and destruction as well as communication through DMA
  - It implements pop/push and work directives
  - Work is the part done by the SPE engines

Phase 1: Coarsen the Stream Graph



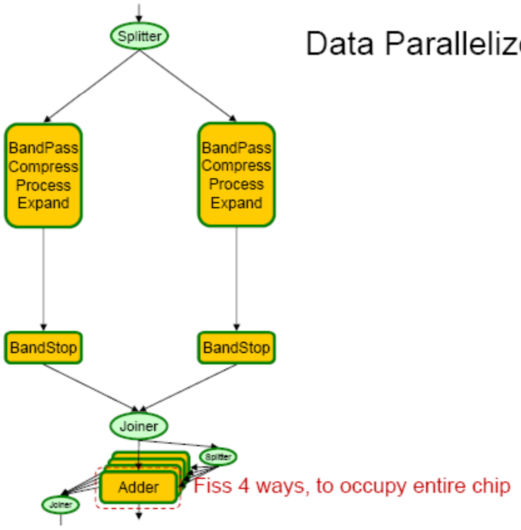
- Before data-parallelism is exploited
- *Fuse stateless pipelines as much* as possible without introducing state
  - Don't fuse stateless with stateful
  - Don't fuse a peeking filter with anything upstream

Phase 1: Coarsen the Stream Graph



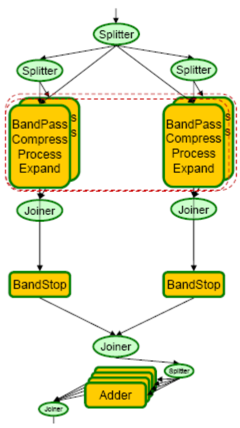
- Before data-parallelism is exploited
- *Fuse stateless pipelines as much* as possible without introducing state
  - Don't fuse stateless with stateful
  - Don't fuse a peeking filter with anything upstream
- Benefits:
  - Reduces global communication and synchronization
  - Exposes inter-node optimization opportunities

Phase 2: Data Parallelize



Data Parallelize for 4 cores

Phase 2: Data Parallelize



Data Parallelize for 4 cores

Task parallelism!
Each fused filter does equal work
Fiss each filter 2 times to occupy entire chip

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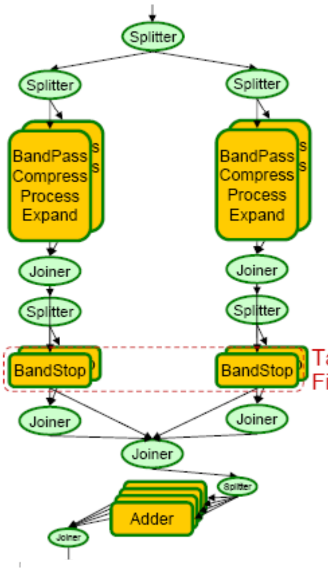


Data parallelize for 4 cores

Task-conscious data parallelization

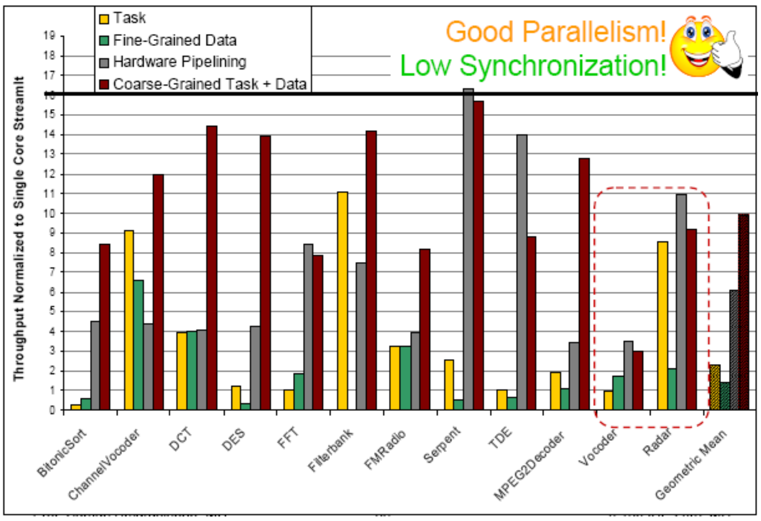
- Preserve task parallelism

Benefits:

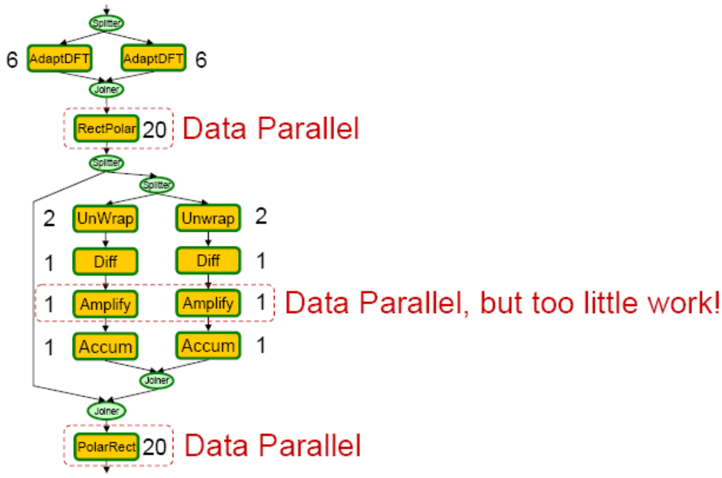
- Reduces global communication and synchronization

Task parallelism, each filter does equal work
Fiss each filter 2 times to occupy entire chip

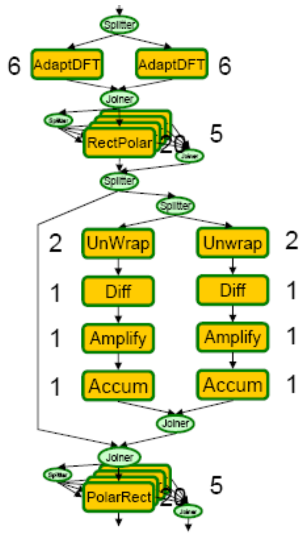
Evaluation: Coarse-Grained Data Parallelism



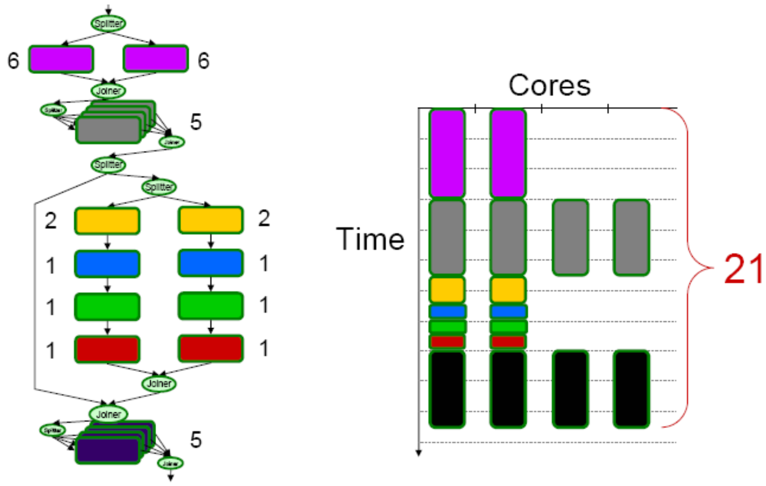
Simplified Vocoder



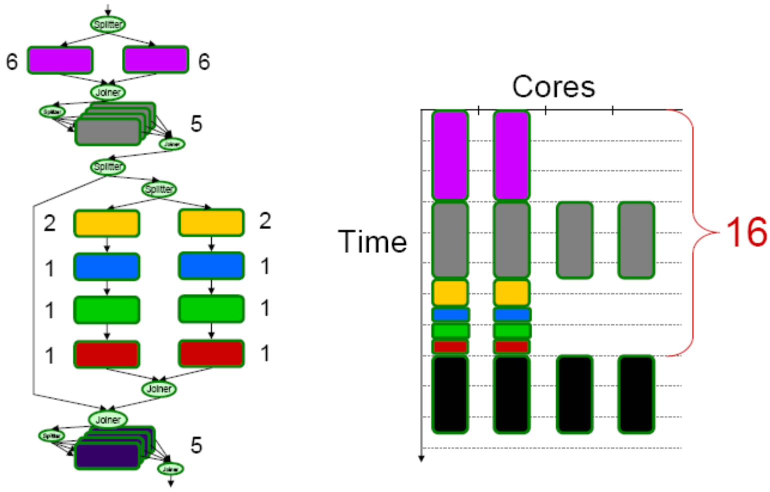
Data Parallelize



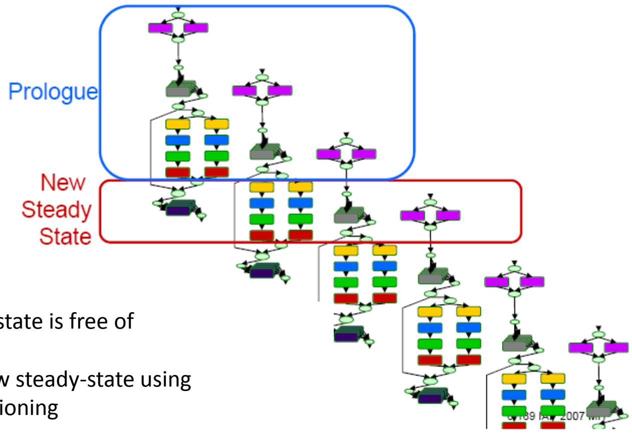
Data + Task Parallel Execution



We Can Do Better!

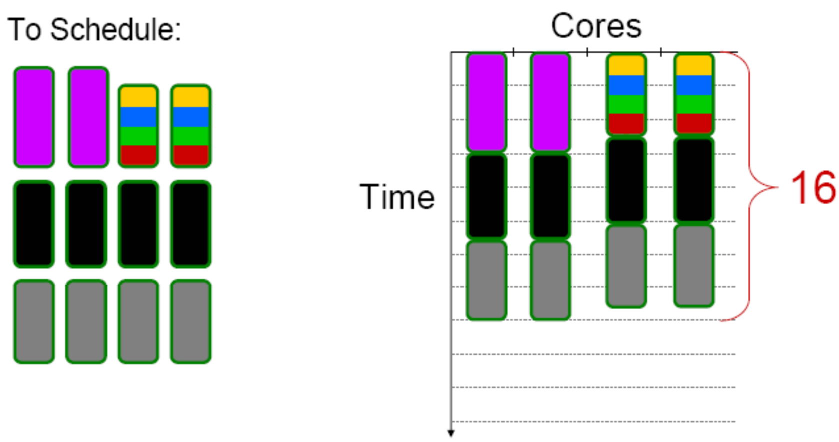


Phase 3: Coarse-Grained Software Pipelining

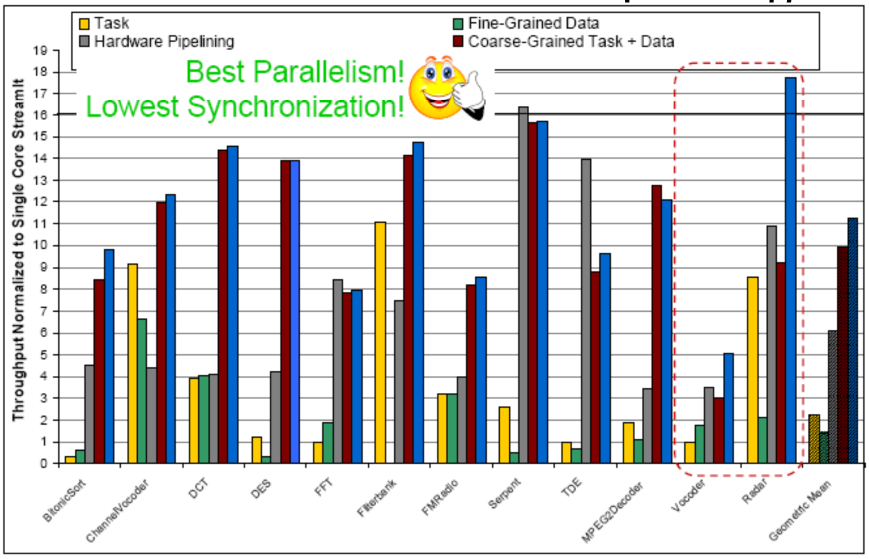


- New steady-state is free of dependencies
- Schedule new steady-state using a greedy partitioning

Greedy Partitioning



Evaluation: Coarse-Grained Task + Data + Software Pipelining



Summary

- Streaming model naturally exposes task, data, and pipeline parallelism
- This parallelism must be exploited at the correct granularity and combined correctly

	Task	Fine-Grained Data	Hardware Pipelining	Coarse-Grained Task + Data	Coarse-Grained Task + Data + Software Pipeline
Parallelism	Application Dependent	Good	Application Dependent	Good	Best
Synchronization	Application Dependent	High	Application Dependent	Low	Lowest