System Comparisons

CS315B

Lecture 14

Recap

- We’ve looked at a variety of parallel/distributed system designs

- SPMD
  - MPI, Charm++
- Tasking
  - Regent, StarPU
- Thread-based
  - Chapel, X10

- There are also data analytics systems such as Spark and TensorFlow

How Do We Compare Systems

- Benchmarks!

- Implement program X on systems A and B
    - Compare performance!

- Major pitfall: Making the comparison fair
    - Is it really apples to apples?

- Practical problem:
    - Expensive to write many X's
    - For many A's and B's

Is there a better way?

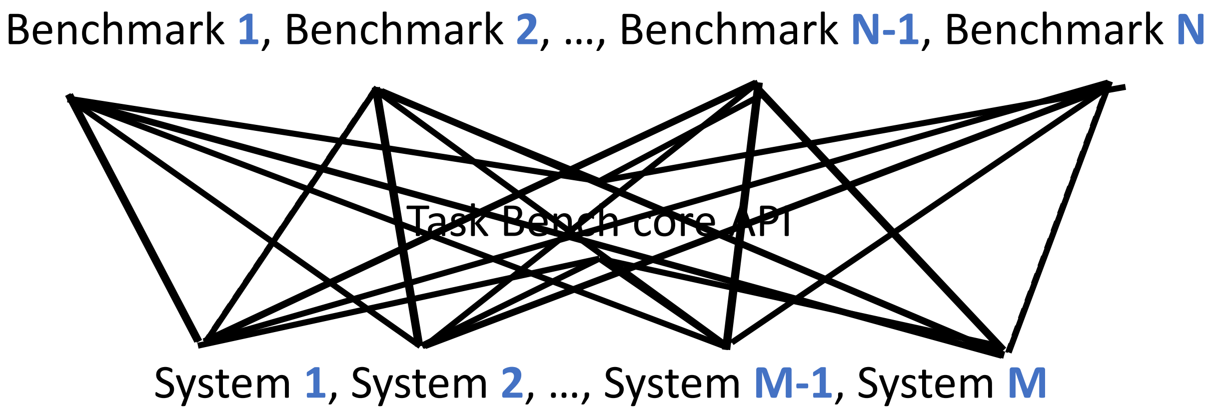
The Focus

- We want to
  - Compare the programming systems
  - Not the applications themselves

Benchmarking Programming Systems

- Benchmarks are expensive to implement
  - For **N** benchmarks and **M** programming systems, **O(NM)** effort
  - Must be tuned for performance
- Could try proxy apps
  - Cut down benchmarks
- Or microbenchmarks
  - But not benchmarks
  - Consequence: few papers evaluate many systems

Task Bench



Benchmark **1**, Benchmark **2**, …, Benchmark **N-1**, Benchmark **N**

Task Bench core API

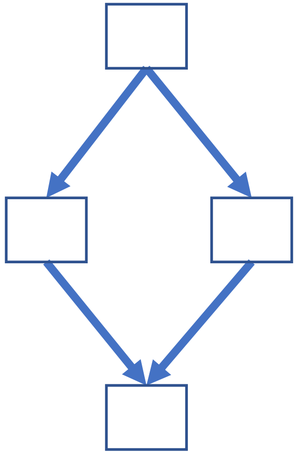
System **1**, System **2**, …, System **M-1**, System **M**

Task Bench reduces the effort to **O(N + M)**

Model Space of Application Behaviors

- Model application as a **task graph**
  - Task: units of code with no communication

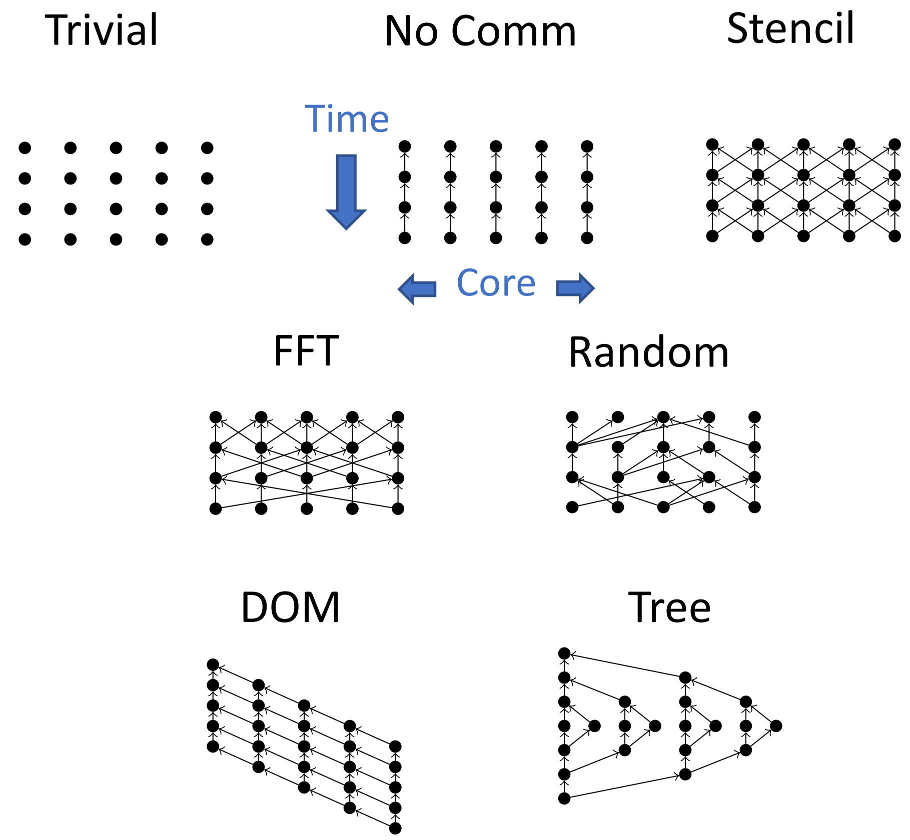
- **Parameterize** the task graph to explore a space of modeled behaviors
  - Set of tasks
  - Dependencies between tasks
  - Kernels executed by each task
  - Data produced by each task (and communicated by dependencies)



Task Graphs

- Task graph is product of:
  - Iteration space
  - Dependence relation

- An extensible set



Task = Kernel

- Executed at every point in a task graph.

- Examples
  - Empty
  - Compute-bound (achieves peak compute)
  - Memory-bound (achieves peak memory BW)
  - Load-imbalanced (randomly varying duration)
  - Also extensible

- Implemented once for all systems
  - exposed by the core API

Implementations

- 15 parallel and distributed systems:
  - Traditional HPC: **MPI** and **MPI+OpenMP, MPI+CUDA**
  - PGAS/Actor: **Chapel**, **Charm++** and **X10**
  - Task-based: **OmpSs**, **OpenMP 4**, **PaRSEC**, **Realm**, **Regent**, and **StarPU**
  - Data analytics, machine learning, workflows: **Dask**, **Spark**, **Swift/T**, and **TensorFlow**

- Implementations are tuned
  - With help from the system developers

Tasks in MPI?!

- A “task” is a communication-free section of application code

```
RECEIVE(...)                  -- Dependence
for(...) {
  ... application code ...   -- Task
}
SEND(...)                     -- Dependence
```

Metrics

- Task Bench makes it easy to gather data
  - Lots of data

- But how do we compare systems?
  - What is the metric(s)?

Idea #1: Tasks/Second

- Problem: How big are the tasks?

- Most common choice: Empty tasks
  - Intuition: Measures only runtime overhead
  - Problem: All resources can be devoted to the runtime system

- Other extreme: Huge tasks
  - But that minimizes runtime costs
  - Any amount of overhead can be hidden by some task size

Idea #2: Weak Scaling

- Keep problem size the same per processor
  - Double number of processors, double problem size

- Problem
  - Runtime system performance sensitive to choice of problem size
  - Double problem size => halve runtime overhead

Idea #3: Strong Scaling

- Problem size stays fixed as processor numbers scale
  - Double parallel resources
  - Problem size per processor is halved

- Plus: Strong scaling limit captures when overheads become dominant

- Minus: But overheads are not just from the programming system
  - Communication costs increase with strong scaling

Discussion

- We want a metric that measures the cost of a runtime system

- Must constrain efficiency
    - Minimum amount of application work must be getting done
    - Avoids problems of TPS w/empty tasks, weak scaling

- Want point at which efficiency goal is *just* met
    - Least application work that achieves the efficiency metric
    - Avoids problems of TPS w/huge tasks, weak scaling

Minimum Effective Task Granularity (METG)

- METG(50%) is the smallest task granularity where an application achieves 50% efficiency

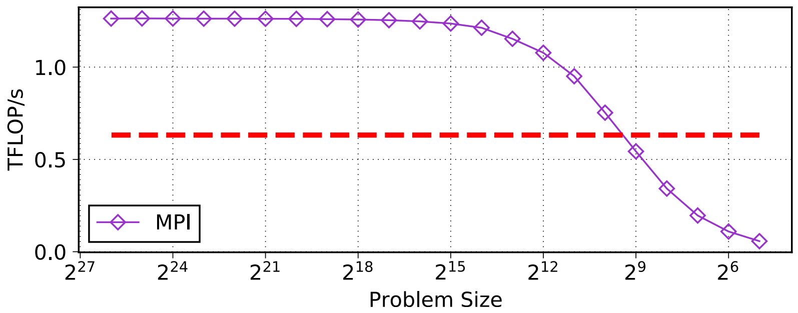
- Parameterized on the efficiency metric:
    - E.g.: machine's peak performance is 1.2 TFLOP/s, so 50% is 0.6 TFLOP/s
    - E.g.: application's peak is 1×10^9 mesh cells/s, so 50% is 0.5×10^9

- Efficiency constrained: useful work is performed
- Exposes overhead: the limit of a system under load

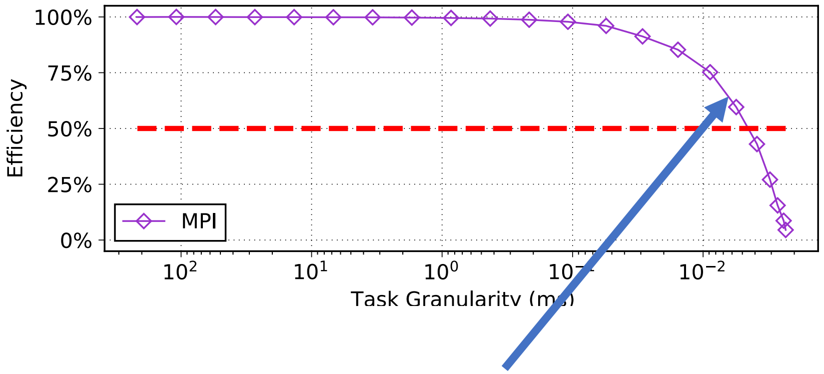
Calculating METG(50%)

- **Step 1**: measure performance with decreasing problem size

- **Step 2**: convert to efficiency vs. task granularity and intersect with 50%



Performance drops with problem size



Intersection with 50% efficiency (METG(50%) is 4.6 µs)

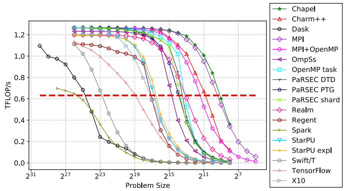
Understanding METG(50%)

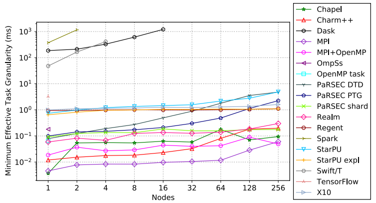
- METG is a *minimum*
  - Two systems with METG of 1 ms and 5 ms
  - Application has an average task granularity of
    - 100 ms: doesn’t matter
    - 10 ms: matters a little
    - 1 ms: huge difference
    - METG imposes a floor on task granularity that is efficient

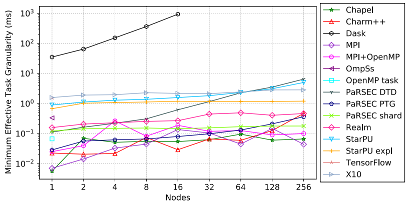
Evaluation

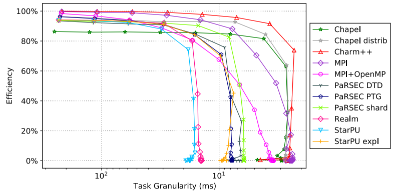
- 15 programming systems
  - On up to 256 nodes
- Cori Supercomputer
  - Cray XC40
  - 2× Intel Xeon E5-2698 v3 processors (32 physical cores/node)
  - 128 GB RAM
  - Cray Aries interconnect
  - GCC 7.3.0, Cray MPICH 7.7.3

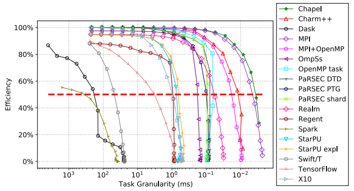
Results


TFLOP/s
Problem Size
Chapel
Charm++
Dask
MPI
MPI+OpenMP
OmpSs
OpenMP task
PaRSEC DTD
PaRSEC PTG
PaRSEC shard
Realm
Regent
Spark
StarPU
StarPU expl
Swift/T
TensorFlow
X10


Minimum Effective Task Granularity (ms)
Nodes
Chapel
Charm++
Dask
MPI
MPI+OpenMP
OmpSs
OpenMP task
PaRSEC DTD
PaRSEC PTG
PaRSEC shard
Realm
Regent
Spark
StarPU
StarPU expl
Swift/T
TensorFlow
X10


Minimum Effective Task Granularity (ms)
Nodes
Chapel
Charm++
Dask
MPI
MPI+OpenMP
OmpSs
OpenMP task
PaRSEC DTD
PaRSEC PTG
PaRSEC shard
Realm
StarPU
StarPU expl
TensorFlow
X10


Efficiency
Task Granularity (ms)
Chapel
Chapel distrib
Charm++
MPI
MPI+OpenMP
PaRSEC DTD
PaRSEC PTG
PaRSEC shard
Realm
StarPU
StarPU expl


Efficiency
Task Granularity (ms)
Chapel
Charm++
Dask
MPI
MPI+OpenMP
OmpSs
OpenMP task
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Realm
Regent
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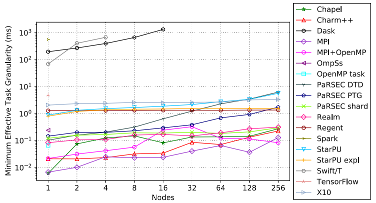
StarPU
StarPU expl
Swift/T
TensorFlow
X10


Minimum Effective Task Granularity (ms)
Nodes
Chapel
Charm++
Dask
MPI
MPI+OpenMP
OmpSs
OpenMP task
PaRSEC DTD
PaRSEC PTG
PaRSEC shard
Realm
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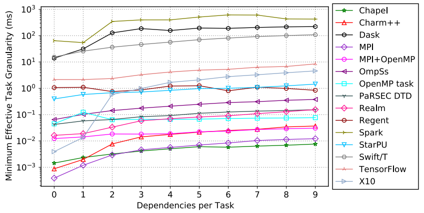
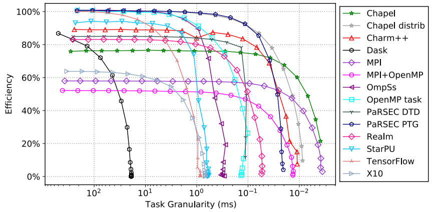
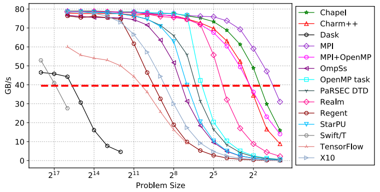
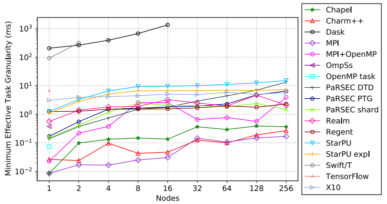

Minimum Effective Task Granularity (ms)
Dependencies per Task
Chapel
Charm++
Dask
MPI
MPI+OpenMP
OmpSs
OpenMP task
PaRSEC DTD
Realm
Regent
Spark
StarPU
Swift/T
TensorFlow
X10


Efficiency
Task Granularity (ms)
Chapel
Chapel distrib
Charm++
Dask
MPI
MPI+OpenMP
OmpSs
OpenMP task
PaRSEC DTD
PaRSEC PTG
Realm
StarPU
TensorFlow
X10


GB/s
Problem Size
Chapel
Charm++
Dask
MPI
MPI+OpenMP
OmpSs
OpenMP task
PaRSEC DTD
Realm
Regent
StarPU
Swift/T
TensorFlow
X10


Minimum Effective Task Granularity (ms)
Nodes
Chapel
Charm++
Dask
MPI
MPI+OpenMP
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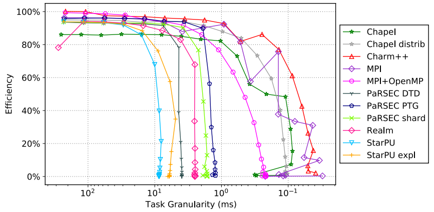
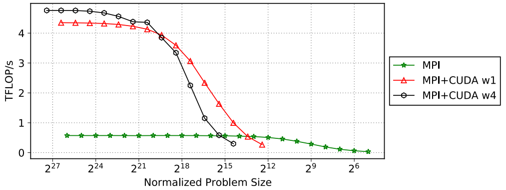
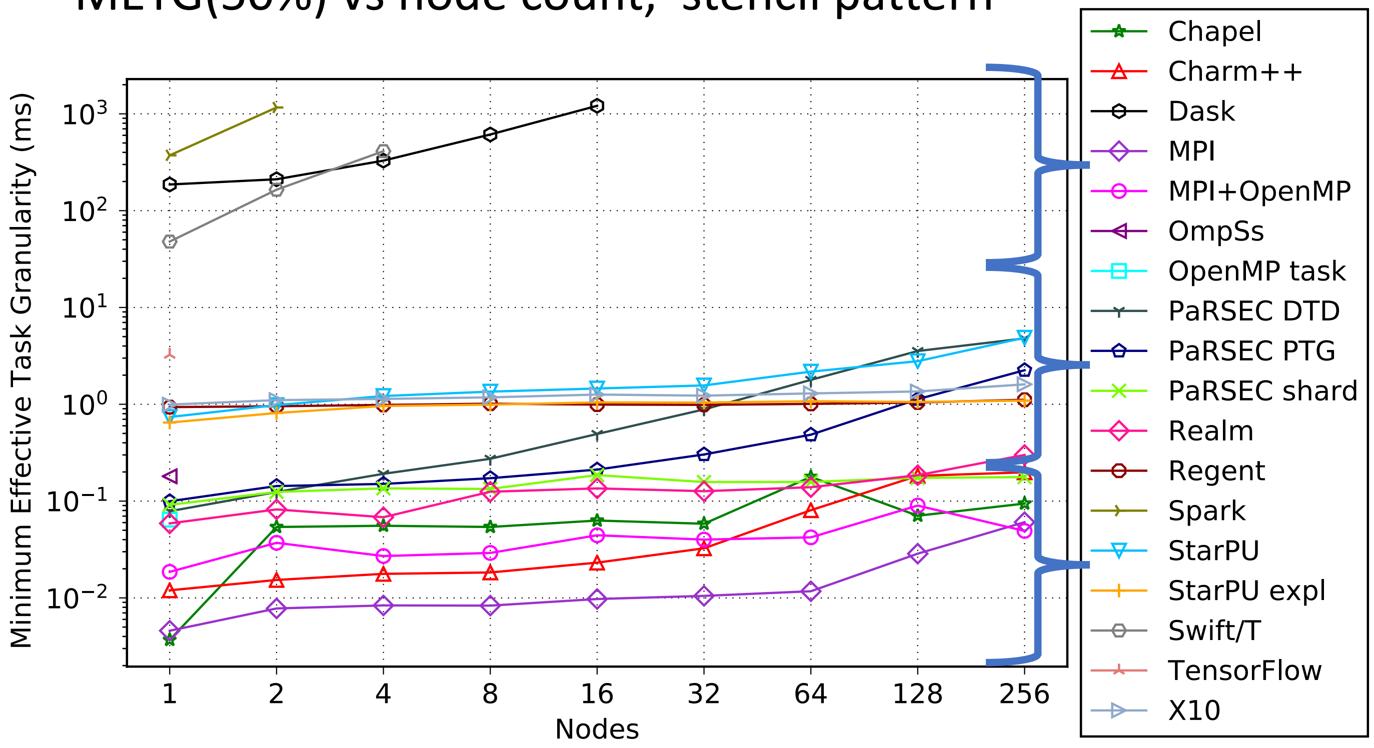

Efficiency
Task Granularity (ms)
Chapel
Chapel distrib
Charm++
MPI
MPI+OpenMP
PaRSEC DTD
PaRSEC PTG
PaRSEC shard
Realm
StarPU
StarPU expl


TFLOP/s
Normalized Problem Size
MPI
MPI+CUDA w1
MPI+CUDA w4

Overhead and Scalability

METG(50%) vs node count, stencil pattern



Lower is better

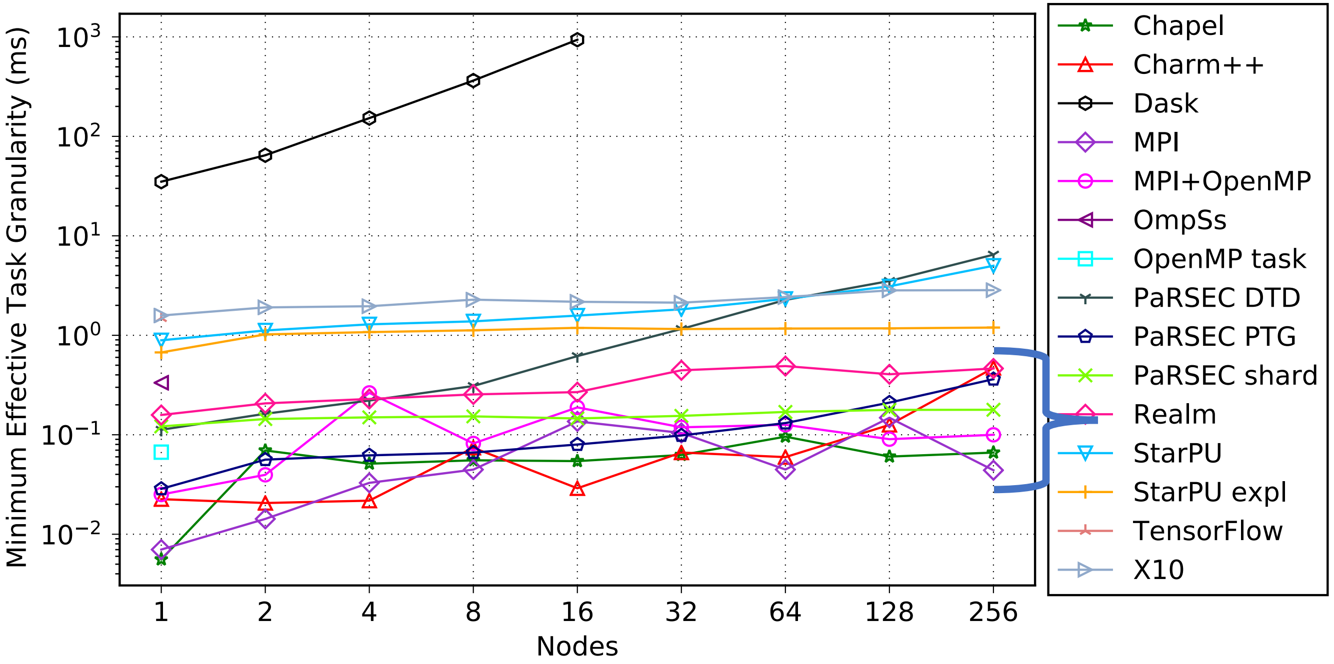
Data analysis, machine learning, workflows

Task-based (implicit)

Explicitly parallel (message, actor, PGAS, etc.)

More Complicated Dependencies

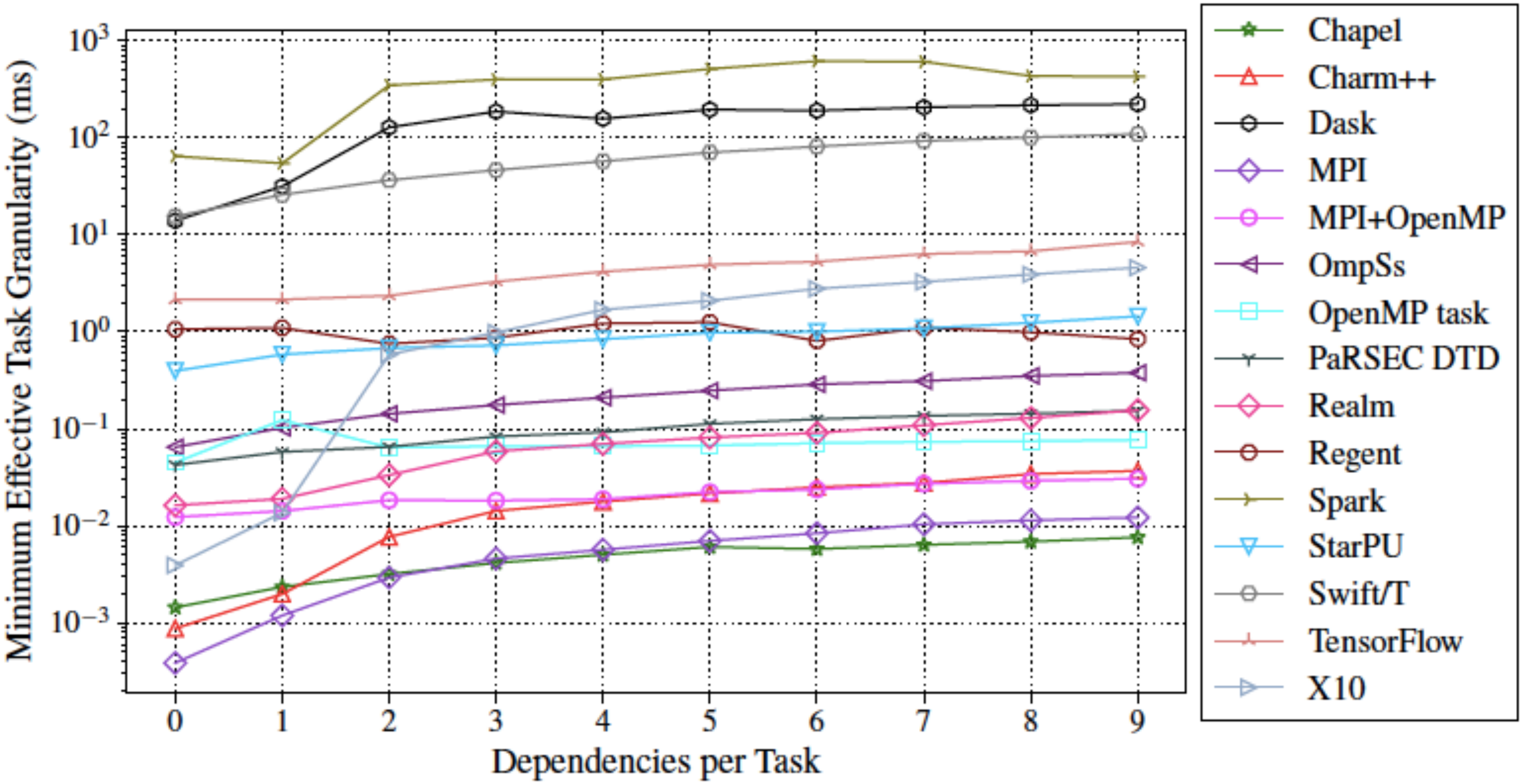
METG(50%) vs node count, 4 nearest neighbors, 4 task graphs



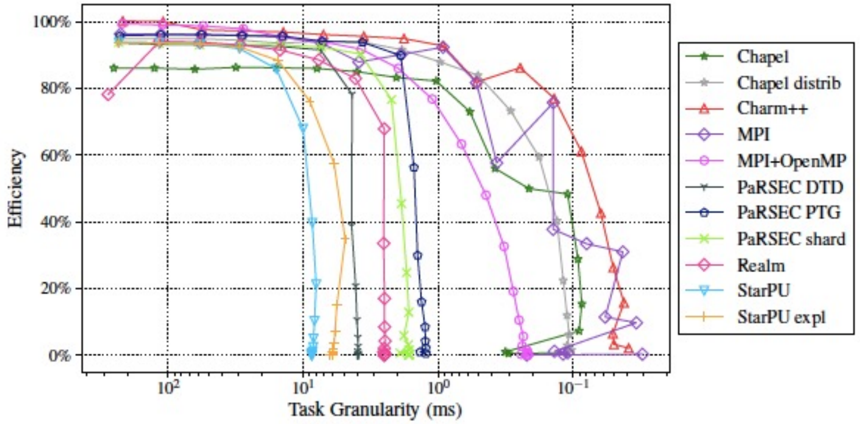
Lower is better

Gap shrinks or even closes with more complicated dependence pattern

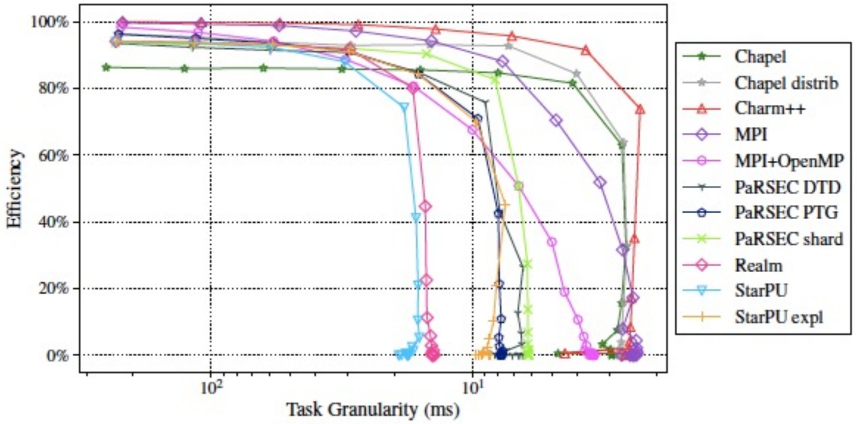
METG vs Dependencies/Task



METG vs Bytes/Dependence

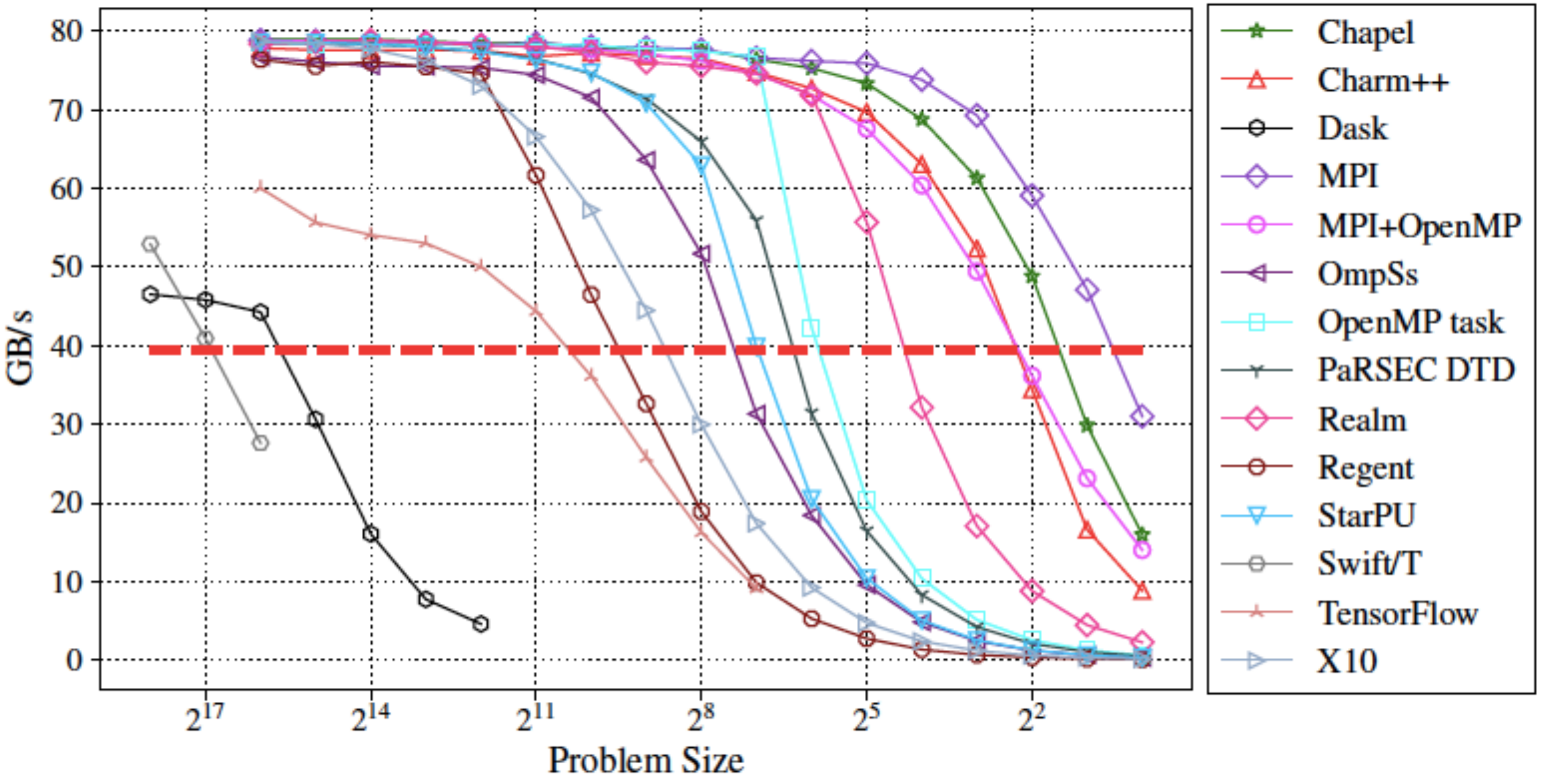


(a) 16 bytes per task dependency.

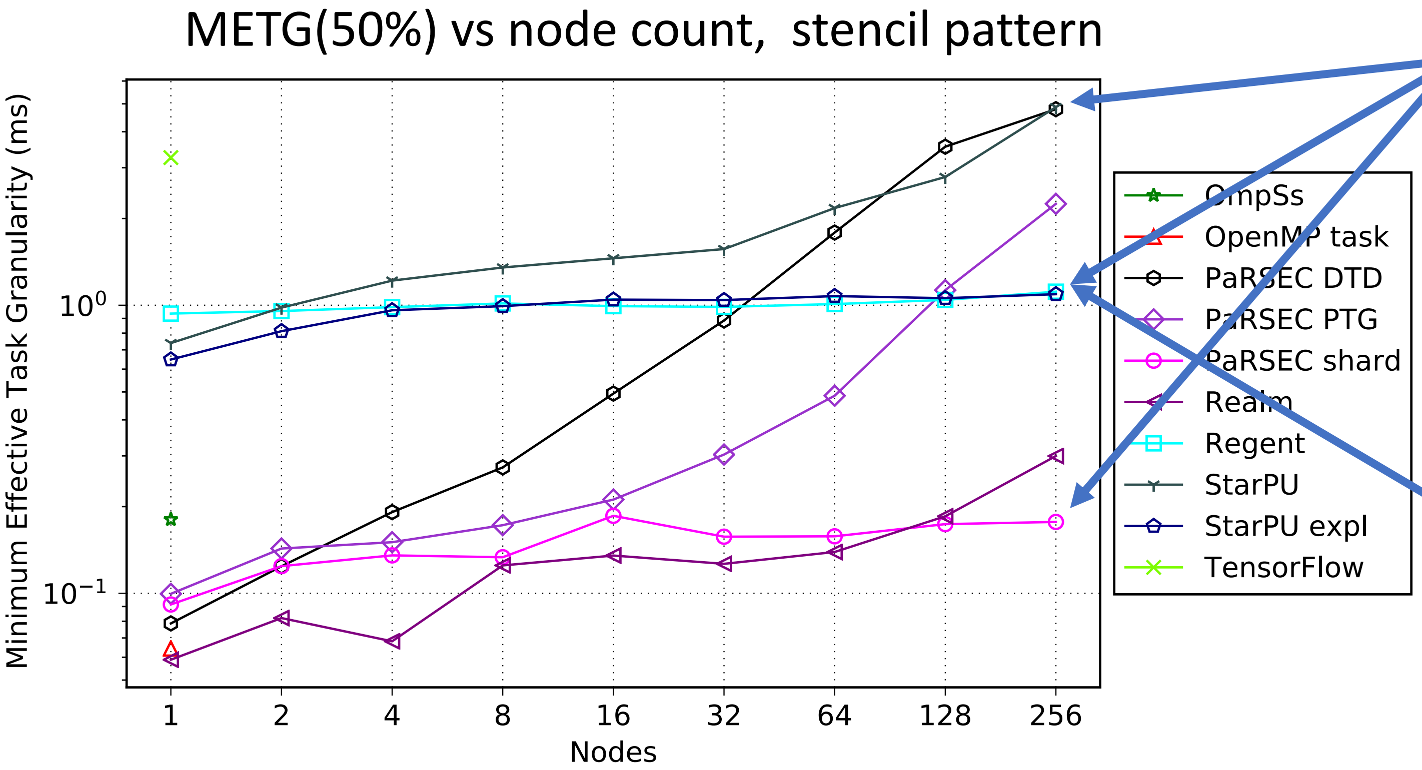


(b) 65536 bytes per task dependency.

Badwidth Bound Kernels



Task-Based Systems



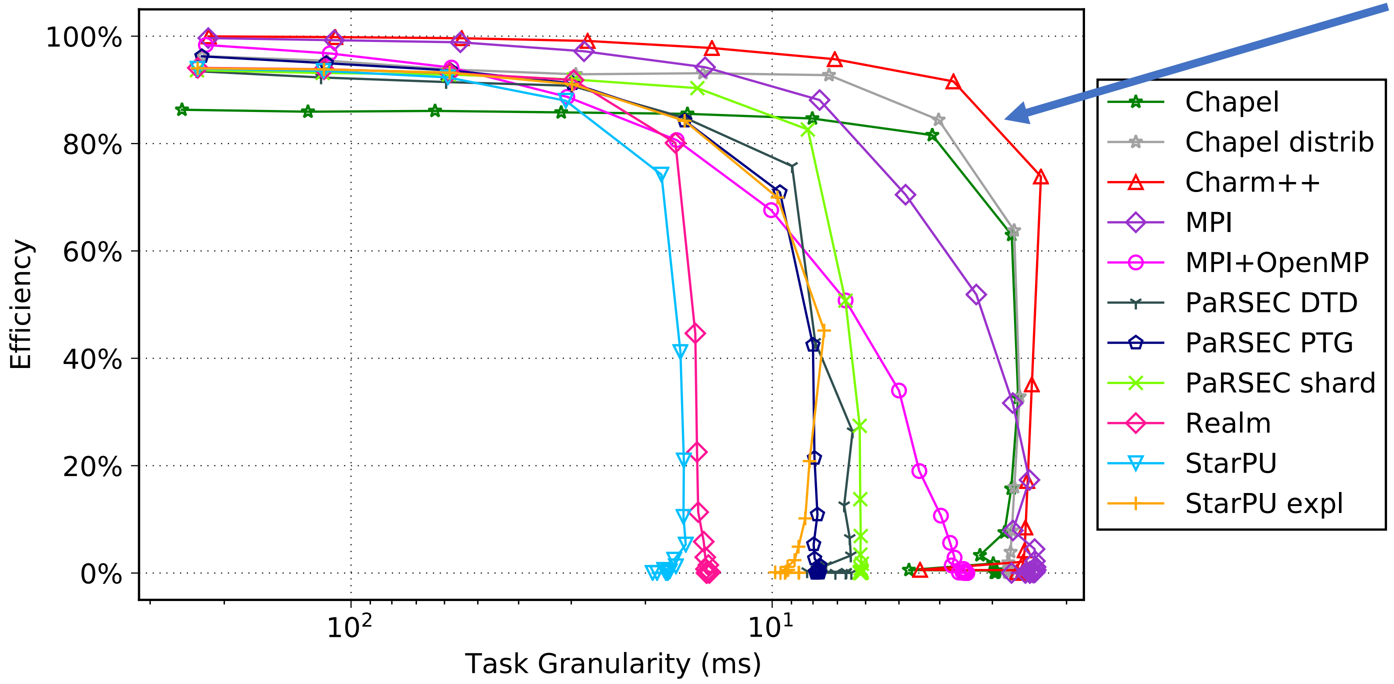
Lower is better

Scaling gap between PaRSEC, StarPU implicit and explicit programming models

Regent has flat scaling using control replication

Overlap Communication and Computation

Efficiency vs task granularity, 4 distant neighbors, 4 task graphs



Lower is better

Asynchronous systems gain advantage when computation and communication are balanced…

… as long as METG(50%) is lower than about 100 µs

Impact

- Task Bench has already made some of these systems better
    - Intensive effort to find and fix performance issues

- Should provide a new “microscope” for future work

Limitations

- Only compare on the intersection of features
  - CPU-only workloads
  - Dense problems

- Performance only
  - Not productivity

- Kernels
  - Single kernel is good, but also hides differences in writing kernels for specific systems

Summary

- Lowest overhead systems get METG(50%) of about 100µs at >= 100 nodes

- Asynchronous systems:
  - Better overlap between computation and communication
  - Better for complex task graphs
  - As long as they're not too slow! (METG about 100µs)

- Task-based systems:
  - Scaling bottlenecks not entirely resolved by task pruning
  - Regent's control replication does solve the scaling bottleneck