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Performance of HPC Applications on the Amazon Web Services Cloud

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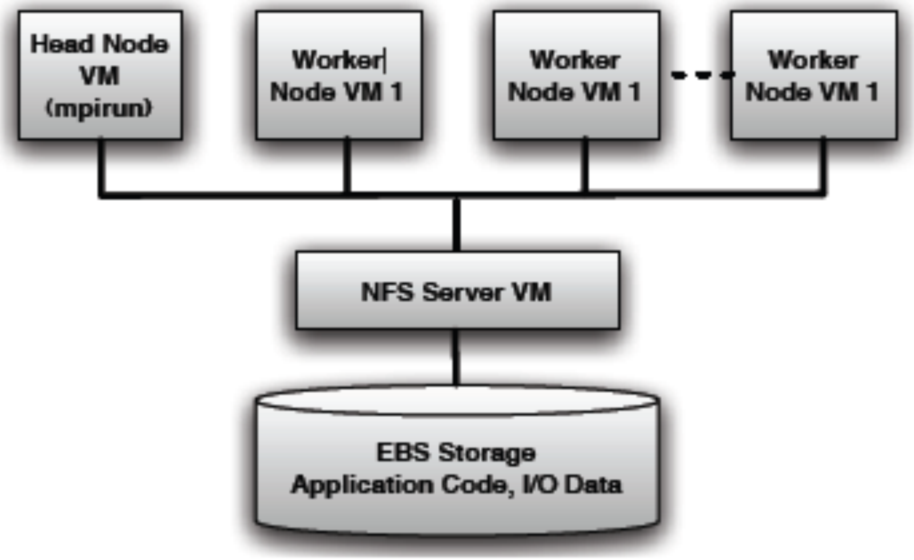
Goals

- Understand the performance of Amazon EC2 for realistic HPC workloads
  - Cover both the application space and algorithmic space of typical HPC workloads
- Characterize EC2 performance based on the communication patterns of applications

Methodology

- Create cloud virtual clusters
    - configure a file server, head node, and a series of worker nodes.
- Compile codes on local LBNL system with Intel Compilers / OpenMPI, move binary to EC2



Virtual Cluster Architecture

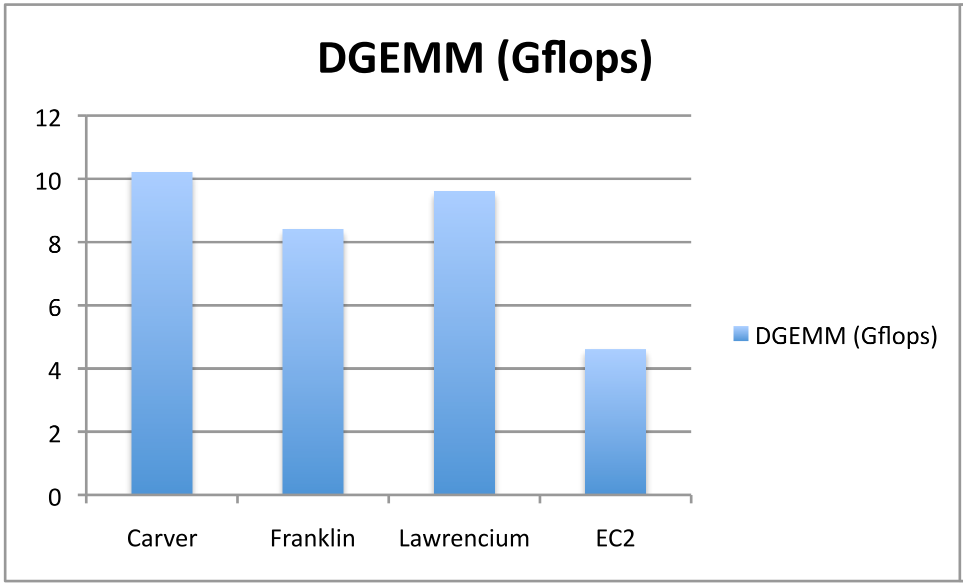
Hardware Platforms

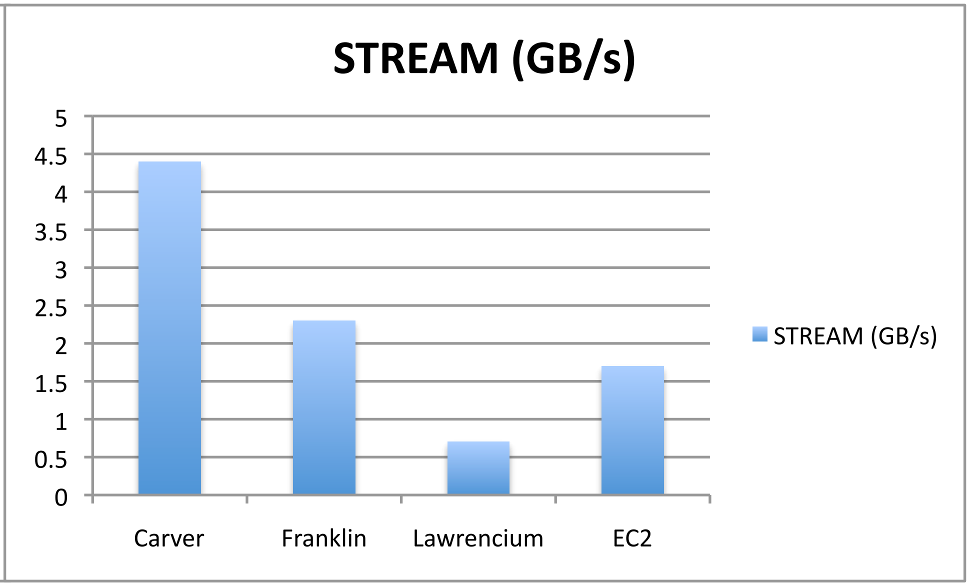
- Franklin:
  - Cray XT4
  - Linux environment / Quad-core, AMD Opteron / Seastar interconnect, Lustre parallel filesystem
  - Integrated HPC system for jobs scaling to tens of thousands of processors; 38,640 total cores
- Carver:
  - Quad-core, dual-socket Linux / Nehalem / QDR IB cluster
  - Medium-sized cluster for jobs scaling to hundreds of processors; 3,200 total cores

Hardware Platforms

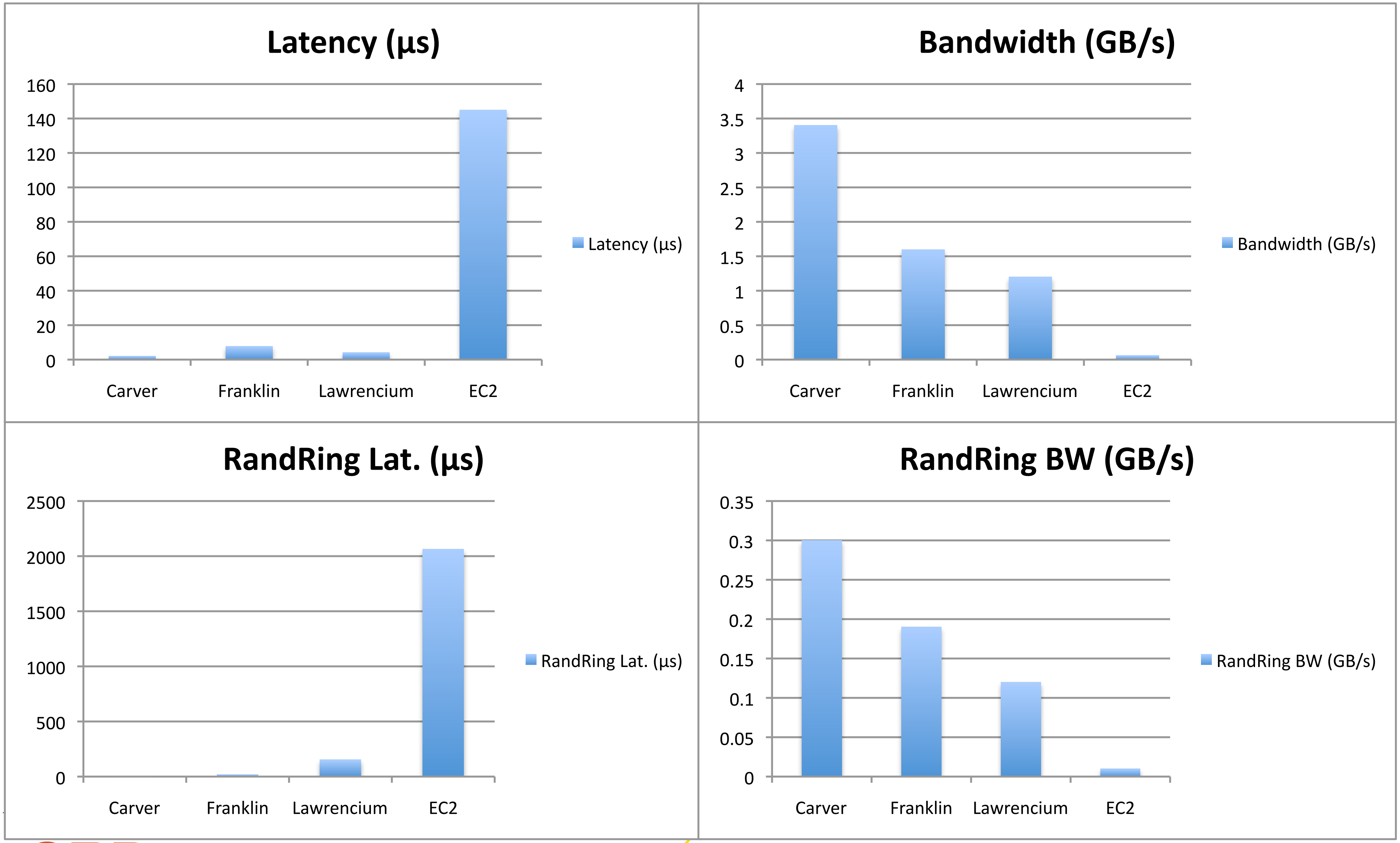
- Lawrencium:
  - Quad-core, dual-socket Linux / Harpertown / DDR IB cluster
  - Designed for jobs scaling to tens-hundreds of processors; 1,584 total cores
- Amazon EC2:
  - m1.large instance type: four EC2 Compute Units, two virtual cores with two EC2 Compute Units each, and 7.5 GB of memory
  - Heterogeneous processor types

HPC Challenge





HPC Challenge (cont.)



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NERSC 6 Benchmarks

- A set of applications selected to be representative of the broader NERSC workload
  - Covers the science domains, parallelization schemes, and concurrencies, as well as machine-based characteristics that influence performance such as message size, memory access pattern, and working set sizes

Applications

- CAM: The Community Atmospheric Model
  - Lower computational intensity
  - Large point-to-point & collective MPI messages
- GAMESS: General Atomic and Molecular Electronic Structure System
  - Memory access
  - No collectives, very little communication
- GTC: GyrokineticTurbulence Code
  - High computational intensity
  - Bandwidth-bound nearest-neighbor communication plus collectives with small data payload

Applications (cont.)

- IMPACT-T: Integrated Map and Particle Accelerator Tracking Time
  - Memory bandwidth & moderate computational intensity
  - Collective performance with small to moderate message sizes
- MAESTRO: A Low Mach Number Stellar Hydrodynamics Code
  - Low computational intensity
  - Irregular communication patterns
- MILC: QCD
  - High computation intensity
  - Global communication with small messages
- PARATEC: PARAllel Total Energy Code
  - Global communication with small messages

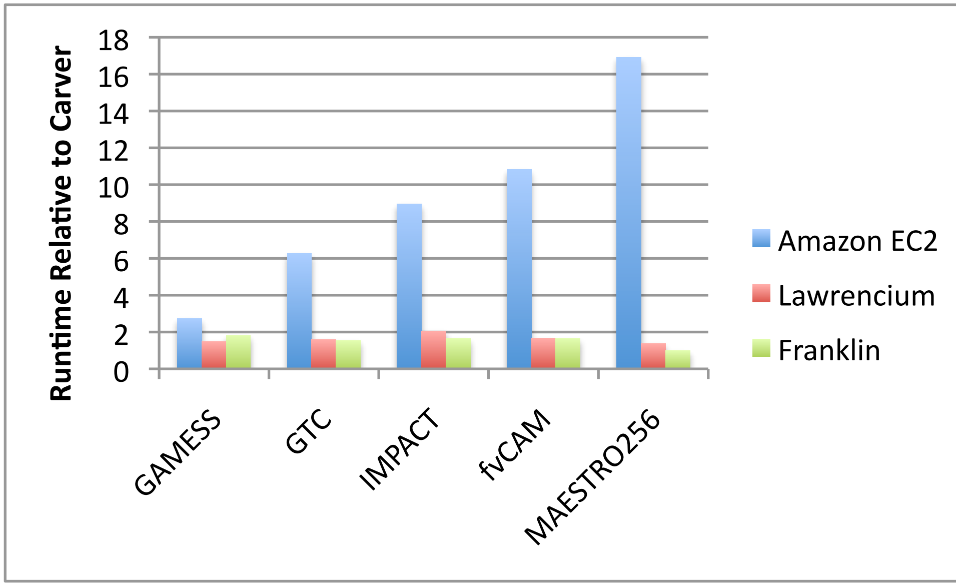
Application and Algorithmic Coverage

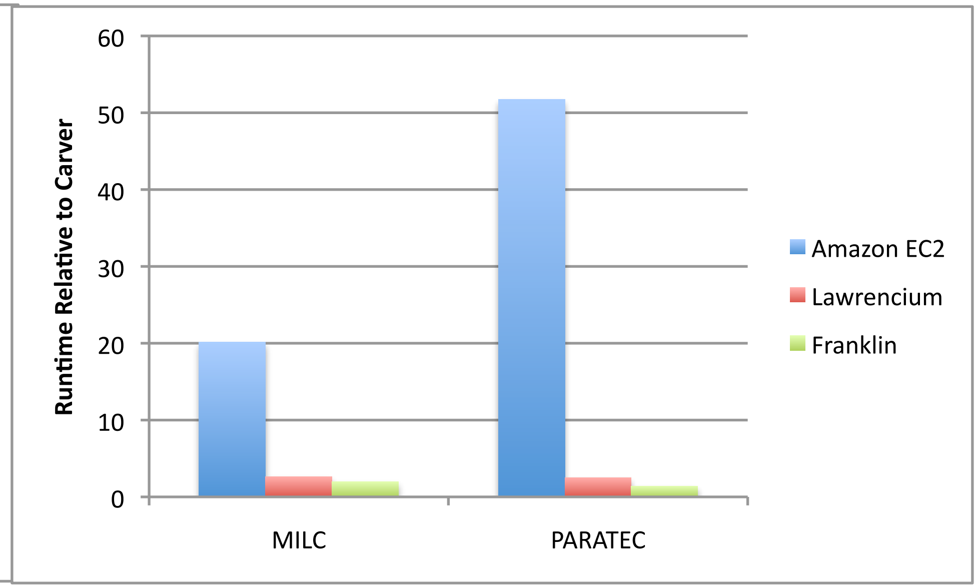
Science areas	*Dense linear algebra*	*Sparse linear algebra*	*Spectral Methods (FFT)s*	*Particle Methods*	*Structured Grids*	*Unstructured or AMR Grids*
Accelerator Science		X	X **IMPACT-T**	X **IMPACT-T**	X **IMPACT-T**	X
Astrophysics	X	X **MAESTRO**	X	X	X **MAESTRO**	X **MAESTRO**
Chemistry	X **GAMESS**	X	X	X		
Climate			X **CAM**		X **CAM**	X
Fusion	X	X		X **GTC**	X **GTC**	X
Lattice Gauge		X **MILC**	X **MILC**	X **MILC**	X **MILC**	
Material Science	X **PARATEC**		X **PARATEC**	X	X **PARATEC**	

Performance Comparison

Communication intensive applications suffer disproportionately on EC2

(Time relative to Carver)





NERSC Sustained System Performance (SSP)

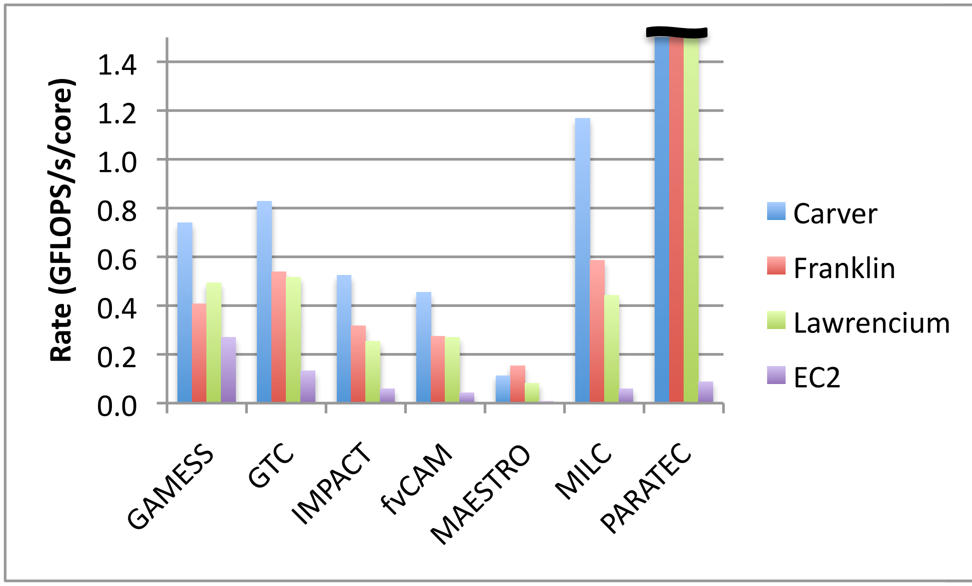
SSP represents delivered performance for a real workload

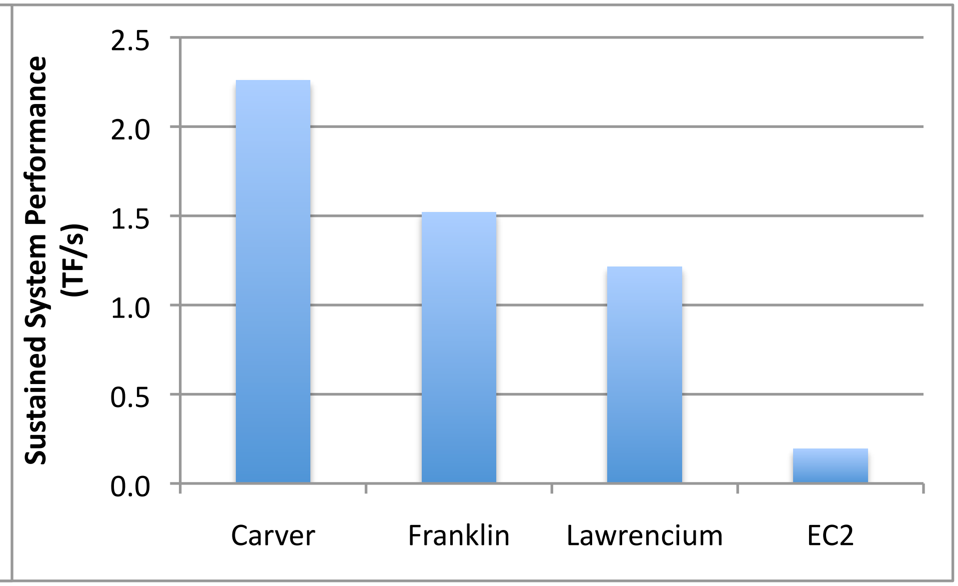
CAM Climate	*GAMESS* Quantum Chemistry	*GTC* Fusion	*IMPACT-T* Accelerator Physics	*MAESTRO* Astro-physics	*MILC* Nuclear Physics	*PARATEC* Material Science

- **SSP: aggregate measure of the workload-specific, delivered performance of a computing system**
- **For each code measure**
  - **FLOP counts on a reference system**
  - **Wall clock run time on various systems**
  - ***N* chosen to be 3,200**
- **Problem sets drastically reduced for cloud benchmarking**

$$SSP = N \left(\prod_{i=1}^{M} P_i \right)^{(1/M)}$$

Application Rates and SSP





Problem sets drastically reduced for cloud benchmarking

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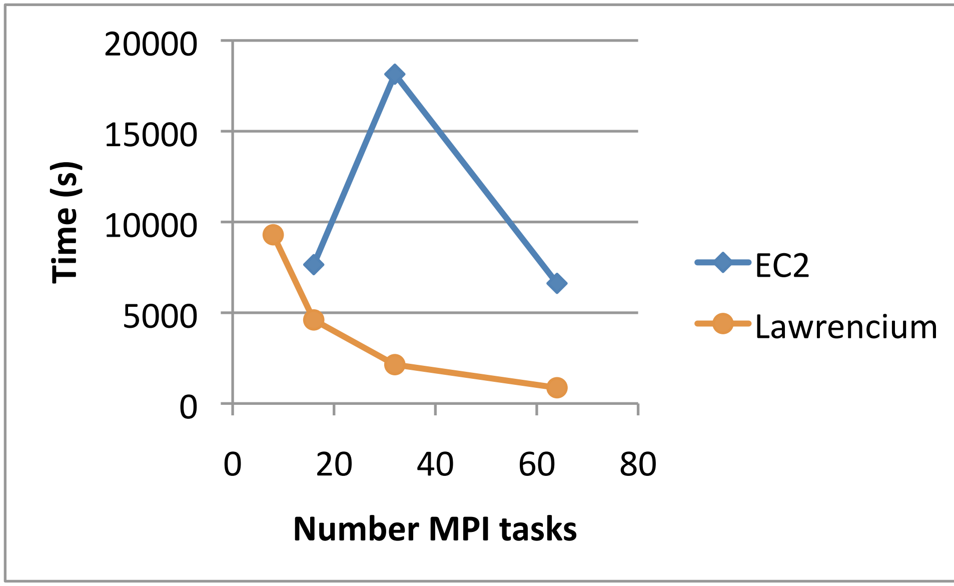
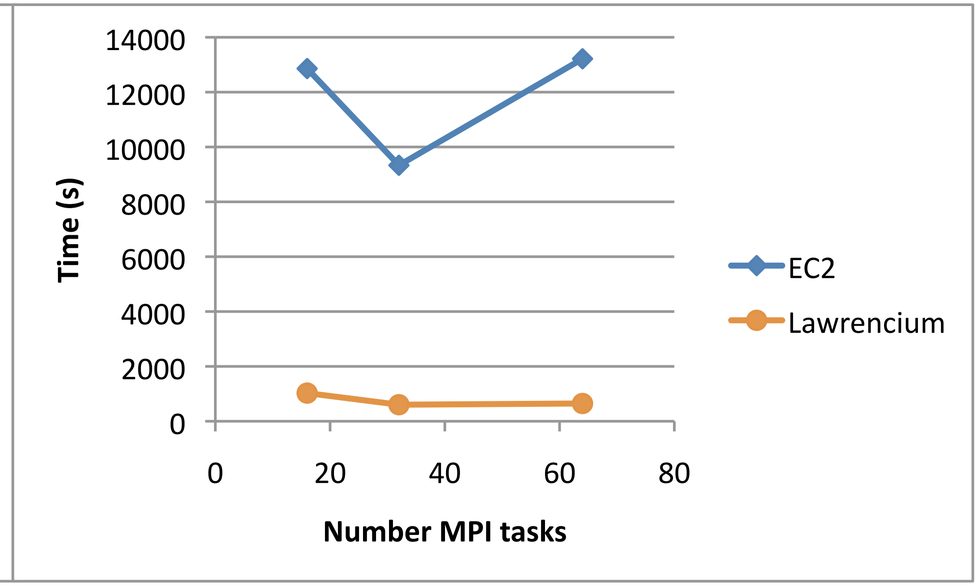
Application Scaling & Variability

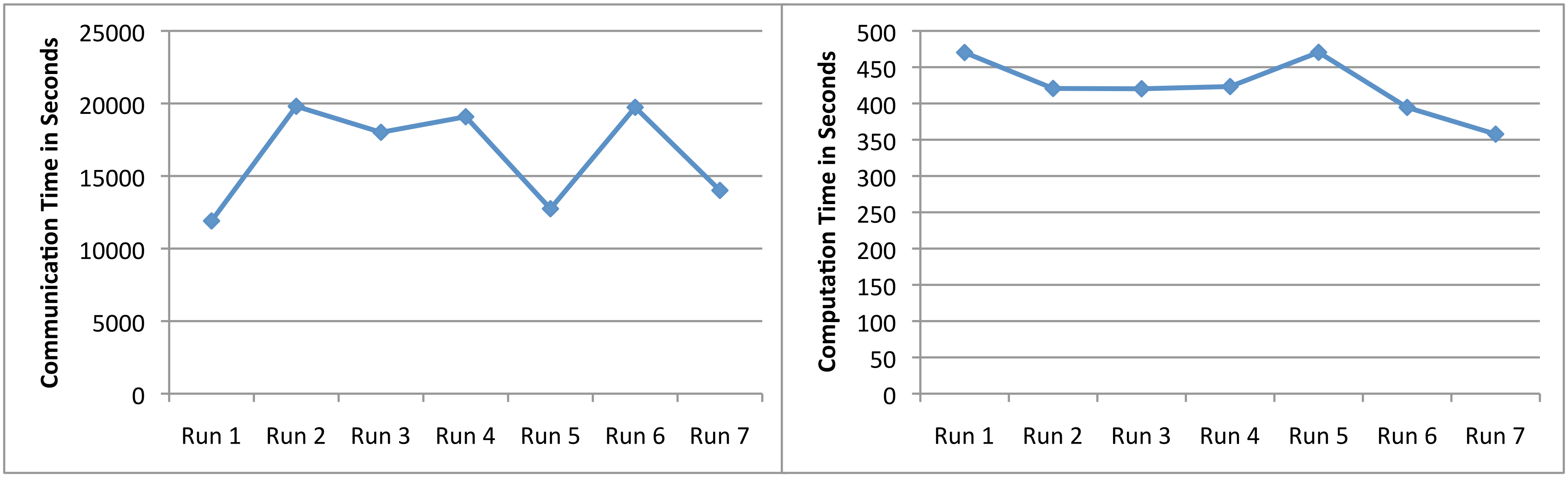


MILC

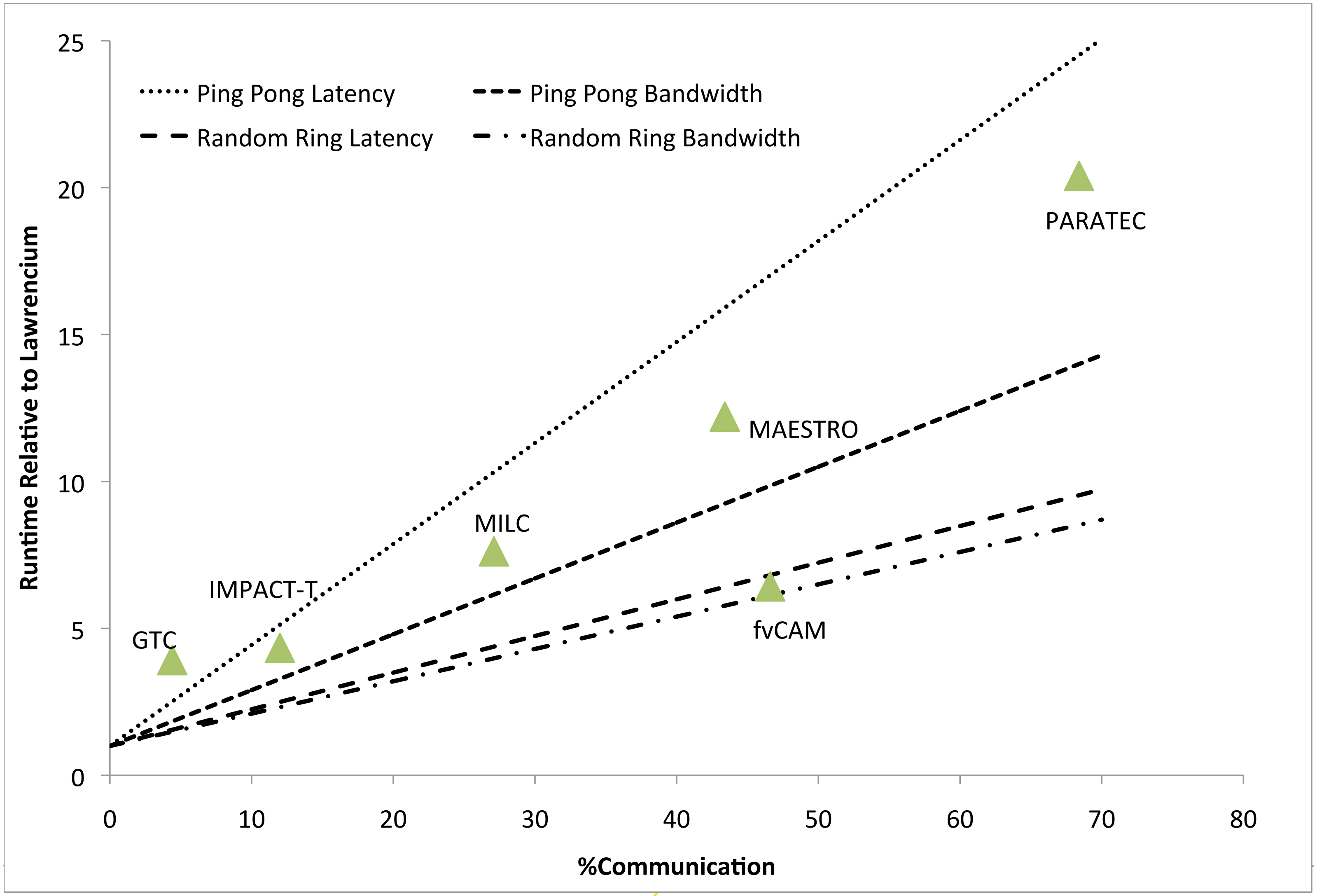


PARATEC

PARATEC Variability



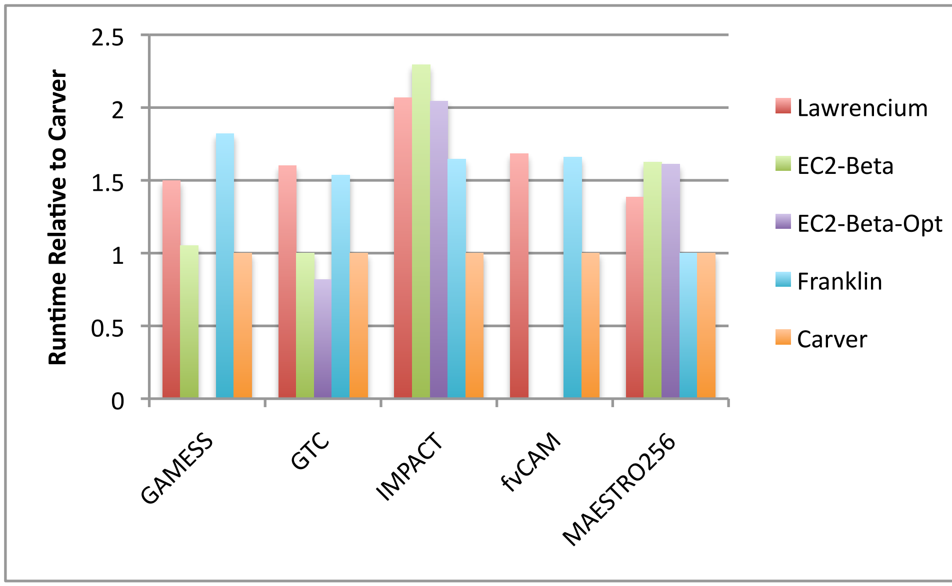
Communication/Perf Correlation

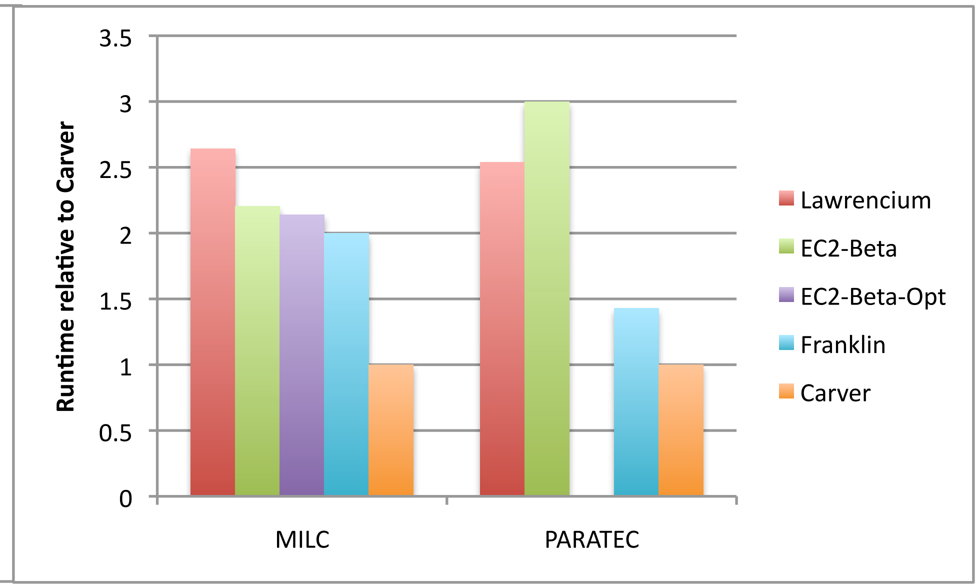


Observations

- Significant performance variability
  - Heterogeneous cluster: 2.0-2.6GHz AMD, 2.7GHz Xeon
  - Shared interconnect
  - sharing un-virtualized hardware?
- Significantly higher MTBF
- Variety of transient failures, including
  - inability to access user data during image startup;
  - failure to properly configure the network;
  - failure to boot properly;
  - intermittent virtual machine hangs;
  - Inability to obtain requested resources.

Amazon Cluster Compute Instances





Conclusions

- Standard EC2 performance degrades significantly as applications spend more time communicating
- Applications that stress global, all-to-all communication perform worse then those that mostly use point-to-point communication
- The Amazon Cluster Compute offering has significantly better performance for HPC applications then standard EC2

Acknowledgements

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