Evaluation of Parallel Application-Level Behavioral Attributes

ICS - First International Workshop on Characterizing Applications for Heterogeneous Exascale Systems *CACHES 2011*

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Agenda

1. Motivation
   - Executive Order 13423
   - Gaps in our Understanding
2. Technical Approach
3. Experiments
   - Attribute Evaluation
   - Verification
   - Surprises
4. Concluding Remarks

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Table of Contents

Systemic Performance Management

- Improve *systemic performance consistency*
  - **Goal:** Minimize application run time *extension* and *variability*
- Prior work on the T_{comm} component of parallel applications
  - Application level perspective
  - Monolithic (single processor, single core) compute nodes
  - Message preparation, Congestion, Errors
  - Methods and metrics to quantify application *run time sensitivity* to network performance variation
- Nature of communication has changed
  - Multi-core complicates things (hybrid DMP, SMP)
- Q: Do the models and metrics still hold?

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Energy Management

- Improve energy efficiency
- Reduce greenhouse gases
- Reduction in energy intensity by 3 percent/yr or
- 30% by 2015 based on 2003 baseline
- Energy intensity = consumption per sq ft building space
- Q: Can better performance management improve energy efficiency?

Research Opportunity

- Combine systemic performance and energy management
  - Use application behavioral performance data
  - Develop standard interfaces for HPC/data center management
- Challenges
  - Conflicting subsystem operational objectives
  - Subsystem interactions can trigger autonomous subsystem behavior
  - Cost of state transition
  - Centralized control of semi-autonomous subsystems
  - Need to understand subtleties at core, processor, node, system levels
  - OS, libraries, applications may not behave as assumed

Table of Contents

Application-Level Behavioral Attributes

- Describe run time performance affects due to subsystem interactions
- Major Subsystems
  - Resource Manager, Scheduler
  - Communication Subsystem
  - Set of executing applications

Application-Level Behavioral Attributes

- Describe run time performance affects due to subsystem interactions
- Major Subsystems
  - Resource Manager, Scheduler
  - Communication Subsystem
  - Set of executing applications
- Resource advice tuple

$$R = \begin{cases} \{S, D, E, \ldots\} & : \quad S = \{1 \ldots\} \\ & : \quad D = \{1 \ldots\} \\ & : \quad E = \{1 \ldots\} \\ & : \quad \ldots = TBD \end{cases}$$

Emulating Parallel Applications - PACE

$$T_{app} = \sum_{1}^{n} T_{cycle}, \quad T_{cycle} = T_{comm} + T_{comm}$$

$$T_{comm} = \alpha + \beta n, \quad T_{comp} = \frac{T_{comm} \cdot 100}{L} - T_{comm}$$

- Emulate parallel simulation (cycles or run time) PACE
  - Simulated T_{comp}, Real T_{comm}
  - Measure T_{comm} parameters just prior to run
  - Determine T_{comp} from T_{comm} and load L
  - Determine T_{run} from T_{comm}, T_{comp}, and cycles or
  - Determine cycles from T_{comm}, T_{comp}, and T_{run}

Attribute Evaluation - PARSE

- Parallel Application Run time Sensitivity Evaluation - PARSE
- Python wrapper
- PARSE Manages
  - Process allocation on processors - depreciated
  - Synchronization of PACE & App. Under Test (AUT) execution
  - Progression of attribute evaluation tests
- PARSE Performs
  - Post processing
    - Sensitivity
    - Disruptiveness
    - Intermediate values and supplementary statistics

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Quantifying AUT Sensitivity

- Compare baseline vs. perturbed run times
- Perturb AUT using PACE ⇒ measure AUT runtime
- Combine calculated coefficients of mean and variation between operational scenarios

$$COM_{ij} = \left(\frac{\left(\frac{\sum^n T_{run}}{n} \right)_i}{\left(\frac{\sum^n T_{run}}{n} \right)_j} \right), \quad COV_k = \left(\frac{\sigma_k}{\bar{x}_k} \cdot 100 \right)$$

$$ROV_{ij} = \left(\frac{COV_i}{COV_j} \right)$$

$$S_{ij} = COM_{ij} \cdot ROV_{ij}$$

$$\lim_{P[d] \to 0} S_{i0} = \lim_{i \to 0} S_{00} = COM_{00} \cdot ROV_{00} = 1.$$

Quantifying AUT Disruptiveness

- Compare baseline vs. perturbed run times
- Perturb PACE using AUT $\Rightarrow$ measure PACE runtime
- Combine calculated coefficients of mean and variation between operational scenarios

$$COM_{ij} = \left(\frac{\left(\frac{\sum^n T_{run}}{n} \right)_i}{\left(\frac{\sum^n T_{run}}{n} \right)_j} \right), \quad COV_k = \left(\frac{\sigma_k}{\bar{x}_k} \cdot 100 \right)$$

$$ROV_{ij} = \left(\frac{COV_i}{COV_j} \right)$$

$$D_{ij} = COM_{ij} \cdot ROV_{ij}$$

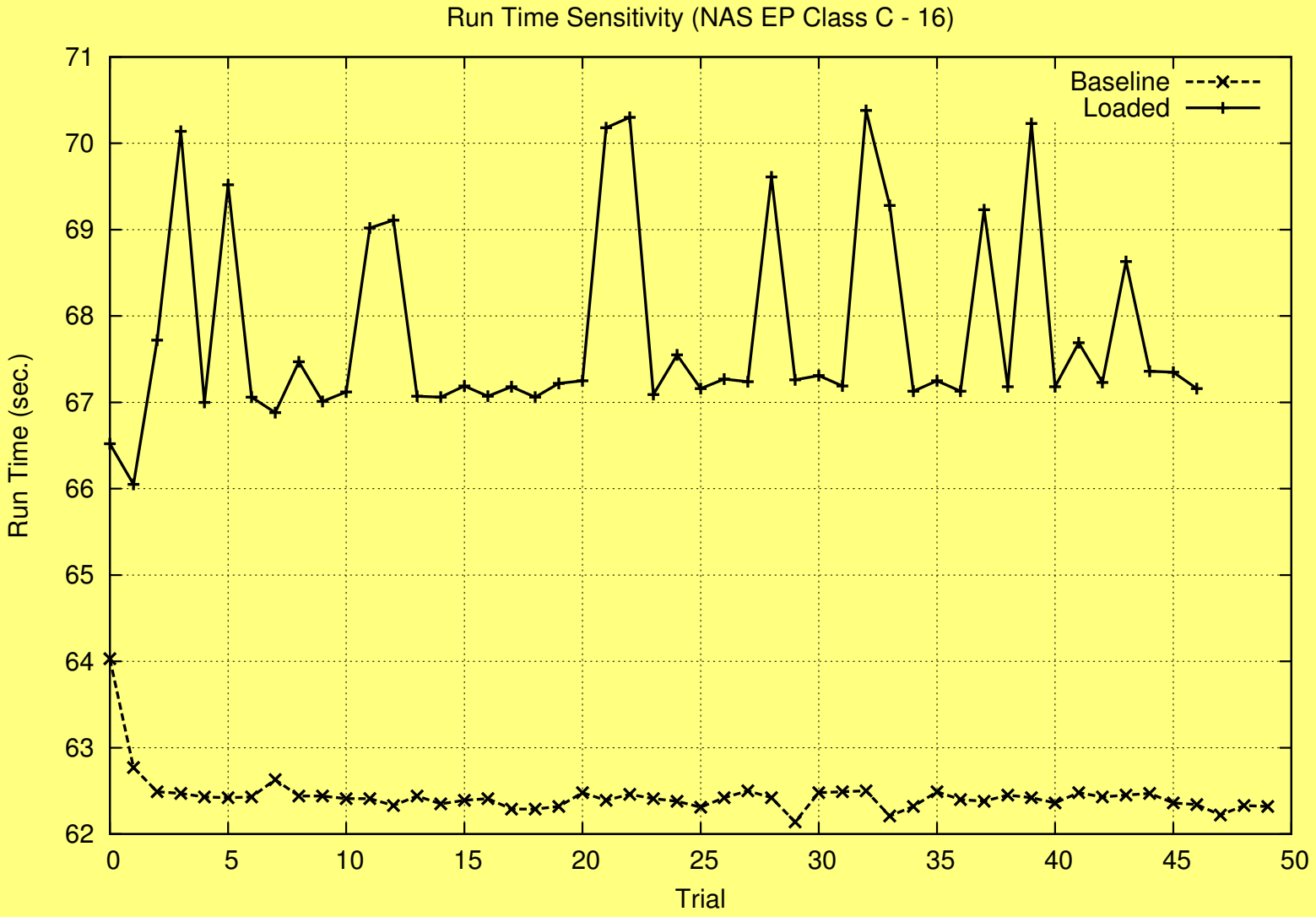
$$\lim_{P[d] \to 0} D_{i0} = \lim_{i \to 0} D_{00} = COM_{00} \cdot ROV_{00} = 1.$$

Table of Contents

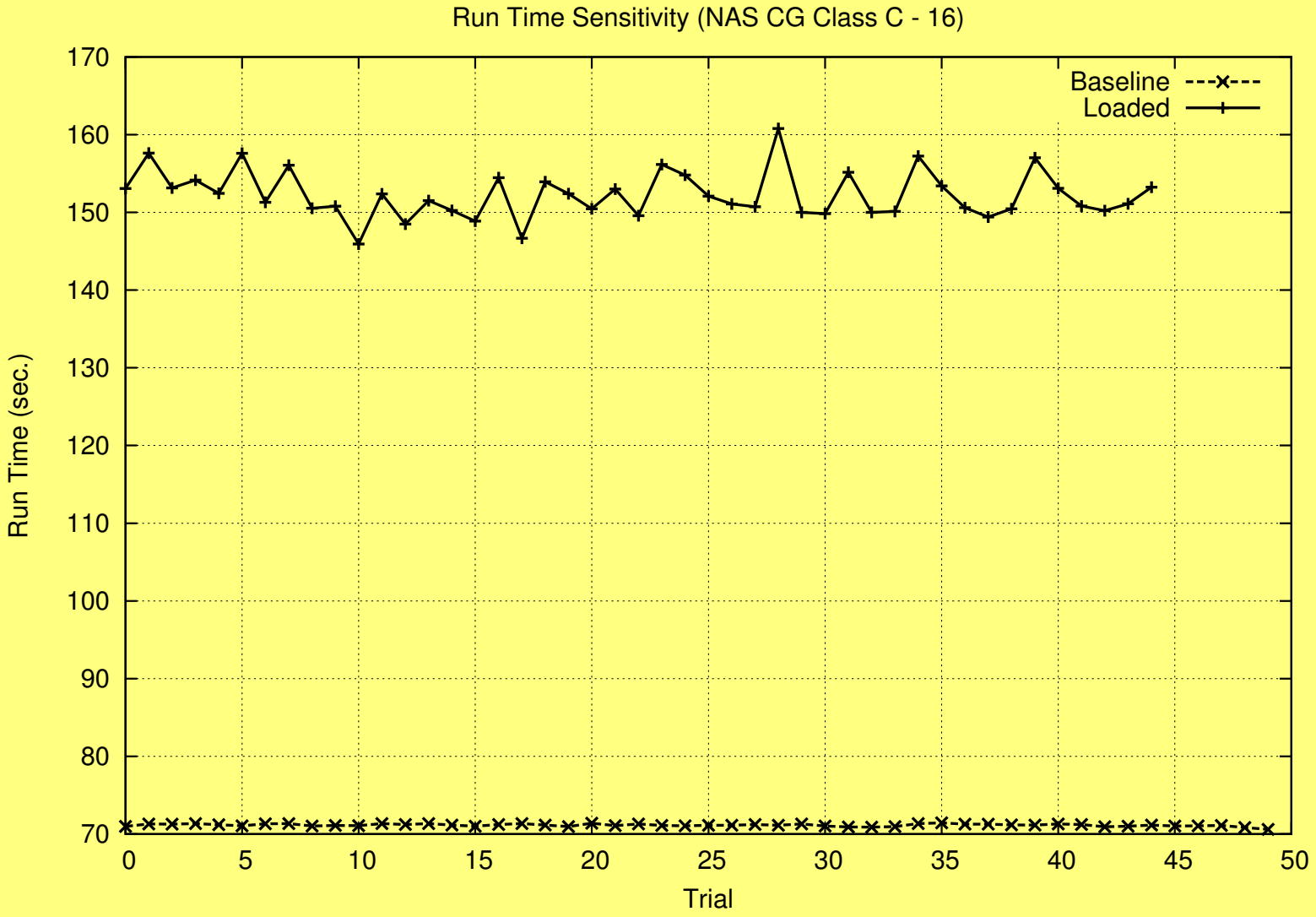
Platform

- 10 node, 80-core HP Proliant DL165 G5p Cluster
  - 2 Quad-core AMD Opteron 2384 (Shanghai) per node
  - 16GB RAM, 500GB HD
  - 2 1000Mbps Ethernet
  - Red Hat Enterprise Linux 5.4 (2.6.18-194.26.1.el5)
  - gcc 4.4.0, PGI, Intel compilers
  - MPICH2 communication libraries (1.2.1p1, 1.3b1)

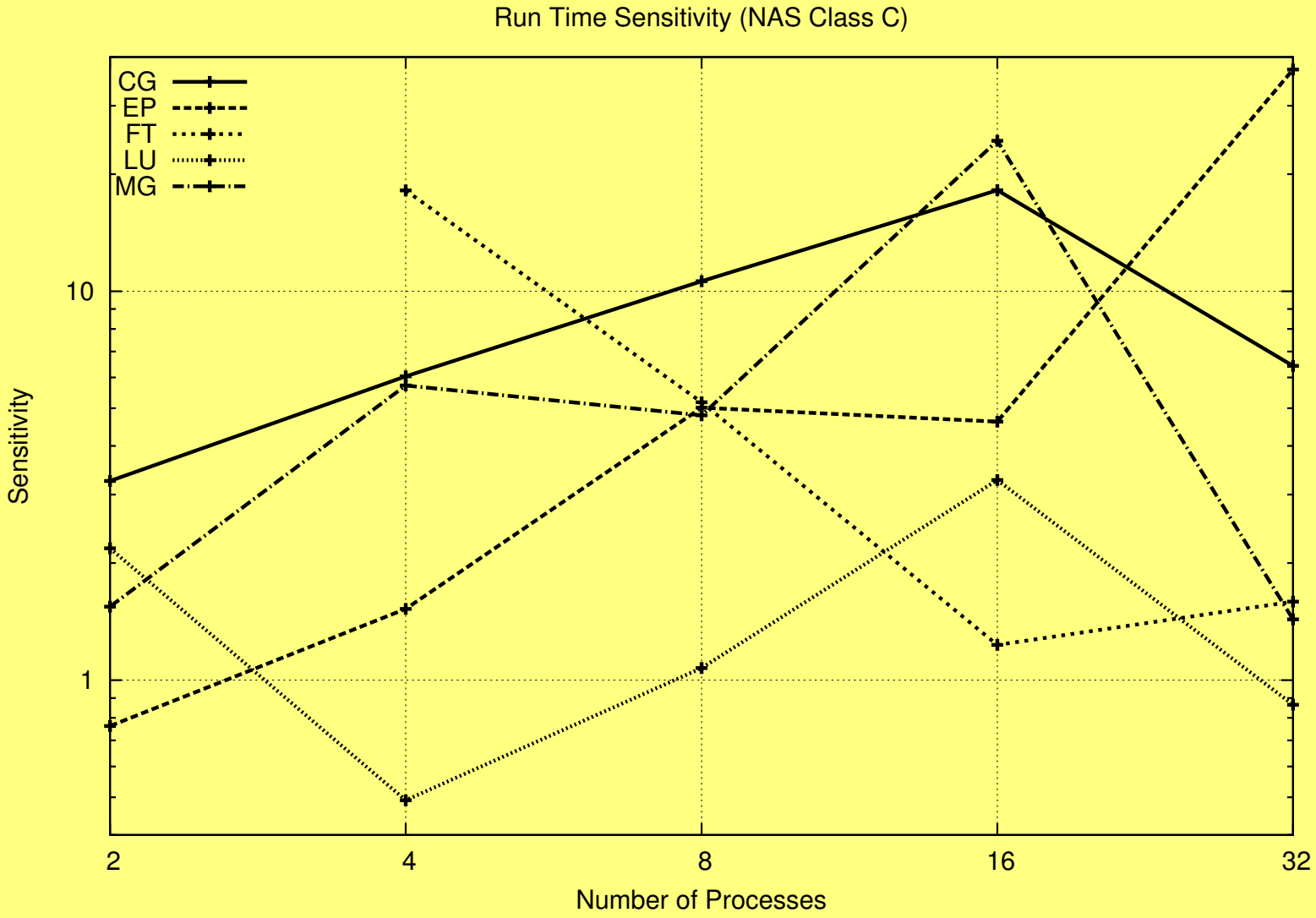
Sensitivity Trials



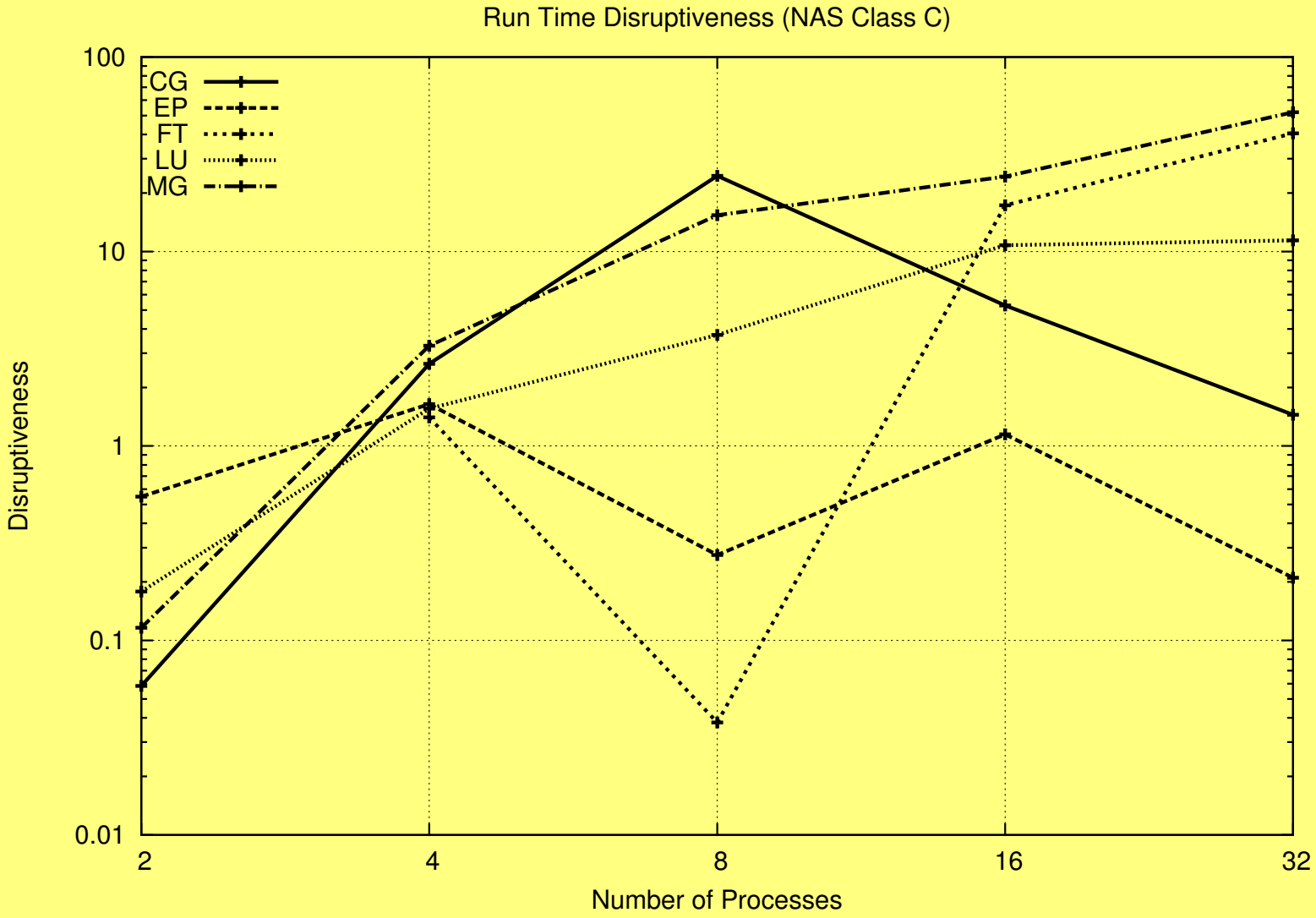
Sensitivity Trials



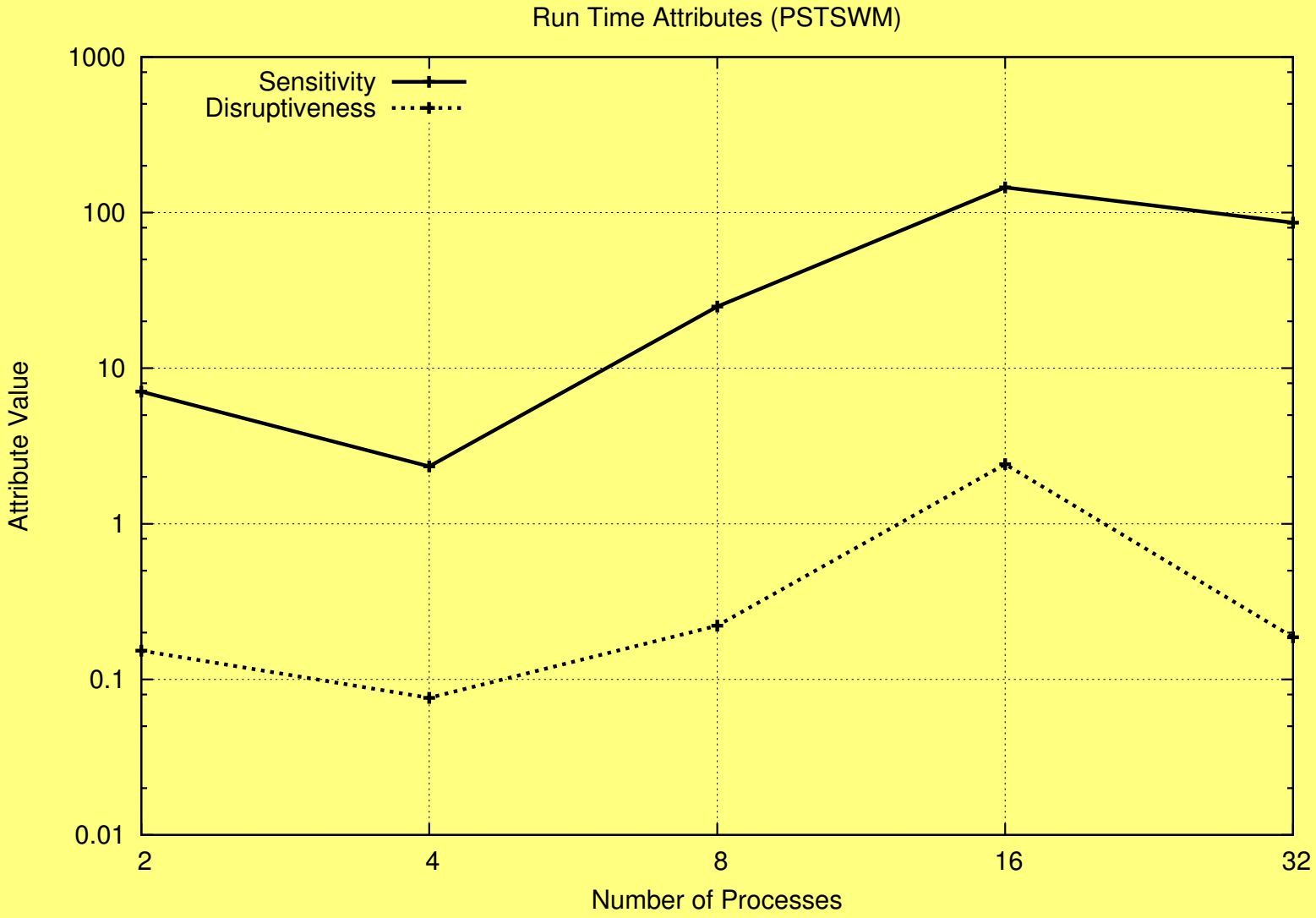
NAS Class C Attributes



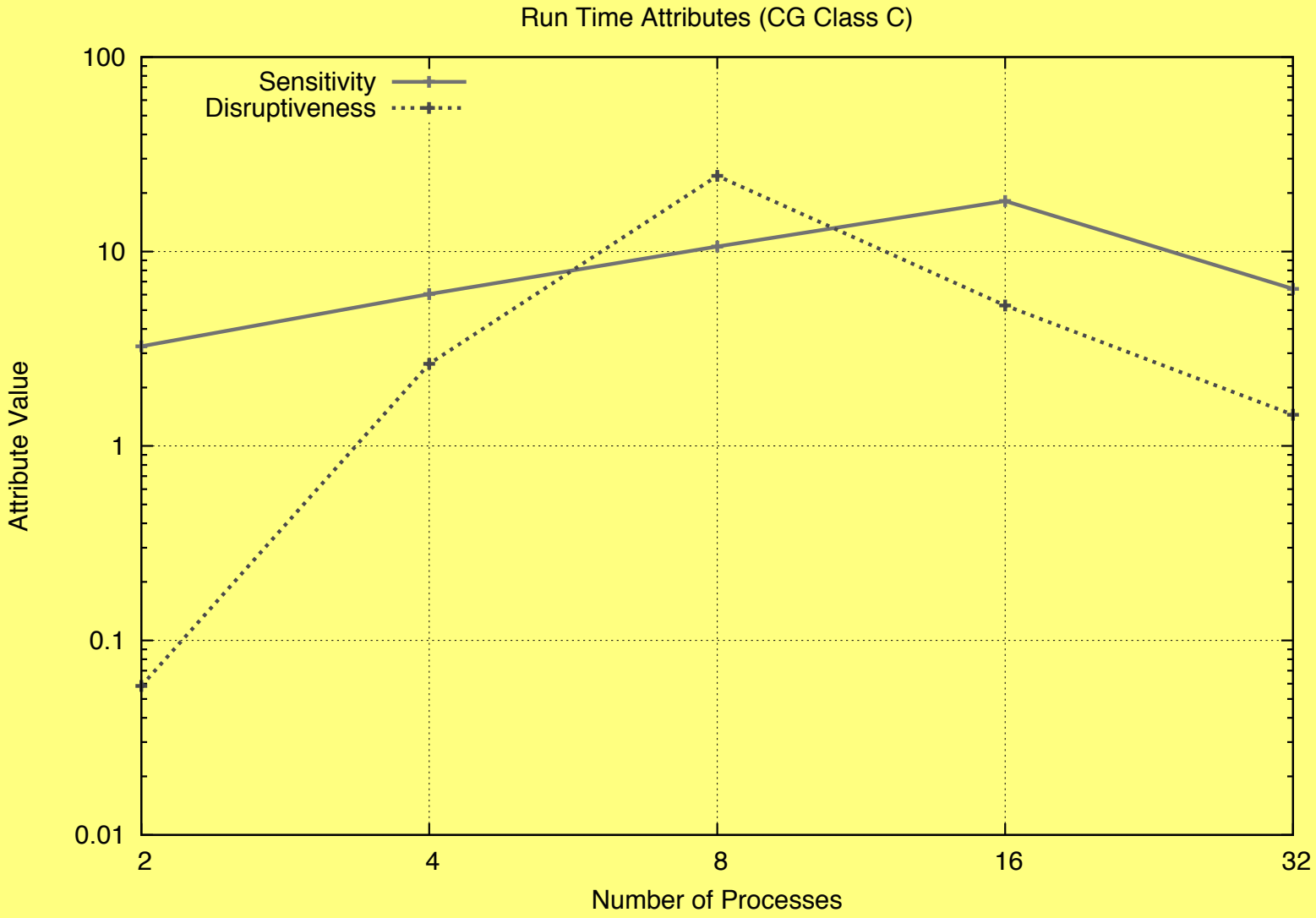
NAS Class C Attributes



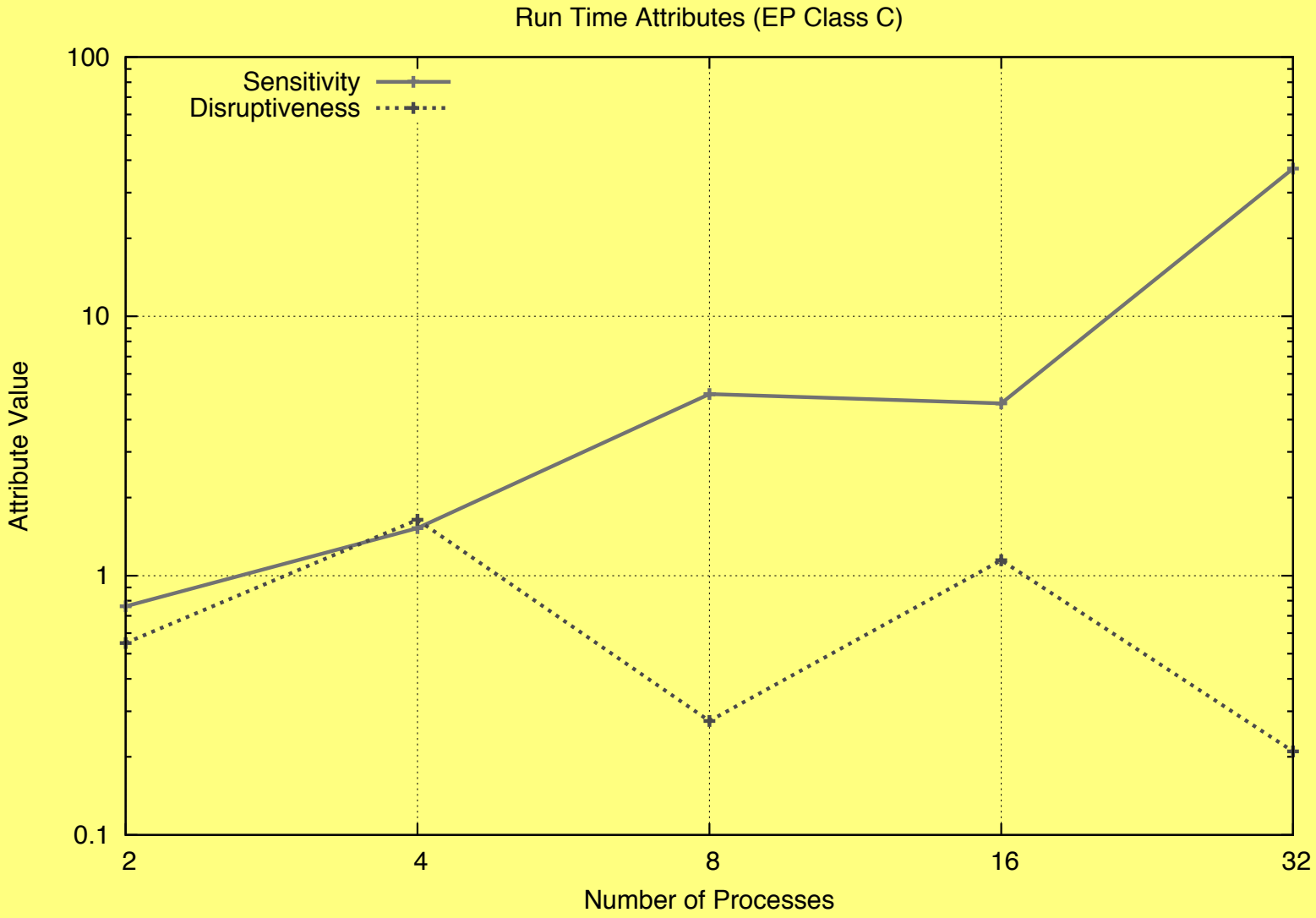
PSTSWM


Run Time Attributes (PSTSWM)
Sensitivity
Disruptiveness
Attribute Value
1000
100
10
1
0.1
0.01
2
4
8
16
32
Number of Processes

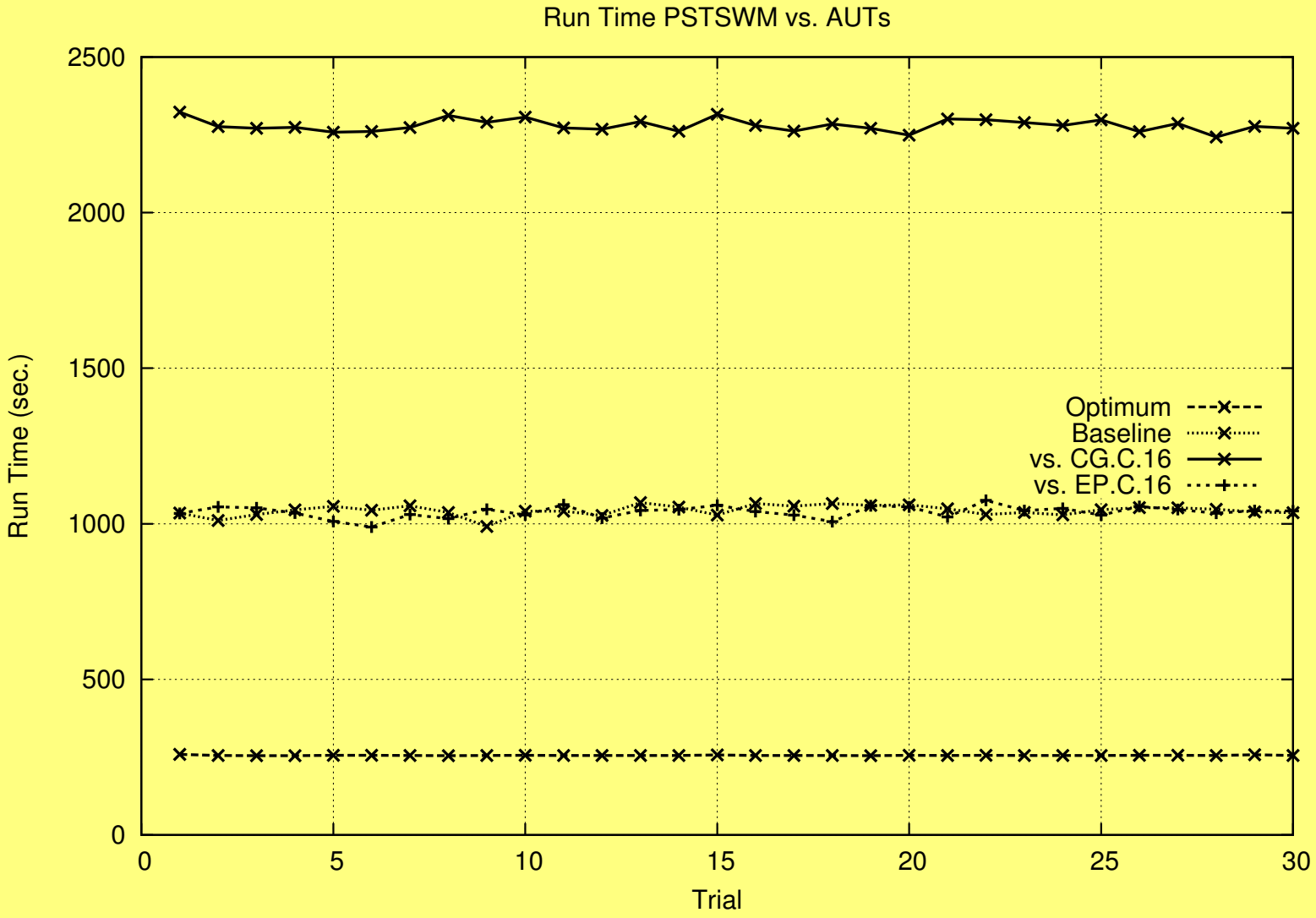
Concurrent Applications



Concurrent Applications



Concurrent Applications



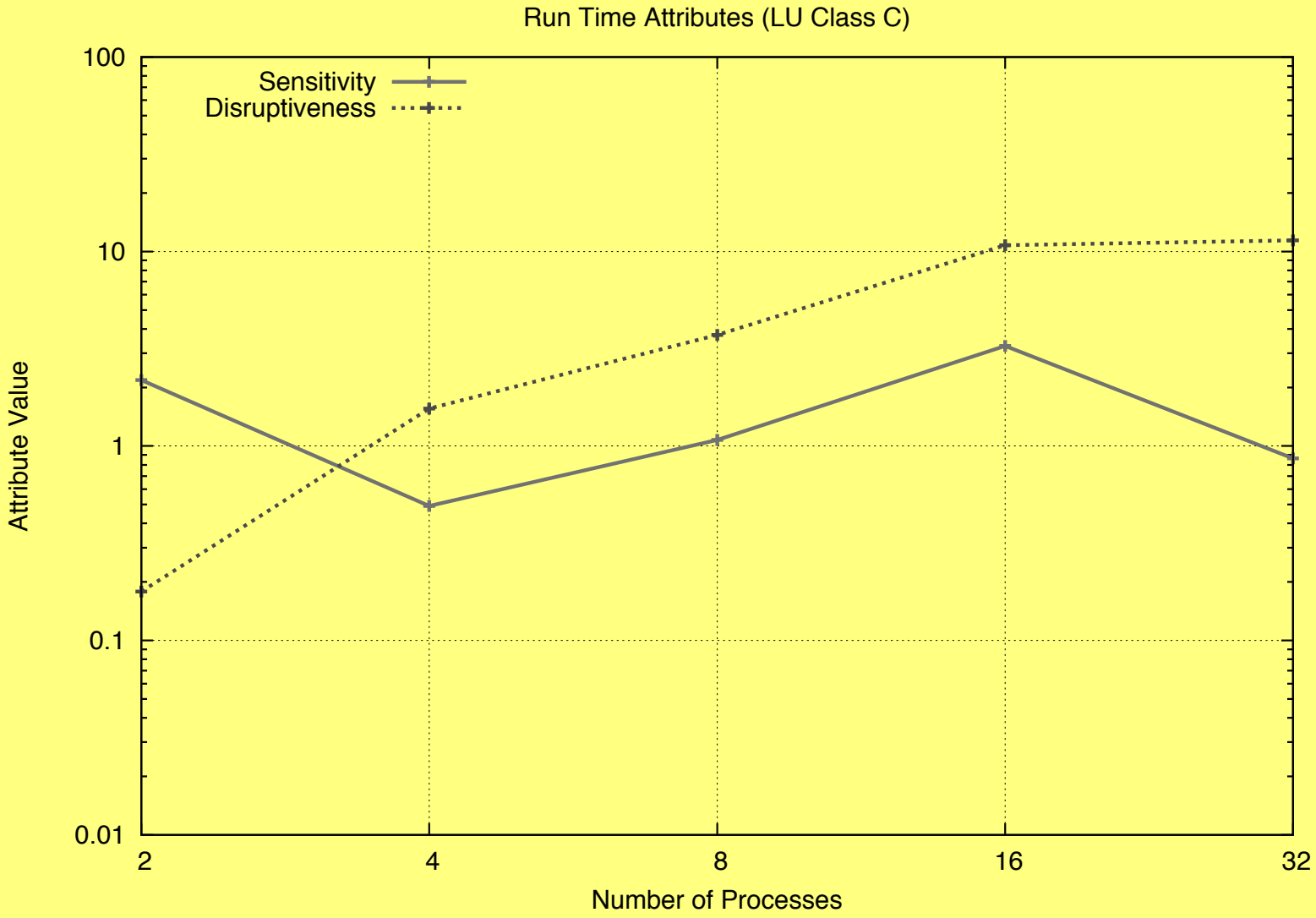
Process Binding

- MPICH2-(pre 1.3x) vs. MPICH2-1.3x
  - Hydra process manager: specified at build time vs. default
  - core-binding interface: non-functional vs. functional
  - verified using `top`
- core-binding (repeatable process placement) makes a significant difference
- Ramifications to PACE, PARSE
  - None to PACE
  - PARSE process placement (stride) in multi-core, multi-processor cases - depreciated

Process Locality

- Optimum process location
  - Best case: Co-locating processes to adjacent cores
  - Some applications better off spread across processors, nodes
  - Verified during AUT baseline tests
- 71% run time (= energy) difference observed in some cases
- Ramifications
  - Work in progress

NAS LU-4 Class C



NAS LU-4 Class C

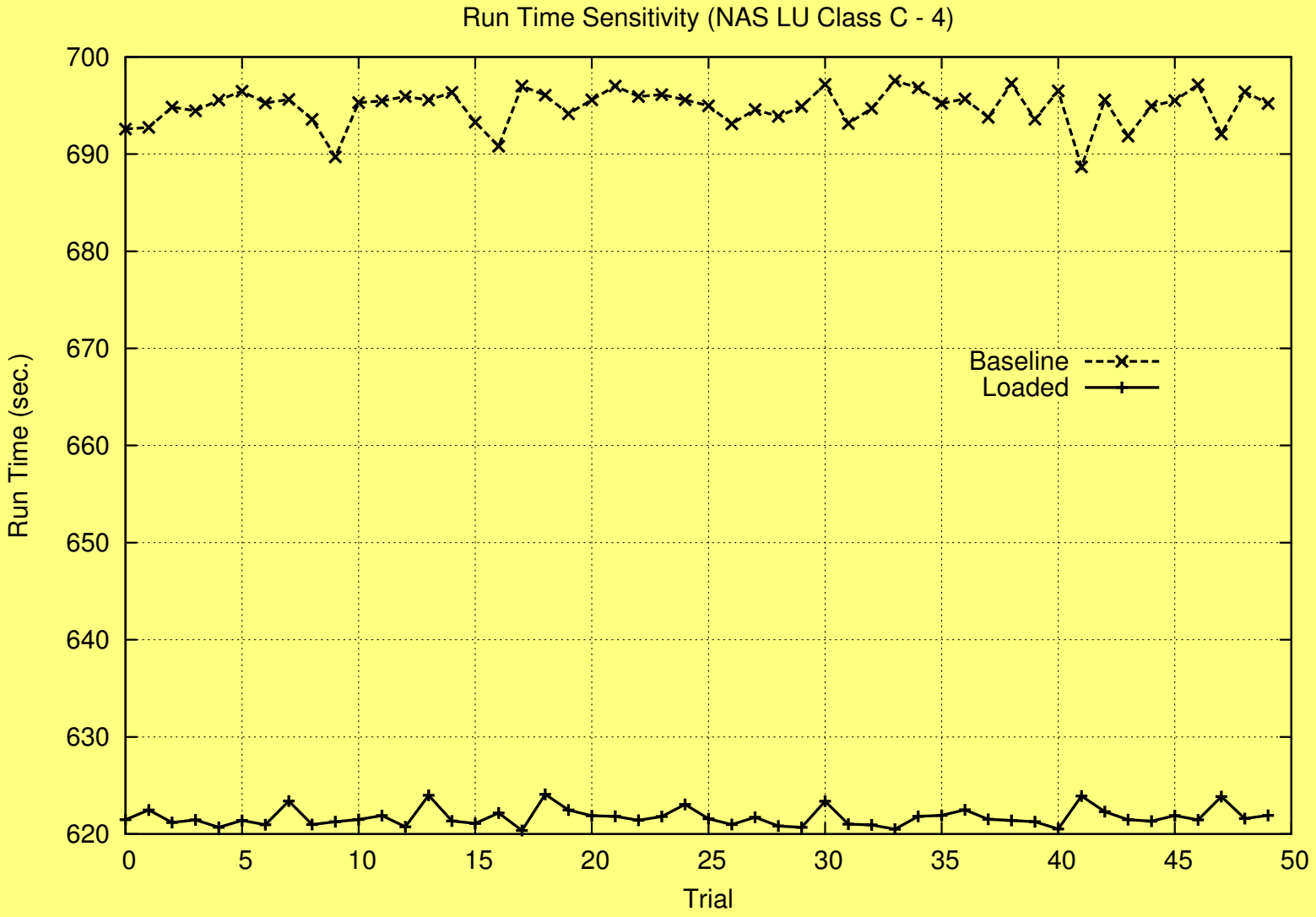


Table of Contents

Contributions

- Disruptiveness Attribute
  - Inverse of sensitivity
  - Application's tendency to disrupt others
- Verification
  - PSTSWM vs. non-disruptive application (EP)
  - PSTSWM vs. disruptive application (CG)
- Surprises
  - Process binding
  - Post MPICH2-1.3b1 "Hydra" implementation binds processes
  - Process location - now more of a sensitivity issue

Ongoing Work

- Characterize sensitivity to process locality
  - Optimum baseline configuration
  - Ramifications to other attributes
- Investigate disruptiveness assessment more rigorously
  - $D_{ij} < 1 \Rightarrow$ Investigate *COM* and *ROV* components
  - Optimize PACE parameters for disruptiveness evaluation
- Investigate attributes at scale
  - Scientific applications
  - Hybrid architectures - accelerators (GPU)
- Correlation to managing both performance and energy efficiency
  - Attribute components (*COM* and *ROV*)
  - Standard interfaces to HPC and HVAC systems

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Thank You

Questions?

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