Implementing a Philosophy for Transitioning Existing Software to Network Processing

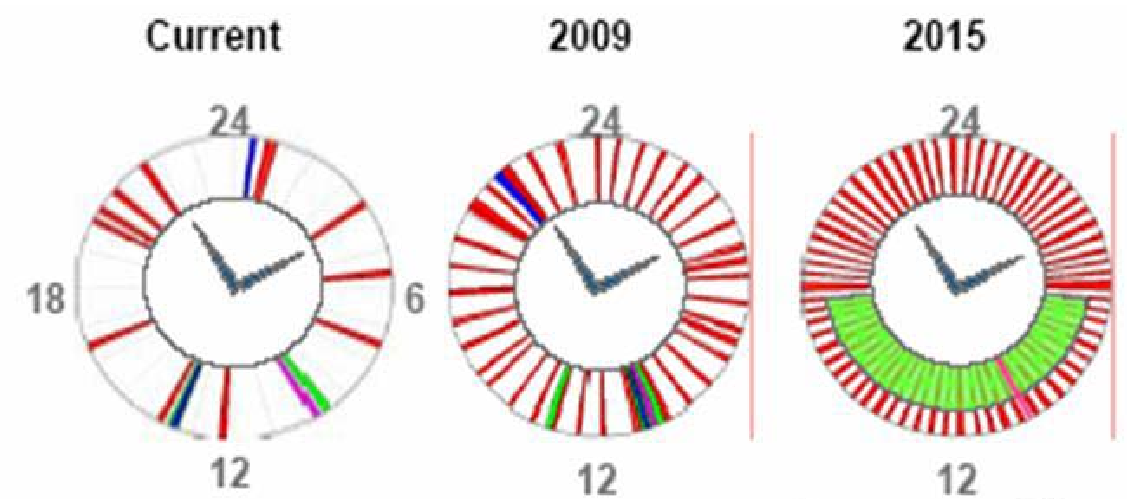
Peter Raeth
Ball Aerospace & Technologies Corp
praeth@ball.com

An Overview of our Discussion

- Roots of our customers' throughput problems
- Philosophy for addressing throughput problems
- Creating a generic extensible approach
- Applying philosophy to specific applications

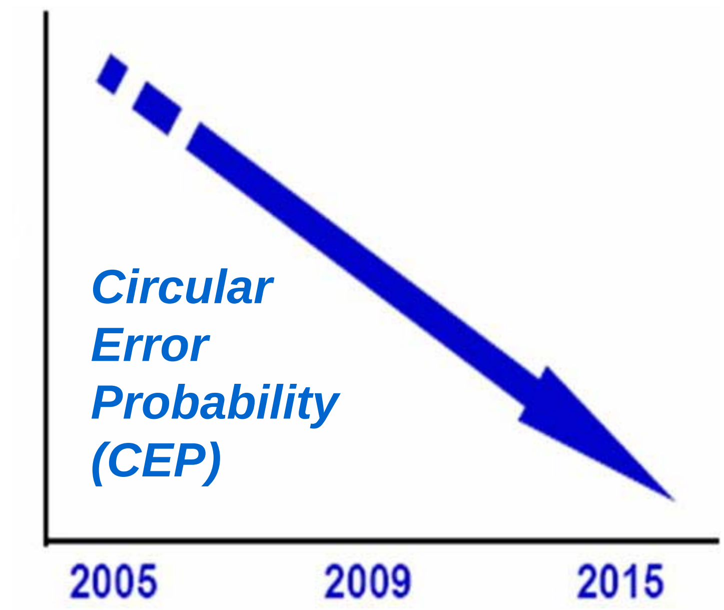
Throughput Problem Roots

Data Velocity



J. Loger, 7 Sep 2005

Calculation Accuracy



- Constant observation
- Continuous data flow
- Real-time decisions
- React to evolving environments
- Know now - Act now

- Modeling that approaches reality
- Simulation first - Construction second
- Increasing model fidelity
- Rising simulation sampling rates
- Realistic training via virtual reality

Moving Toward a General Philosophy

- Start with existing infrastructure
  - multi-processing, distributed processing, cluster processing
  - wholesale replacement is expensive, time consuming, risky
- Yet, enable opportunities in new hardware types
  - remain compatible with evolving infrastructure
  - physics chips, graphics chips, RISC, multi-core, DSP, FPGA, ASIC
  - low-latency networks
  - increased network speed
  - increased network capacity
  - faster memory bus
  - more and faster memory
  - enlarged data storage and handling
- Open source and open standards to facilitate generality and portability
  - network messaging
  - user interfaces
  - threads
  - web services
  - job management
  - network management

Moving Toward a General Philosophy

- Establish clear path from theory to production reality
  - good applications are founded on good theory
  - but, theory alone is not enough
  - can not declare problem solved until production processes are improved
  - good theoretical foundations yield technology reusability
    - if implementation is sound

Moving Toward a General Philosophy

- Take modular and generic approach
- Problem solving should span languages and operating systems
- Software should be generic, not specific to given operating system
- View components as independent cooperative objects
  - software, algorithms, data
- Transition original code while interacting with domain experts
  - start with restructuring input and output to algorithm driver
  - produce same results when compared to original
- Do not fall for application-specific hard-wiring
  - what we learn in one application should transfer easily to new applications
- Do not accept build warnings
  - nothing should be allowed to obscure issues as the project proceeds
  - "warnings" accumulate, lead to production system failure, in our experience

Moving Toward a General Philosophy

- Take into account matters beyond hardware and software
  - customer is key focus
  - some of them have very strict transition standards
  - never ask for a waiver of those standards
  - "ilities" matter
    - **modifiability**
    - **reusability**
    - **accessibility**
    - **extensibility**
    - **scalability**
    - **flexibility**
    - **system portability**
    - **workload manageability**
    - **predictability**
    - **maintainability**
    - **usability**
    - **programmability**
    - **net centricity**
    - **availability**
    - **reliability**
    - **off-shelf commodity h/w, s/w**
    - **avoid proprietary components**
    - **compatibility with existing tools**
    - **integration with exiting systems**
    - **consideration of human factors**

Employ Open Source Products

- Removes cost of licensing
- Takes advantage of community's initiatives and for-fee support
- Remain generic so that choice of tool is not a major factor
- In our case, we have made the following choices
  - MPICH2 implementation of MPI
    - cluster processing
  - Condor
    - distributed processing, workflow management, job management, resource allocation
  - pthreads
    - multi processing
  - Opticks
    - data visualization and plug-in manager
  - Axis
    - translate Java classes into web services, generate Java wrappers for web services

Most organizations have existing codes

- Lots of existing analysis algorithms and simulation models
- Written over last 20 years
- Certified as accurate and complete, in the formal sense
- Very accurate and effective in the functional sense
- Low throughput relative to advancing needs
- Need timely results, within decision/action windows of opportunity
- Desire is for improved throughput without touching algorithms
- Want transition with minimal re-engineering or new infrastructure
- Networked version of codes need to produce same results as original
  - run faster with no change in functional behavior or user view of operation

Throughput Expansion in Stages

- Single-process baseline
- Improve algorithm efficiency
- Multi-processing extension
- Cluster processing expansion for single jobs
- Distributed processing for multiple jobs
- Generic framework for porting existing codes to network environment

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- Allows for phased improvement in consultation with domain experts
- Avoids rapid climb in complexity
- Makes best use of existing infrastructure
- Moves technical staff from what they know to what they need to learn
- Encourages coaching and teaching, marked by patience
- Organization can gradually embrace new approach to systems

Partitioning Existing Programs

- Data and Functional Partitioning
- Employ either or both, depending on application
- Look for opportunities where computation would exceed message passing in networked version

3 Basic Ways to Achieve Data Partitioning

- By data group
  - each network process gets a number of data groups to work with
  - node holding a group performs all calculations on that group
  - example: image analysis, pixel is a data group
  - results sent to managing process
- By data group component
  - each node gets a number of a data group's components
  - node holding data group's components analyzes those components
  - example: red, green, or blue component
  - results sent to process having remaining components or to managing process
- By library component
  - combined with first two
  - each node receives its data and applies a portion of the analysis to that data
  - example: material detection applies only part of spectral library to pixel subset
  - results returned to managing node or to node(s) performing other analyses

Functional Partitioning Examples

- Time-consuming modules being run in series but not dependent on outcome of preceding blocks during the same code cycle
- Pipe-line processing for cases where multiple code cycles can be going on at the same time
- Independent blocks feeding a using function
- Processes that bear no relationship to each other
- Independent processes occasionally communicating with each other

Important to Maintain Objectivity

Use clear metrics when judging throughput improvement *(S.H. Morse, p33,1994)*

- Speedup: Clock time with one process
  divided by clock time using N processes
  - ideal equals number of processes
- Efficiency: Actual speedup divided by ideal speedup
  - speedup on N processes divided by N

- Speedup and efficiency should not be confused
- With increasing speedup, it may be possible to meet throughput goal
- But, may be necessary to add “inefficient” number of processes
- End Goal: Provide results fast enough to make a positive difference within decision/action windows of opportunity

Watch Evaluation Process

- Do not begin network computing experiments with weakest machine
- Then adding more and more capable machines
- Gives false impression that experiment exceeded theoretical limits

Avoid These Routes to Subjective Results

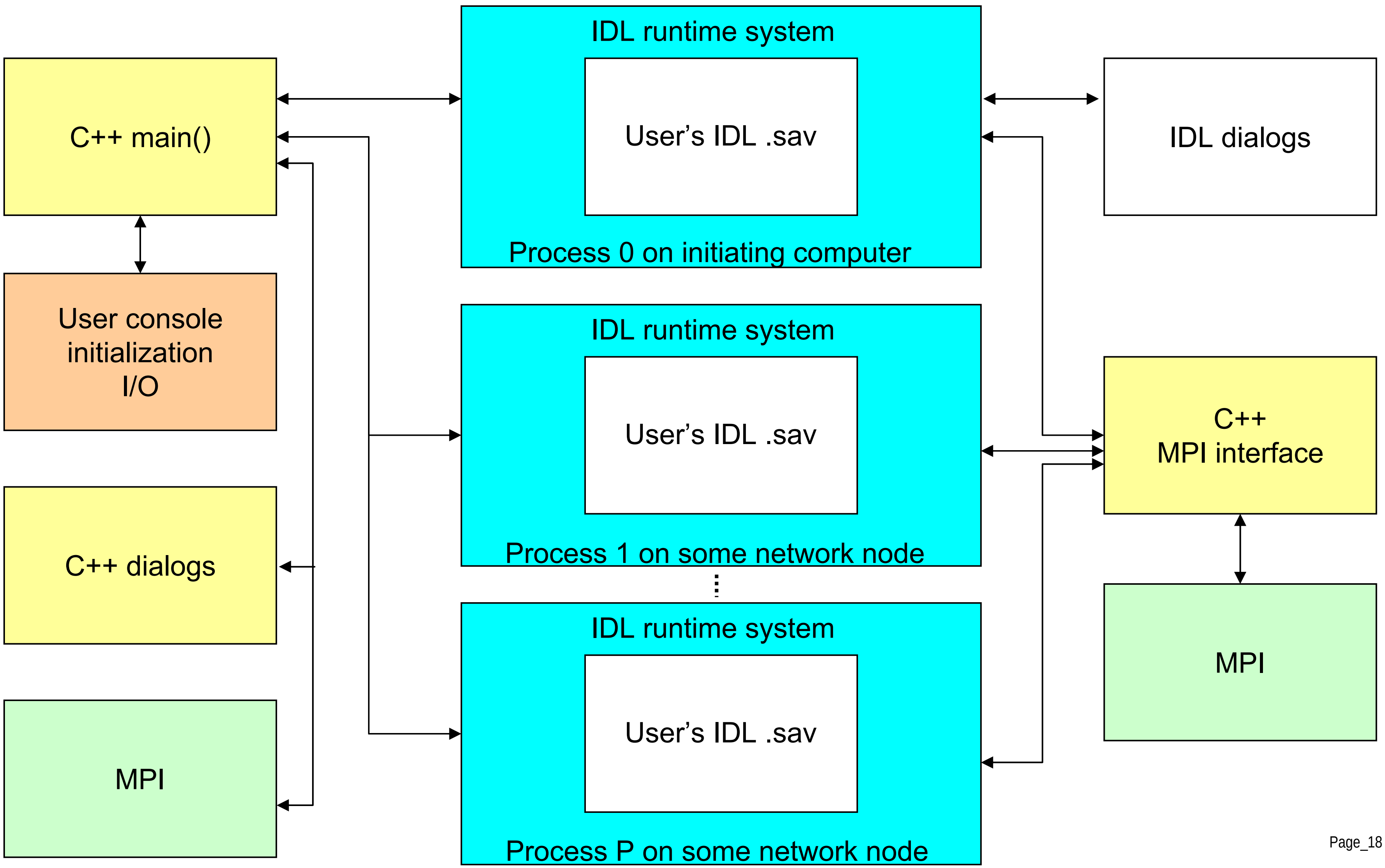
(D.H. Bailey, 1991)

- Compare 32-bit performance to 64-bit performance
- Assume inner kernel of application is sole performance determinant
- Use assembly code and other low-level language constructs for performance and compare them with Fortran or C implementations
- Scale problem size with number of processors, but do not disclose this fact
- Estimate linear scaling of performance without proof
- Compare performance of heavily optimized benchmarks against unoptimized benchmarks
- Compare with old code on obsolete system
- Base MFLOPS operation counts on the parallel implementation instead of on the best sequential implementation
- Give performance in terms of processor utilization, parallel speedup, or peak MFLOPS per $, avoiding issue of "fast enough to matter"
- Use numerically inefficient algorithms to show artificially high MFLOPS
- Measure parallel run times on dedicated system, but measure conventional run times on heavily loaded system

Success in Application

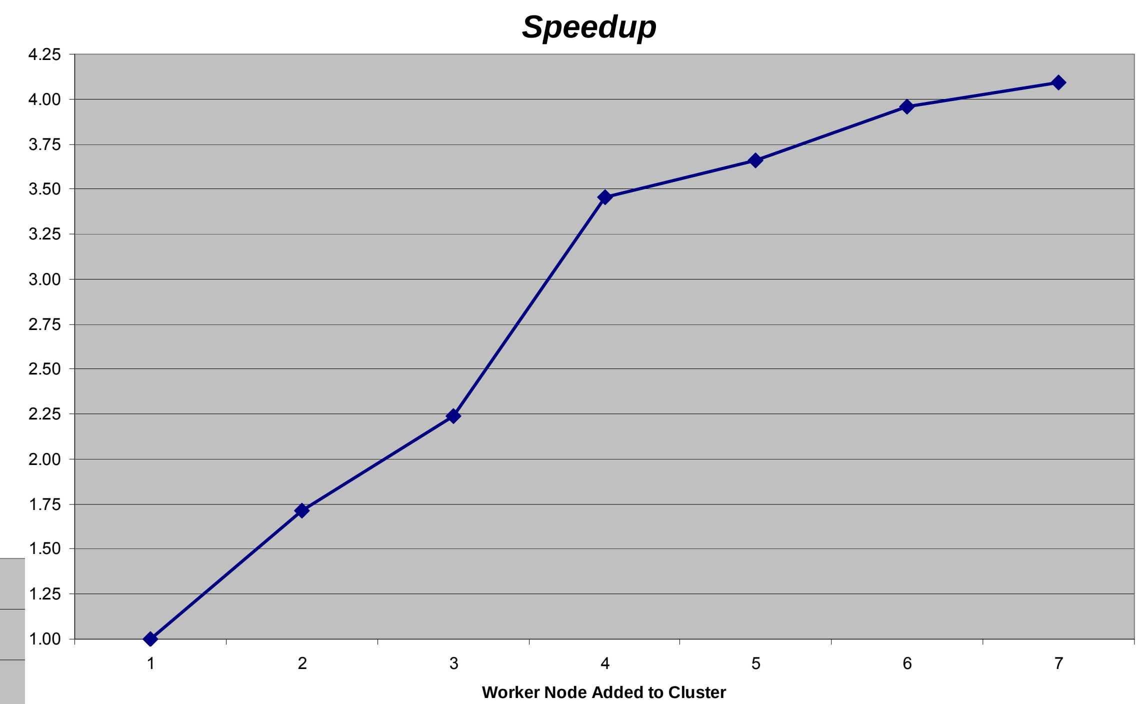
- Applied our approach to several languages and operating systems
  - Linux and Windows
  - IDL, MatLab, Simulink, C++
- Same basic philosophy applied to each
- Lessons learned on any one of these applied to all
- Enables use on plug-ins to larger tool sets
  - user interfaces
  - job management
  - workflow management
  - resource management
  - web services

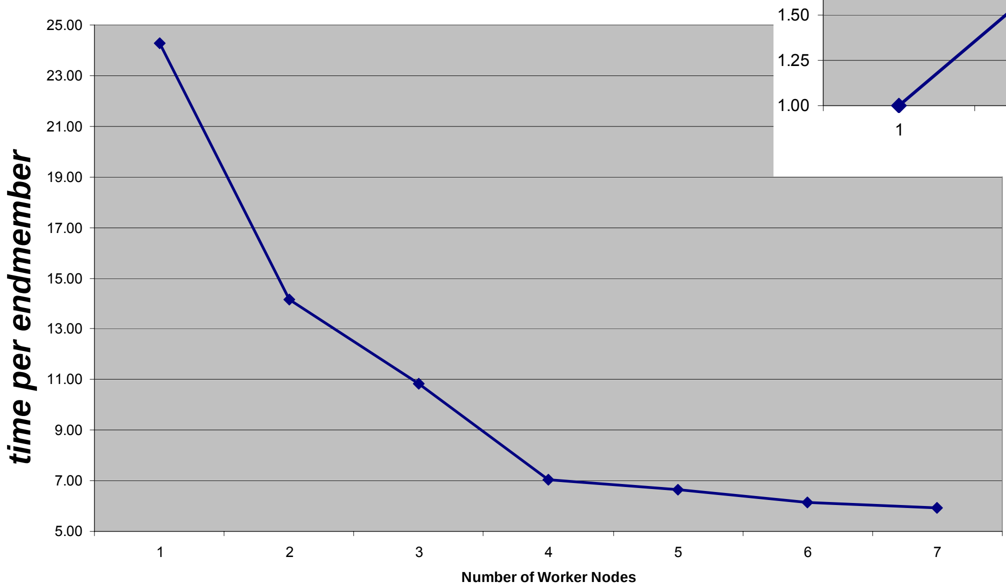
One Approach to Cluster IDL



IDL Runtime – Finding unique spectral elements

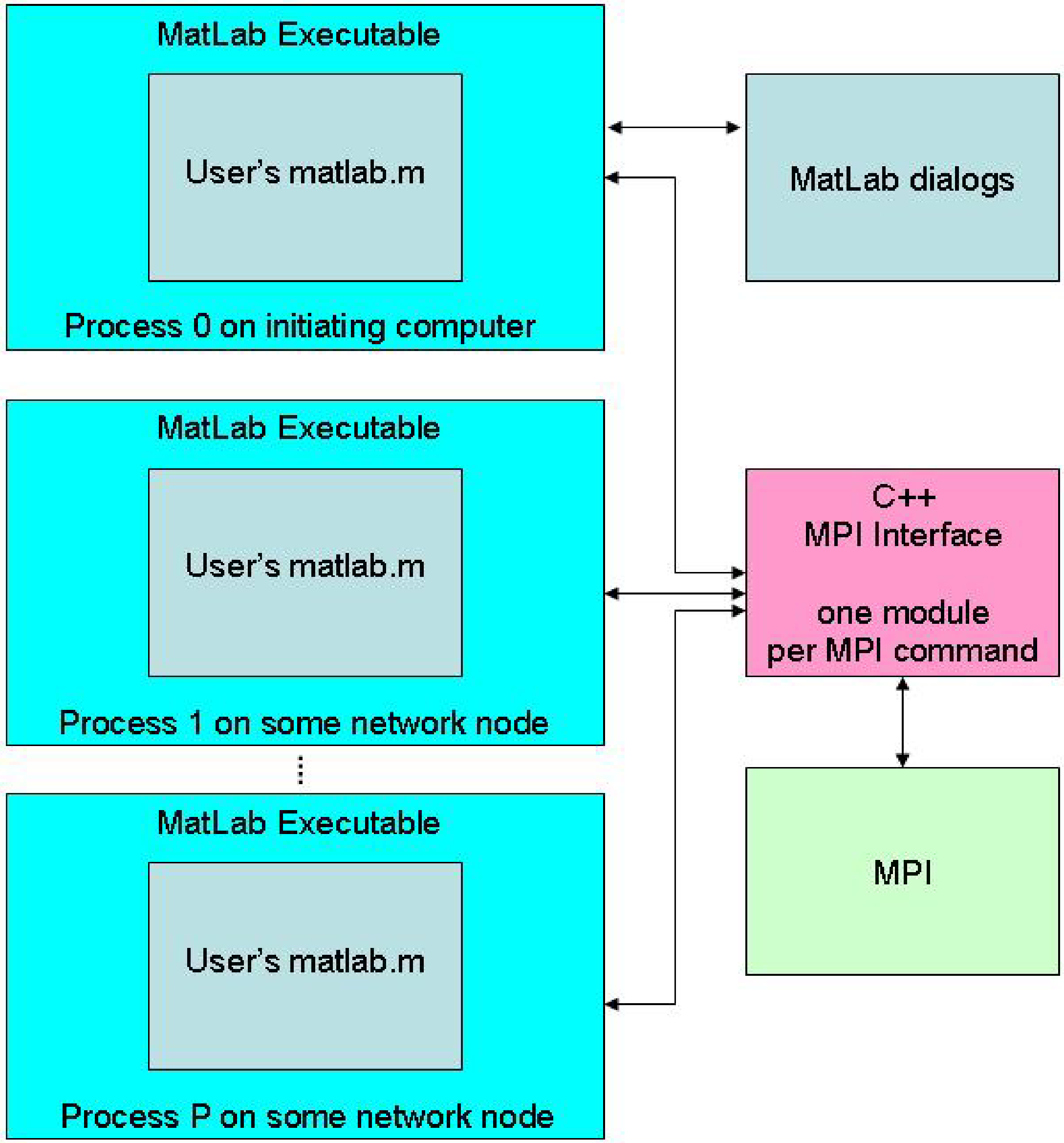
- Sought 20 unique spectral elements (endmembers)
  - hyperspectral data cube
  - 200 bands per pixel
  - 1000 x 256 pixels





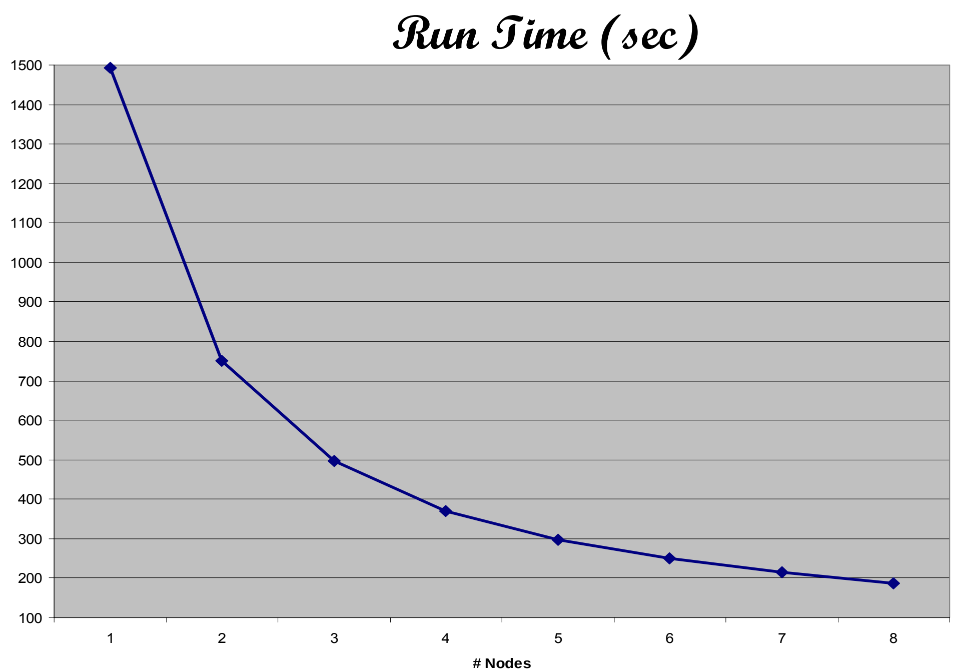
An Approach to Cluster MatLab

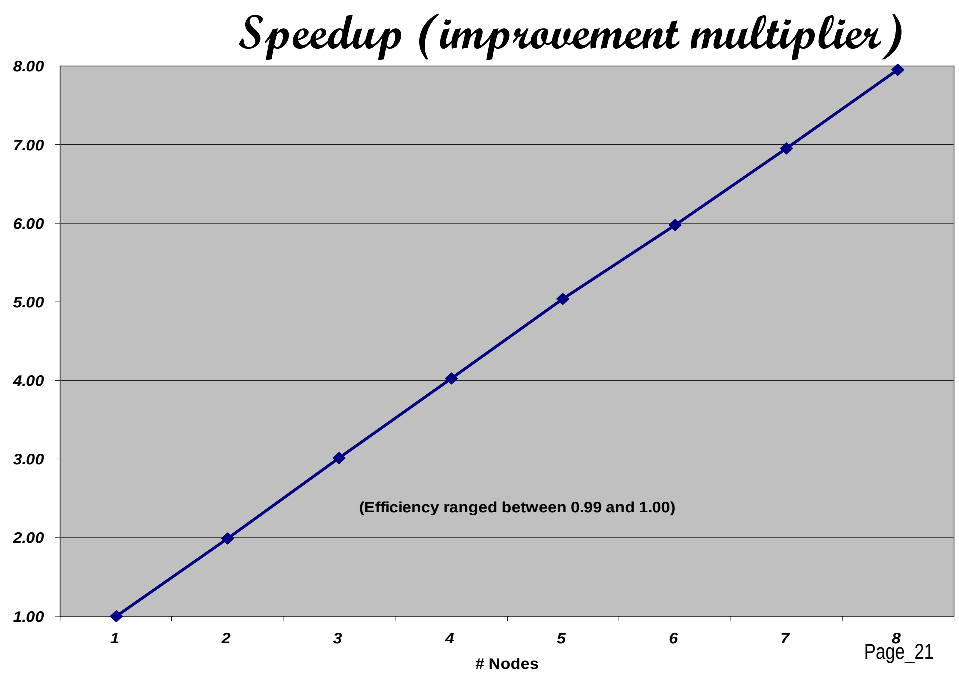
- Similar to what we do in IDL
- Avoids tool integration issues with current IDL approach
- Accommodates MatLab's "pass by value" approach to sending variables to external modules
  - MatLab paradigm based on Fortran ("pass by value")
  - MPI assumes "pass by reference"
  - MatLab can not pass new values back through function arguments



Example MatLab Run: Image Convolution

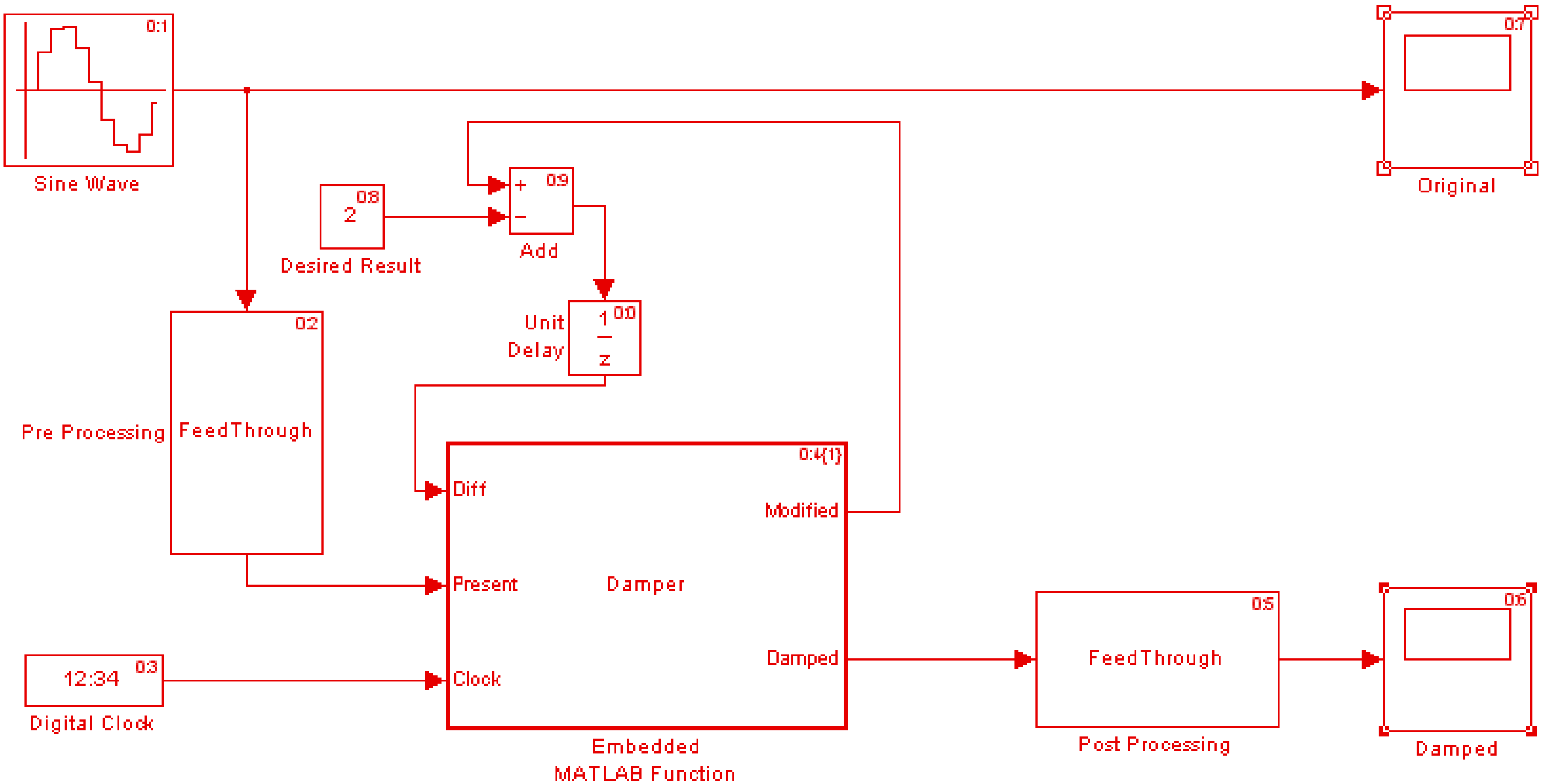
- Fundamental to image analysis
  - assigns new value to a pixel based on weighted average of neighbors
  - used to filter images in many ways for many reasons
- Convolution code written in MatLab
- 3 x 3 filter over a 2112 x 2816 grayscale image
- For this case, efficiency was nearly perfect (0.99 – 1.00)





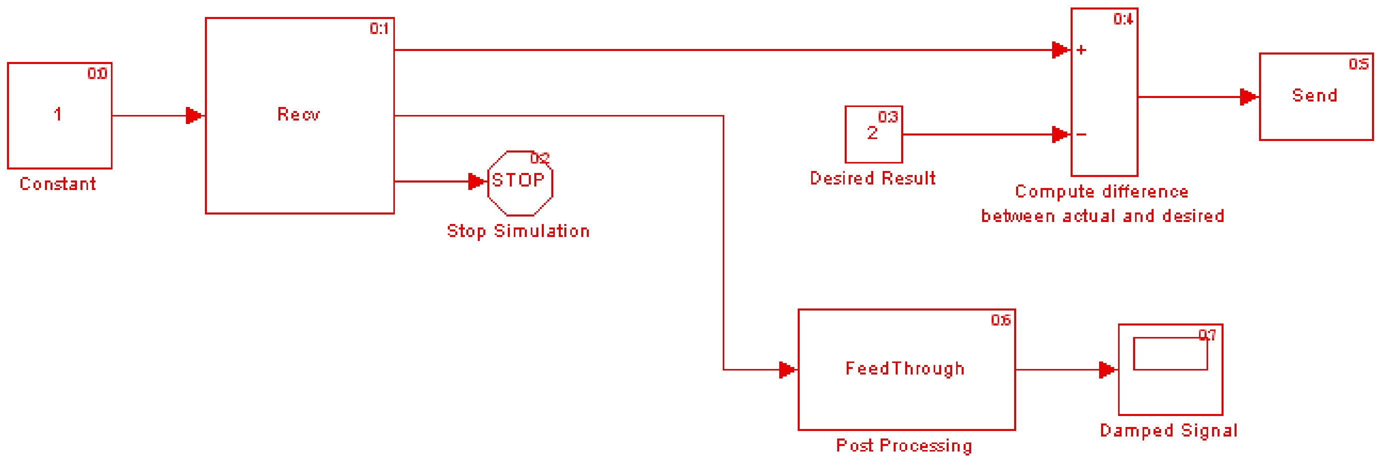
One Approach to Simulink/RTW Models

- Decompose model into independent cooperating components
- For example: dampen a signal to desired value

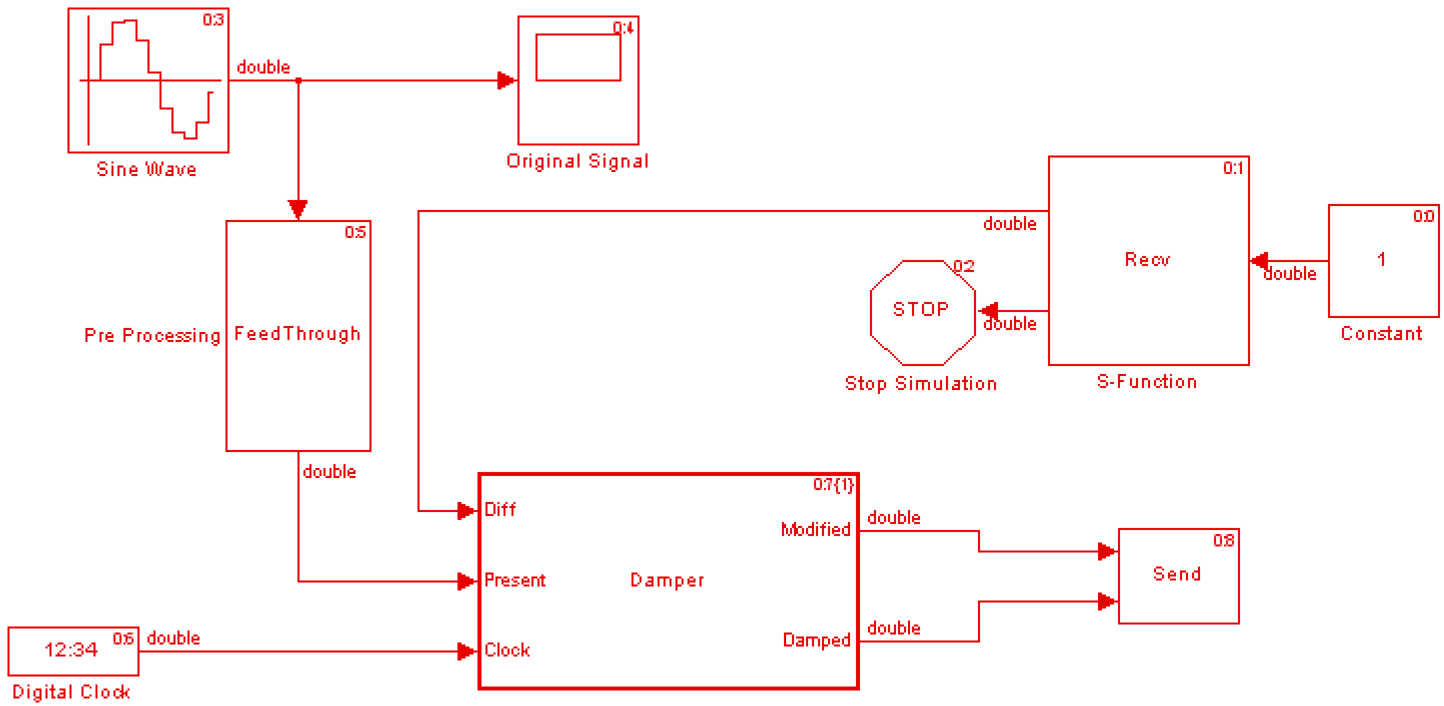


Decomposed Model
(two independent cooperating components)

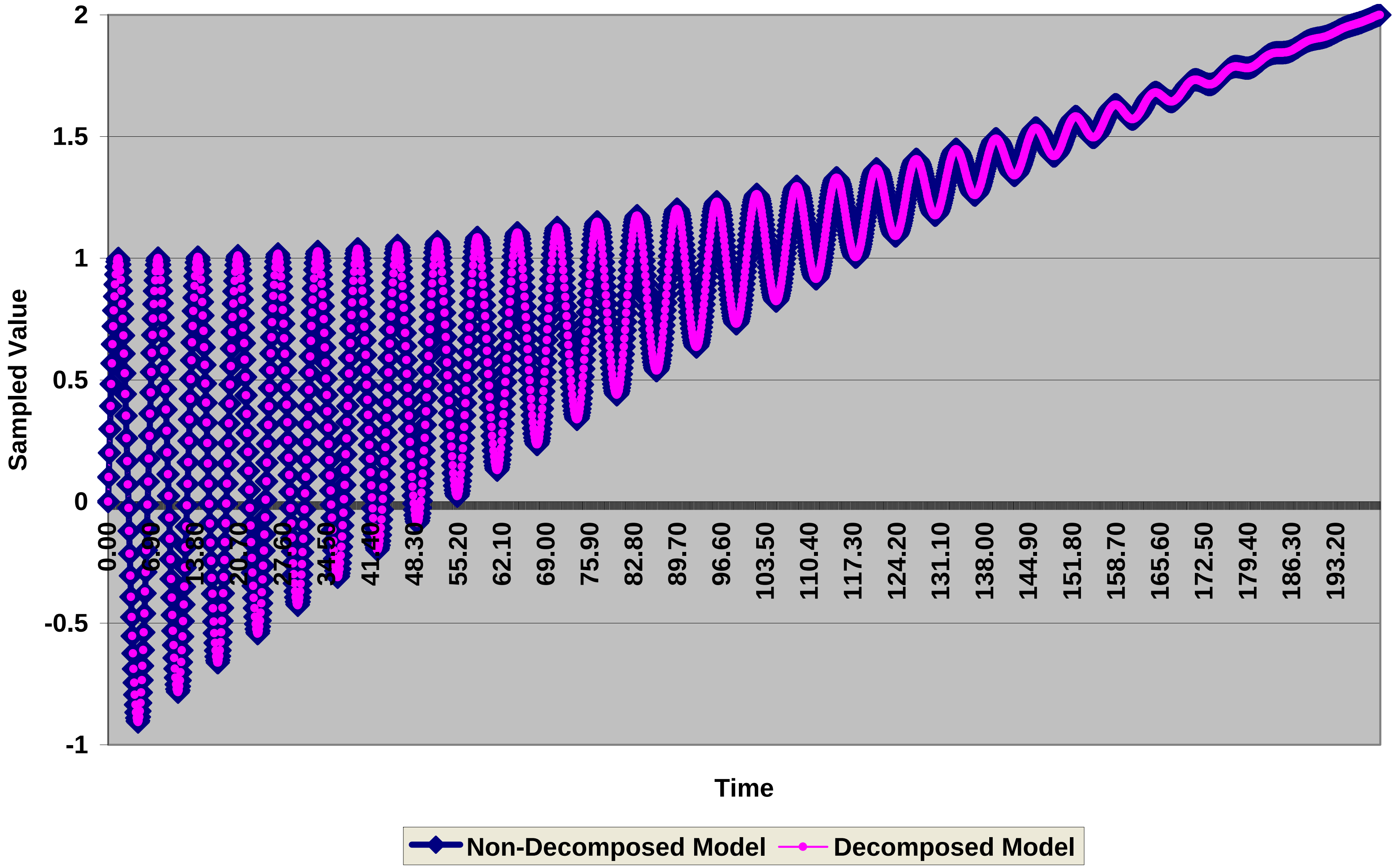
- Employ Signal



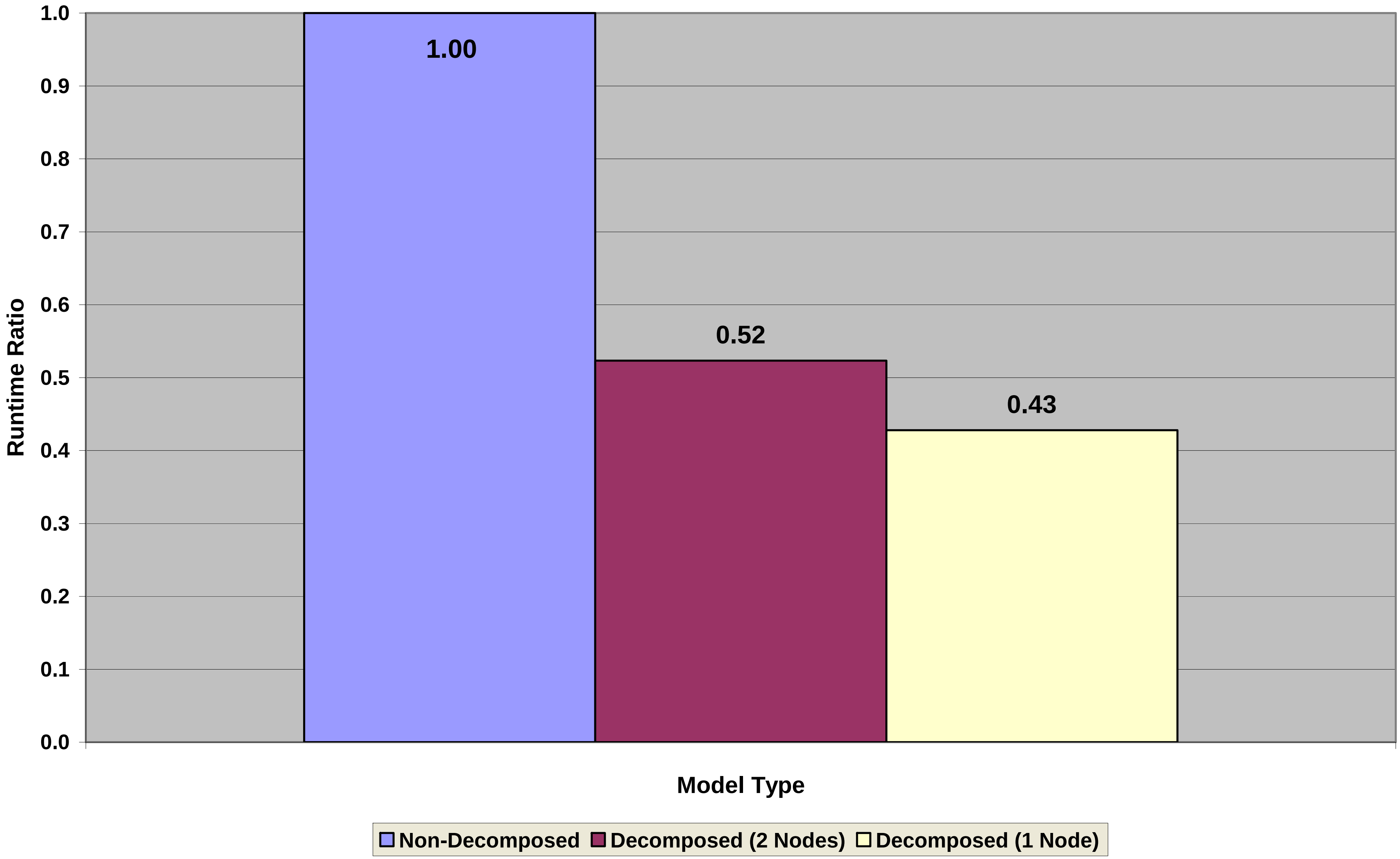
- Generate Signal



Comparing Results (non-Decomposed vs. decomposed)

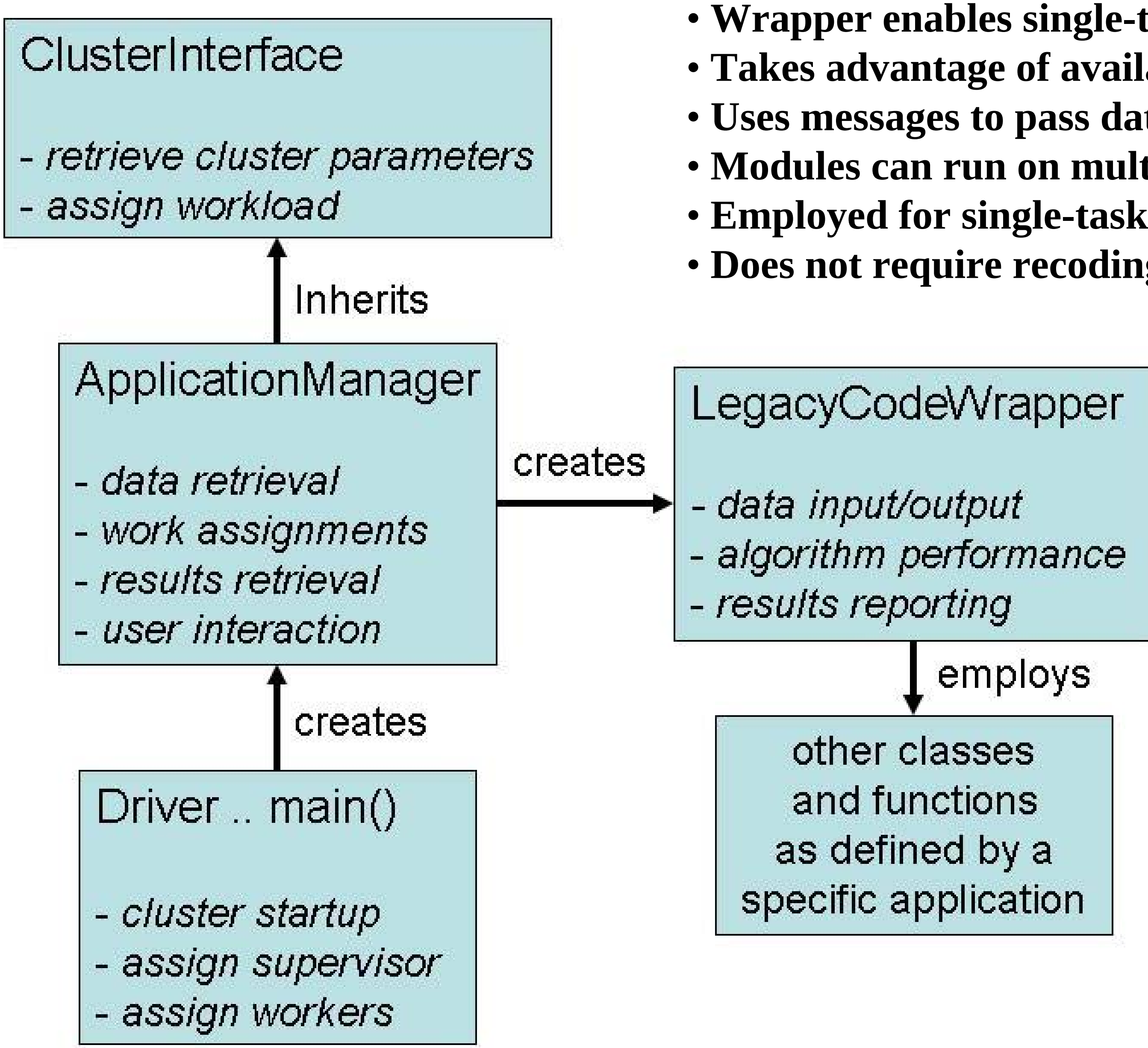


Ratio of Wall-Clock Times

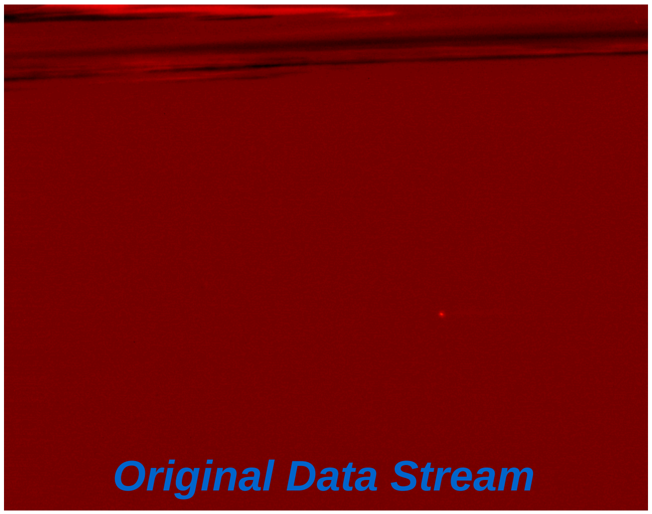


Class Wrappers for Existing Code

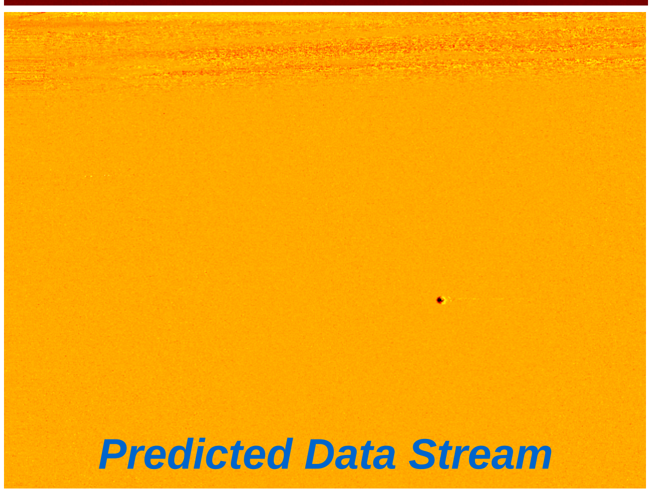
- **Wrapper enables single-task / multiple-resources**
- **Takes advantage of available cores and nodes**
- **Uses messages to pass data between modules**
- **Modules can run on multiple cores on same node**
- **Employed for single-task throughput improvement**
- **Does not require recoding to accommodate threads**



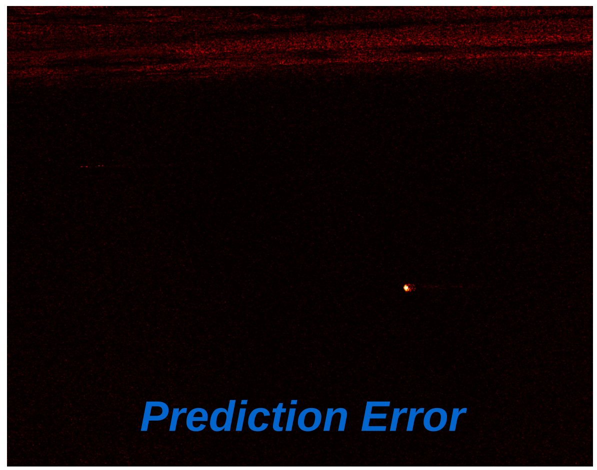
Example Application
Predictive Anomaly Detection (PAD)



Original Data Stream



Predicted Data Stream



Prediction Error

Target Nomination

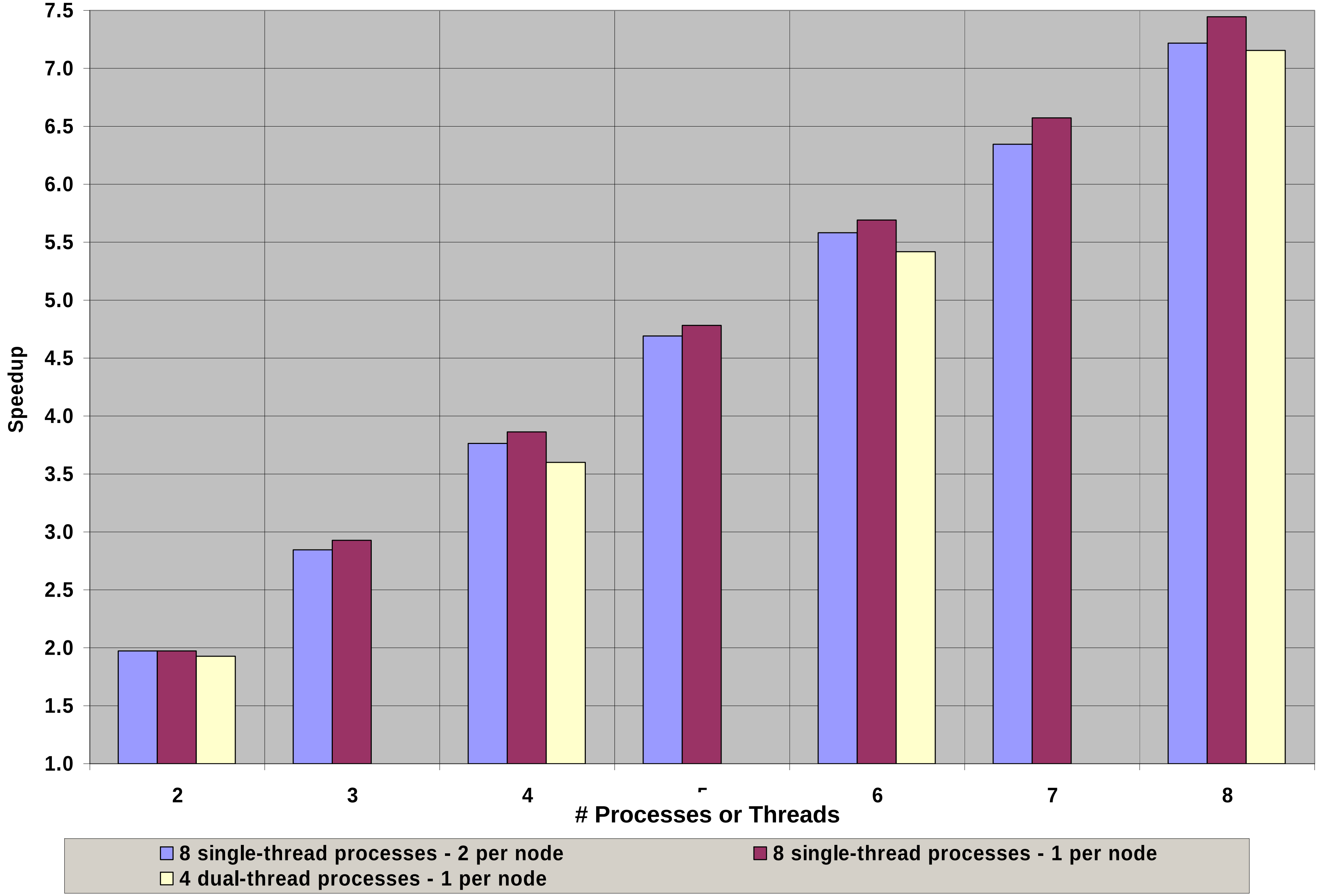
- **Target nomination in streaming data**
- **Highly generic**
- **No dependence on sensor type**
- **No physics model required**
- **Not deterministic**
- **Depends only on data temporal relationship**

Sample PAD Run

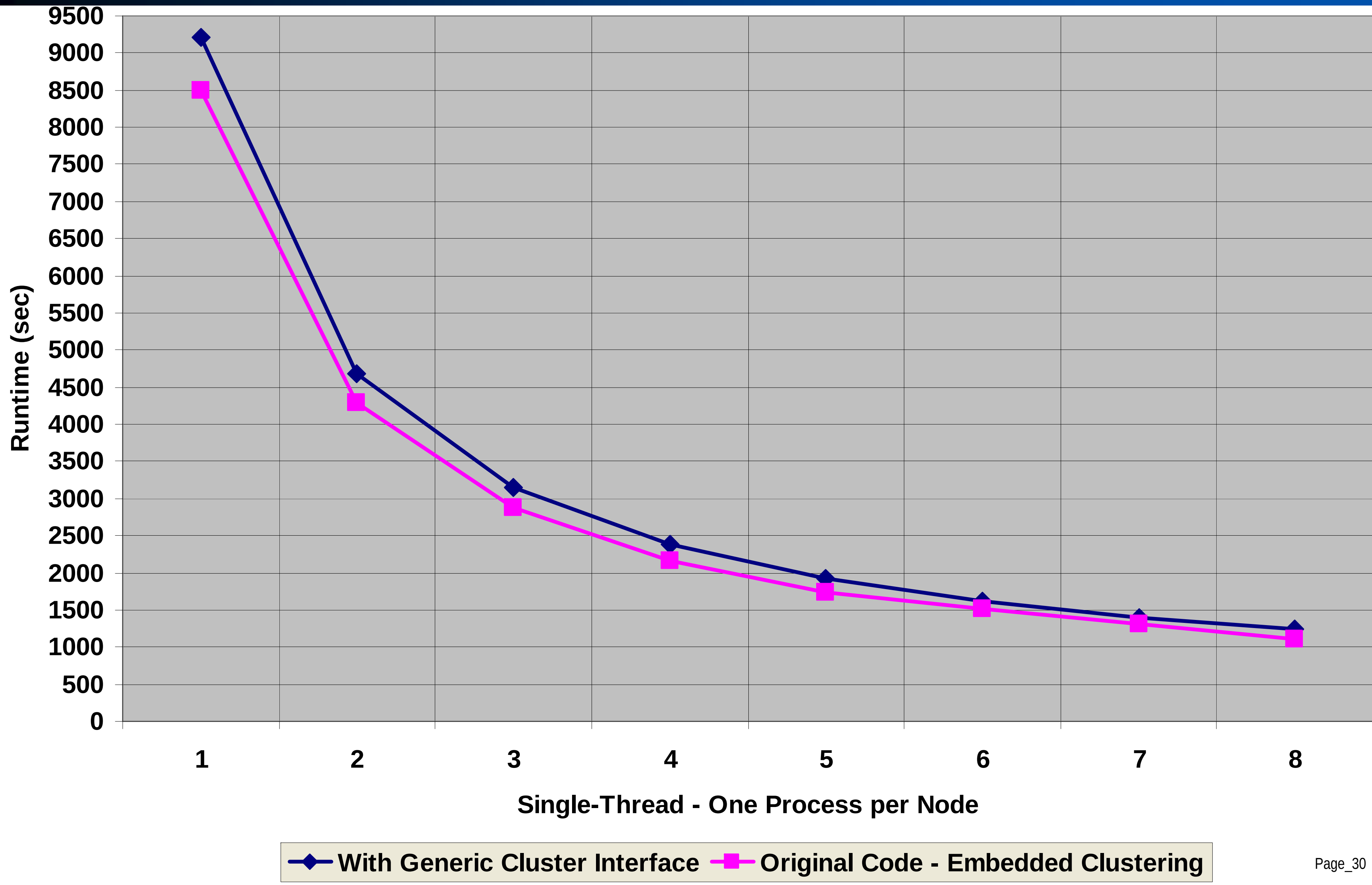
- 2200 frames (NightConqueror IR sensor, widely used in DOD)
- 512 x 640 pixels
- 60 Gaussian basis functions per pixel (19,660,800 terms total)
  - evaluate and update every frame

- Supervisor reads frame from disk
- Sends appropriate frame components to each process
- Workers process frame components
- Workers send results to supervisor
- Supervisor organizes, reports, stores results

Speedup Results
(single and multiple threads)

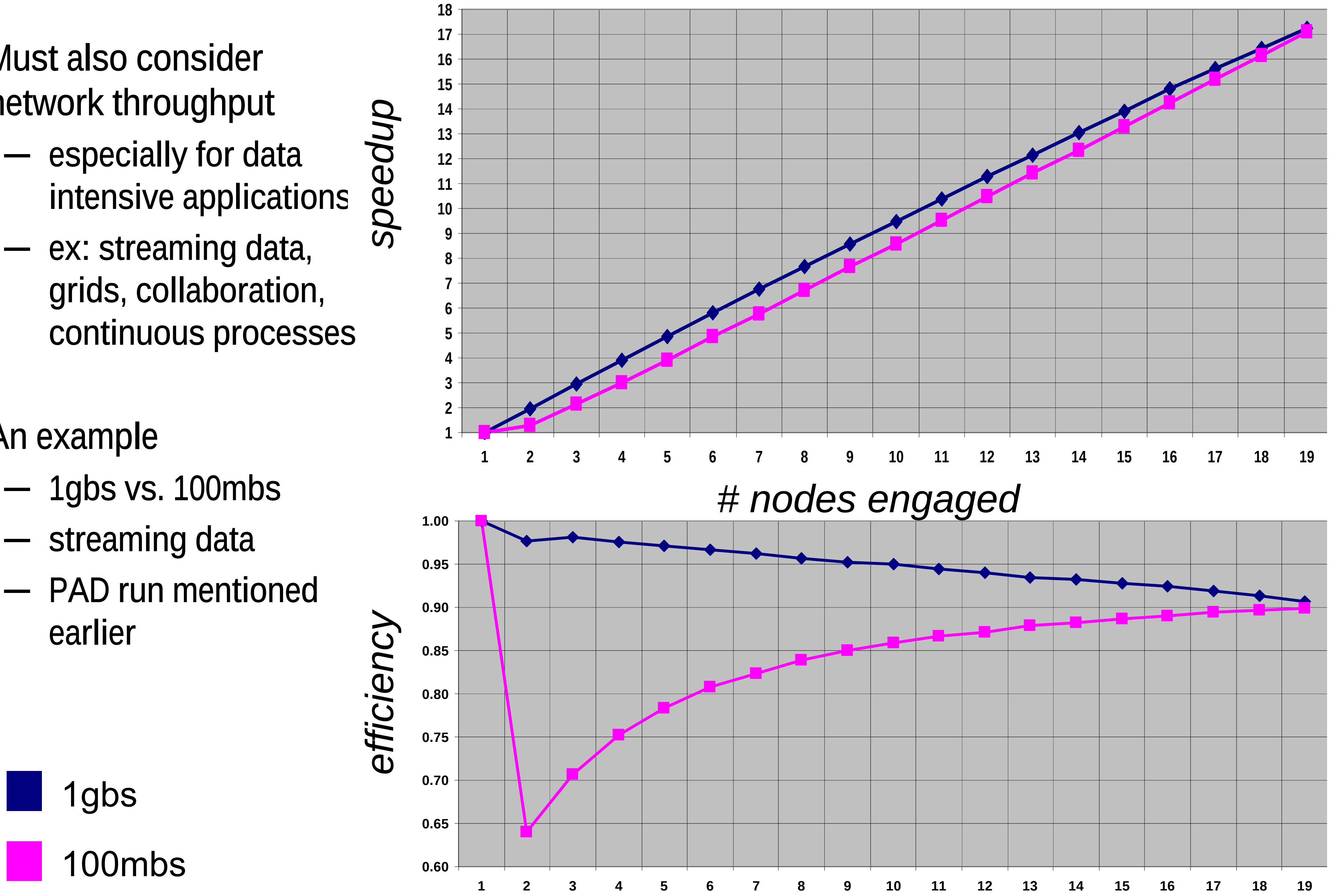


Performance Hit Using Class Wrapper



Not Just Computational Throughput

- Must also consider network throughput
  - especially for data intensive applications
  - ex: streaming data, grids, collaboration, continuous processes
- An example
  - 1gbs vs. 100mbs
  - streaming data
  - PAD run mentioned earlier



Source of Declining Throughput Gains

- Overhead
  - operating system
  - network
  - memory
  - bus speeds
  - CPU speed
  - required serial performance
  - granularity (ratio of processing vs. data passing)

Overhead can be estimated

```
f  = overhead estimation
N  = number of nodes engaged
Sn = speedup for that number of nodes
```

$$f = \frac{\frac{N}{S_N} - 1}{N - 1}$$

Amdahl (1967, 1988)
Zomaya (1996)
Raeth (2003)

Summary

- Developed philosophy for transitioning existing code to networks
- Resulted in generic approach
- Reusable - not specific to language, OS, platform, algorithm
- Dealing with application throughput, not just computational issues
- Benefits of the work
  - transition existing software to network environment without re-engineering
  - risk reduction during transition process
  - combines of network architectures with object-oriented concepts
    - but, does not require OO languages
  - employs independent, yet cooperative, processes
  - results in portable network processes
  - does not require new capital investment to yield significant benefits

Biography

Amdahl, G.M. (1967). “Validity of the Single-Processor Approach to Achieving Large Scale Computing Capabilities”. Proc AFIPS, v 30, 483-485.

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