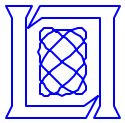

# Parallel Matlab: The Next Generation


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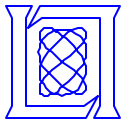
## Ms. Nadya Travinin / MIT Lincoln Laboratory



**This work is sponsored by the Department of Defense under Air Force Contract F19628-00-C-0002. Opinions, interpretations, conclusions, and recommendations are those of the author and are not necessarily endorsed by the United States Government.**



# Outline

- **Introduction**
  - *Motivation*
  - *Challenges*
- Approach
- Performance Results
- Future Work and Summary

# Motivation: DoD Need

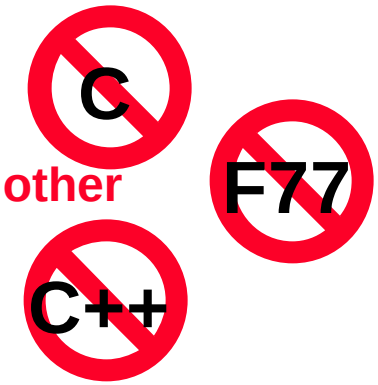
- **Cost**

**= 4 lines of DoD code**

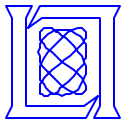
- **DoD has a clear need to rapidly develop, test and deploy new techniques for analyzing sensor data**
  - **Most DoD algorithm development and simulations are done in Matlab**
  - **Sensor analysis systems are implemented in other languages**
  - **Transformation involves years of software development, testing and system integration**

- **MatlabMPI allows any Matlab program to become a high performance parallel program**

# Challenges: Why Has This Been Hard?



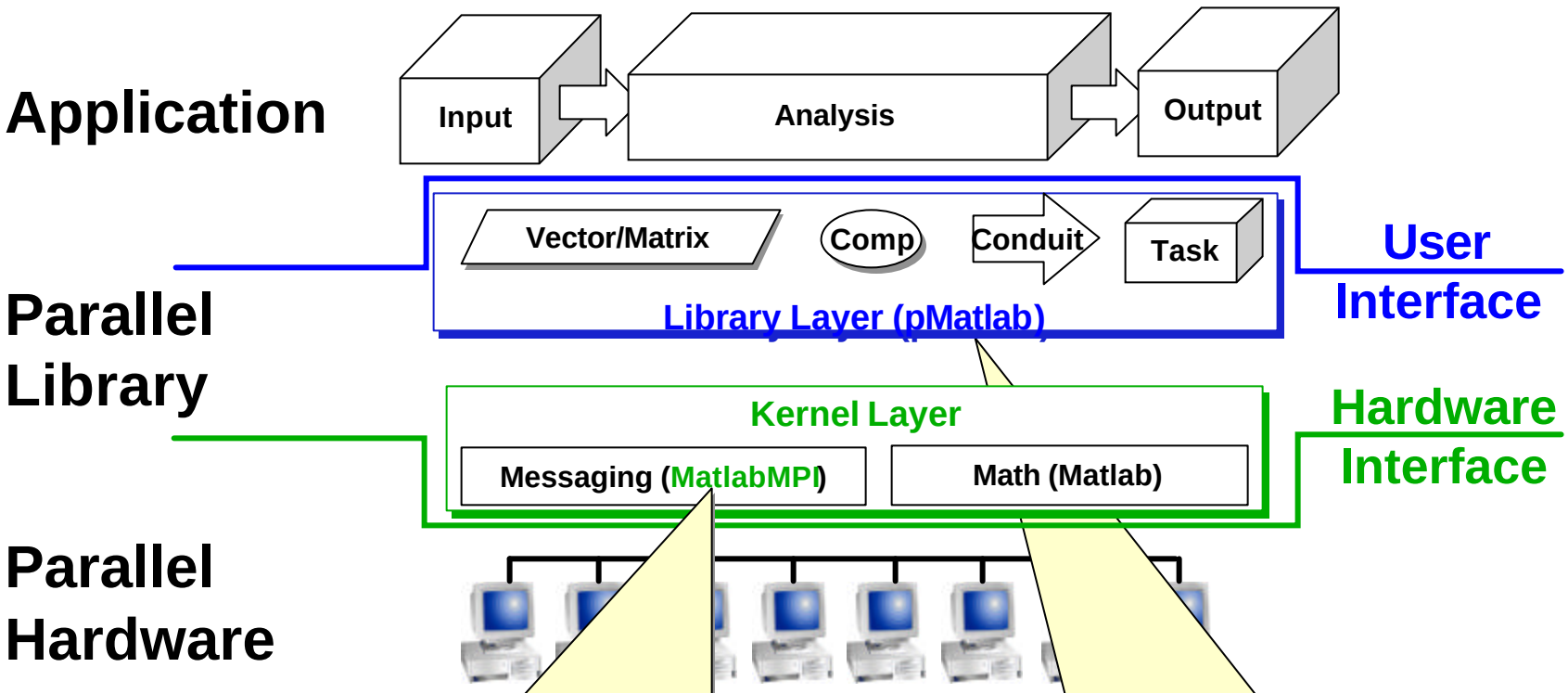

- **Productivity**
  - **Most users will not touch any solution that requires other languages (even cmex)**
- **Portability**
  - **Most users will not use a solution that could potentially make their code non-portable in the future**
- **Performance**
  - **Most users want to do very simple parallelism**
  - **Most programs have long latencies (do not require low latency solutions)**



# Outline

- Introduction
- **Approach**
  - ***MatlabMPI messaging***
  - ***pMatlab programming***
- Performance Results
- Future Work and Summary

# MatlabMPI & pMatlab Software Layers

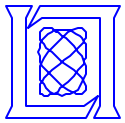



- Can build a parallel library with a few messaging primitives
- MatlabMPI provides this messaging capability:

```
MPI_Send(dest,comm,tag,X);
X = MPI_Recv(source,comm,tag);
```

- Can build a application with a few parallel structures and functions
- pMatlab provides parallel arrays and functions

```
X = ones(n,mapX);
Y = zeros(n,mapY);
Y(:,:) = fft(X);
```



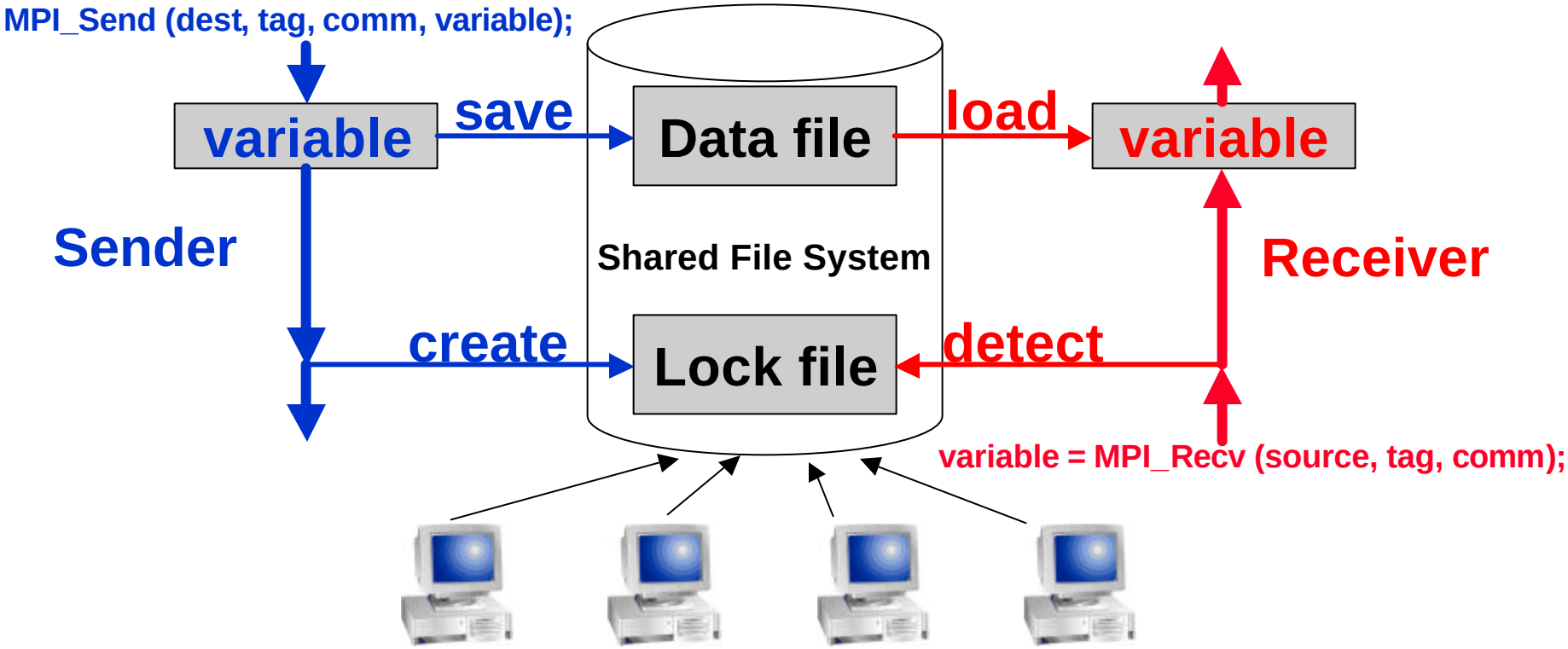
# MatlabMPI fuctionality

- "Core Lite" Parallel computing requires eight capabilities
  - MPI_Run launches a Matlab script on multiple processors
  - MPI_Comm_size returns the number of processors
  - MPI_Comm_rank returns the id of each processor
  - MPI_Send sends Matlab variable(s) to another processor
  - MPI_Recv receives Matlab variable(s) from another processor
  - MPI_Init called at beginning of program
  - MPI_Finalize called at end of program

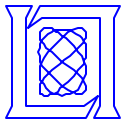
- Additional convenience functions
  - MPI_Abort kills all jobs
  - MPI_Bcast broadcasts a message
  - MPI_Probe returns a list of all incoming messages
  - MPI_cc passes program through Matlab compiler
  - MatMPI_Delete_all cleans up all files after a run
  - MatMPI_Save_messages toggles deletion of messages
  - MatMPI_Comm_settings user can set MatlabMPI internals

# MatlabMPI: Point-to-point Communication

- Any messaging system can be implemented using file I/O
- File I/O provided by Matlab via load and save functions
  - Takes care of complicated buffer packing/unpacking problem
  - Allows basic functions to be implemented in ~250 lines of Matlab code




- Sender saves variable in Data file, then creates Lock file
- Receiver detects Lock file, then loads Data file



# Example: Basic Send and Receive

- **Initialize**
- **Get processor ranks**

- **Execute send**
- **Execute recieve**

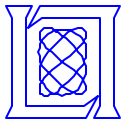
- **Finalize**
- **Exit**

```
MPI_Init;                              % Initialize MPI.
comm = MPI_COMM_WORLD;                 % Create communicator.
comm_size = MPI_Comm_size(comm);       % Get size.
my_rank = MPI_Comm_rank(comm);         % Get rank.
source = 0;                            % Set source.
dest = 1;                              % Set destination.
tag = 1;                               % Set message tag.

if(comm_size == 2)                     % Check size.
  if (my_rank == source)               % If source.
    data = 1:10;                       % Create data.
    MPI_Send(dest,tag,comm,data);      % Send data.
  end
  if (my_rank == dest)                 % If destination.
    data=MPI_Recv(source,tag,comm);    % Receive data.
  end
end

MPI_Finalize;                          % Finalize Matlab MPI.
exit;                                  % Exit Matlab
```

- **Uses standard message passing techniques**
- **Will run anywhere Matlab runs**
- **Only requires a common file system**



# pMatlab Goals

- ***Allow a Matlab user to write parallel programs with the least possible modification to their existing matlab programs***

- **New parallel concepts should be intuitive to matlab users**
  - **parallel matrices and functions instead of message passing**
  - **Matlab*P interface**

- **Support the types of parallelism we see in our applications**
  - **data parallelism (distributed matrices)**
  - **task parallelism (distributed functions)**
  - **pipeline parallelism (conduits)**

- **Provide a single API that potentially a wide number of organizations could implement (e.g. Mathworks or others)**
  - **unified syntax on all platforms**

- **Provide a unified API that can be implemented in multiple ways,**
  - **Matlab*P implementation**
  - **Multimatlab**
  - **matlab-all-the-way-down implementation**
  - **unified hybrid implementation (desired)**

# Structure of pMatlab Programs

Initialize globals

```
pMATLAB_Init;

mapX = map([1 N/2],{},[1:N/2]);
mapY = map([N/2 1],{},[N/2+1:N]);
X = ones(n, mapX);
Y = zeros(n, mapY);
Y(:,:) = fft(X);

pMATLAB_Finalize;
```

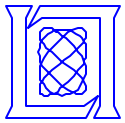
Clear globals

Map to sets of processors

Distributed matices

Parallel FFT and "Corner Turn" Redistribution

- Can parallelize code by changing a few lines
- Built on top of MatlabMPI (pure Matlab)
- Moving towards Matlab*P interface



# pMatlab Library Functionality

- "Core Lite" Provides distributed array storage class (up to 4D)
  - Supports reference and assignment on a variety of distributions:
    - Block, Cyclic, Block-Cyclic, Block-Overlap

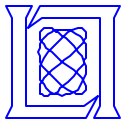
  Status: Available

- "Core" Overloads most array math functions
  - good parallel implementations for certain mappings

  Status: In Development

- "Core Plus" Overloads entire Matlab library
  - Supports distributed cell arrays
  - Provides best performance for every mapping

  Status: Research



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  - *pMatlab*
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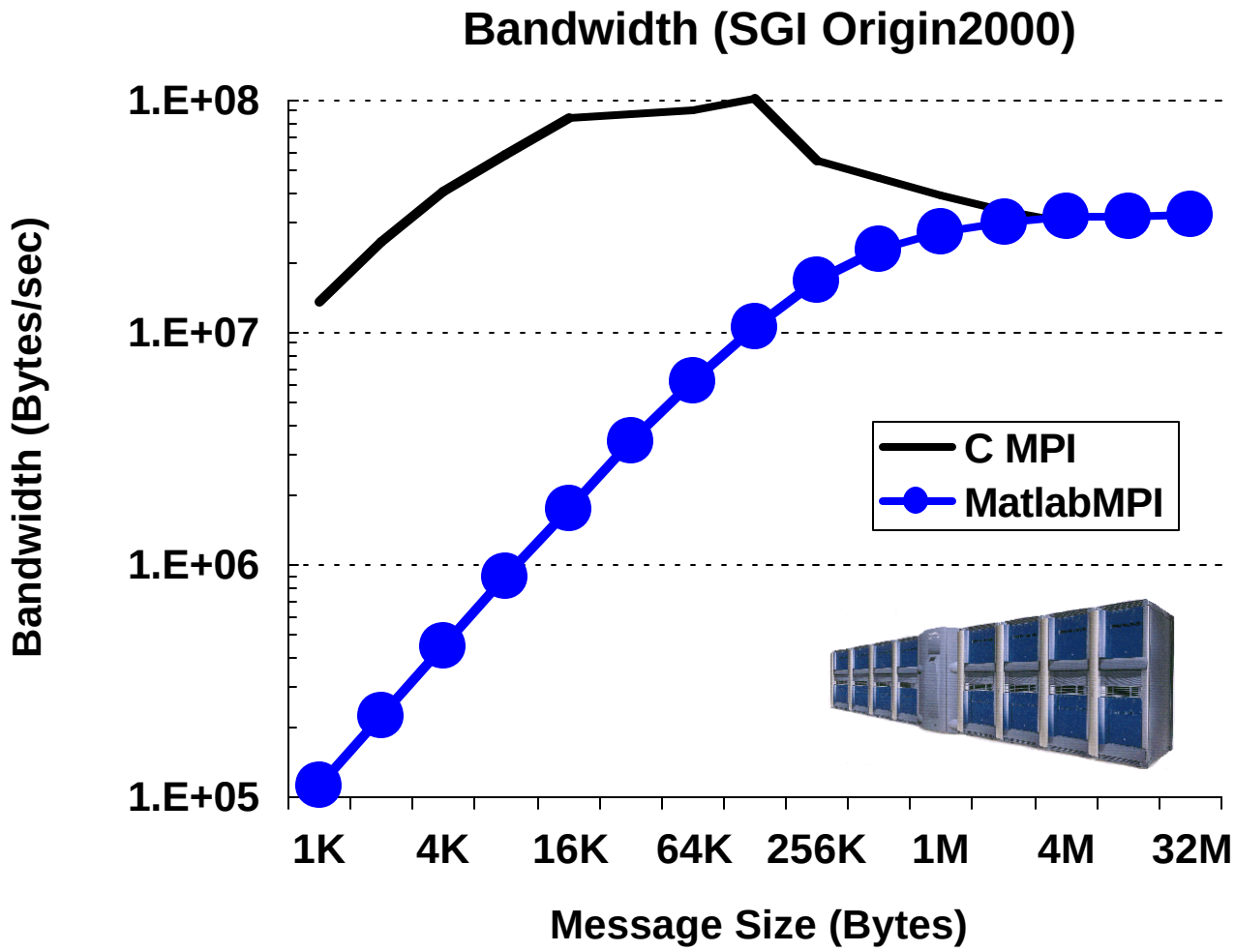
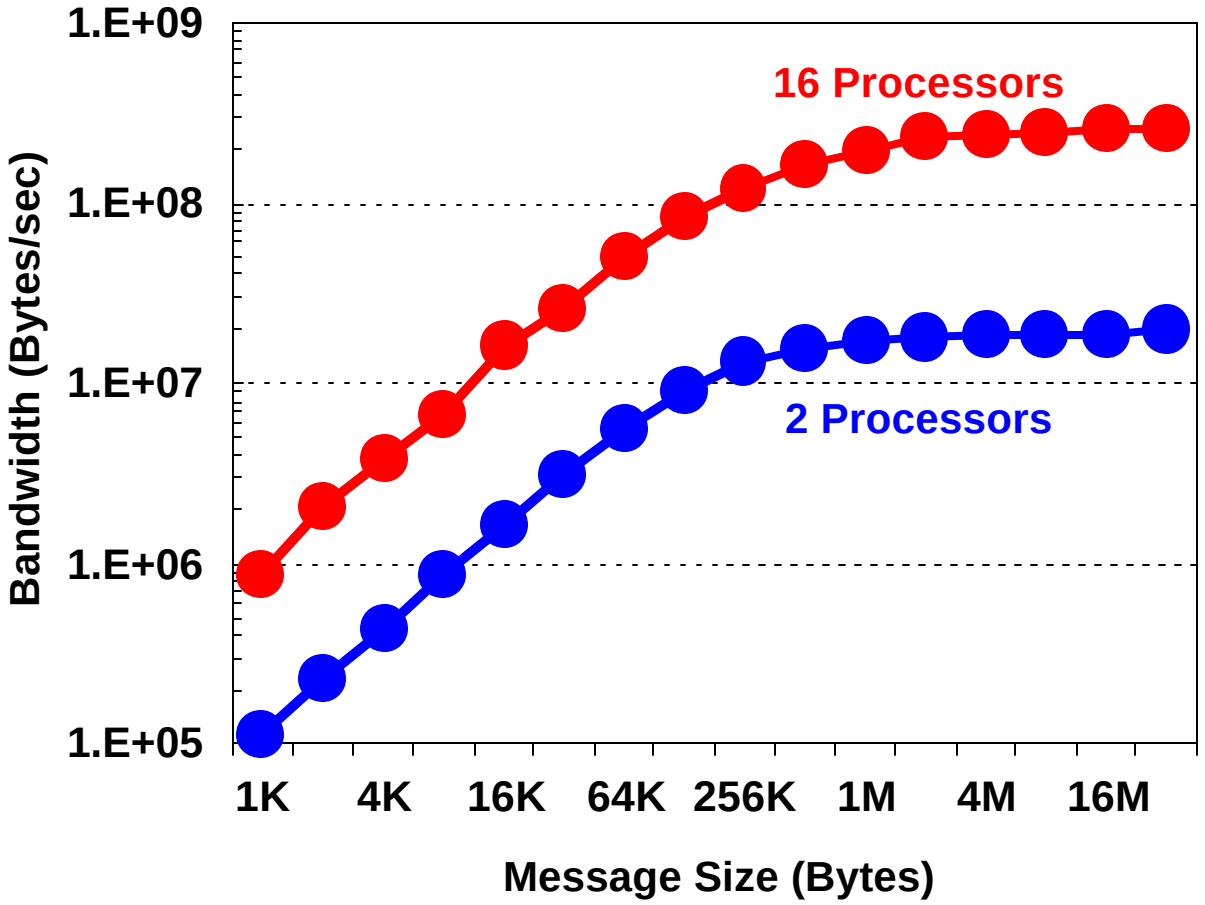
# MatlabMPI vs MPI bandwidth




- Bandwidth matches native C MPI at large message size
- Primary difference is latency (35 milliseconds vs. 30 microseconds)

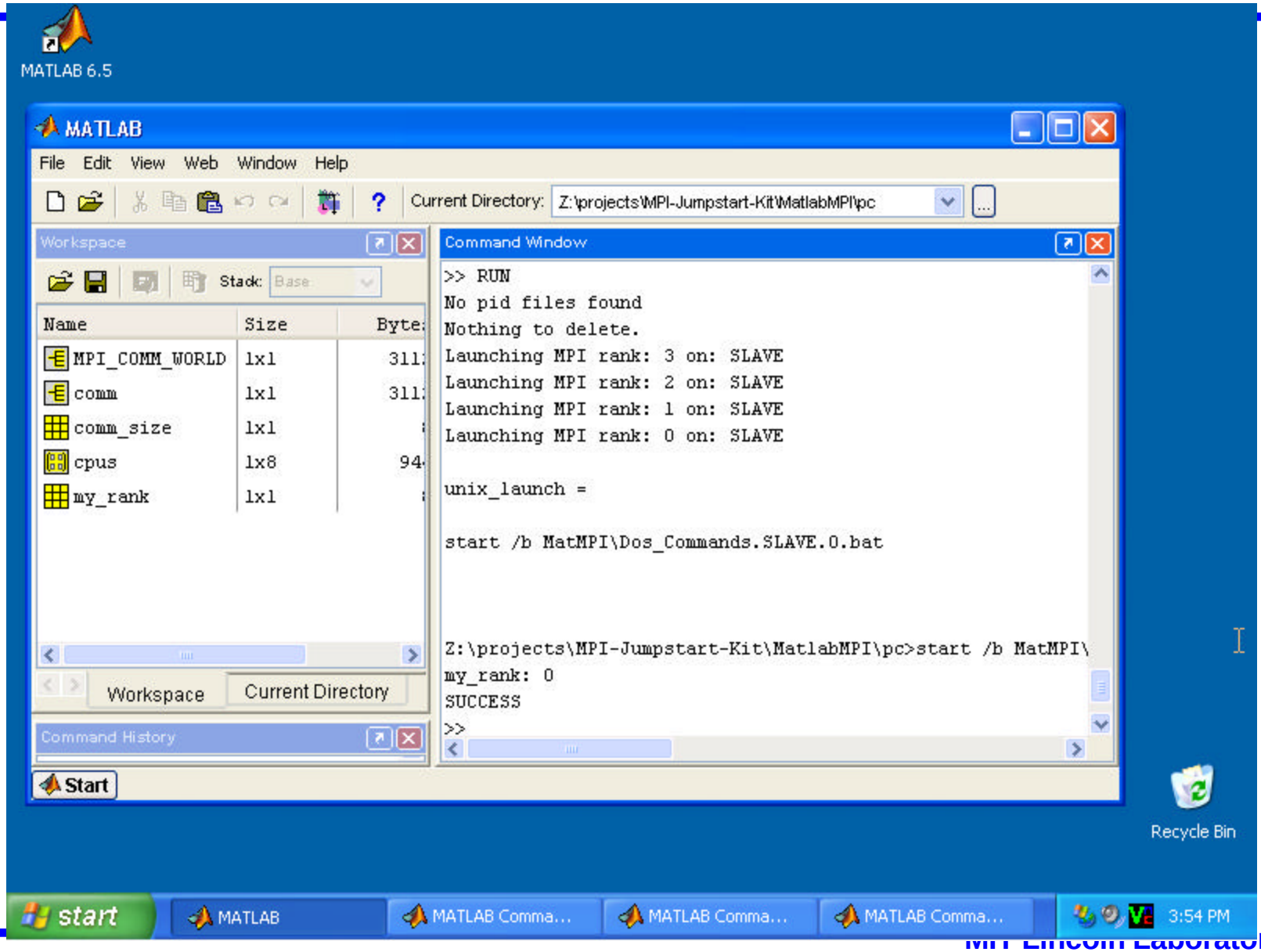
# MatlabMPI bandwidth scalability

## Linux w/Gigabit Ethernet

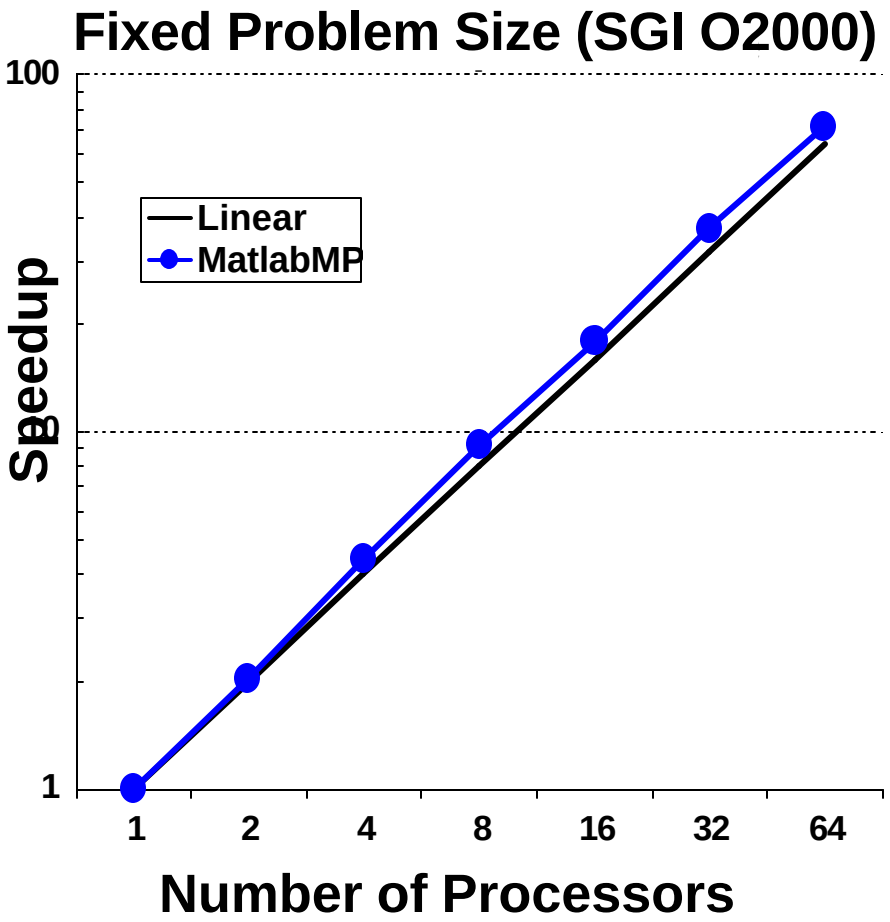


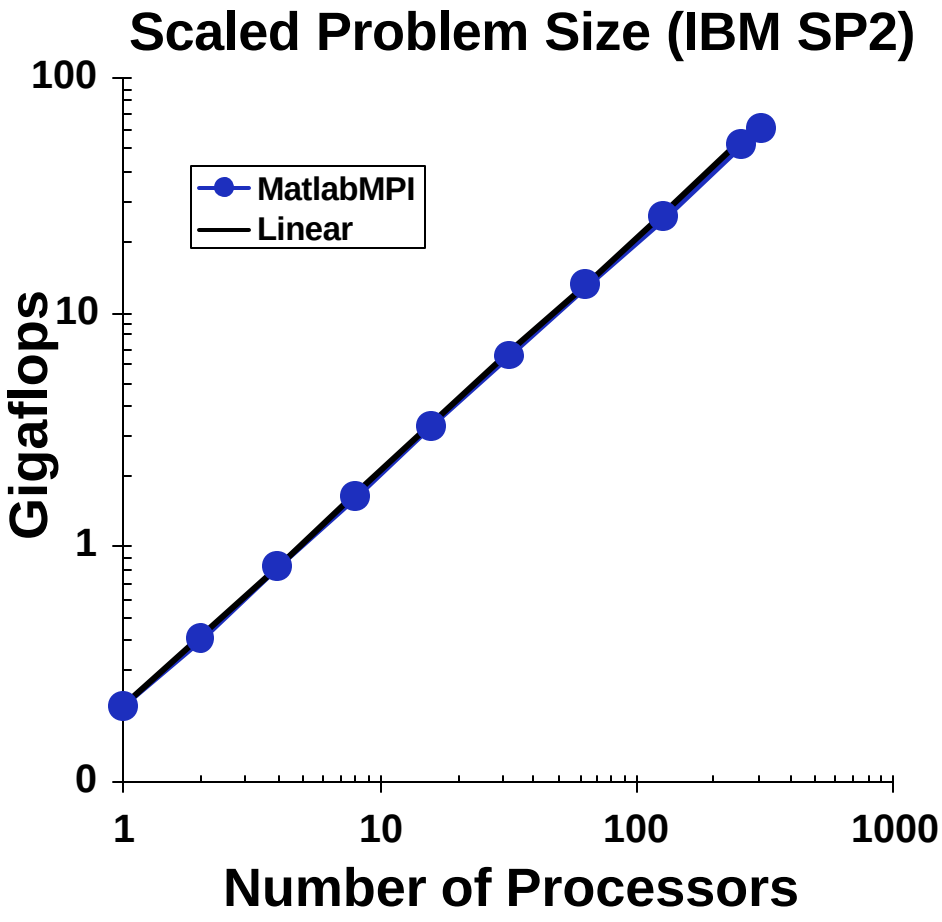

- Bandwidth scales to multiple processors
- Cross mounting eliminates bottlenecks

# MatlabMPI on WindowsXP



# MatlabMPI Image Filtering Performance




- Achieved "classic" super-linear speedup on fixed problem
- Achieved speedup of ~300 on 304 processors on scaled problem

# “Cognitive” Algorithms

- Challenge: applications requiring vast data; real-time; large memory
- Approach: test parallel processing feasibility using MatlabMPI software
- Results: algorithms rich in parallelism; significant acceleration achieved with minimal (100x less) programmer effort

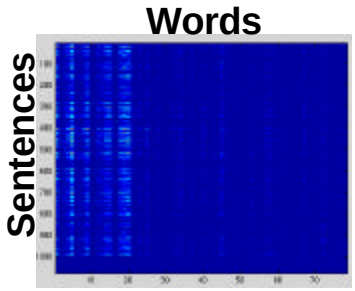
## Contextual vision

Image Face Map

Torralba (AI Lab) / Kepner (Lincoln)

Coarse Grained
Image Parallel
(Static Client Server)

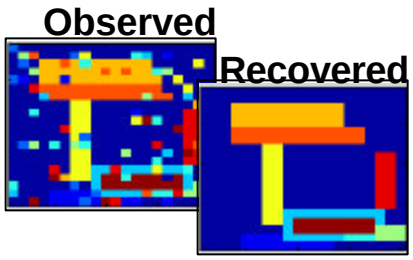
## Text Processing




Murphy (AI Lab) / Kepner (Lincoln)

Medium Grained
Sentence Parallel
(Block Cyclic Dynamic Client Server)

## Image Segmentation




Murphy (AI Lab) / Kepner (Lincoln)

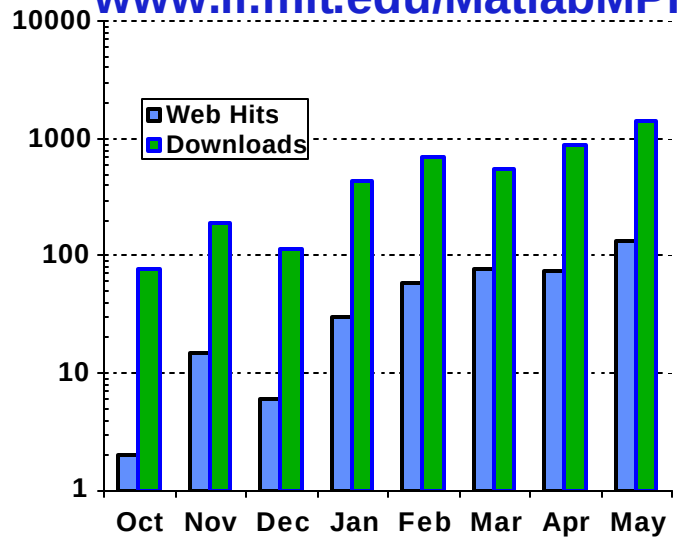
Fine Grained
Pixel Parallel
(Block Nearest Neighnor Overlap)

| Application | Algorithm | CPUs / Speedup / Effort |
|---|---|---|
| Contextual vision | Statistical object detection | 16 / 9.4x / 3 hrs |
| Text processing | Expectation maximization | 14 / 9.7x / 8 hrs |
| Image segment. | Belief propagation | 12 / 8x - x / 4 hrs |

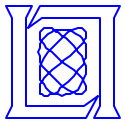
# Current MatlabMPI deployment

- Lincoln Signal processing (7.8 on 8 cpus, 9.4 on 8 duals)
- Lincoln Radar simulation (7.5 on 8 cpus, 11.5 on 8 duals)
- Lincoln Hyperspectral Imaging (~3 on 3 cpus)
- MIT LCS Beowulf (11 Gflops on 9 duals)
- MIT AI Lab Machine Vision
- OSU EM Simulations
- ARL SAR Image Enhancement
- Wash U Hearing Aid Simulations
- So. Ill. Benchmarking
- JHU Digital Beamforming
- ISL Radar simulation
- URI Heart modeling

www.ll.mit.edu/MatlabMPI




- Rapidly growing MatlabMPI user base
- Web release creating hundreds of users
  http://www.ll.mit.edu/MatlabMPI



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  - ***pMatlab***
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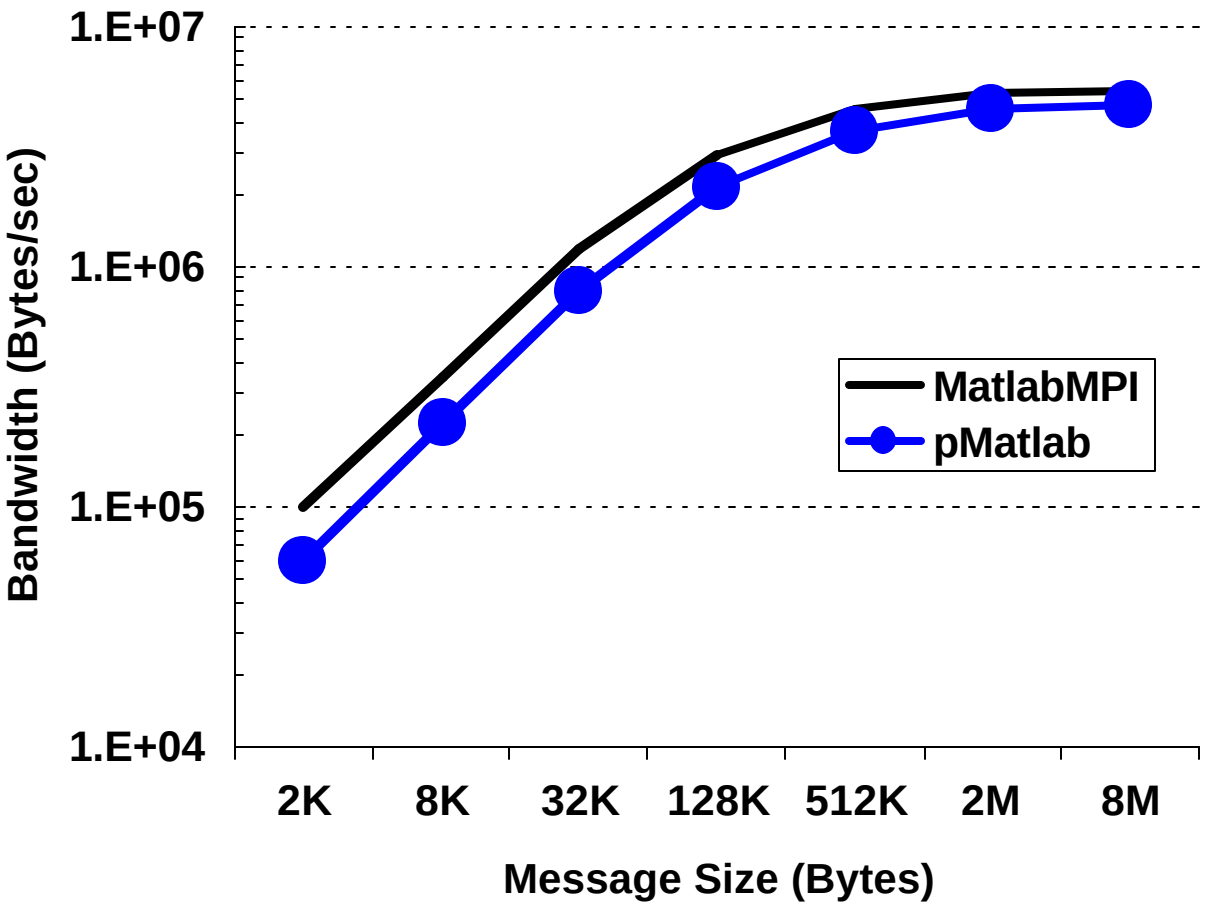
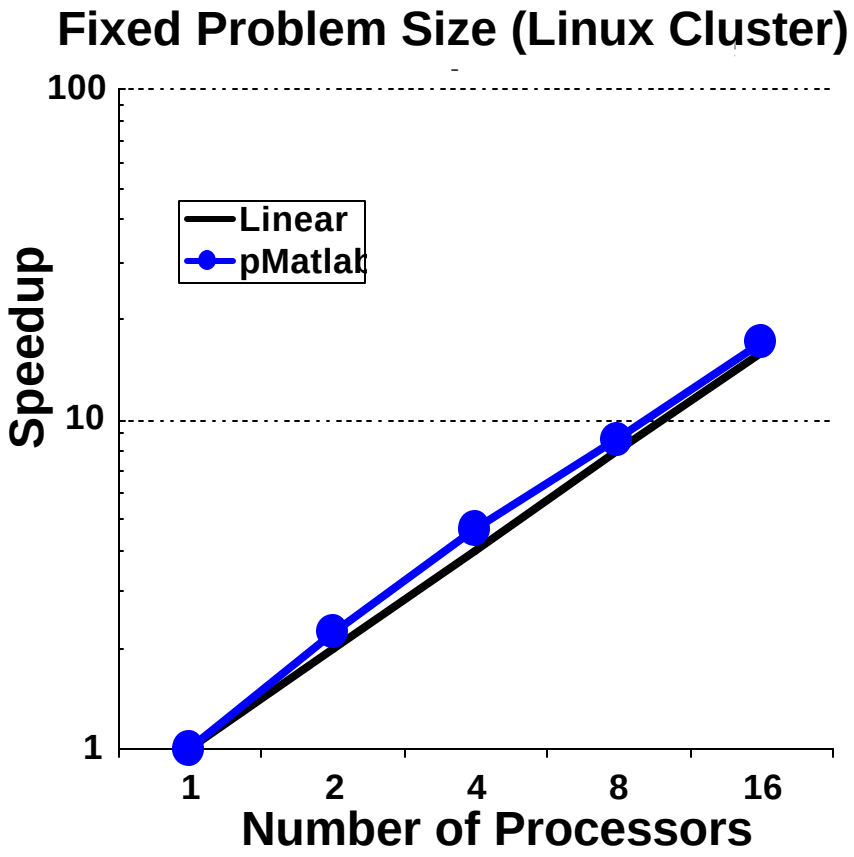
# pMatlab vs. MatlabMPI bandwidth




Linux Cluster

- Bandwidth matches underlying MatlabMPI
- Primary difference is latency (35 milliseconds vs. 70 milliseconds)

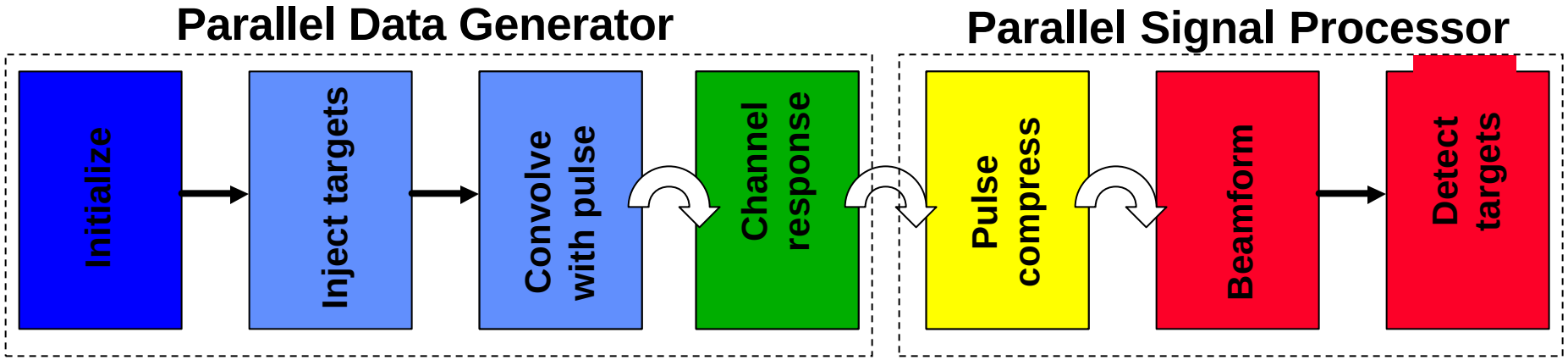
# Clutter Simulation Performance




```
% Initialize
pMATLAB_Init; Ncpus=comm_vars.comm_size;

% Map X to first half and Y to second half.
mapX=map([1 Ncpus/2],{},[1:Ncpus/2])
mapY=map([Ncpus/2 1],{},[Ncpus/2+1:Ncpus]);

% Create arrays.
X = complex(rand(N,M,mapX),rand(N,M,mapX));
Y = complex(zeros(N,M,mapY);

% Initialize coefficents
coefs = ...
weights = ...

% Parallel filter + corner turn.
Y(:,:) = conv2(coefs,X);
% Parallel matrix multiply.
Y(:,:) = weights*Y;

% Finalize pMATLAB and exit.
pMATLAB_Finalize; exit;
```

- Achieved “classic” super-linear speedup on fixed problem
- Serial and Parallel code “identical”

# Eight Stage Simulator Pipeline



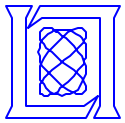

Example Processor Distribution

- 0, 1
- 2, 3
- 4, 5
- 6, 7
- all

## Matlab Map Code

```
map3 = map([2 1], {}, 0:1);
map2 = map([1 2], {}, 2:3);
map1 = map([2 1], {}, 4:5);
map0 = map([1 2], {}, 6:7);
```

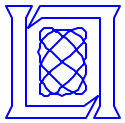
- Goal: create simulated data and use to test signal processing
- parallelize all stages; requires 3 “corner turns”
- pMatlab allows serial and parallel code to be nearly identical
- Easy to change parallel mapping; set map=1 to get serial code



# pMatlab Code

```
pMATLAB_Init; SetParameters; SetMaps;       %Initialize.
Xrand = 0.01*squeeze(complex(rand(Ns,Nb, map0),rand(Ns,Nb, map0)));
X0 = squeeze(complex(zeros(Ns,Nb, map0)));
X1 = squeeze(complex(zeros(Ns,Nb, map1)));
X2 = squeeze(complex(zeros(Ns,Nc, map2)));
X3 = squeeze(complex(zeros(Ns,Nc, map3)));
X4 = squeeze(complex(zeros(Ns,Nb, map3)));
...
for i_time=1:NUM_TIME                    % Loop over time steps.

  X0(:,:) = Xrand;                       % Initialize data
  for i_target=1:NUM_TARGETS
    [i_s i_c] = targets(i_time,i_target,:);
    X0(i_s,i_c) = 1;                     % Insert targets.
  end
  X1(:,:) = conv2(X0,pulse_shape,'same');    % Convolve and corner turn.
  X2(:,:) = X1*steering_vectors;             % Channelize and corner turn.
  X3(:,:) = conv2(X2,kernel,'same');         % Pulse compress and corner turn.
  X4(:,:) = X3*steering_vectors';            % Beamform.
  [i_range,i_beam] = find(abs(X4) > DET);    % Detect targets
end
pMATLAB_Finalize;                        % Finalize.
```

Implicitly Parallel Code  Required Change



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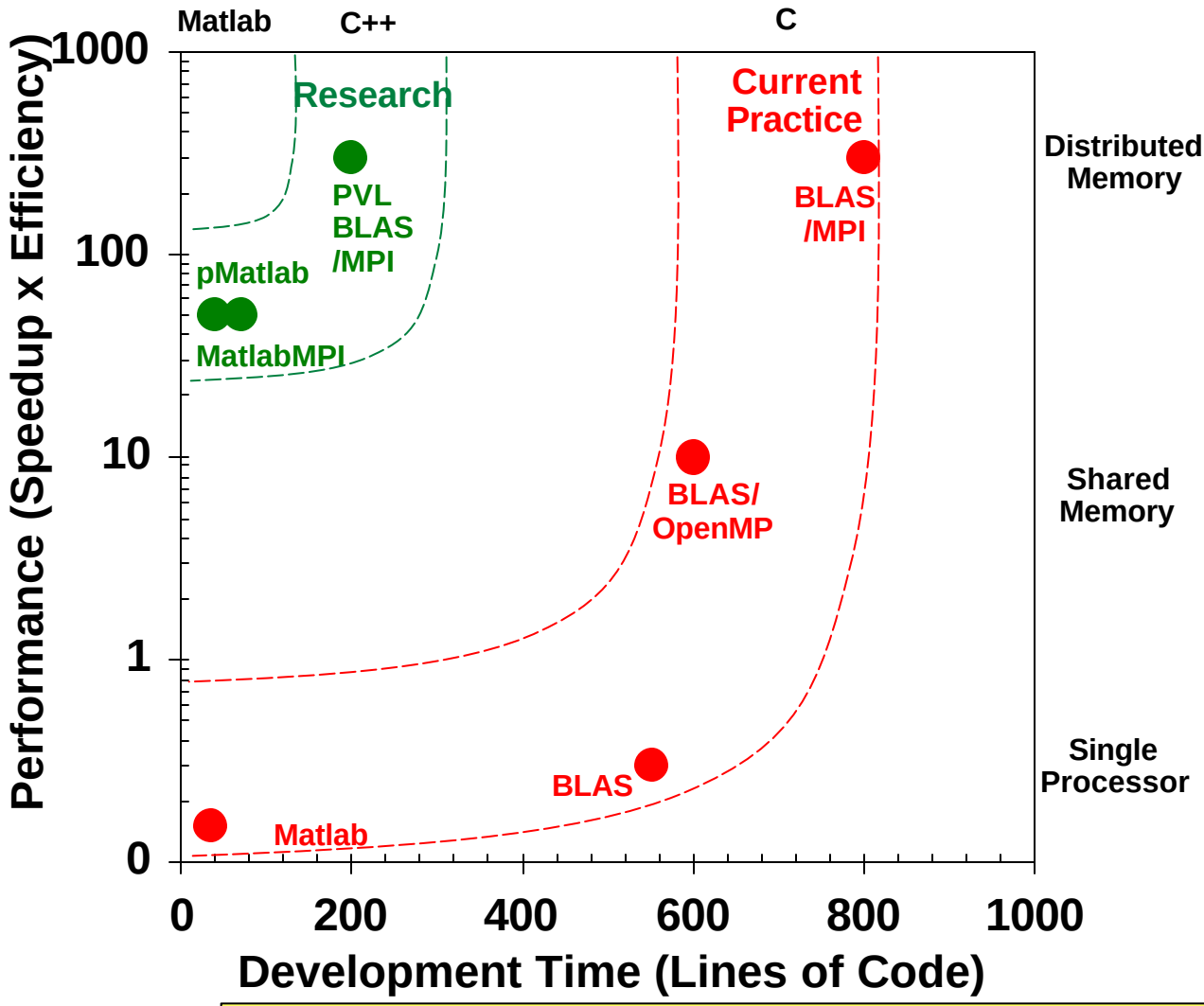
# Peak Performance vs Effort

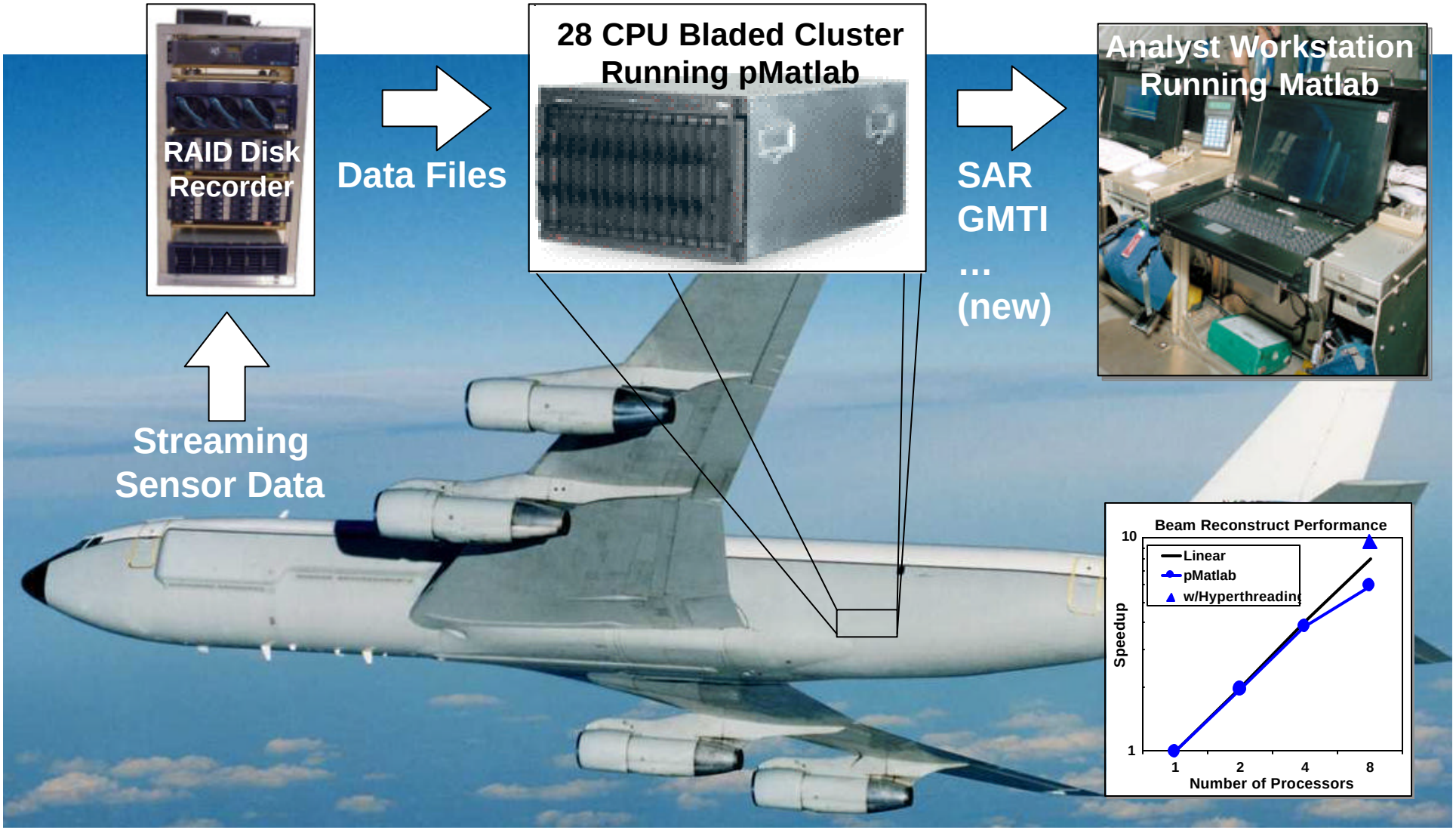



- Same application (image filtering)
- Same programmer
- Different langs/libs
  - Matlab
  - BLAS
  - BLAS/OpenMP
  - BLAS/MPI*
  - PVL/BLAS/MPI*
  - MatlabMPI
  - pMatlab*

*Estimate

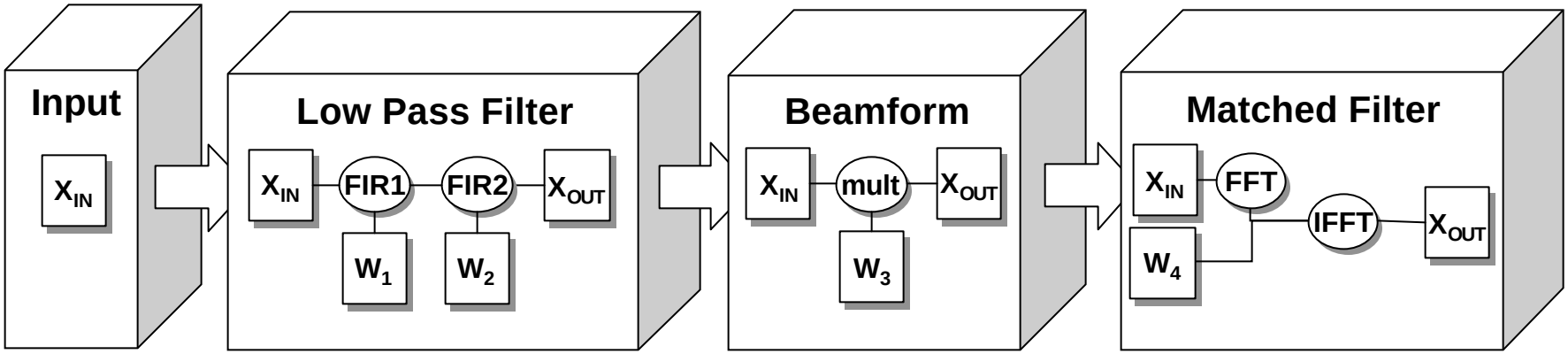
**pMatlab achieves high performance with very little effort**

# Airborne Sensor "QuickLook" Capability



# pMatlab Future Work

## 1. Demonstrate in a large multi-stage framework



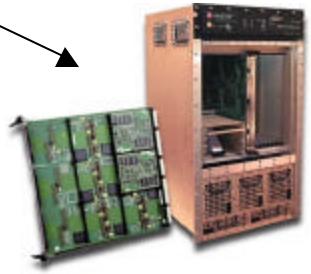

## 2. Incorporate Expert Knowledge into Standard Components

User Workstation

Lincoln GRID

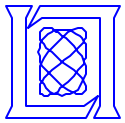
Special Cluster

Embedded Board



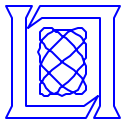
Embedded Multi-computer

## 3. Port pMatlab to HPEC systems



# Summary

- MatlabMPI has the basic functions necessary for parallel programming
  - Size, rank, send, receive, launch
  - Enables complex applications or libraries
- Performance can match native MPI at large message sizes
- Demonstrated scaling into hundreds of processors
- pMatlab allows user's to write very complex parallel codes
  - Built on top of MatlabMPI
  - Pure Matlab (runs everywhere Matlab runs)
  - Performace comparable to MatlabMPI
- Working with MIT LCS, Ohio St. and UCSB to define a unified parallel Matlab interface

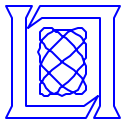


# Acknowledgements


- **Support**
  - Charlie Holland DUSD(S&T) and John Grosh OSD
  - Bob Bond and Ken Senne (Lincoln)

- **Collaborators**
  - Nadya Travinin (Lincoln)
  - Stan Ahalt and John Nehrbass (Ohio St.)
  - Alan Edelman and Ron Choy (MIT LCS)
  - John Gilbert (UCSB)
  - Antonio Torralba and Kevin Murphy (MIT AI Lab)

- **Centers**
  - Maui High Performance Computing Center
  - Boston University
  - MIT Earth and Atmospheric Sciences



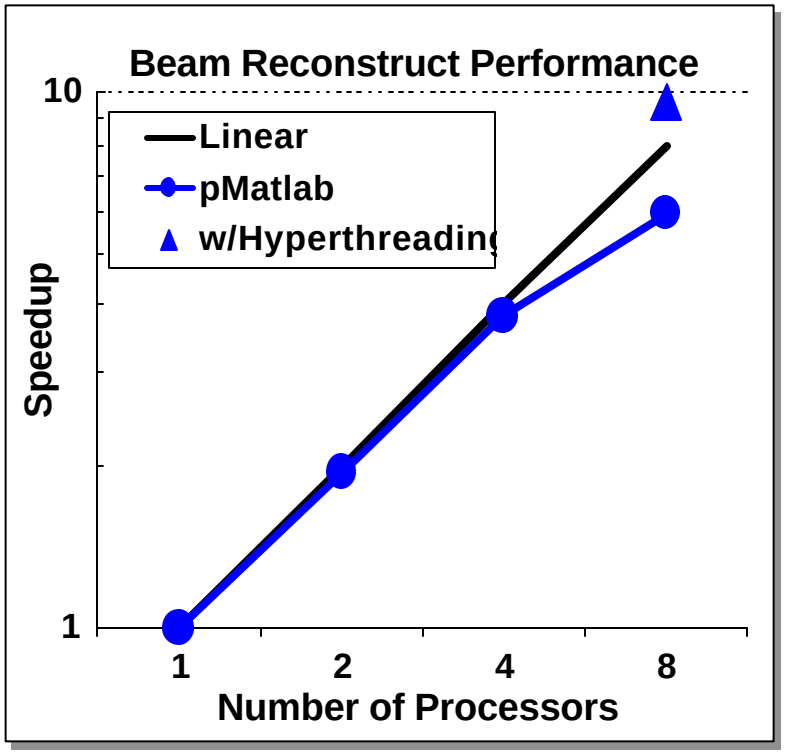
# Web Links

**MatlabMPI**

**http://www.ll.mit.edu/MatlabMPI**

**High Performance Embedded Computing Workshop**

**http://www.ll.mit.edu/HPEC**


Beam Reconstruct Performance
10
1
Linear
pMatlab
w/Hyperthreading
Speedup
1
2
4
8
Number of Processors