# HPEC Challenge SAR Benchmark: pMatlab Implementation and Performance

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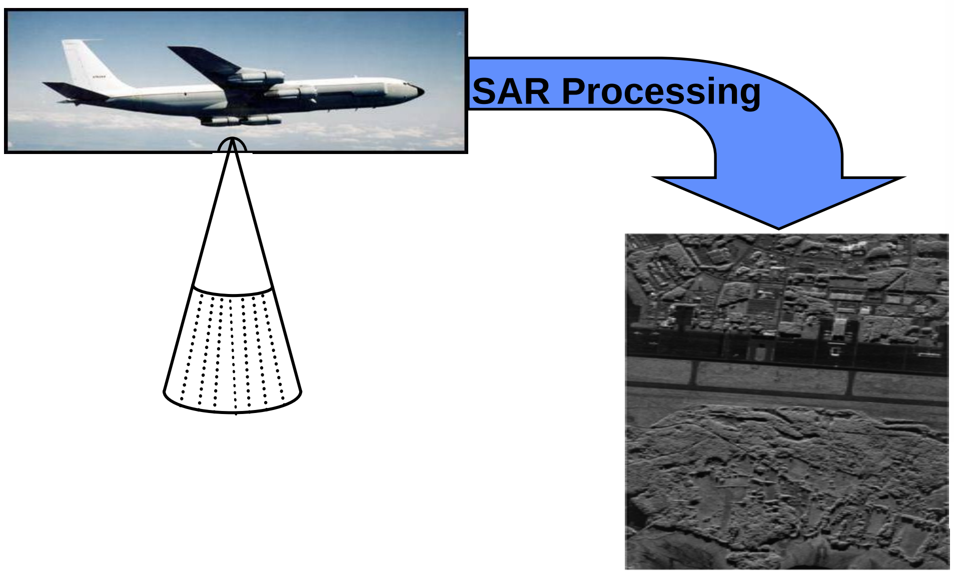
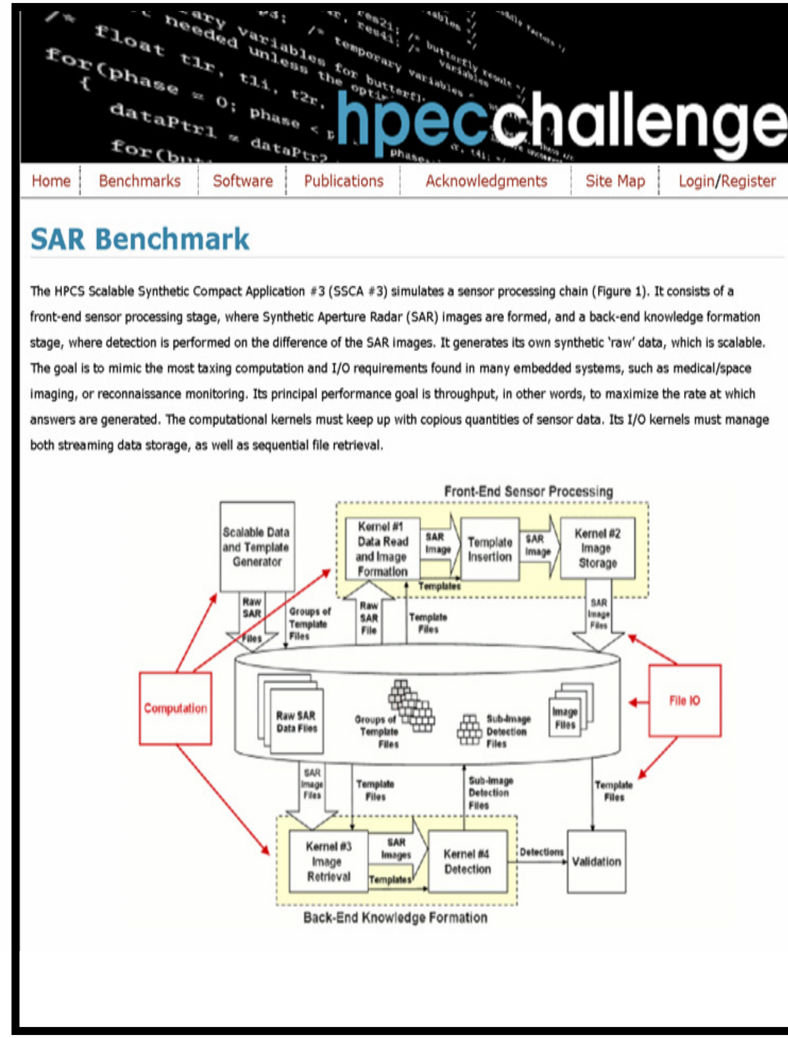
# Outline

- **Introduction**
- **Parallel Strategies**
  - **Coarse**
  - **Fine grained**
  - **Pipelined**
- **Results**
- **Summary**

# HPEC Challenge: SAR Benchmark

- Key part of HPEC Challenge
- End-to-End Benchmark
- Parallel extension of SAR Benchmark Specification needed
- Prototype and test parallel strategies using pMatlab





hpecchallenge

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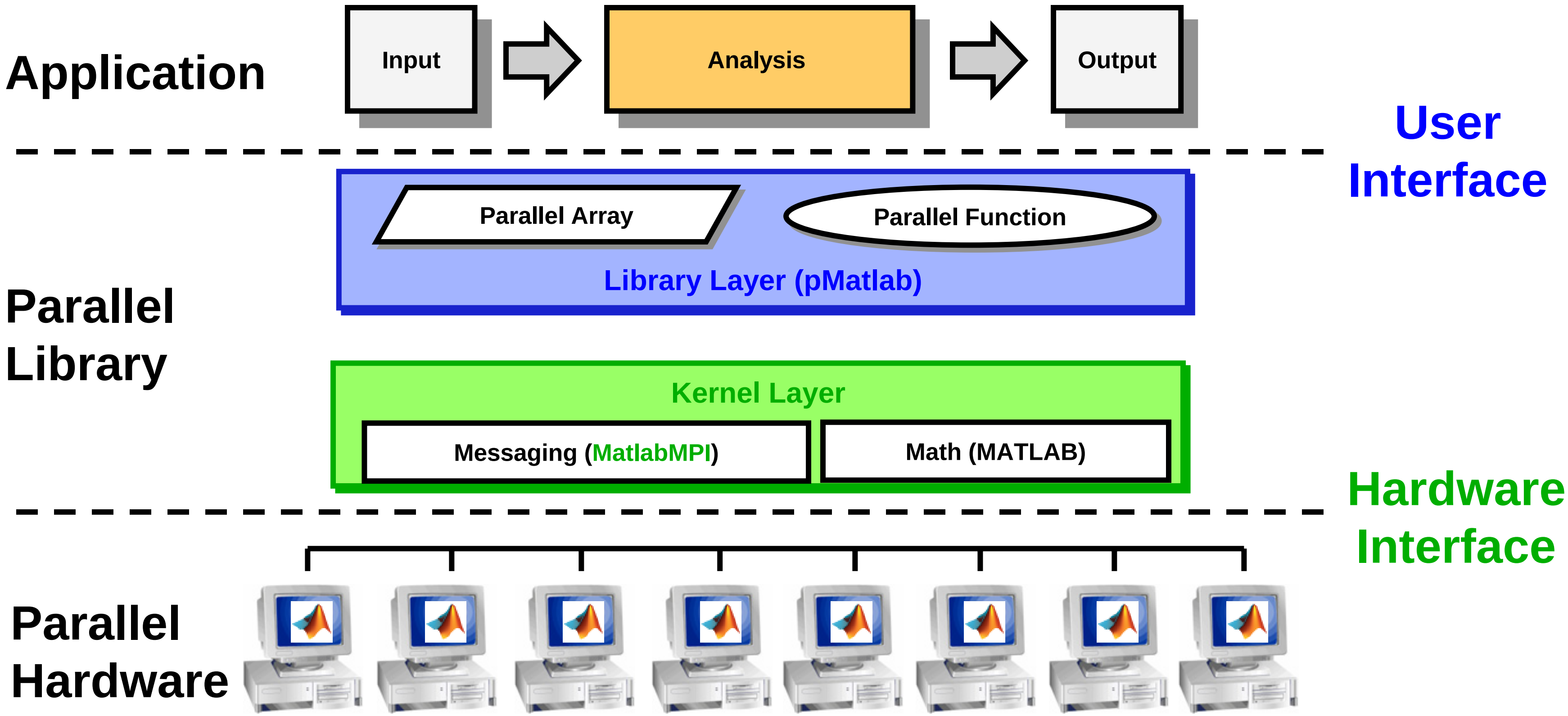
## SAR Benchmark

The HPCS Scalable Synthetic Compact Application #3 (SSCA #3) simulates a sensor processing chain (Figure 1). It consists of a front-end sensor processing stage, where Synthetic Aperture Radar (SAR) images are formed, and a back-end knowledge formation stage, where detection is performed on the difference of the SAR images. It generates its own synthetic 'raw' data, which is scalable. The goal is to mimic the most taxing computation and I/O requirements found in many embedded systems, such as medical/space imaging, or reconnaissance monitoring. Its principal performance goal is throughput, in other words, to maximize the rate at which answers are generated. The computational kernels must keep up with copious quantities of sensor data. Its I/O kernels must manage both streaming data storage, as well as sequential file retrieval.

# Approach: MatlabMPI & pMatlab Software Layers




**Layered Architecture for parallel computing**

- Kernel layer does single-node math & parallel messaging
- Library layer provides a parallel data and computation toolbox to Matlab users via maps
- Good pseudo-code for expressing parallel constructs

# Anatomy of a Map

**Maps separate algorithm development from algorithm distribution**

```
mapA = map( [2 2], {}, 0:3 );
```

**Grid specification together with processor list describe where the data is distributed.**

**Distribution specification describe how the data is distributed (default is block).**

```
A = zeros(4,6,mapA);
```

| | |
|---|---|
| P0 | P2 |
| P1 | P3 |

**MATLAB constructors are overloaded to take a `map` as an argument, and return a `dmat`, a distributed array.**

A =

| | | | | | |
|---|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 |

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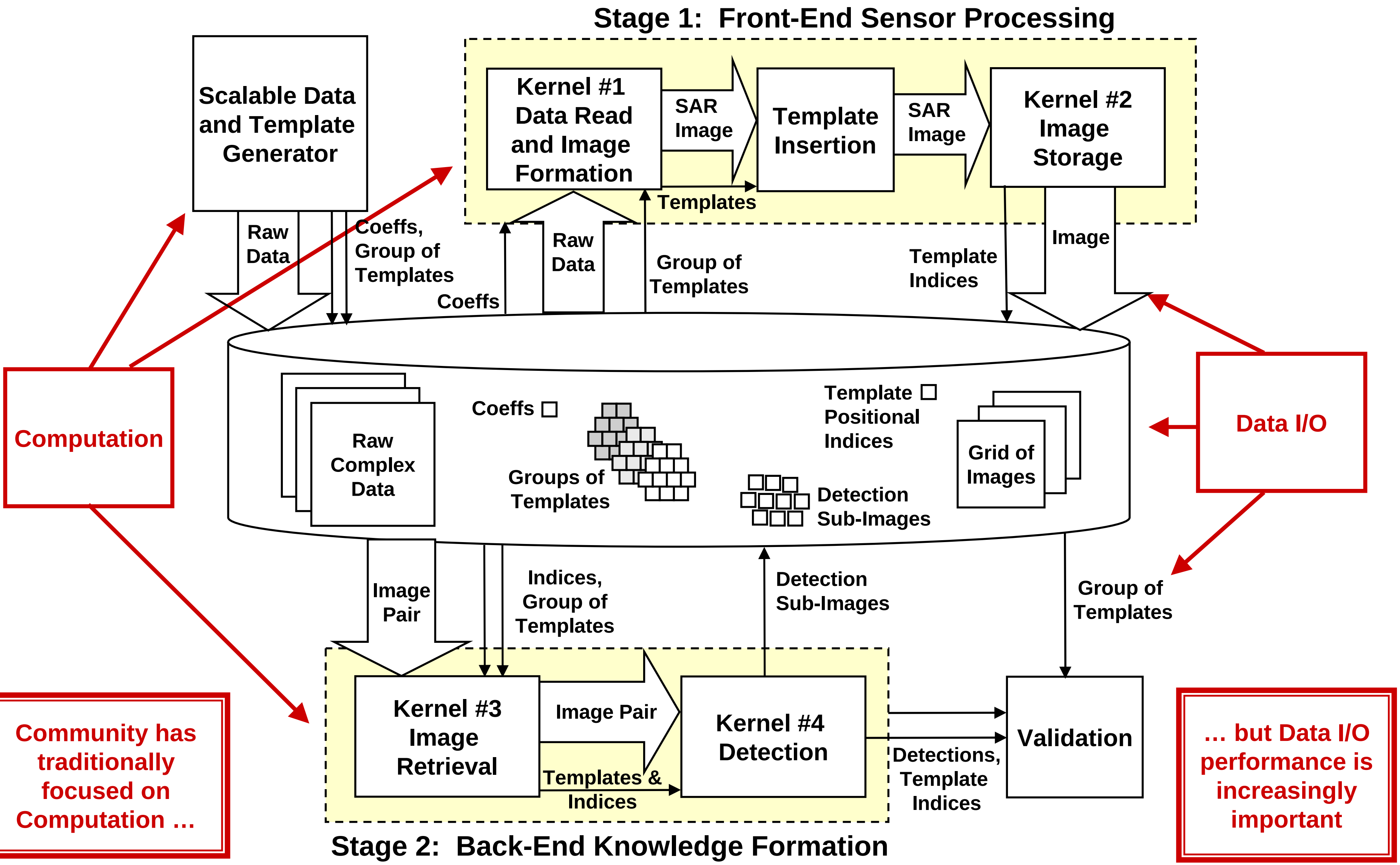
# HPEC SAR Benchmark System Architecture




Community has traditionally focused on Computation …

… but Data I/O performance is increasingly important

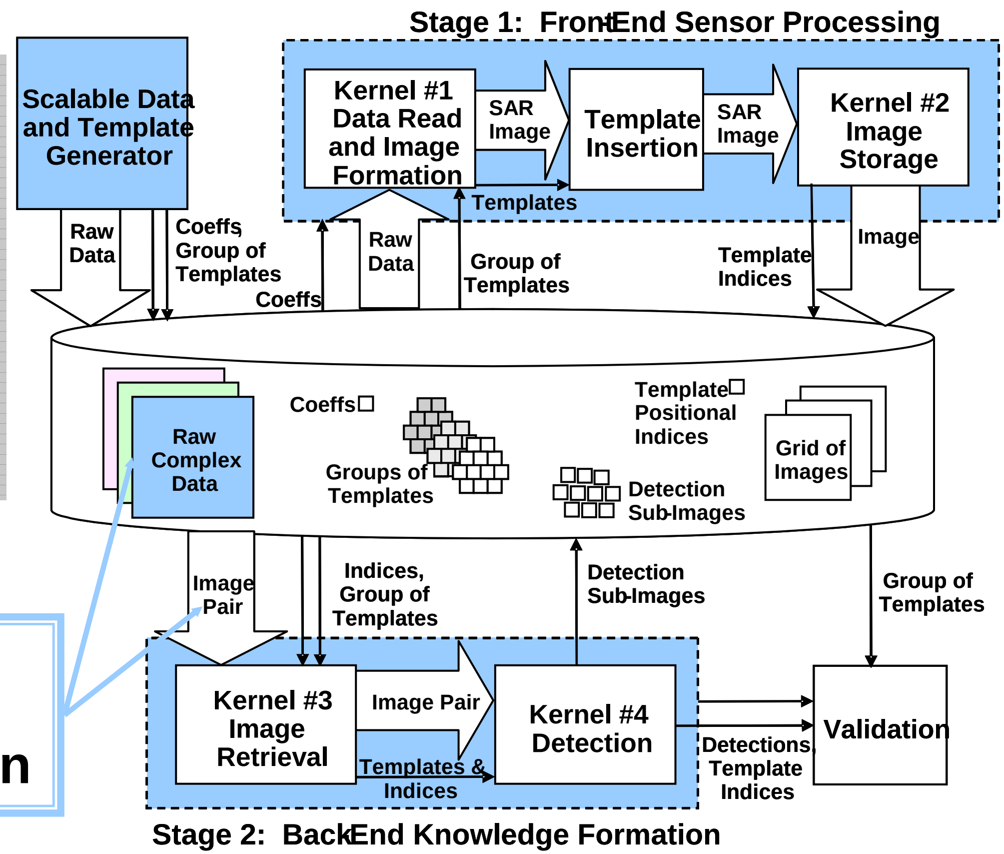
# SAR Coarse Grained Parallelization

## Coarse Grained Parallelism

- Parallelize system mode
- End-to-End (computation and I/O components)
- Look for independence
- Stages, images, detection are independent

**Process images independently:**

**no inter-processor communication**




**Caveats:**

- Higher latency
- Fit on one processor

# Coarse Grained pMatlab Example

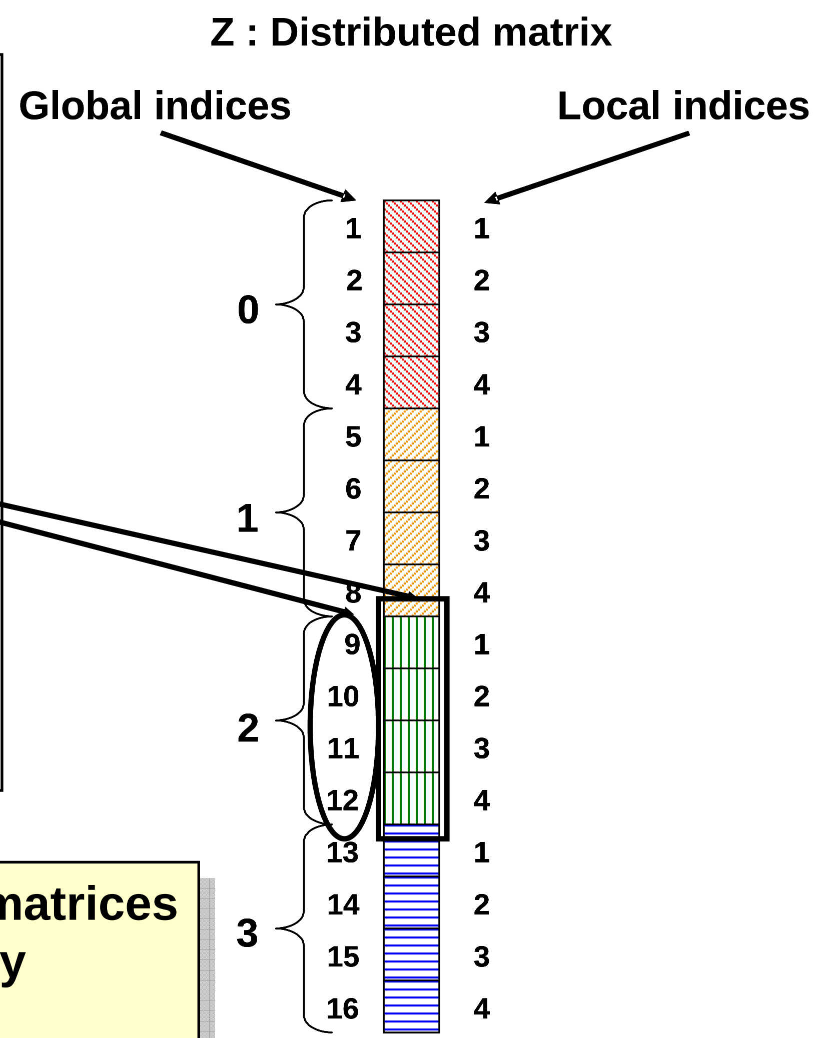
```
% Create Maps – distribute rows
map1 = map([Ncpus 1],{},0:Ncpus-1);

% Create z - distributed matrix.
Z = zeros(n, m, map1);

% Get the local indices
my_Z = local(Z);
my_ind = global_ind(Z,1);

for ilocal = 1:length(my_ind)
  iglobal = my_ind(ilocal);
  my_Z(ilocal,:)= userfunction(iglobal);
end %

% Copy local portion to global
Z = put_local(Z, my_Z);
```




- Example illuminates use of distributed matrices
- Local-global mapping is abstracted away
- Parallelism is derived from locality
- Communication automatic via use of maps

# SAR – Coarse Grained Implementation

## Map Creation

```
mapImage = map([1 Ncpus],{},0:Ncpus-1);
GlobalImages =zeros(numImages,mapImage);
LocalImages = global_ind(GlobalImages);
```

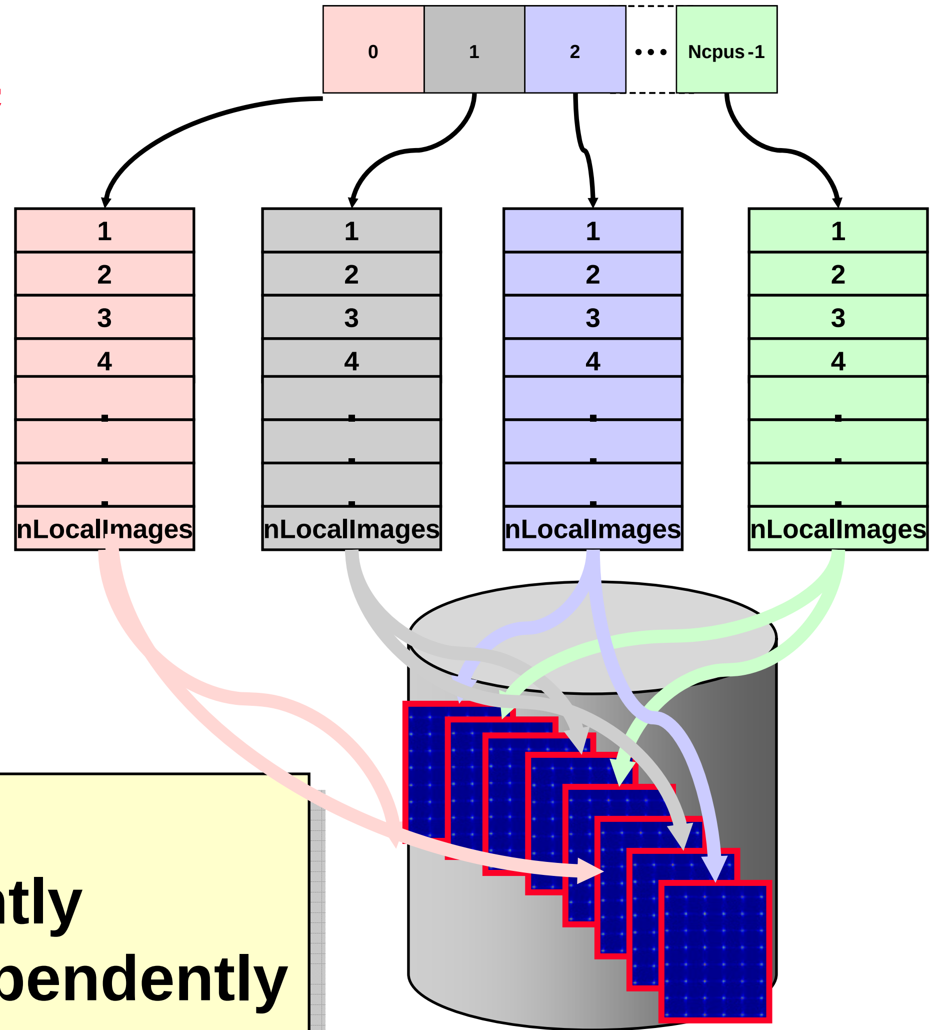
## Stage 1, Kernel 1 (Form Images)

```
for iImageLoop = 1:nLocalImages
iImage = LocalImages(iImageLoop);
readRawData;
formImage(iImage);
insertTemplates;
```

## Stage 1, Kernel 2 – Image Storage

```
fwrite(image);
```

- Create map for images
- Images created independently
- Images written to disk independently
- Minimal code modification




Parallel File System

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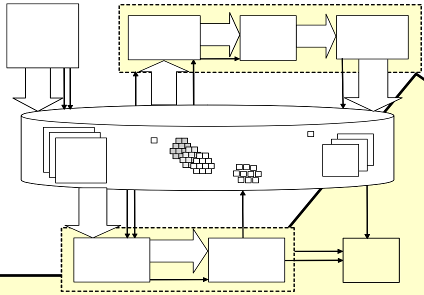
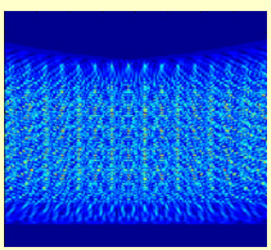
# HPEC SAR Benchmark
# Fine Grained Parallel Challenges

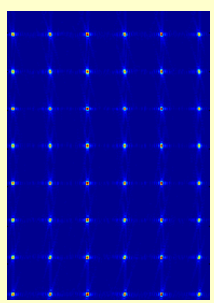


- Extract computational chain
- Focus on Stage 1, Kernel 1

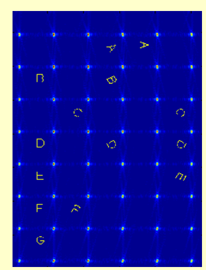
Scalable Data and Template Generator
Raw SAR
Templates
Kernel #1 Image Formation
SAR Image
Templates
Template Insertion
SAR Image
Templates
Kernel #4 Detection
Detections
Validation



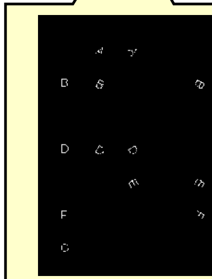
- I/O larger than single processor memory



- FFT, IFFT
- Corner Turn (3)
- FFTShits

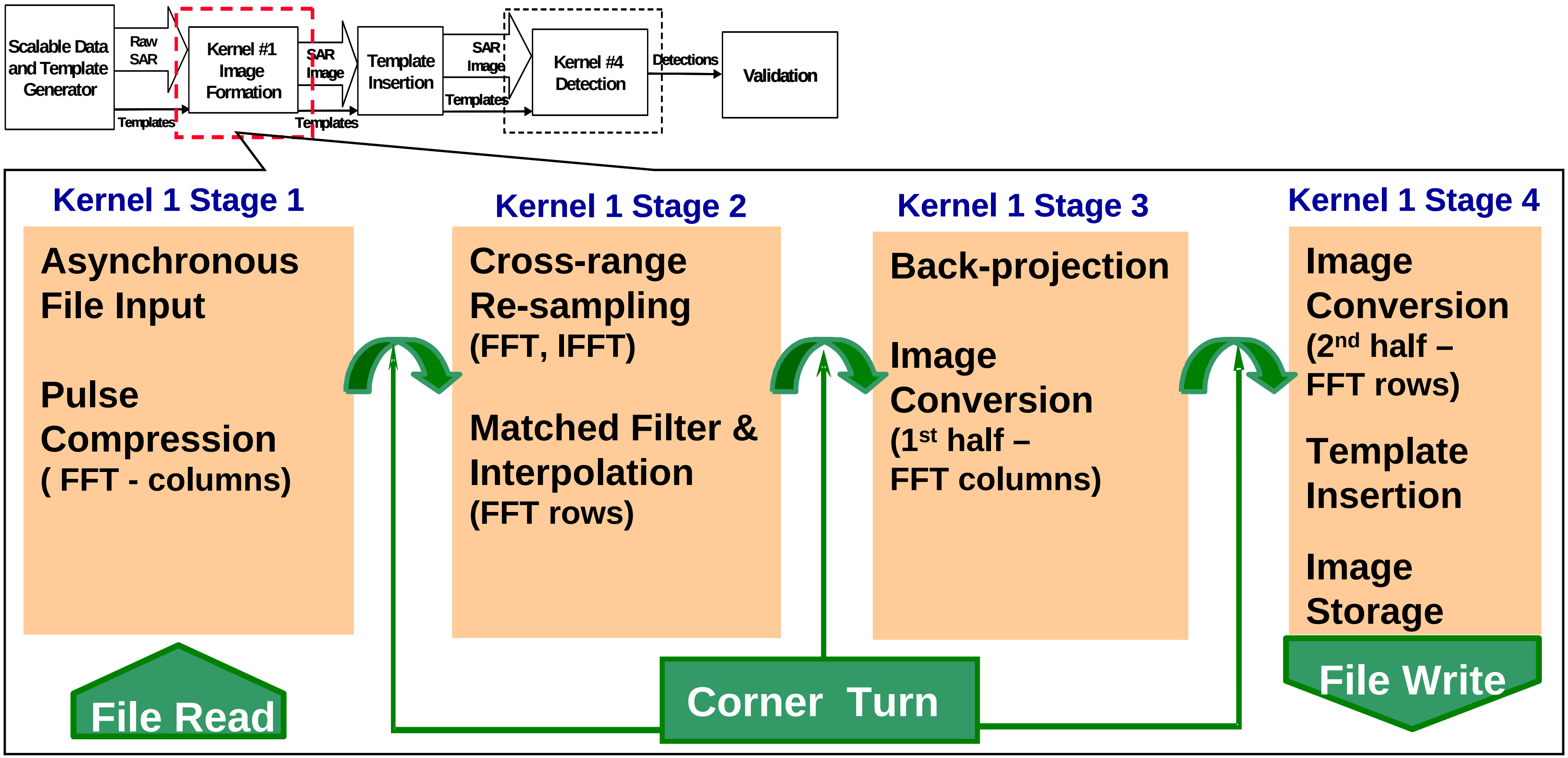


- Load balancing
- Large & small I/O



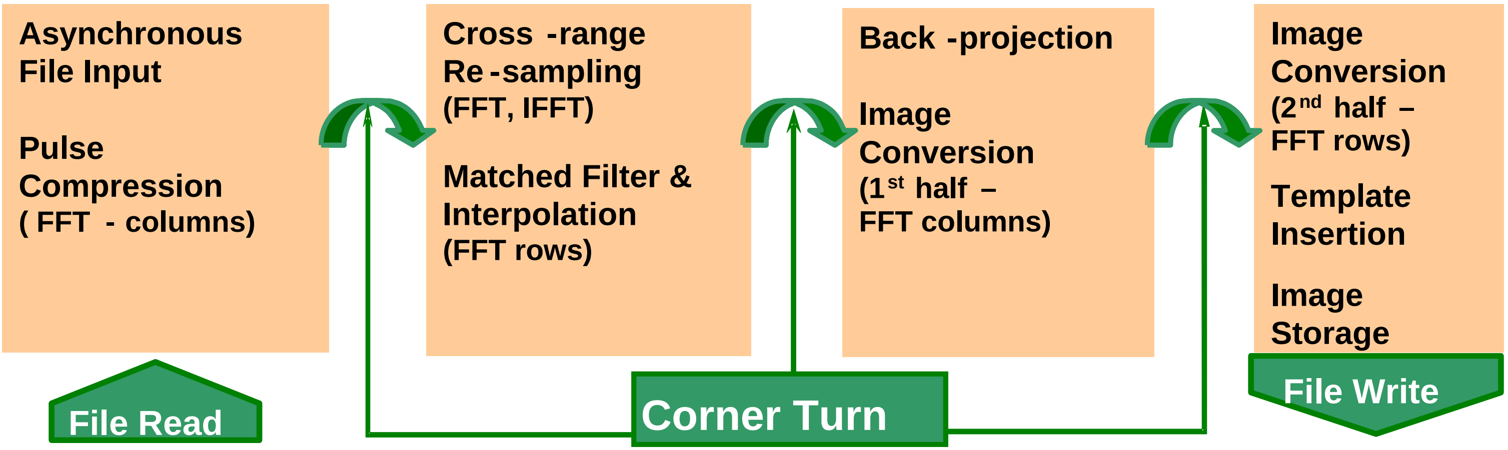
- Distributed Images
  - Differencing
  - Thresholding
- Distributed ROI
- Load balancing

# Front-End: SAR Image Formation Stages



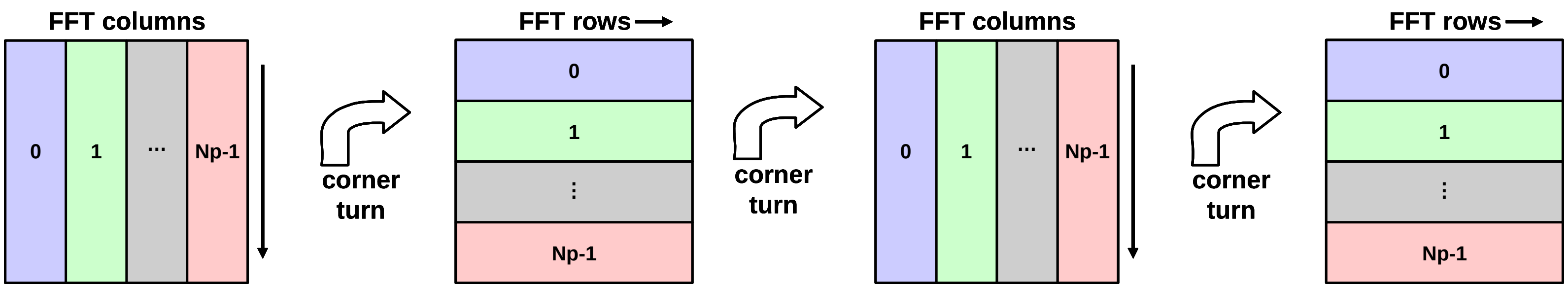

- **Assumption: Input raw SAR data exceeds processor DRAM**
- **All stages can be block distributed**
- **Dominated by the corner turns (all-to-all communication)**

# Front-End: SAR Image Formation Maps



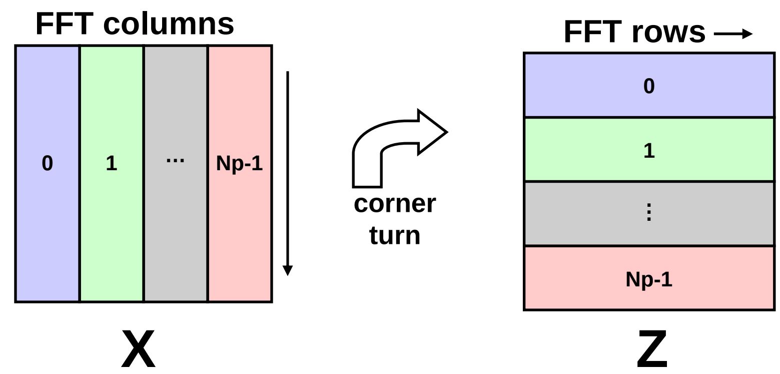

**Map structures look like:**

- **Columns: ColMap = map([1 Np], {}, 0:Np-1);**
- **Rows: RowMap = map([Np 1], {}, 0:Np-1);**



# Corner Turn: All-to-All

```
my_rank=MPI_Comm_rank(comm);
if (my_rank==0)|(my_rank==1)|(my_rank==2)|(my_rank==3)
  Xlocal=rand(M,N/4);end
if (my_rank==4)|(my_rank==5)|(my_rank==6)|(my_rank==7)
  Zlocal=zeros(M/4,N);end
Xlocal=fft(Xlocal);
tag=0;
if (my_rank==0)|(my_rank==1)|(my_rank==2)|(my_rank==3)
  start=1;
  len=M/4;
  for dest_rank=4:7
    last=start+len-1;
    MPI_Send(dest_rank,tag,comm,Xlocal(start:last,:));
    start=last+1;
  end
end
if (my_rank==4)|(my_rank==5)|(my_rank==6)|(my_rank==7)
  start=1;
  len=N/4;
  for recv_rank=0:3
    last=start+len-1;
    Zlocal(:,start:last)=MPI_Recv(recv_rank,tag,comm);
    start=last+1;
  end
End
Zlocal=fft(Zlocal);
```




```
X = fft(X,[],2);
Z(:,:) = X;
Z = fft(Z,[],1);
```

```
X = fft(X);
Z = transpose_grid(X);
Z = fft(Z);
```

**MatlabMPI:**
- \+ Efficient
- \- Complicated
- \- Inelegant

**pMatlab**
- \+ Elegant
- \- 2x slower

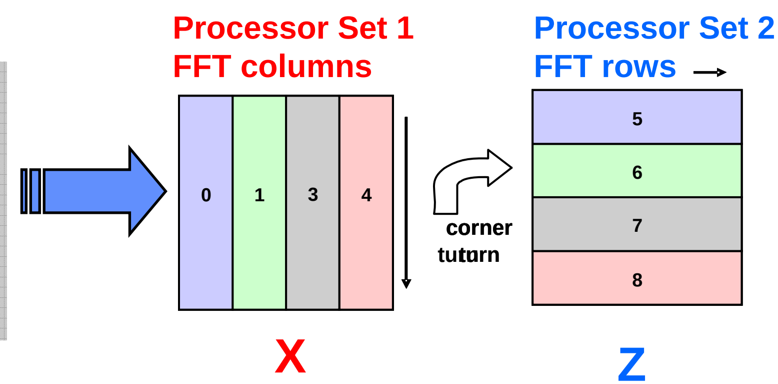
**Transpose_grid**
- \+ Elegant
- \+ Optimized messaging
- \+ Efficient

- **Transpose_Grid balances trade-off between efficiency and simplicity**

# pMatlab 2D FFT Code – Pipelined
# 8 Processor Example

```
1.  Np = pMATLAB.comm_size;                   % Set number of processors.
2.  P = 2^10;   Q = 2^10;                     % Set dimensions of array.

3.  Zmap = map([1 4],{},4:Np-1);              % Row map – processor set 1
4.  Xmap = map([4 1],{},0:3);                 % Column map – processor set 2

% Create complex global arrays X and Z for FFT.

5.  X = complex(rand(P,Q,Xmap),rand(P,Q,Xmap));
6.  Z = complex(zeros(P,Q,Zmap));

7.  X = fft(X,[],2);                          % FFT rows.
9.  Z(:,:) = X;                               % Redistribute data.
10. Z = fft(Z,[],1);                          % FFT columns.
```

- Maps use different processors sets
- Two line change – map creation
- Remaining code is unchanged
- No double buffering



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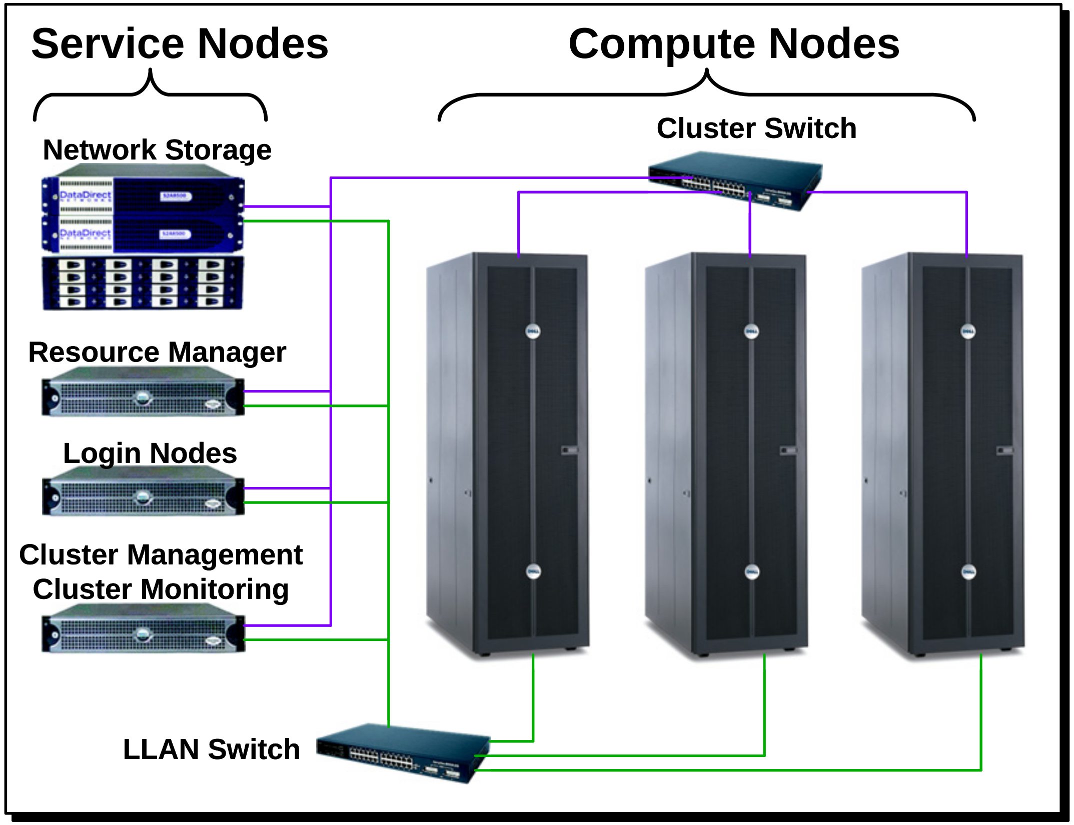
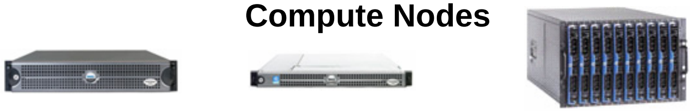
# Lincoln Laboratory Grid
# LLGrid





Compute Nodes

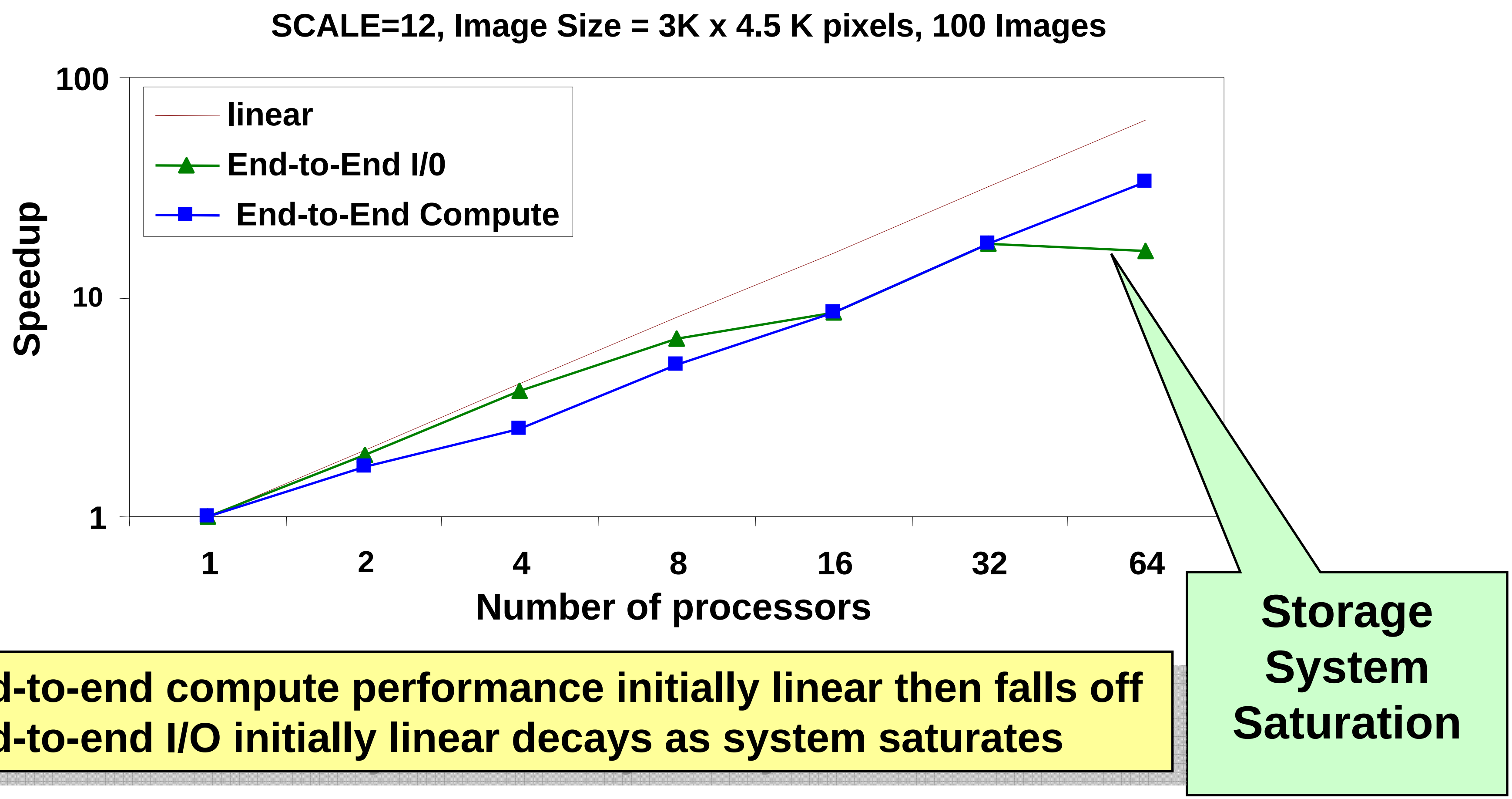


| DELL PowerEdge 2650 | DELL PowerEdge 1750 | DELL PowerEdge 1855MC |
|---|---|---|
| 64 CPUs (32 nodes) | 96 CPUs (48 nodes) | 300 CPUs (150 nodes, 10 chassis) |
| 2.8 GHz Xeon (32-bit) | 3.06 GHz Xeon (32-bit) | 3.2 GHz EM64T Xeon (64-bit) |
| 4 GB RAM | | 6 GB RAM |
| Two Gigabit Ethernet interfaces | | |
| Red Hat Enterprise Linux 3 | | |

- 280 processors (900+ processors, soon)
- Gigabit Ethernet
- 1 Terabyte of storage – growing to 36 Terabytes
- Standard Parallel Software

# Coarse Grained Speedup Results End-to-End

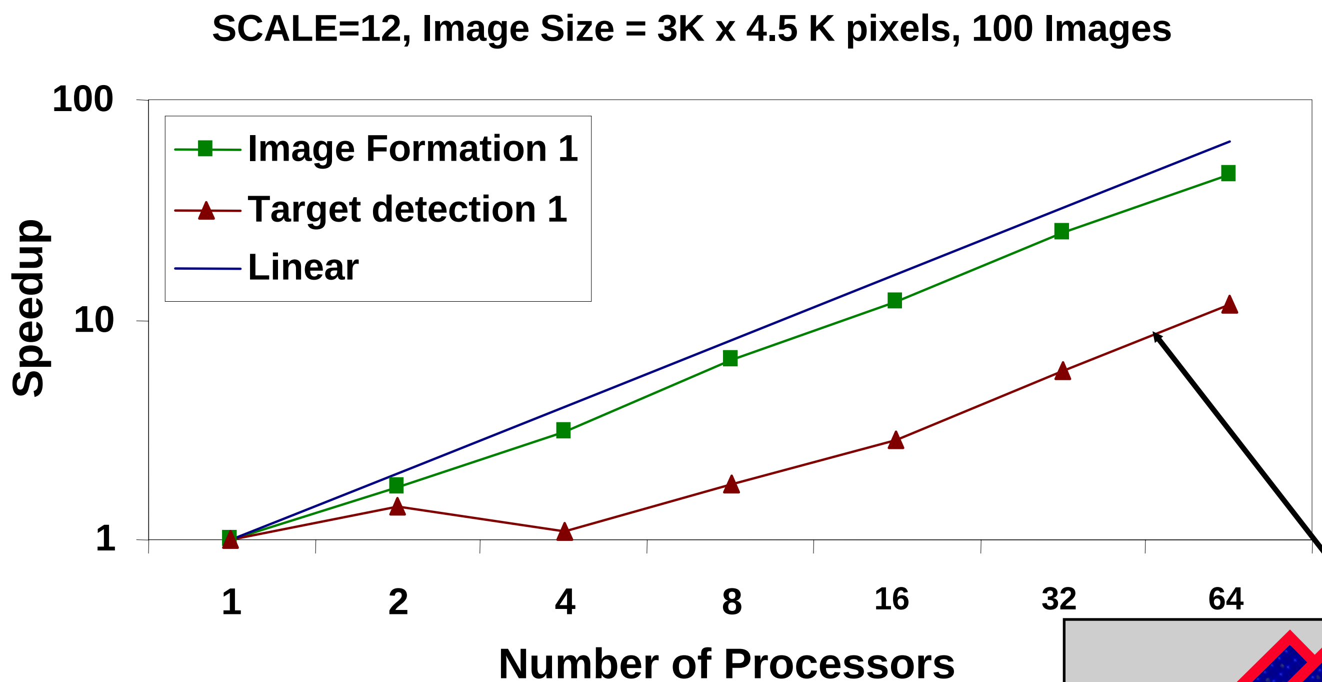
## End-to-End File I/O and Computation Performance for 2, 4, 8, 16, 32, and 64 processors

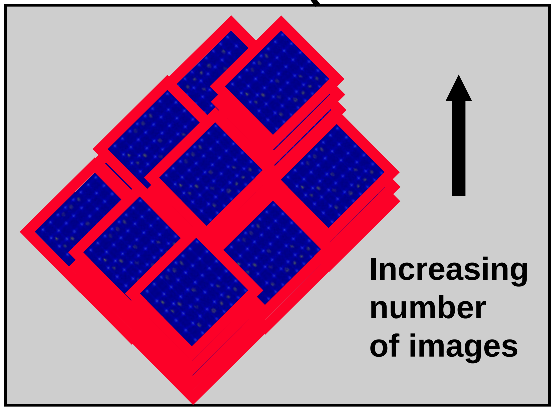



- End-to-end compute performance initially linear then falls off
- End-to-end I/O initially linear decays as system saturates

# Coarse Grained Speedup Results Computational Kernels

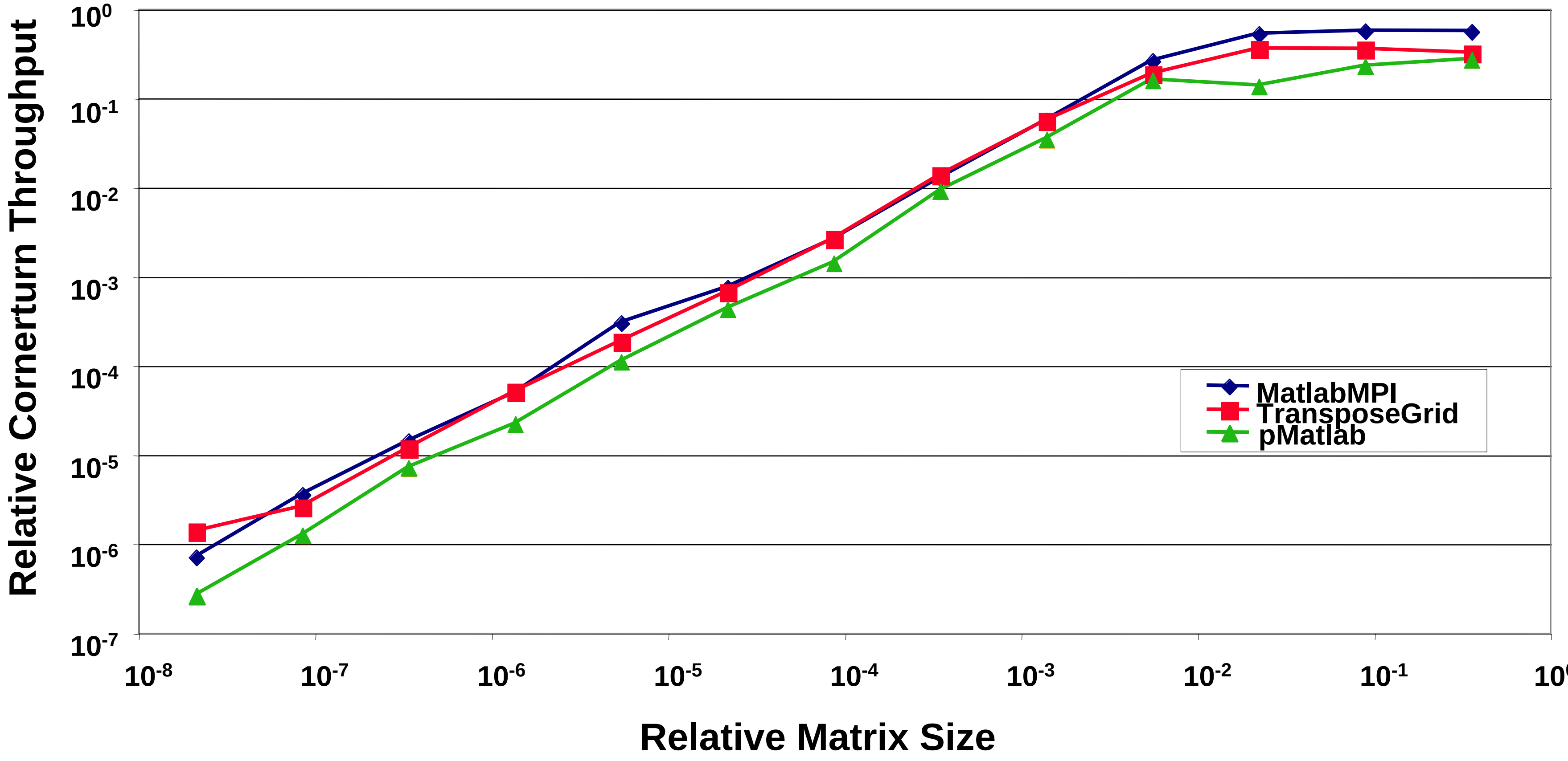
## Speedup for 2, 4, 8, 16, 32, and 64 processors




- Image Formation nearly linear performance
- Target Detection victim of load imbalance

# Corner Turn Performance




- MatlabMPI has slightly higher efficiency than Transpose_Grid
- Both Transpose_Grid and MatlabMPI achieve higher efficiency than pMatlab
- Transpose_Grid provides efficiency and simplicity

# Summary

- **Summary**
  – Coarse Grained Strategy yields linear speed-up
  – Approximately 30 lines of new code were added to 1400 lines of SSCA#3
  – Evaluation of Corner Turn performance indicates that Transpose_Grid provides efficiency and elegance
  – Maps provide a means for creating fine grained parallel process chain
  – Use of maps in pipelined corner turn requires minimal code changes
- **Future Work**
  – Fine Grained Implementation
  – Pipelined Implementation

# Acknowledgements


- Lincoln Laboratory pMatlab Team
  - Nadya Bliss
  - Hahn Kim
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- Code adapted from Soumekh, Mehrdad, *Synthetic Aperture Radar Signal Processing with Matlab Algorithms,* Wiley, 1999