Interactive Supercomputing's Star-P Platform: Parallel MATLAB and MPI Homework Classroom Study on High Level Language Productivity

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Productivity through High Level Infrastructure

The thesis of this extended abstract is simple. High productivity comes from high level infrastructures. To measure this, we introduce a methodology that goes beyond the tradition of timing software in serial and tuned parallel modes. We perform a classroom productivity study involving 29 students who have written a homework exercise in a low level language (MPI message passing) and a high level language (Star-P with MATLAB client). Our conclusions indicate what perhaps should be of little surprise: 1) the high level language is always far easier on the students than the low level language. 2) The early versions of the high level language perform inadequately compared to the tuned low level language, but later versions substantially catch up. Asymptotically, the analogy must hold that message passing is to high level language parallel programming as assembler is to high level environments such as MATLAB, Mathematica, Maple, or even Python.

We follow the Kepner method [6] that correctly realizes that traditional speedup numbers without some discussion of the human cost of reaching these numbers can fail to reflect the true human productivity cost of high performance computing. Traditional data compares low level message passing with serial computation. With the benefit of a high level language system in place, in our case Star-P running with MATLAB client, and with the benefit of a large data pool: 29 students, each running the same code ten times on three evolutions of the same platform, we can methodically demonstrate the productivity gains. To date we are not aware of any high level system as extensive and interoperable as Star-P, nor are we aware of an experiment of this kind performed with this volume of data.

Star-P Architecture

The Star-P research project begun at MIT in 1998 [1,2,3] and is commercialized by Interactive Supercomputing, founded in 2004 (see [4]). Interactive Supercomputing's Star-P platform (architecture illustrated below) is designed to bring the first two author's dream of faster computing on larger data sets to the millions of scientists and engineers who wish to concentrate on their specialties rather than take the time and expense to learn how to write traditional parallel programs. In Star-P, MATLAB users insert the simple characters "*p" to tag large data sizes for data parallelism. Users identify the task parallelism when appropriate with a "ppeval" or parallel evaluate call reminiscent of feval for function evaluation. Their serial MATLAB code is transformed into parallel MATLAB code far more readily than traditional approaches

The Star-P 2.3 system appears to the user as a "parallel MATLAB" but Figure 1 below shows that architecturally Star-P is a language agnostic platform. In Star-P 2.3, users can write MATLAB codes and add serial and parallel extensions.

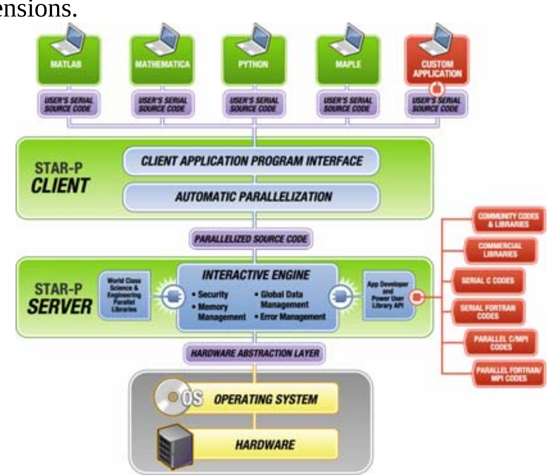

Fig 1: Architecture of the Star-P Platform

MIT Graduate Class Experimental Data

The first author has been teaching a large cross section of graduate students at MIT since 1994 about the realities and myths of high performance computing (see [5]). He is proud that among his students have been the authors of FFTW, some of the authors of pMATLAB,[7,8] and of course many of the students who have worked on and tested Star-P (a project formerly known as MITMATLAB, pMATLAB itself, MATLABp, and MATLAB*p) most particularly the second and third authors.

This course has participated in performance studies as part of the development time study experiment of the HPEC program [6]. What has become increasingly clear from these studies is that a few very talented students who have the knack, can find ways to improve the performance of codes, but even the most talented and inclined still expend a great deal of time.

The students were given a by now standard programming assignment in parallel computing classes, the two dimensional Buffon needle problem. A typical parallel MATLAB solution in Star-P looked like:

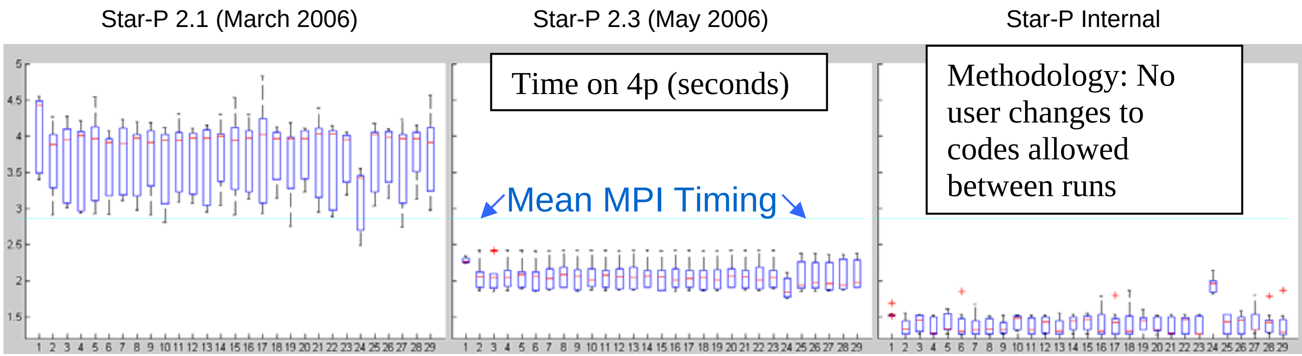

Fig 2: The Buffon Needle Problem executed by 29 students in three evolutionary versions of Star-P each executed ten times and compared with MPI runs written by the same students. The mean MPI timing was 2.8 seconds. We have not here normalized per student but we should report that a handful of students who worked hard achieved what might be considered the optimum of 1 sec on 4 processors in MPI. In a boxplot, the blue box ranges from the 25^{th} to 75^{th} percentiles of the ten data points. The red line is at the median. The whisker is the full extent of the data omitting outliers which are the red plusses. Writing message passing code was widely considered an unpleasant chore while the insertion of the two characters "*p" hardly seemed to be worthy of an MIT problem set.

```
function z=Buffon(a,b,l, trials)
r=rand(trials*p,3);
x=a*r(:,1)+l*cos(2*pi*r(:,3));
y=b*r(:,2)+l*sin(2*pi*r(:,3));
inside = (x >= 0) & (y>=0) & (x <= a) & (y <= b);
buffonpi=(2*l*(a+b) - l^2)/ (a*b*(1-
sum(inside)/trials));
```

The serial MATLAB code differs from the parallel one by the "*p" in red above. We ran each code ten times in three evolutions Star-P. Figure 2 plots the students timings on 4 processors (ten million trials).

We can only report anecdotal evidence about the human time for all 29 students, but overwhelmingly the students preferred adding the two characters "*p" to their code as compared to writing the MPI code. The mean time was 2.8 seconds on four processors. A handful of the students who were determined to performance tune their MPI code reached times close to 1 second. Thus the Star-P system brings users to within 40% of the hand coded optimum. The Star-P design allows for even this overhead to be shaved down further in future releases.

To understand scalability, the following times are the mean run times on the internal version of Star-P. (We note that the other versions of Star-P indicate similar scalability characteristics:) Each number is the average of 290 runs, 10 runs for each of 29 student codes.

Processors	1	2	4	8
Avg Seconds	5.7	2.9	1.4	0.7

Our view of this experiment is best illustrated as in the cartoon in Figure 3 which follows the productivity methodology introduced by Kepner and colleagues.

Conclusion

High level systems such as Star-P can allow users to write in high level languages such as MATLAB thereby providing the look and feel of a "parallel MATLAB." In much the same way that productivity has been obtained from underneath by faster cpu speeds, users of Star-P need not change codes between releases, and yet obtain faster execution as the infrastructure continues to squeeze out the best performance possible.

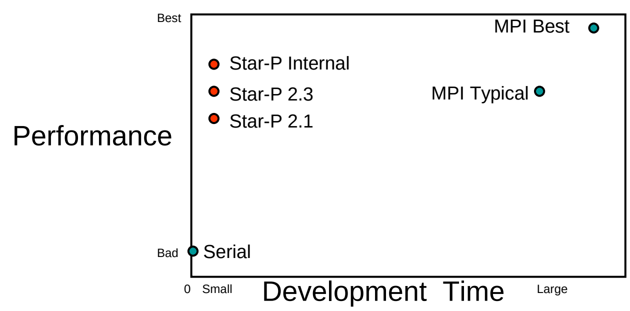

Fig 3: Kepner diagram illustrating the main point of this study. Productivity may be thought of as best slope on line to the origin. The vertical rise in performance of Star-P may be thought of as riding the technology curve as students expended no additional effort. Typical methodologies only report MPI vs serial on the vertical axis. The Kepner methodology provides the means of seeing productivity on a two dimensional scatter plot.

We thank Lorin Hochstein for his assistance in setting up the classroom studies. Funding for the studies was generously provided to the first author as part of the HPEC Productivity Study in the DOE Petascale Application Development Program. We particularly thank Jeremy Kepner for numerous interesting conversations and his leadership in the productivity area.

References.

[1] R. Choy and A. Edelman, "Parallel MATLAB doing it right," Proceedings of the IEEE, Vol.93, No.2, Feb 2005, pages 331-341.
[2] P. Husbands and C. Isbell, "The Parallel Problems Server: A Client-Server Model for Large Scale Scientific Computation." Proceedings of the Third International Conference on Vector and Parallel Processing. Portugal, 1998.
[3] P. Husbands, Interactive Supercomputing, PhD Thesis, Massachusetts Institute of Technology, Cambridge, 1999.
[4] Interactive Supercomputing: http://www.interactivesupercomputing.com.
[5] A Edelman, MIT Course 18.337: http://beowulf.csail.mit.edu.
[6] J. Kepner, http://www.highproductivity.org
[7] J. Kepner and S. Ahalt, "MatlabMPI," Journal of Parallel and Distributed Computing (JPDC), 64(8): 997-1005 (2004). (http://www.ll.mit.ede/MatlabMPI).
[8] N. Travinin and J. Kepner, pMatlab Parallel Matlab Library IJHPCA 2006. (http://www.ll.mit.edu/pMatlab).

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MIT and ISC

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LBNL and ISC

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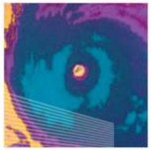
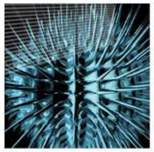
INTERACTIVE supercomputing

Company

- Background:
  - Founded in 2004, venture-backed
  - M.I.T. spin-off
  - Exclusive technology license
  - Parallel Computing Harder than most realize:
  - Technology: Star-P software platform supporting automatic parallelization and interactive execution of desktop technical applications on parallel servers
  - Not just a parallel MATLAB
- Market:
  - Value prop: reduction in time-to-solution for large and complex problems
  - Can plug in existing parallel and serial software seamlessly

Star-P™ Enables Easy Parallel Computing on Multi-core Servers and Clusters.
Today, with MATLAB® environment.





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Easiest Parallel use of MATLAB

- Run MATLAB on each machine

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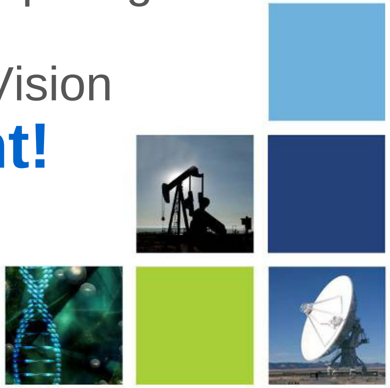
The Parallel MATLABS (no one such beast)

multiMATLAB
Cornell Multitasking Toolbox
DP-Toolbox
MPITB/PVMTB
MATmarks
MatlabMPI
pMatlab
MULTI Toolbox
Paralize
PMI
PLab
Parmatlab
DistributePP

Netsolve
DLab
Matpar
PLAPACK
Paramat
Otter
RTExpress
ParAL
FALCON
CONLAB
MATCH
Menhir
MATHWORKS MATLAB
MATHWORKS Distributed Computing Toolbox
MATHWORKS Cleve Moler’s Vision

Star-P with the MATLAB client environment!



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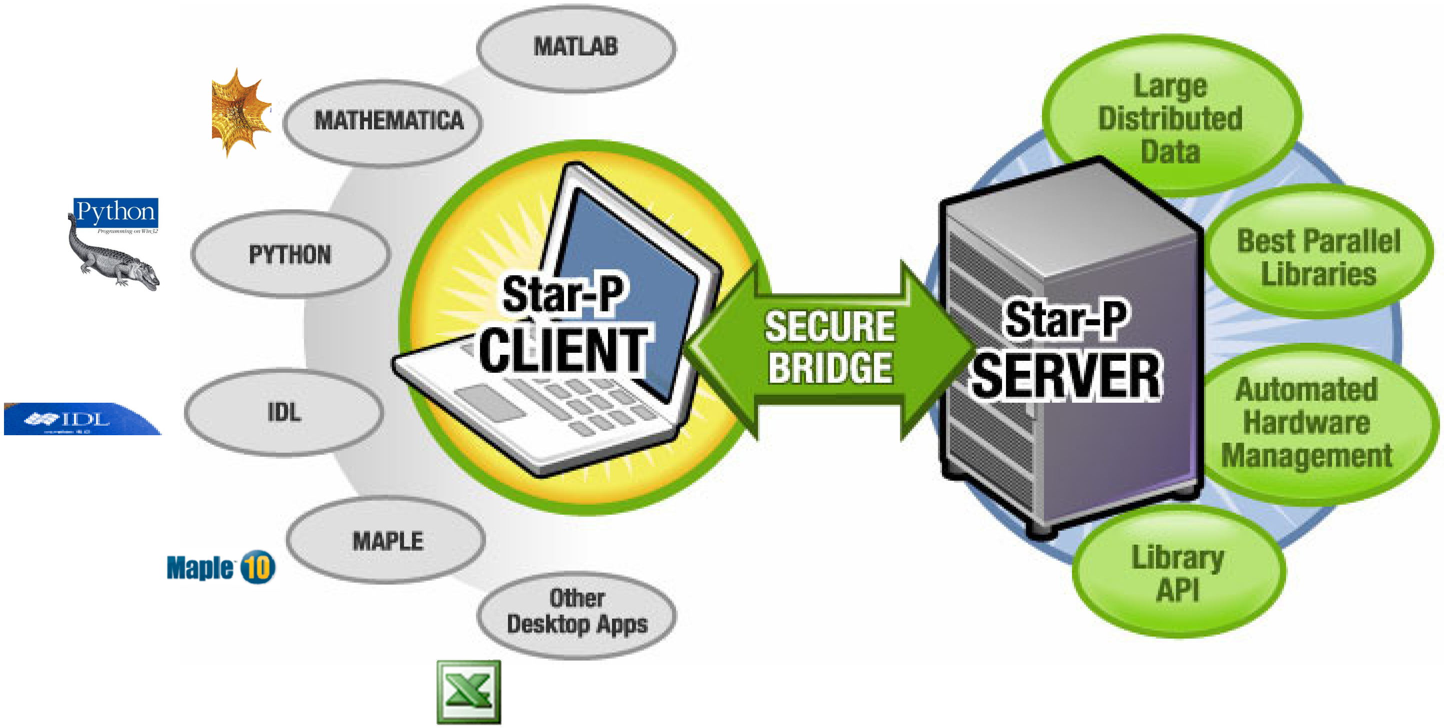
The Client (a math lab) is the browser!



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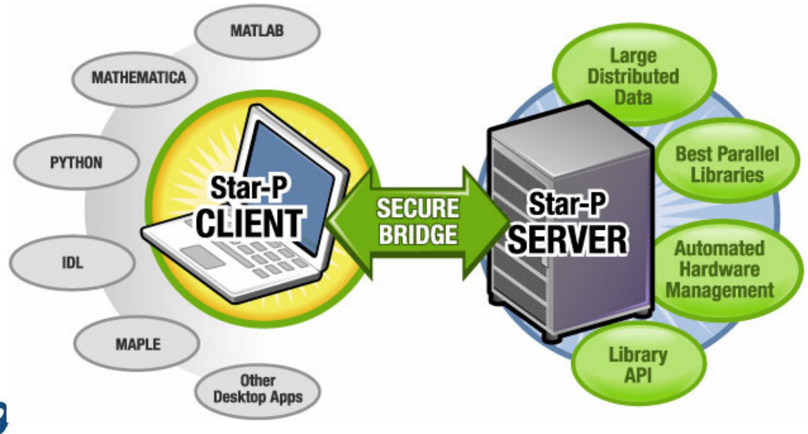
Client-Server Parallel Computing

- Your bank & financial data
- Your email
- Your travel
- Your photos
- 2006: MIT students hw grades
- Your parallel computing



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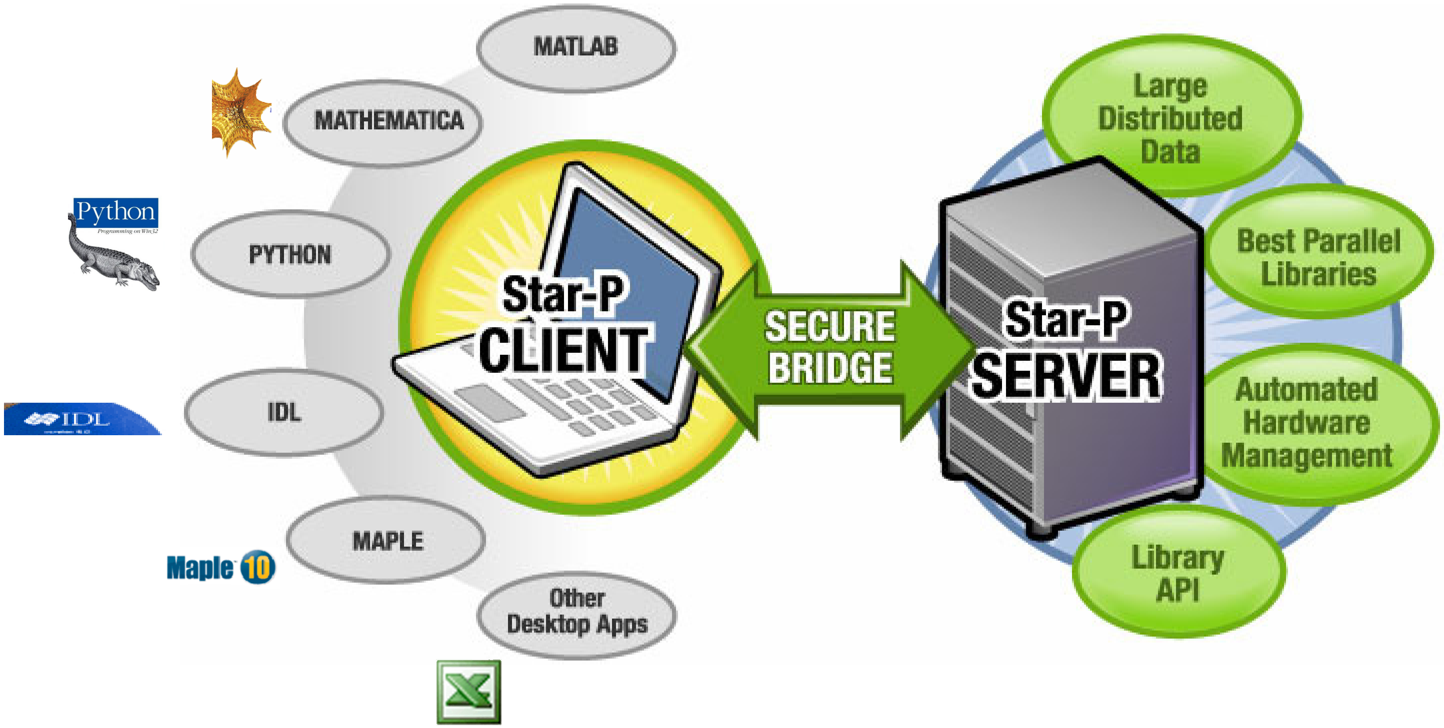
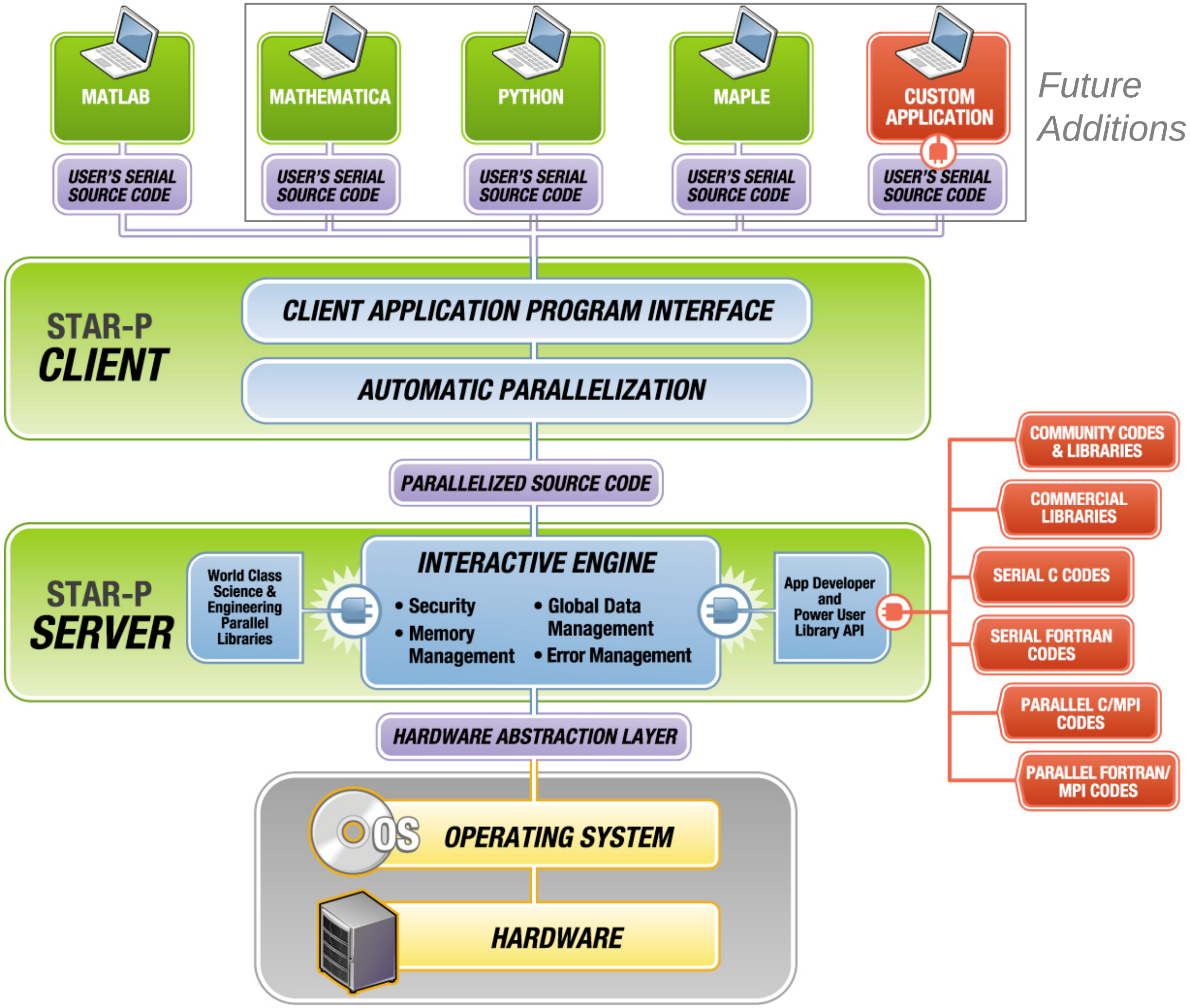
Client-Server Parallel Computing

Platform for automatic parallelization
and interactive execution of desktop apps
on HPCs



INTERACTIVE supercomputing

The Key to Star-P™ Value: Architecture



Client-Server Software

- Client interacts with HLL environments
- Distributed server for SMP and cluster systems

Computing Modes

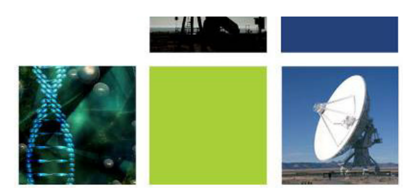
- Serial & parallel computing
- Data- and Task-parallel
- Extensions via API/SDK

Ease of Use

- Simple Star-P commands

Software Platform

- Multiple HLLs and applications *(future)*



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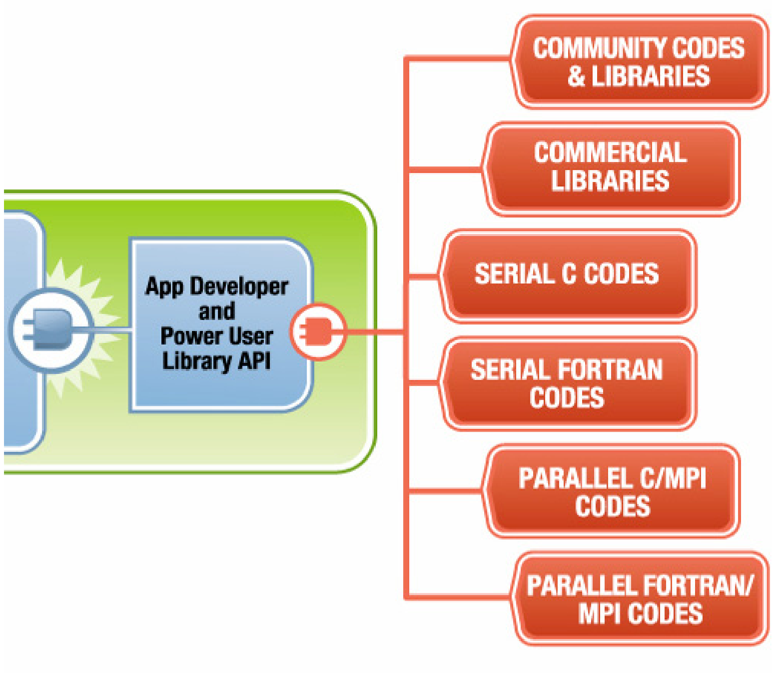
Plug into Star-P through Server API

- Through MATLAB, access:
  - Your own library functions
  - Specialized hardware (FPGA's)
- Serial and parallel codes
  - Coarse-grained "multiply effect"
  - Parallel codes
- Started in MPI?
  - Not too late. Just plug it in and keep moving forward. Access from MATLAB
- Have an old serial fortran code?
  - Run it with multiple paramaters on different processors. Access from MATLAB



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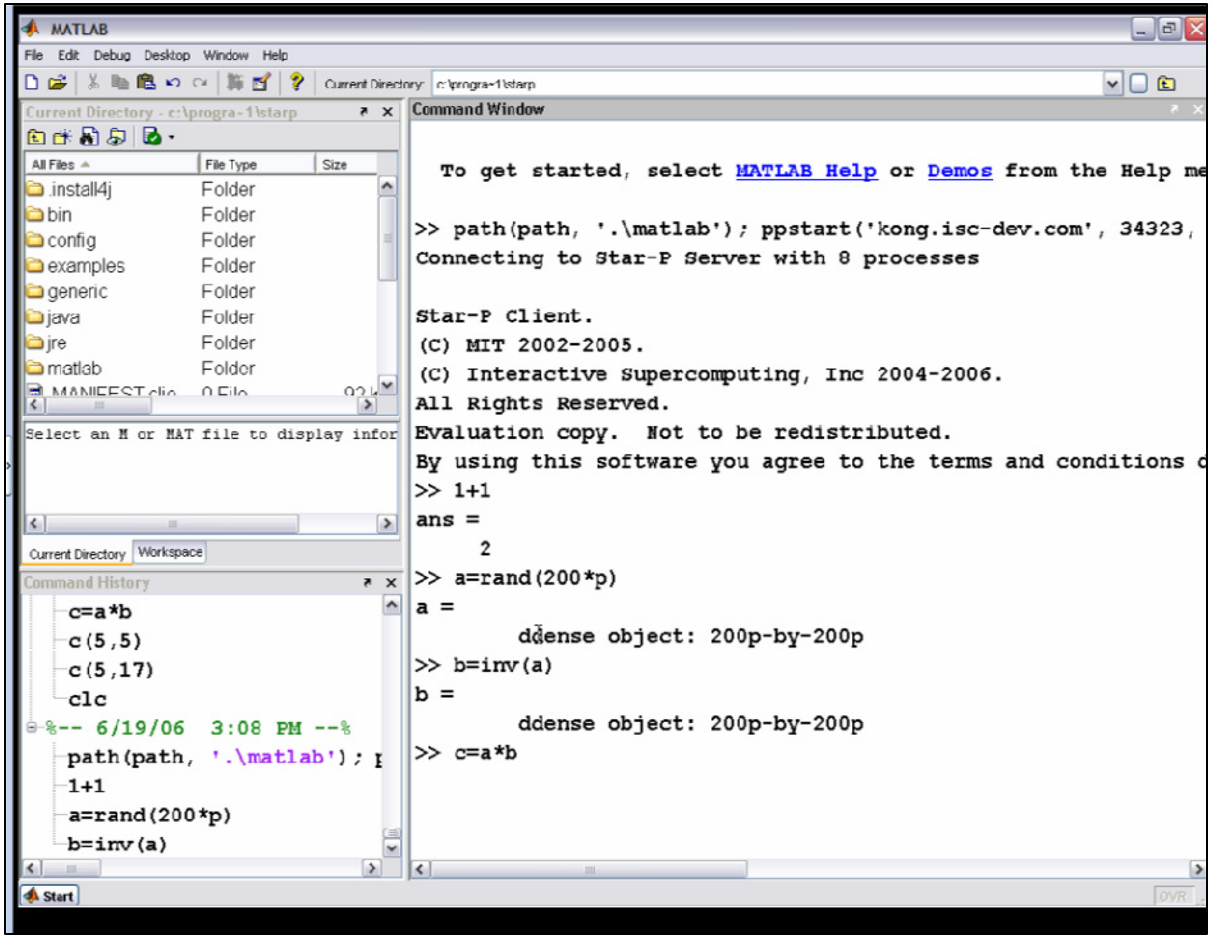
Video



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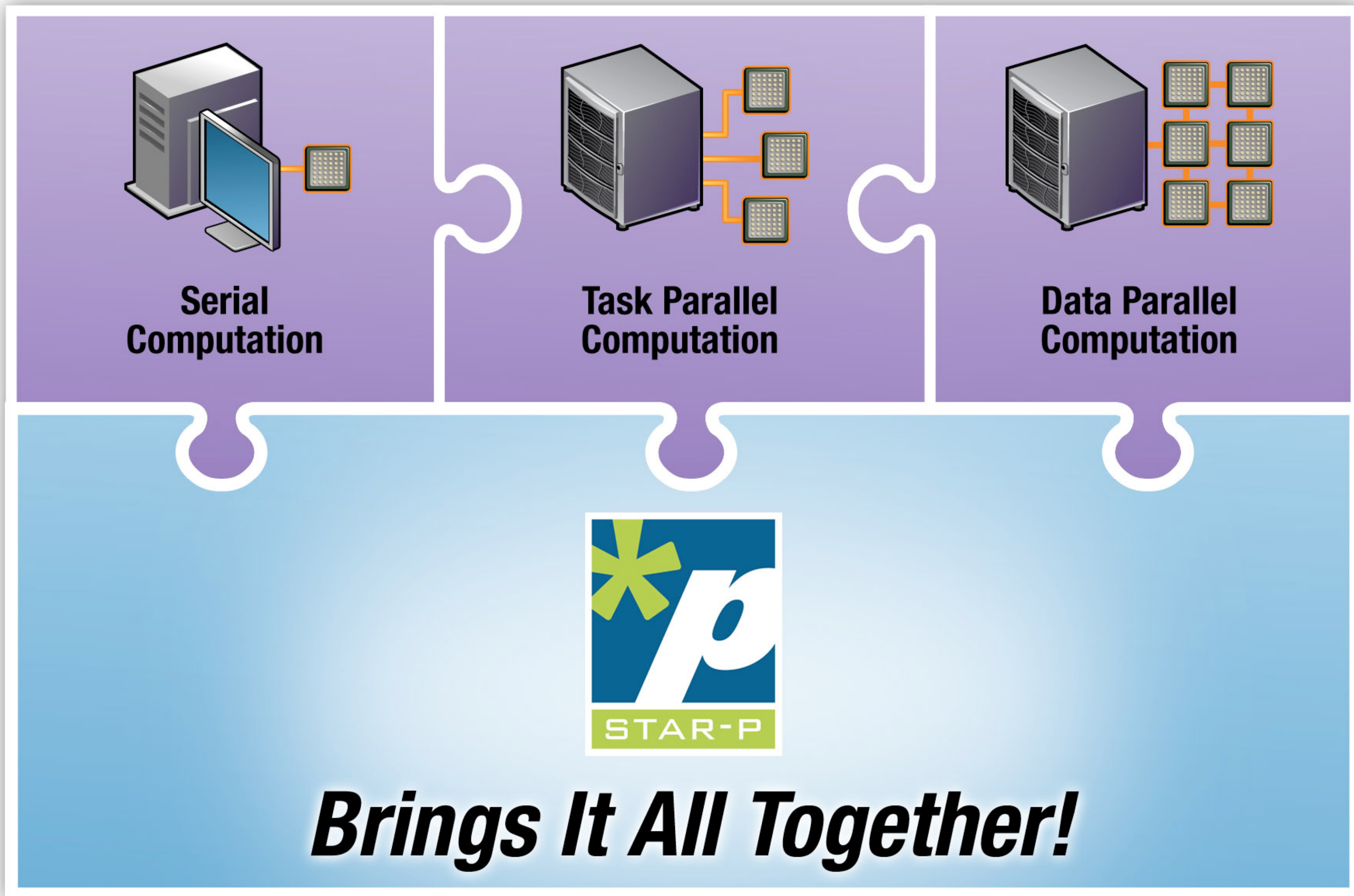
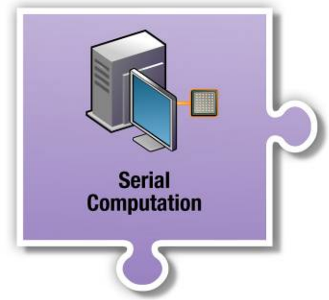
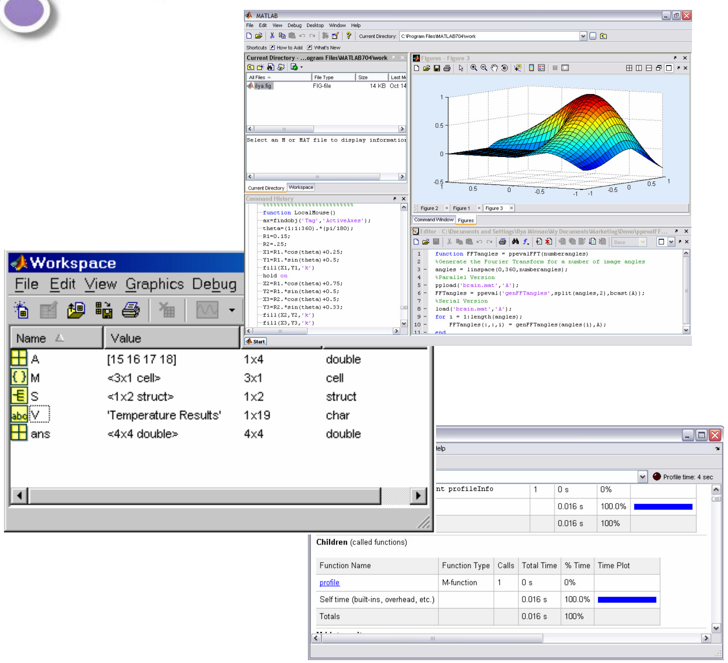
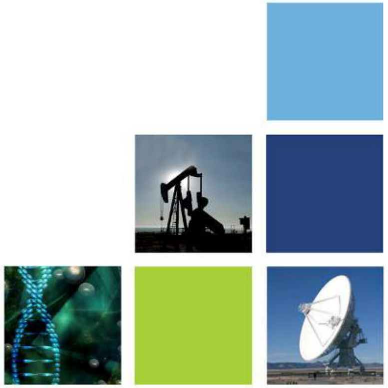

Serial Computation
Task Parallel Computation
Data Parallel Computation
STAR-P
Brings It All Together!

Serial Computing in Star-P™

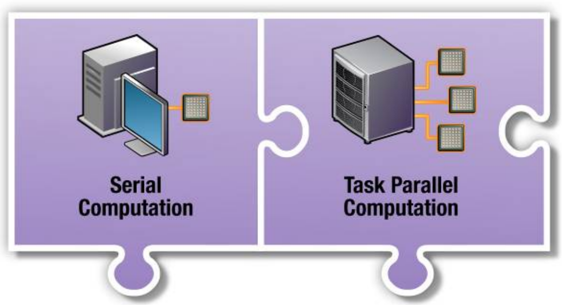


- Use MATLAB
  - File Editor
  - Profiler
  - Debugger
  - Array Editor
  - Desktop
  - Visualization
  - Small Calculations
- Computations taking less than .5 seconds



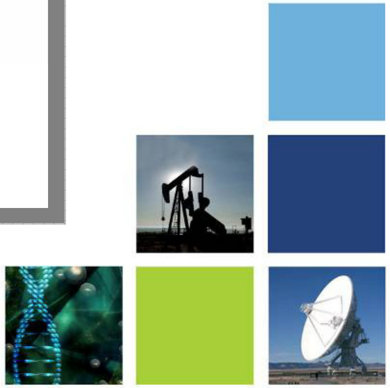


Task Parallel Computing in Star-P™



- Data size < 100MB
- Execution time > .5 second
- Code separable in time
- Embarrassingly parallel apps
- Incorporate Star-P's **ppeval**

```
%Generate the Fourier Transform on 10 degree spacing
angles = linspace(0,360,37);
%Serial Version
load('brain.mat','A');
for i = 1:length(angles);
    FFTangles(:,:,i) = genFFTangles(angles(i),A);
end
```



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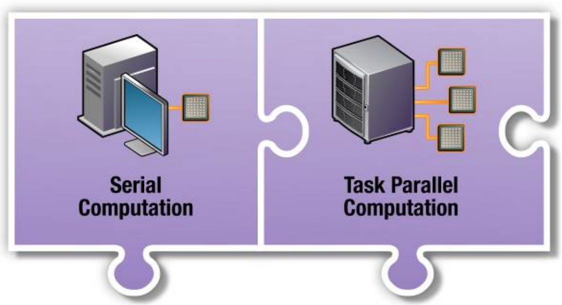
Task Parallel Computing in Star-P™



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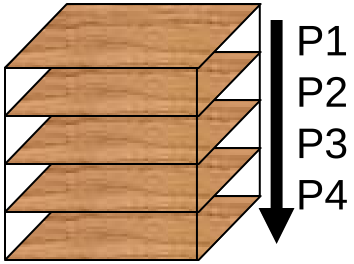
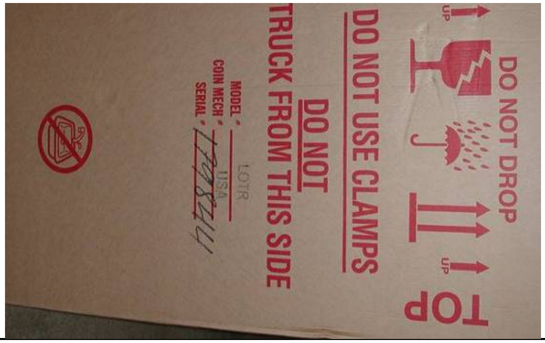
%Serial Version
load('brain.mat','A');
for i = 1:length(angles);
    FFTangles(:,:,i) = genFFTangles(angles(i),A);
end
%Parallel Version
ppload('brain.mat','A');
FFTangles = ppeval('genFFTangles',split(angles),bcast(A));
```

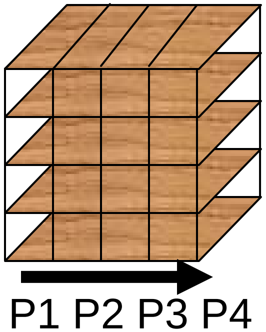
ppeval syntax (parallel function)

- **a=rand(500,500,200*p);**
- **[u,s,v]=ppeval('svd',a); % default svd on z-dim**



- **a=rand(500,500*p,200);**
- **[u,s,v]=ppeval('svd',a); % default svd on z-dim anyway**





Answer does not depend on distribution:

Parallel computers need shapes to enter from all sides.

Pi Recipe


```
>> n=8;   k=1:n;
>> sum(ppeval('quad','4./(1+x.^2)', (k-1)/n, k/n))
```

Parallel Evaluate Pieces of pi:

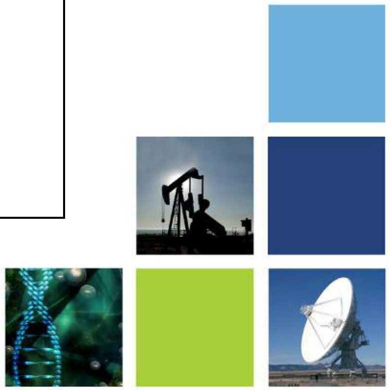
$\int 4/(1+x^2)\,dx$ on [0,1/8],[1/8,2/8],...,[7/8,1]   and sum.

ans =

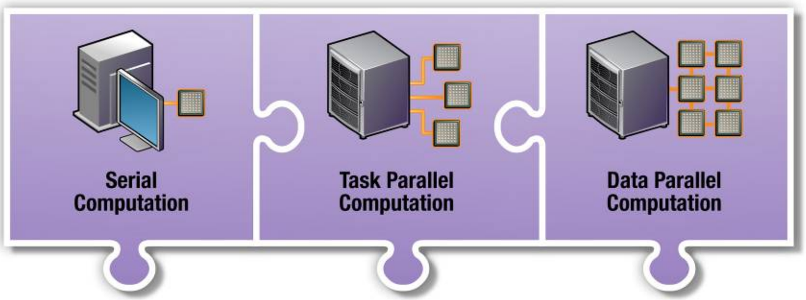
3.14159265358979

Abstraction: Independent of number of processors or processes!
Abstraction: Parameters automatically moved to server!

INTERACTIVE supercomputing



Data Parallel Computing in Star-P™




```
n=10000

A = rand(n, n);

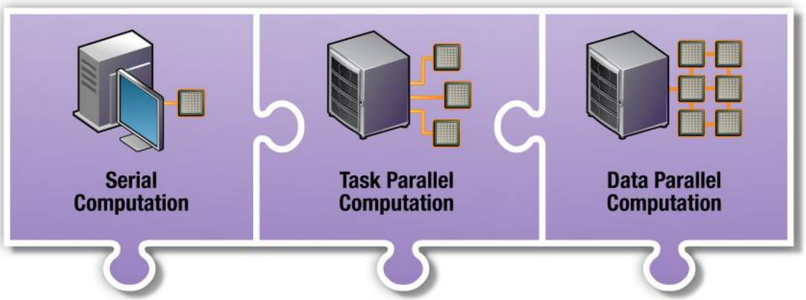
x = randn(n, 1);

y = zeros(size(x));

while norm(x-y) / norm(x) > 1e-11
    y = x;
    x = A*x;
    x = x / norm(x);
end;
```

- Data sizes >100MB
- Execution time > .5 second
- Data not separable
- Operations on vectors and matrices
- Incorporate ***p**
  - Global parallelism
  - Variables become parallel
  - Propagation occurs
    - Results are parallel
    - Functions performed on parallel data

Data Parallel Computing in Star-P™




```
% explicitly parallel with *p
n=10000*p

% implicitly parallel
A = rand(n, n);

% implicitly parallel
x = randn(n, 1);

% implicitly parallel
y = zeros(size(x));

while norm(x-y) / norm(x) > 1e-11
     y = x;
     x = A*x;
     x = x / norm(x);
end;
```

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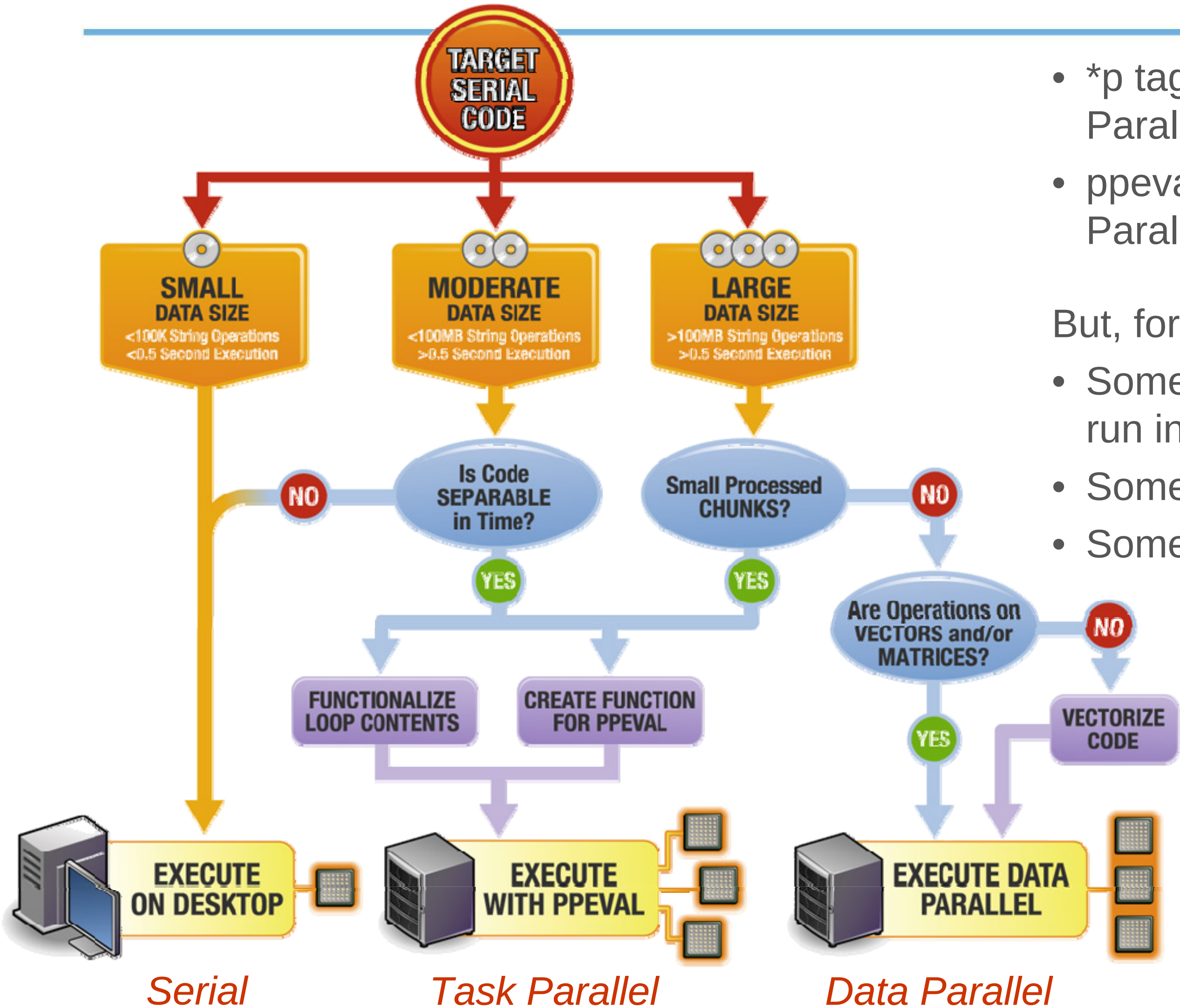
Programming for Best Performance - 1



- *p tag triggers automatic Data Parallel computation
- ppeval triggers automatic Task Parallel computation

But, for high performance:

- Some program segments are best run in Serial mode
- Some in Task Parallel mode
- Some in Data Parallel mode

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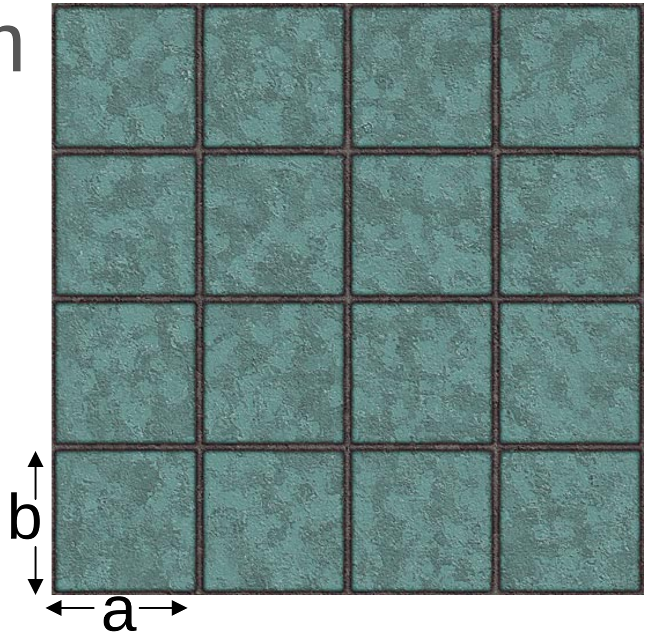
Classroom Homework

- The Buffon Needle Problem



Buffon(1,1,.5,1000*p)

```
function z=Buffon(a,b,l, trials)
r=rand(trials,3);
x=a*r(:,1)+l*cos(2*pi*r(:,3)); y=b*r(:,2)+l*sin(2*pi*r(:,3));
inside = (x >= 0) & (y>=0) & (x <= a) & (y <= b);
buffonpi=(2*l*(a+b) - l^2)/ (a*b*(1-sum(inside)/trials));
```

Classroom Experiment

- A data collector's dream:
  - 29 students, each code run in MPI and three versions of Star-P. Some students more skilled with MPI than others.

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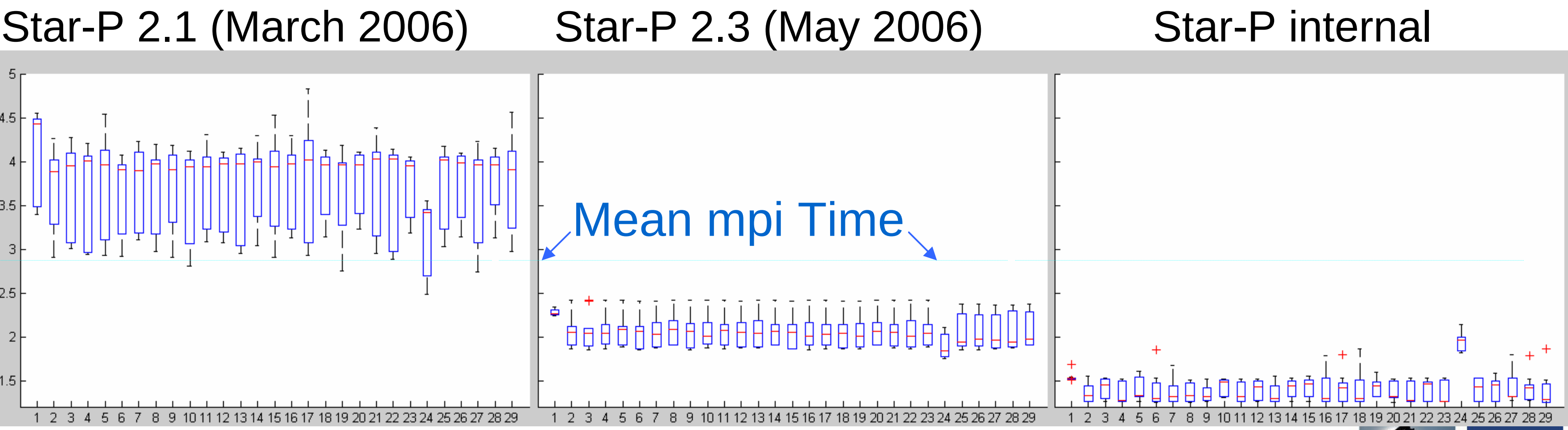
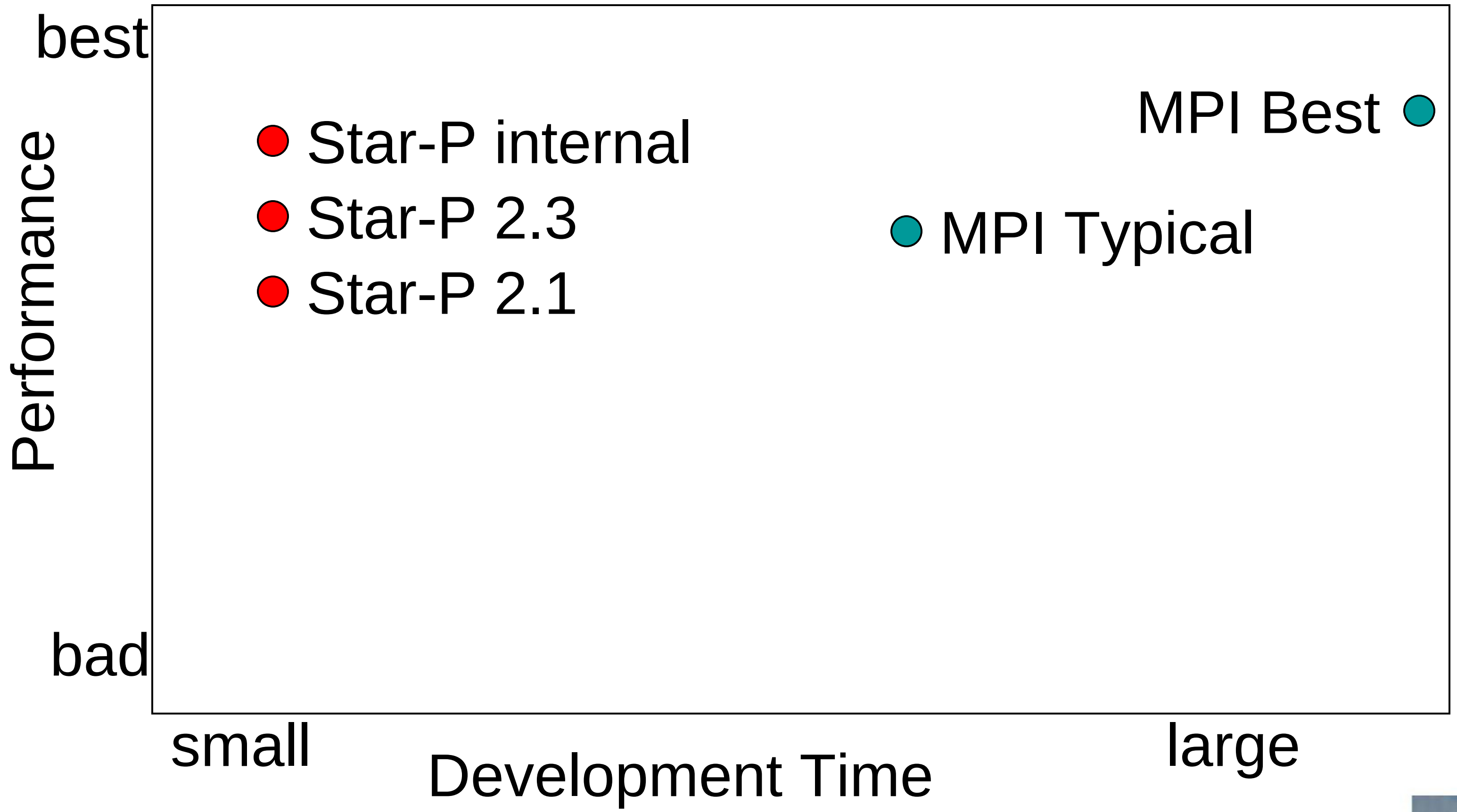


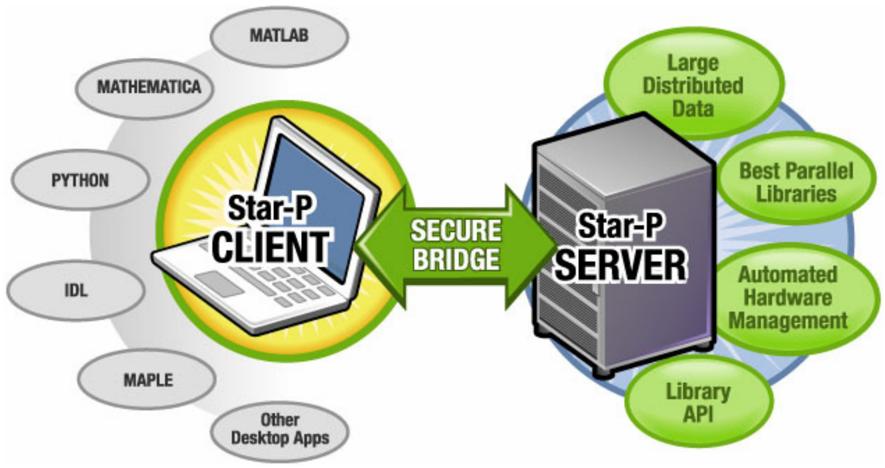
Productivity Study – Kepner diagram



Desktop Applications You Love
The High Performance You Crave

INTERACTIVE SUPERCOMPUTING

“Parallel Computing done right”



INTERACTIVE supercomputing

Information

www.interactivesupercomputing.com

edelman@mit.edu

Star-P™ System Configurations - 1

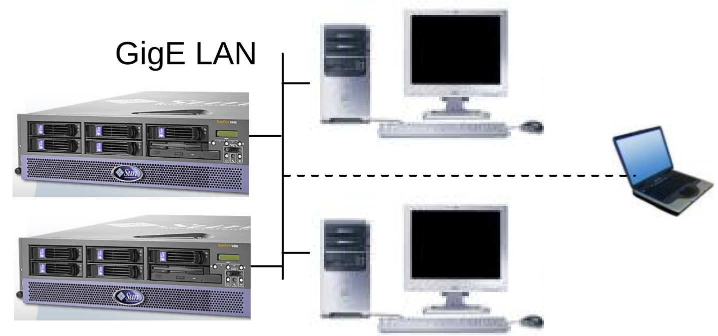
x86/64 Architectures: Opteron and/or Xeon 5100

Multi-core SMP Servers

Example:
Client – Linux/Windows desktop/laptop
Server – Sun Fire X4600, 8 dual-core Opterons (16 cores), SUSE Linux

Star-P Server – 8-socket license
Star-P Client – unlimited number of users
Local or remote access

Multi-core Clusters



Example:
Client – Linux/Windows desktop/laptop
Servers – 4x HP ProLiant BL25p (16 Opteron cores), SUSE
2x SGI Altix XE (8 Xeon 5100 cores), Redhat

Star-P Server – 12-socket license
Star-P Client – unlimited number of users
Local or remote access

Example Systems (SMP Servers and Clusters)

Opteron	Xeon 5100
HP: ProLiant BL25p, DL145G, DL385, DL585	SGI: Altix XE
Sun: SunFire x4100, x4200, x4600	HP: ProLiant BL20p G4, DL140 G3, DL360 G5, DL380 G5
Newisys: 4300-E,	Dell: PowerEdge 1950, 1955, 2950
Verari: 2510,	Penguin: Relion 1600, 2600
Penguin: Altus 3400	Verari:RM2220, VB1220

Star-P™ System Configurations - 2

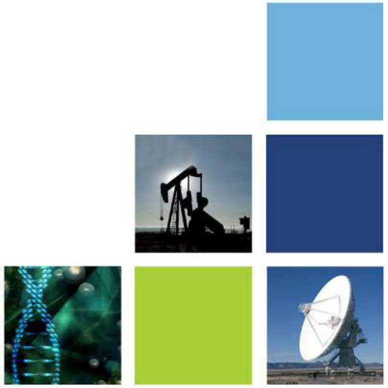
IA64 (Itanium) Architecture

Traditional HPC Servers / SMP

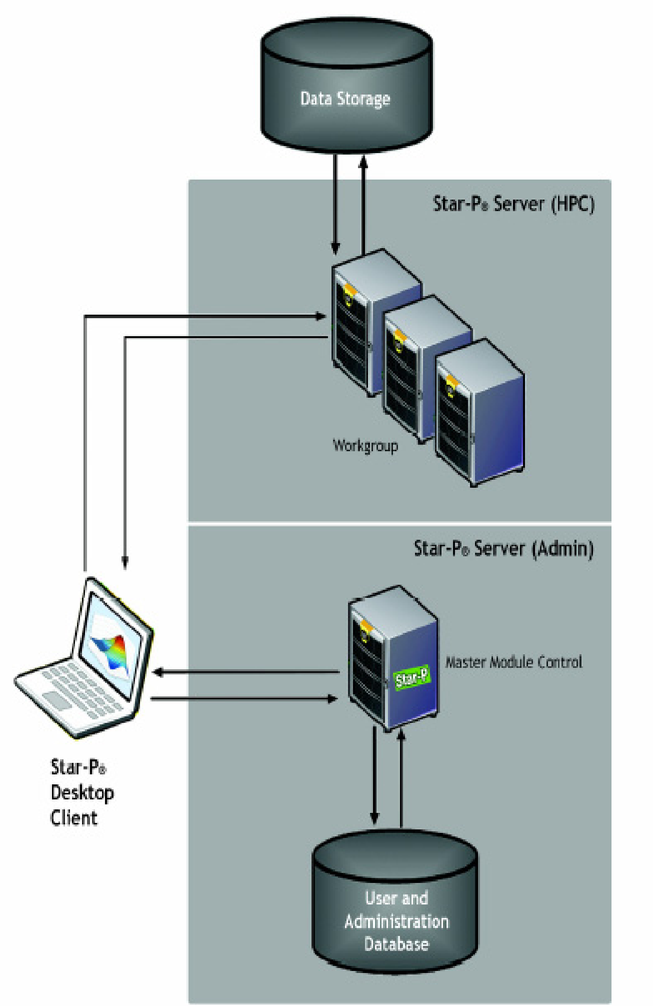
Example:
Client – Linux/Windows desktop/laptop
Server – SGI Altix 32 CPUs, NUMAflex Architecture, SGI ProPak 4 (SUSE SLES9 Linux)

Star-P Server – 32-CPU license
Star-P Client – unlimited number of users,
Star-P Admin Server software for managed access and resource allocation

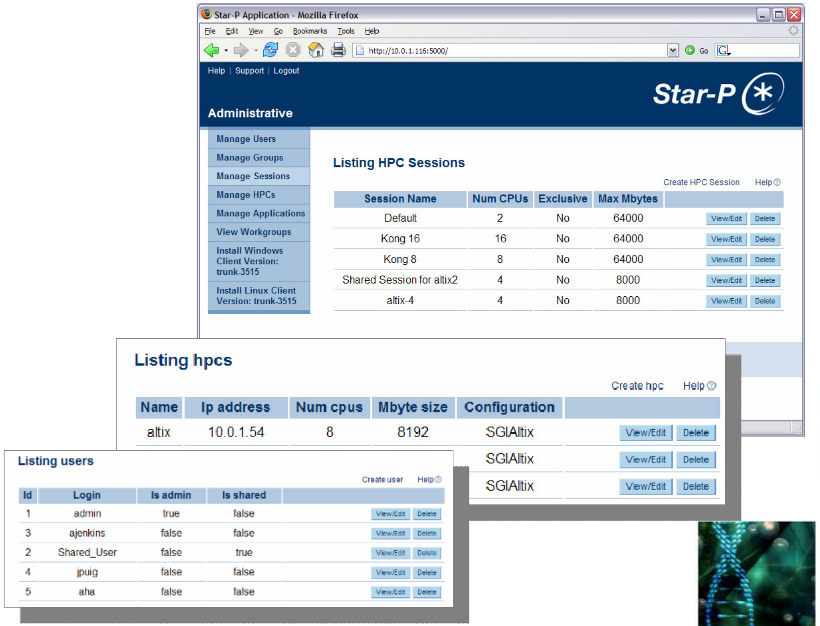
Example IA64 Systems:
SGI Altix 350, SGI Altix 450

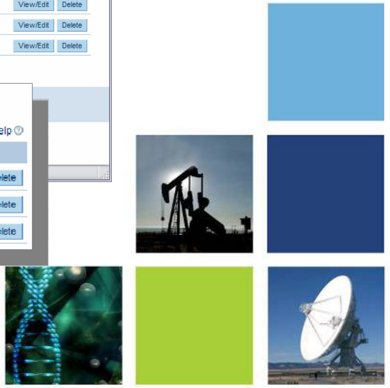


Star-P Architecture - Logical



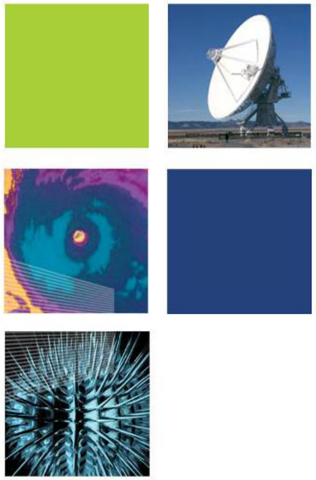
- Client
- Workgroup server(s)
- Master Control Module
- User & Admin database
- Data Storage





INTERACTIVE supercomputing

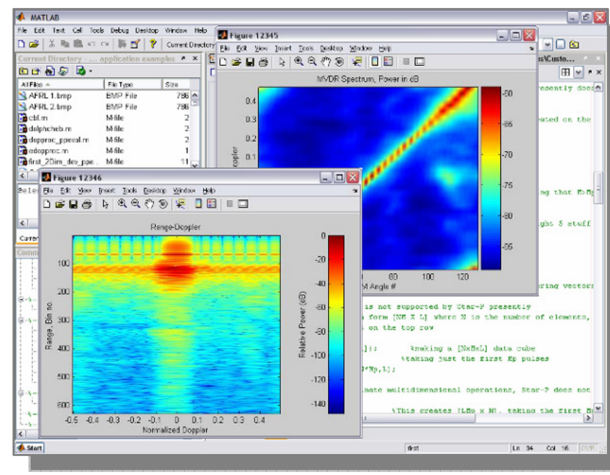
Applications by Industries



INTERACTIVE supercomputing

Radar Signal Processing

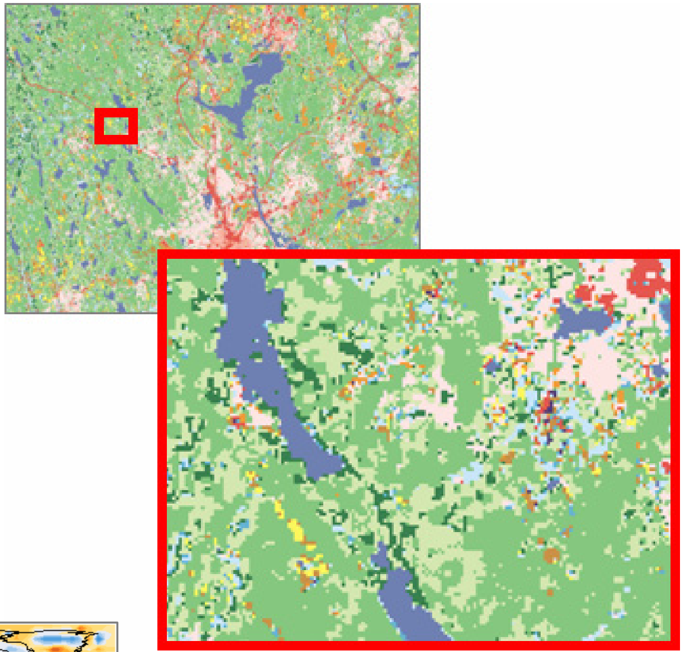
- Air Force Labs in Rome, NY
- Application: Radar Analysis & System Design
- Challenge: analysis of growing data sets
  - Satellite-based
  - Real time
- Star-P Solution:
  - Reuse existing MATLAB codes
  - Solve larger problems (TB's)
  - Interactive "what if" scenarios

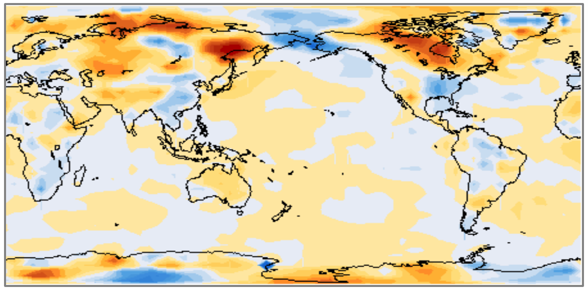


INTERACTIVE supercomputing

Econometric Modeling

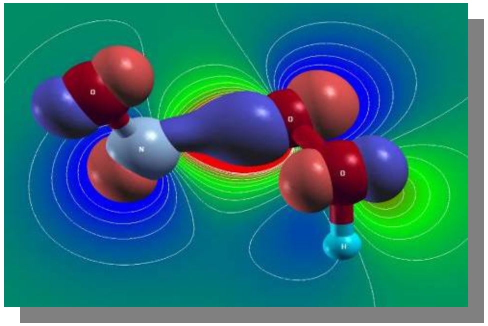
- Columbia University's Earth Institute
- Application:
  - Understanding interactions of climate, crop selection, and impact on local populations
  - Development of public policy, insurance, relief programs
- Star-P Solution:
  - Interactive development of complex statistical model
  - Scale to enormous data sets

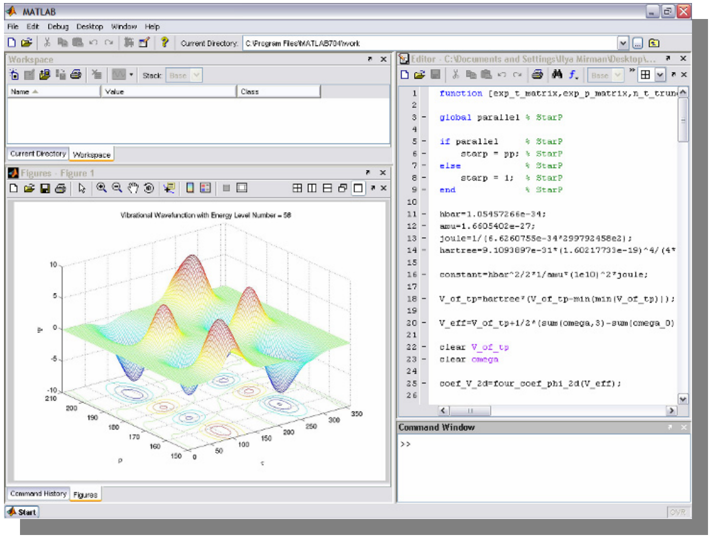




Molecular Simulation

- Department of Chemistry, M.I.T.
- Application:
  - molecular modeling of thermodynamic properties from first principles
  - Impacts smog, weather patterns
- Star-P Solution:
  - Transparent parallelization of existing MATLAB models
  - Global array syntax to solve large systems of equations with 16-P Altix





INTERACTIVE supercomputing