OpenSees

Parallel Processing With OpenSees

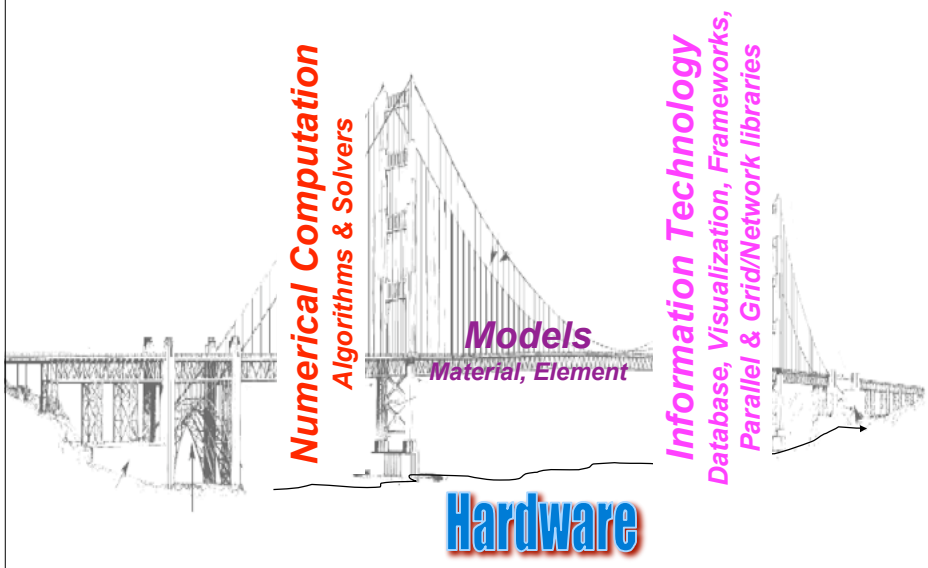
Frank McKenna
UC Berkeley

OpenSeesDays 2011

Overview

- Hardware Trends
- Parallel Computing & OpenSees
- Cloud Computing & OpenSees

Building Blocks for Simulation



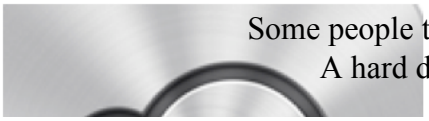
Bell's Law

Bell's Law of Computer Class formation

was discovered about 1972. It states that technology advances in semiconductors, storage, user interface and networking advance every decade enable a new, usually lower priced computing platform to form. Once formed, each class is maintained as a quite independent industry structure. This explains mainframes, minicomputers, workstations and Personal computers, the web, emerging web services, palm and mobile devices, and ubiquitous interconnected networks. We can expect home and body area networks to follow this path.

Gordon Bell, http://research.microsoft.com/~GBell/Pubs.htm

Cloud Computing (according to Steve)



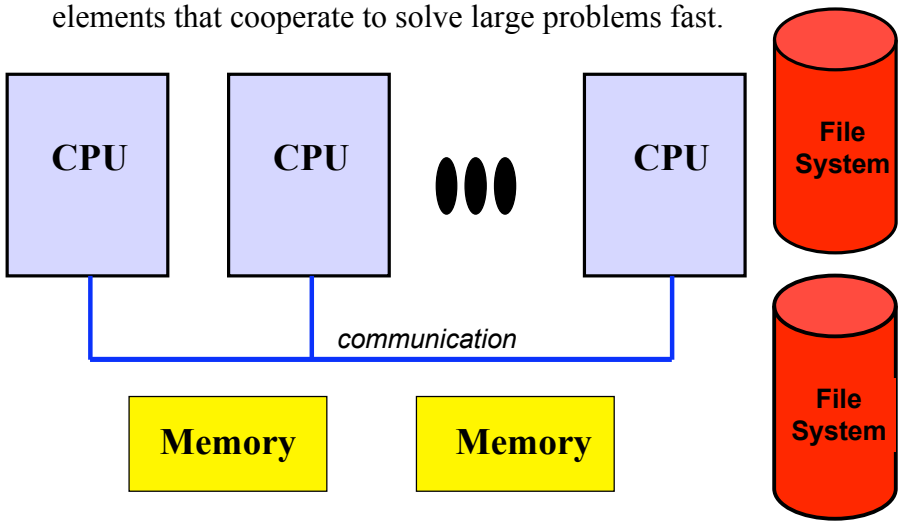
Some people think the cloud is just
A hard drive in the sky!

Cloud computing is internet-based computing , whereby shared resources, software, and information are provided to computers and other devices on demand, like the electricity grid. source: wikipedia

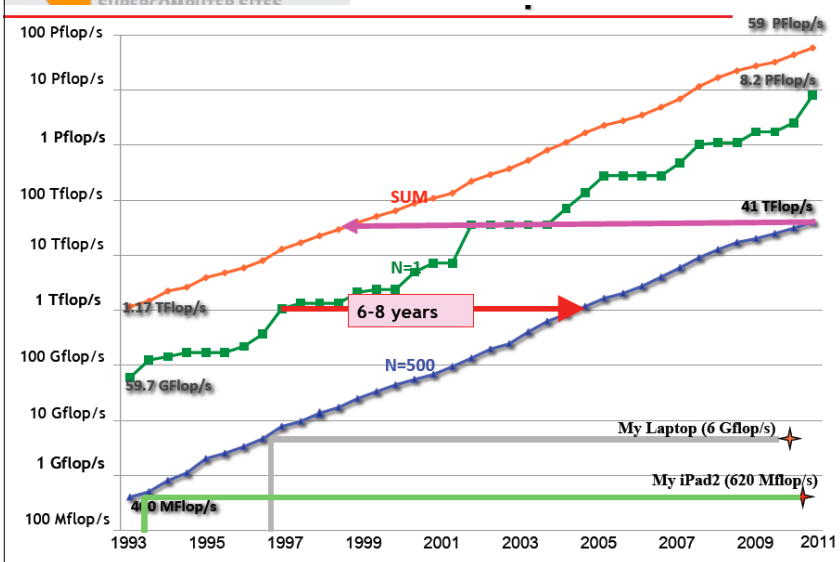
"..PC and Mac Demoted to a Device"

What is a Parallel Computer?

- A *parallel computer* is a collection of processing elements that cooperate to solve large problems fast.



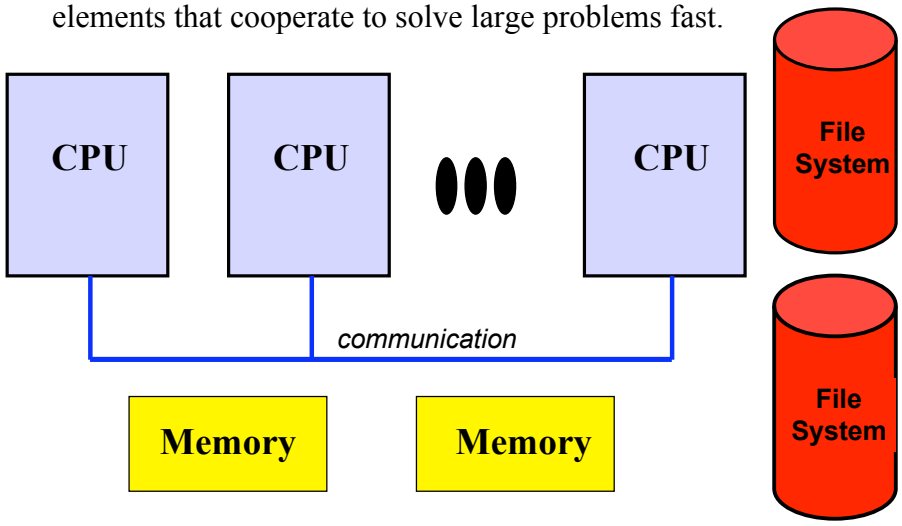
Performance Projection



Source:Jack Dongarra, 2011

What is a Parallel Computer?

- A *parallel computer* is a collection of processing elements that cooperate to solve large problems fast.



Why should you care?

- They will save you time
- They will allow you to solver larger problems.
- They are here whether you like it or not!

K computer: 548,352 cores
8 quadrillion calculations per second (8 petaflops - 8x10^15 flops)

Rank	Site	Computer
1	RIKEN Advanced Institute for Computational Science (AICS) Japan	K computer, SPARC64 VIIIfx 2.0GHz, Tofu interconnect Fujitsu
2	National Supercomputing Center in Tianjin China	Tianhe-1A - NUDT TH MPP, X5670 2.93Ghz 6C, NVIDIA GPU, FT-1000 8C NUDT
3	DOE/SC/Oak Ridge National Laboratory United States	Jaguar - Cray XT5-HE Opteron 6-core 2.6 GHz Cray Inc.
4	National Supercomputing Centre in Shenzhen (NSCS) China	Nebulae - Dawning TC3600 Blade, Intel X5650, NVidia Tesla C
5	GSIC Center, Technol Japan	
6	DOE/NN United St	Cielo - Cray XE6 8-core 2.4 GHz Cray Inc.
7	NASA/Ames Research Center/NAS United States	Pleiades - SGI Altix ICE 8200EX/8400EX, Xeon HT QC 3.0/Xeon 5570/5670 2.93 Ghz, Infiniband SGI
8	DOE/SC/LBNL/NERSC United States	Hopper - Cray XE6 12-core 2.1 GHz Cray Inc.
9	Commissariat a l'Energie Atomique (CEA) France	Tera-100 - Bull bullx super-node S6010/S6030 Bull SA
10	DOE/NNSA/LANL United States	Roadrunner - BladeCenter QS22/LS21 Cluster, PowerXCell 8i 3.2 Ghz / Opteron DC 1.8 GHz, Voltaire Infiniband

BEFORE YOU GET ALL EXCITED

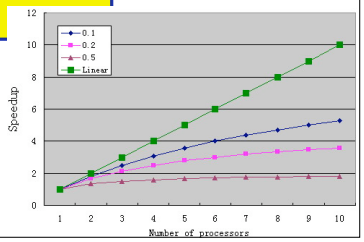
Speedup & Amdahl's Law

$$speedup_{PC}(p) = \frac{Time(1)}{Time(p)}$$

$$Speedup_{PC} = \frac{T_1}{\alpha T_1 + \frac{(1-\alpha)T_1}{n}} \rightarrow \frac{1}{\alpha} \; as \; n \rightarrow \infty$$

Portion of sequential

# of processors



Improving Real Performance

Peak Performance grows exponentially, a la Moore's Law

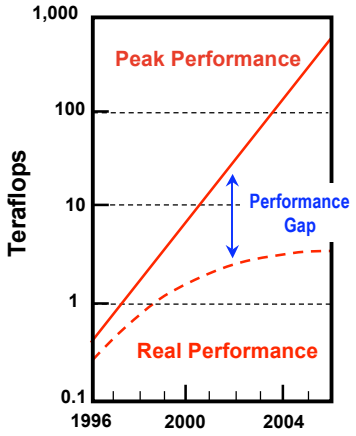
- In 1990's, peak performance increased 100x; in 2000's, it will increase 1000x

But efficiency (the performance relative to the hardware peak) has declined

- was 40-50% on the vector supercomputers of 1990s
- now as little as 5-10% on parallel supercomputers of today

Close the gap through ...

- Mathematical methods and algorithms that achieve high performance on a single processor and scale to thousands of processors
- More efficient programming models and tools for massively parallel supercomputers

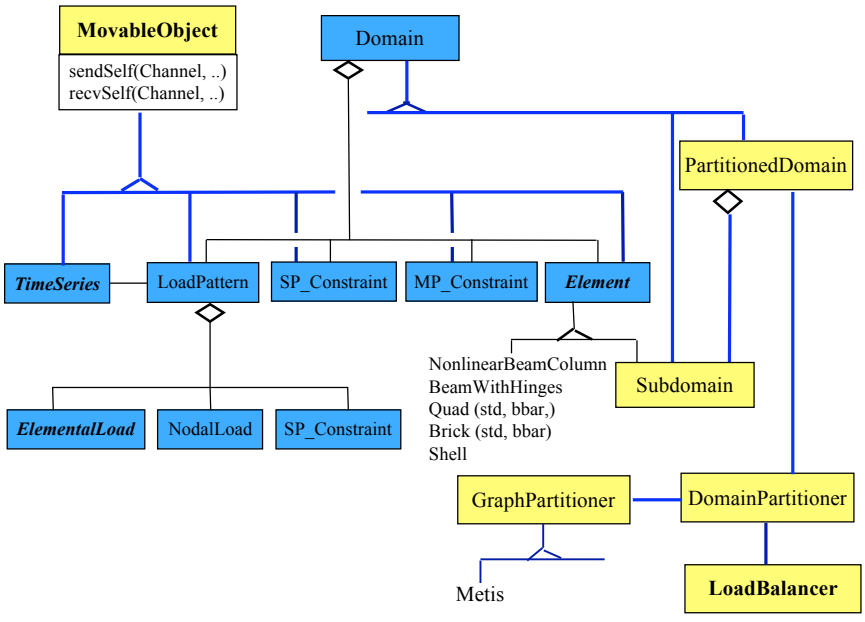


Source: Jim Demmell, CS267 Course Notes

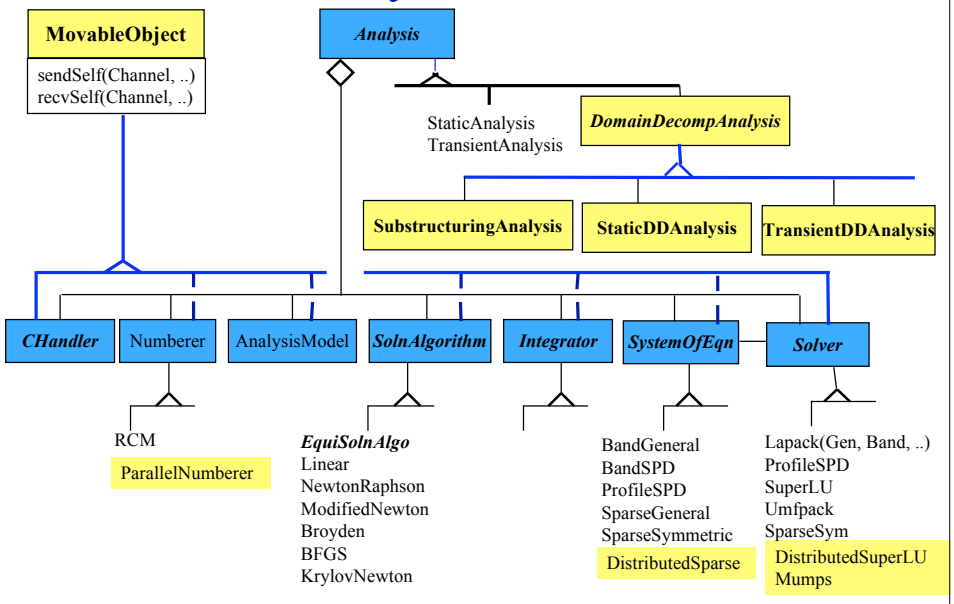
What is OpenSees?

- OpenSees is an Open-Source Software Framework written in C++ for developing nonlinear Finite Element Applications for both sequential and **PARALLEL** environments.

Domain Classes



Analysis Classes



The OpenSees Interpreters

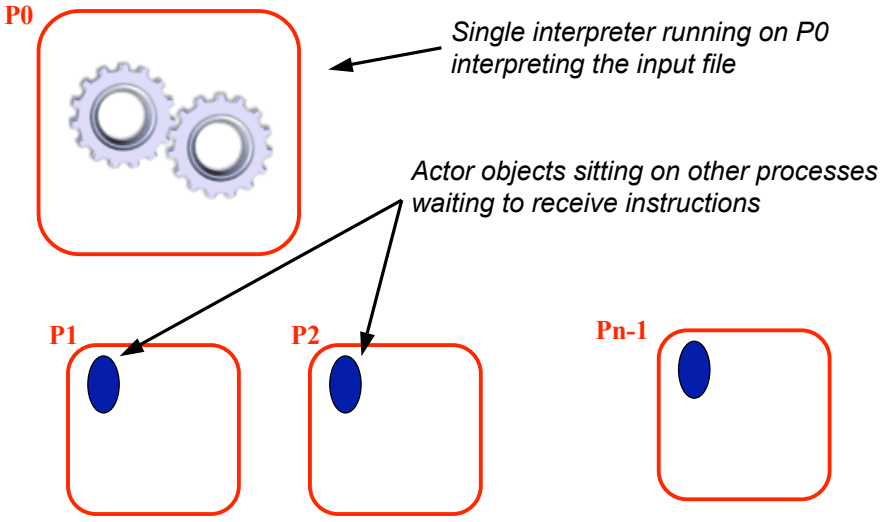
- OpenSees.exe, OpenSeesSP.exe and OpenSeesMP.exe are applications that extend the Tcl interpreter for finite element.

So What are OpenSeesSP.exe and OpenSeesMP.exe ?

Parallel OpenSees Interpreters

- OpenSeesSP: An application for large models which will parse and execute the exact same script as the sequential application. The difference being the element state determination and equation solving are done in parallel.
- OpenSeesMP: An application for **BOTH** large models and parameter studies.

OpenSeesSP: An application for Large Models



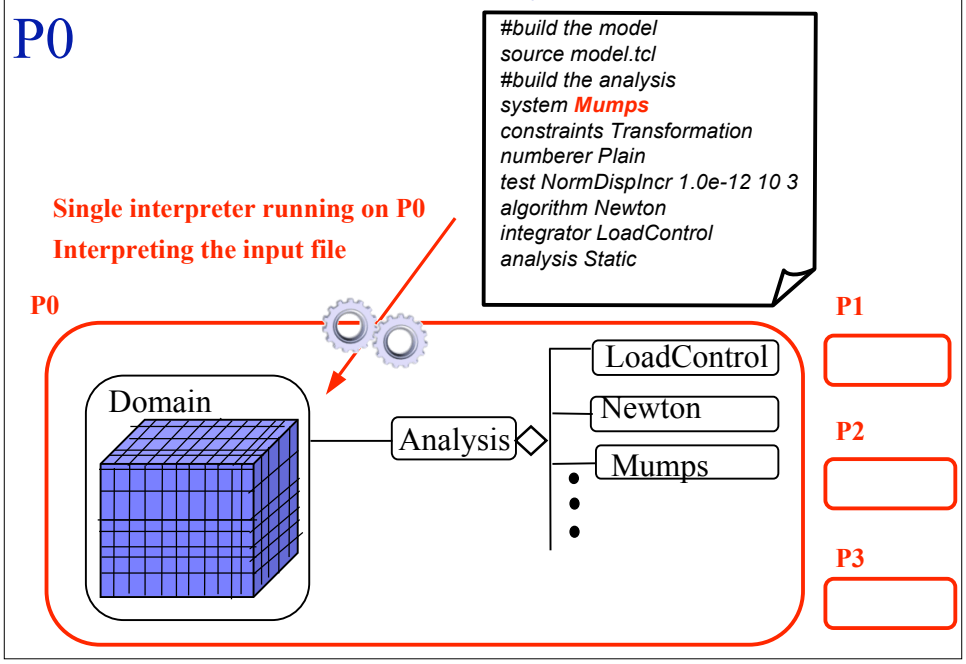
Modified Commands

- System command is modified to accept new parallel equation solvers

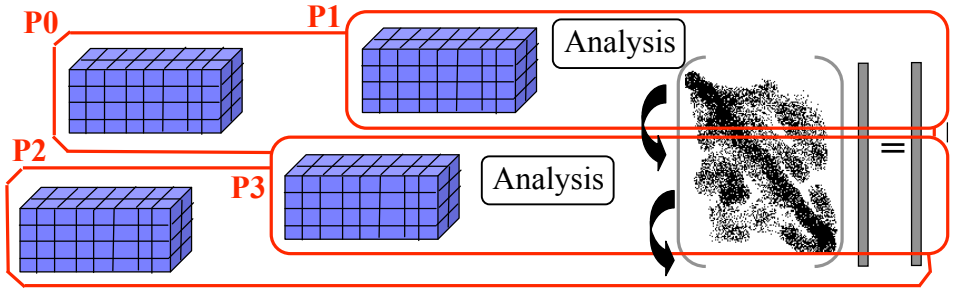
system Mumps

system Diagonal

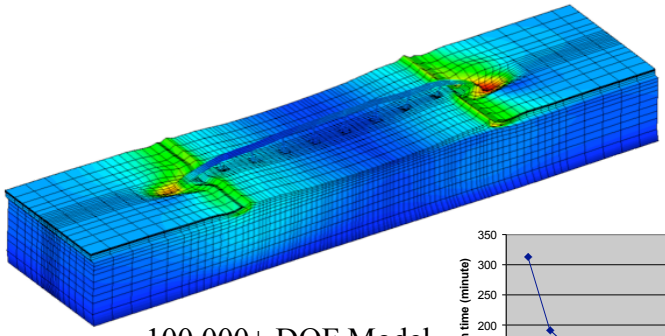
Model Built and Analysis Constructed in P0



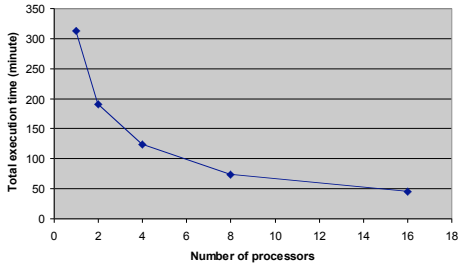
```
#build the model
source modelP.tcl
#build the analysis
system Mumps
constraints Transformation
numberer Plain
test NormDispIncr 1.0e-12 10 3
algorithm Newton
integrator LoadControl
analysis Static
analyze 10
```



Example Usage: Humboldt Bay Bridge Model



100,000+ DOF Model
Implicit Integration
Mumps Direct Solver



Run	el. size (m)	Elements	Nodes	DOFs
A	20	54,026	59,032	156,768
B	10	404,751	424,512	1,193,283
C	5	3,130,301	3,208,822	9,307,563
D	2.5	24,615,801	24,928,842	73,515,123

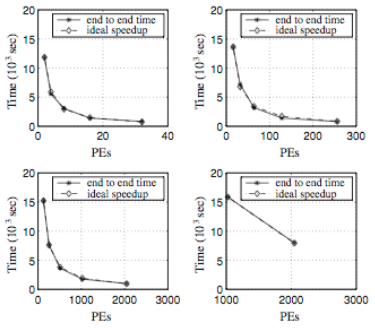
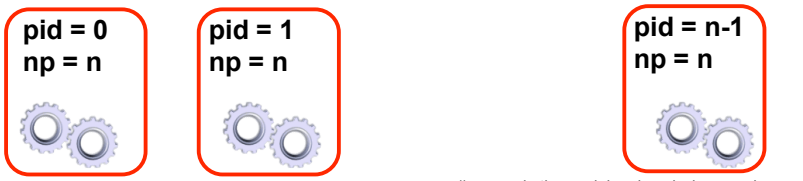


Fig. 18 Fixed-size, scalability plot at SDSC's DataStar. Upper row is runs A (*left*) and B (*right*), lower row is runs C (*left*) and D (*right*) (Table 3)

OpenSeesMP: An application for Large Models and Parameter Studies



Each process is running an interpreter and can determine it's unique process number and the total number of processes in computation

Based on this script can do different things

```
# source in the model and analysis procedures
set pid [getPID]
set np [getNP]

# build model based on np and pid
source modelP.tcl
doModel {$pid $np}

# perform gravity analysis
system Mumps
constraints Transformation
numberer Parallel
test NormDispIncr 1.0e-12 10 3
algorithm Newton
integrator LoadControl 0.1

analysis Static

set ok [analyze 10]
return $ok
```

New Commands added to OpenSeesMP:

- A Number of new commands have been added:

1. getNP returns number of processes in computation.
2. getPID returns unique pocess id {0,1, .. NP-1}
3. send -pid pid? data pid = { 0, 1, .., NP-1}
4. recv -pid pid? variableName pid = {0,1 .., NP-1, ANY}
5. barrier
6. domainChange

- These commands have been added to ALL interpreters (OpenSees, OpenSeesSP, and OpenSeesMP)

Example

ex2.tcl

```
set pid [getPID]
set np [getNP]
if {$pid == 0 } {
   puts "Random:"
   for {set i 1 } {$i < $np} {incr i 1} {
      recv -pid ANY msg
      puts "$msg"
   }
} else {
   send -pid 0 "Hello from $pid"
}
barrier
if {$pid == 0 } {
   puts "\nOrdered:"
   for {set i 1 } {$i < $np} {incr i 1} {
      recv -pid $i msg
      puts "$msg"
   }
} else {
   send -pid 0 "Hello from $pid"
}
```

```
Terminal — bash — 80x32
bin> mpirun -np 10 OpenSeesMP ex2.tcl

        OpenSees -- Open System For Earthquake Engineering Si
        Pacific Earthquake Engineering Research Center -- 1.7.

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                              All Rights Reserved
    (Copyright and Disclaimer @ http://www.berkeley.edu/OpenSe


Random:
Hello from 1
Hello from 3
Hello from 5
Hello from 6
Hello from 8
Hello from 2
Hello from 4
Hello from 7
Hello from 9
Ordered:
Hello from 1
Hello from 2
Hello from 3
Hello from 4
Hello from 5
Hello from 6
Hello from 7
Hello from 8
Hello from 9
```
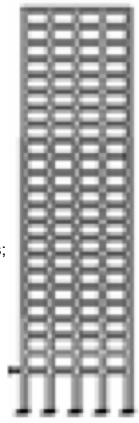

Steel Building Study

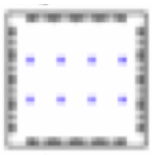
```
set pid [getPID]
set np [getNP]
set recordsFileID [open "peerRecords.txt" r]
set count 0;

foreach gMotion [split [read $recordsFileID] ¥n] {
 if {[expr $count % $np] == $pid} {

 source model.tcl
 source analysis.tcl

 set ok [doGravity]

 loadConst -time 0.0

 set gMotionList [split $gMotion "/"]
 set gMotionDir [lindex $gMotionList end-1]
 set gMotionNameInclAT2 [lindex $gMotionList end]
 set gMotionName [string range $gMotionNameInclAT2 0 end-4 ]

 set Gaccel "PeerDatabase $gMotionDir $gMotionName -accel 384.4 -dT dT -nPts nPts"
 pattern UniformExcitation 2 1 -accel $Gaccel

 recorder EnvelopeNode -file $gMotionDir$gMotionName.out -node 3 4 -dof 1 2 3 disp

 doDynamic [expr $dT*$nPts] $dT

  wipe
 }

 incr count 1;
}
```

7200 records
2 min a record
240 hours or 10 days
Ran on 2000 processors
on teragrid in less than 15 min.

Concrete Building Study

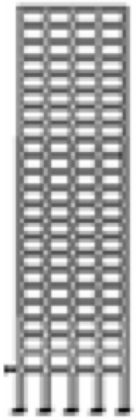
```
set pid [getPID]
set np [getNP]
set count 0;
source parameters.tcl
source ReadSMDFileNewFormat.tcl;
foreach GMfile $iGMFile {
   foreach Factor1248 $iFactor1248 {

     if {[expr $count % $np] == $pid} {

        set inFile $GMdir/$GMfile.AT2
        set outFile $GMdir/$GMfile.g3;
        ReadSMDFileNewFormat $inFile $outFile dt npts;

        wipe
        source GravityAnalysisScript.tcl

        loadConst -time 0.0;
        wipeAnalysis

        source  EQ_Recorder.tcl
        source EQAnalysisScript.tcl

       if {$ok == 0} {
          puts "Process $pid $GMfile x $Factor1248 FINISHED OK modelTime [getTime]]"
       } else {
          puts "Process $pid $GMfile x $Factor1248 FINISHED FAIL modeTime [getTime] desiredTime $TmaxAnalysis]"
       }
       incr count 1
     }
   }
}
```

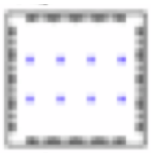




113 records, 4 intensities
3 hour a record, would have
taken 1356 hours or 56.5 days
Ran on 452 processors of a
Teragrid in less than 5 hours.

Concrete Building Study





113 records,
4 intensities
3 hour a record
1356 hours
or 56.5 days
Ran on 452
processors
on teragrid in less
than 5 hours.

Modified Commands

- Some existing commands have been modified to allow analysis of large models in parallel:
  1. numberer

     numberer ParallelPlain

     numberer ParallelRCM
  2. system

     system Mumps <-ICNTL14 %?>
  3. integrator

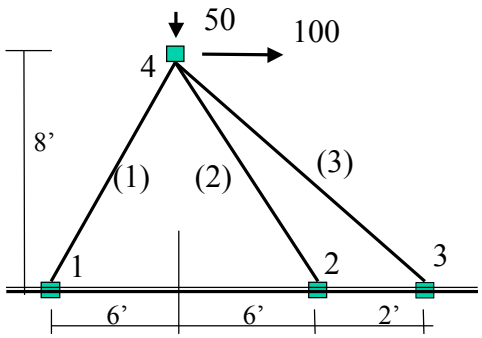
     integrator ParallelDisplacementControl node? Dof? dU?

- Use these ONLY IF PARALLEL MODEL

Example Parallel Model:

ex4.tcl

```
set pid [getPID]
set np [getNP]
if {$np != 2}  exit

model BasicBuilder -ndm 2 -ndf 2
uniaxialMaterial Elastic 1 3000
if {$pid == 0} {
   node 1   0.0  0.0
   node 4  72.0 96.0
   fix 1 1 1
   element truss 1 1 4 10.0 1
   pattern Plain 1 "Linear" {
      load 4 100 -50
   }
} else {
   node 2 144.0  0.0
   node 3 168.0  0.0
   node 4  72.0 96.0
   fix 2 1 1
   fix 3 1 1
   element truss 2 2 4 5.0 1
   element truss 3 3 4 5.0 1
}
```



	E	A
1	3000	10
2	3000	5
3	3000	5

Example Parallel Analysis:

```
#create the recorder
recorder Node -file node4.out.$pid -node 4 -dof 1 2 disp

#create the analysis
constraints Transformation
numberer ParallelPlain
system Mumps
test NormDispIncr 1.0e-6 6 2
algorithm Newton
integrator LoadControl 0.1
analysis Static

#perform the analysis
analyze 10

# print to screen node 4
print node 4
```

```
Terminal — bash — 86x31
bin> mpirun -np 2 OpenSeesMP ex4.tcl

        OpenSees -- Open System For Earthquake Engineering Simulation
       Pacific Earthquake Engineering Research Center -- 1.7.5

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 Node: 4
        Coordinates  : 72 96
        commitDisps: 0.530093 -0.177894
        Velocities   : 0 0
         unbalanced Load: 100 -50
        ID : 0 1

Process Terminating 0

 Node: 4
        Coordinates  : 72 96
        commitDisps: 0.530093 -0.177894
        Velocities   : 0 0
         unbalanced Load: 0 0
        ID : 0 1

Process Terminating 1
bin> diff node4.out.0 node4.out.1
bin>
```

Parallel Displacement Control and domainChange!

ex5.tcl

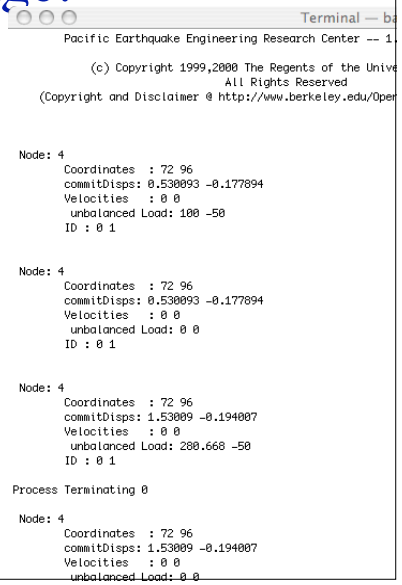
```
source ex4.tcl

loadConst - time 0.0

if {$pid == 0} {
   pattern Plain 2 "Linear" {
      load 4 1 0
   }
}

domainChange

integrator ParallelDisplacementControl 4 1 0.1
analyze 10
```



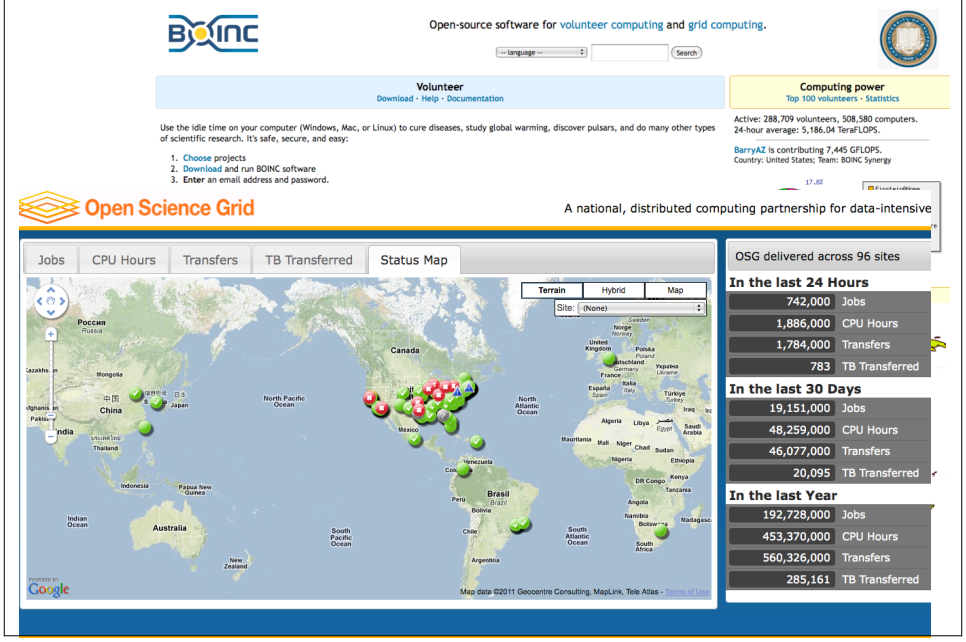
Things to Watch For

1. Deadlock (program hangs)
   - send/recv messages
   - Opening files for writing & not closing them
2. Race Conditions (different results every time run problem)
   - parallel file system.
3. Load Imbalance
   - poor initial task assignment.

Grid Computing

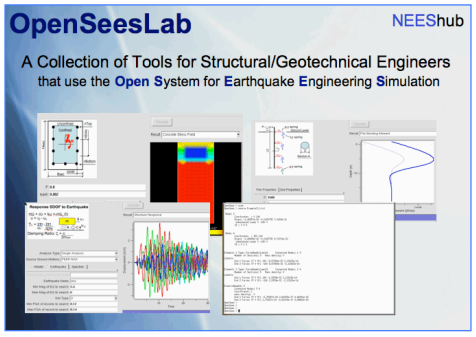
•Most distributed form of parallel computing
•Computers communicating over the internet to solve a given problem
•Low bandwidth and extremely high latency, typically only used for embarrasingly parallel problems, i.e. paramerer studies.

Grid Computing - computational resources



The OpenSeesLab tool:

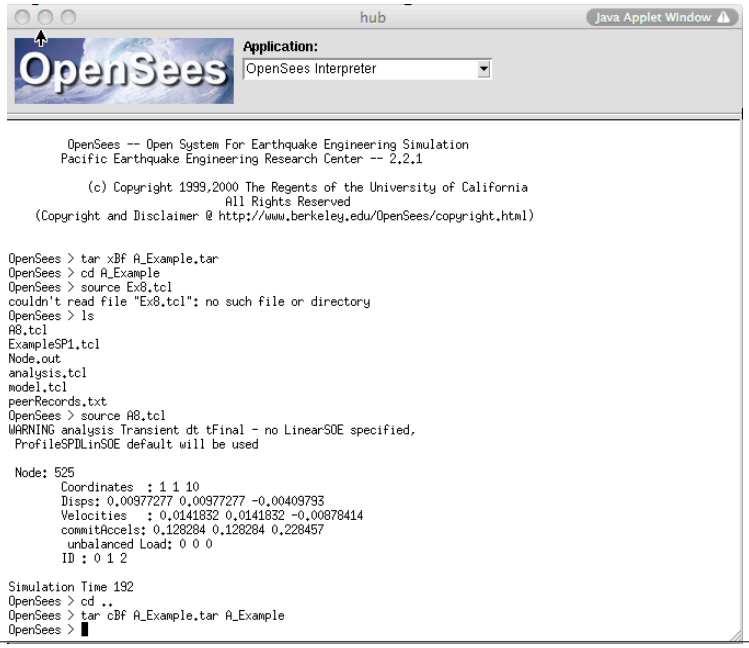
http://nees.org/resources/tools/openseeslab



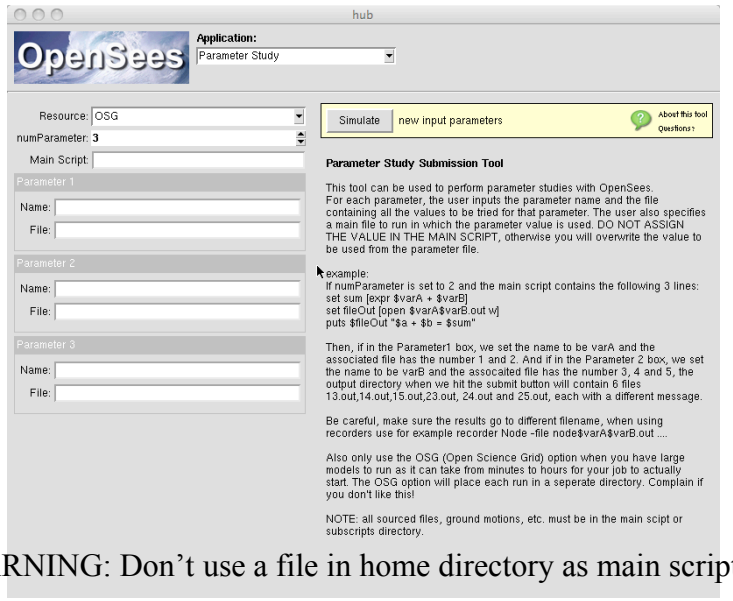
Is a suite of Simulation Tools powered by OpnSees for:

1. Submitting OpenSees scripts (input files) to HUB resources
2. Educating students and practicing engineers
3. Performing useful tasks

OpenSees Interpreter Tool

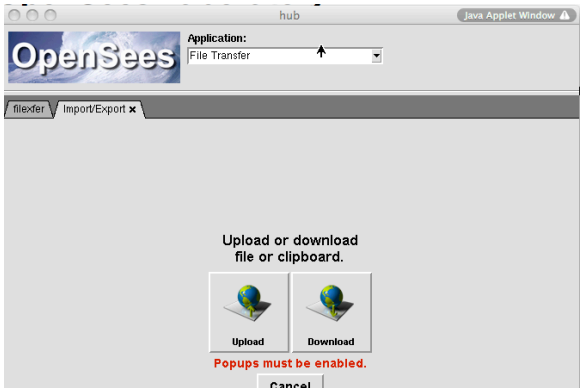


OpenSees Parameter Study Tool



WARNING: Don't use a file in home directory as main script

File Transfer Tool



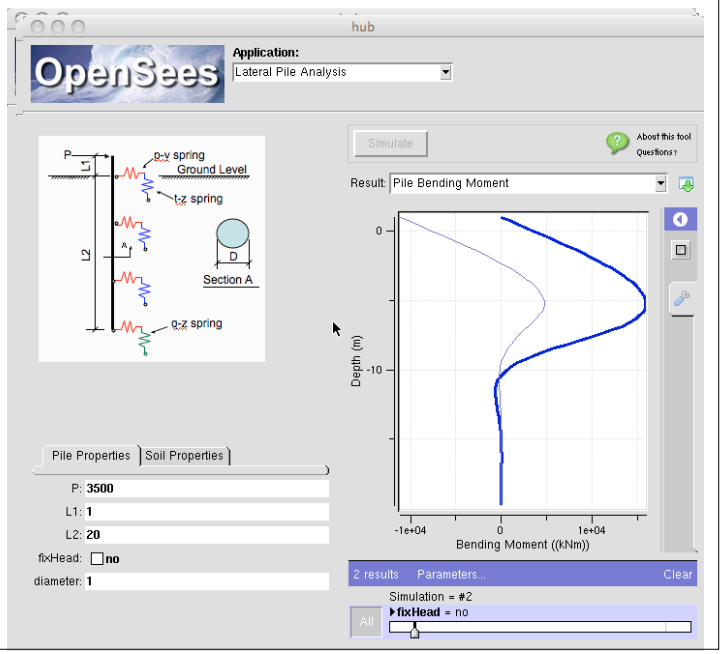
Upload: From Your Machine to NEEShub

Download: From NEEShub to Your Machine

There is also the **SynchoNEES** tool. An application that is Downloaded to your computer & allows you to quickly move Files & directories by moving them between folders.

Lateral Pile Analysis

http://opensees.berkeley.edu/wiki/index.php/Laterally-Loaded_Pile_Foundation
Chris McGann U. Washington



NEEShub things to know:

1. Anyone can get an account (it's free!)
2. You can have 5 sessions running at once
3. The sessions stay alive until you kill them
4. With each session you get a new data directory, some tools by default will store their information there.
5. You have 1GB storage by default (it is expandable to 10Gb!)

Any Questions?