2014 COMSOL conference, Cambridge, Sept 17-19

Cloud Computations for Acoustics with Coupled Physics

Anders Daneryd, ABB Corporate Research, Sweden

Daniel Ericsson, COMSOL AB, Sweden

Pär Mattson, COMSOL, & Marcus Johansson, ABB

COMSOL CONFERENCE 2014 CAMBRIDGE

- Cloud High Performance Computing

  – an Amazon Web Services use case in the petaflop domain

- Cloud computing & Acoustics

- COMSOL & Amazon Web Services – getting started

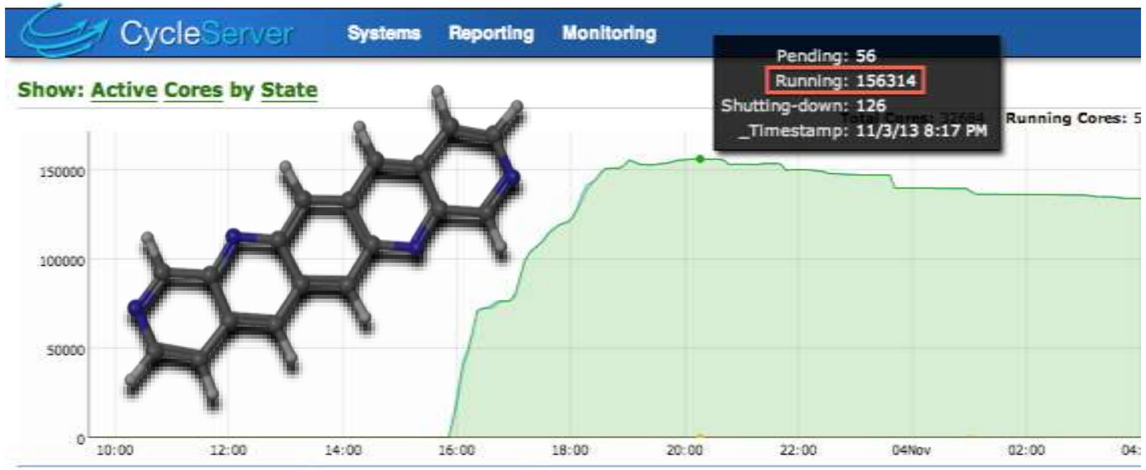
- Experiences w model problem

- Conclusions & Outlook

Amazon EC2 Use Case (Nov 2013)

”Materials design” – 205 000 molecules (materials)

- 16 788 instances (Virtual Machines),
- 156 314 *cores* (peak),
- 1.21 petaflops theoretical (petaflop: 10^{15} floating point operations per second),
- 18 hours ⇔ 264 compute years,
- 33kUSD (university discount was offered …)



http://arstechnica.com/information-technology/2013/11/18-hours-33k-and-156314-cores-amazon-cloud-hpc-hits-a-petaflop/

http://www.cyclecomputing.com/blog/back-to-the-future-121-petaflopsrpeak-156000-core-cyclecloud-hpc-runs-264-years-of-materials-science

Cloud High Performance Simulations @ ABB

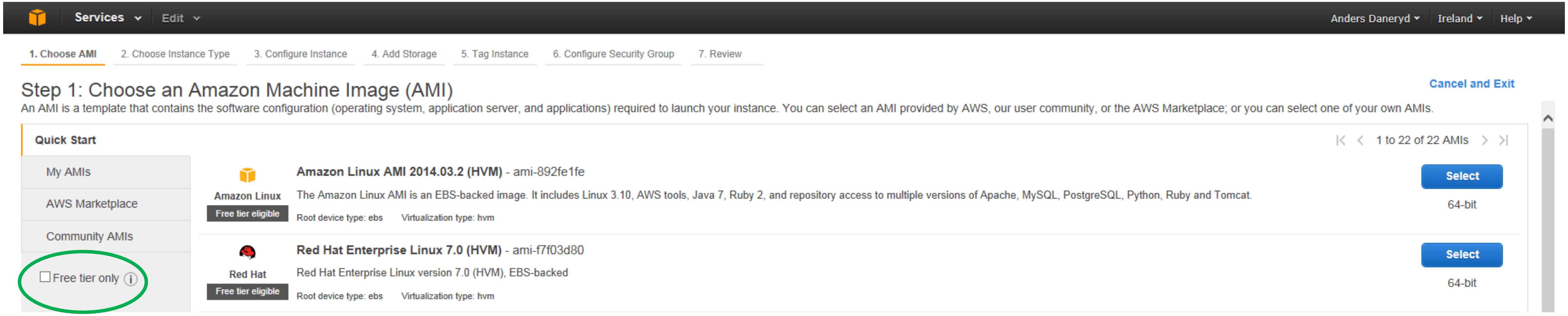
- The Cloud offers, as extension and complement to our in-house cluster (32x16 pCPUs),
  - affordable *gigantic* computing power – w a laptop, thin client
  - flexibility, by ”on-demand” and ”pay-as-you-go”

- Acoustics work flow
  - analytical => 2D R&D model problem => 2½D => 3D w industrial through-put
  - frequency/parametric sweeps

=> compute power needs in line with the ”Materials design” use case!?

Getting started – AWS *Elastic Compute Cloud*, EC2

- aws.amazon.com
- create account – provide credit card details



Getting started – COMSOL on AWS EC2

1. (Find COMSOL on the Amazon Marketplace https://aws.amazon.com/marketplace/)

2. Create AMI - launch one remote *instance*

3. Transfer zip:ed comsol installation to instance – unzip. Edit license file

4. Copy and launch more instances - attach storage volumes

5. Create a connection to your license server for each instance – PuTTY, SCP; port numbers, DNS

6. Set up Cluster Computing (or Sweep)/Batch and associated nodes – or the Client Server

7. Run job. Stop/Terminate instance

The *c3.8xlarge* instance

Compute Optimized

C3

C3 instances are the latest generation of compute-optimized instances, providing customers with the highest performing processors and the lowest price/compute performance available in EC2 currently.

Features:

- High Frequency Intel Xeon E5-2680 v2 (Ivy Bridge) Processors
- Support for Enhanced Networking
- Support for clustering
- SSD-backed instance storage

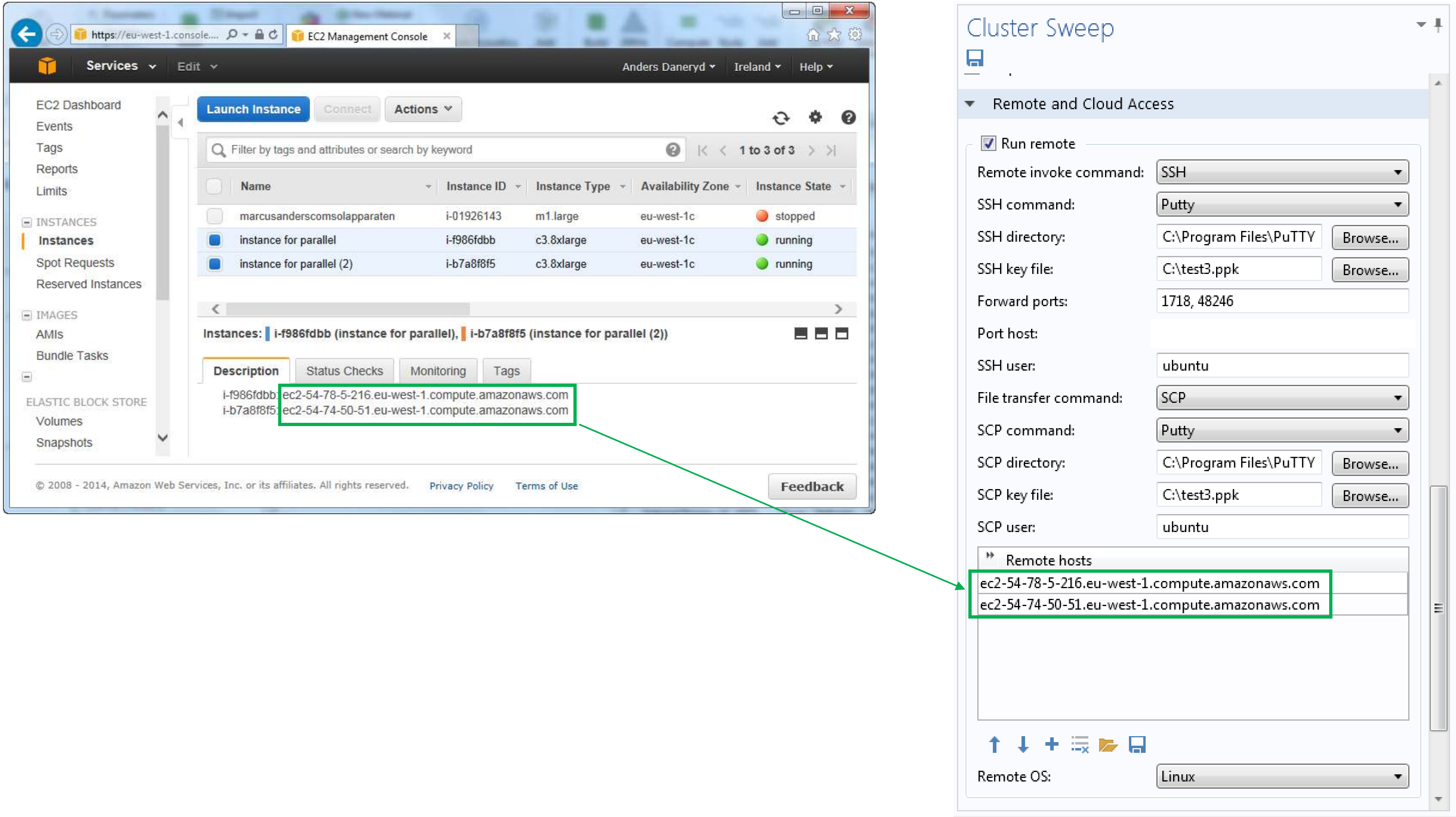
Model	vCPU	Mem (GiB)	SSD Storage (GB)
c3.large	2	3.75	2 x 16
c3.xlarge	4	7.5	2 x 40
c3.2xlarge	8	15	2 x 80
c3.4xlarge	16	30	2 x 160
c3.8xlarge	32	60	2 x 320

USD1.96/hr

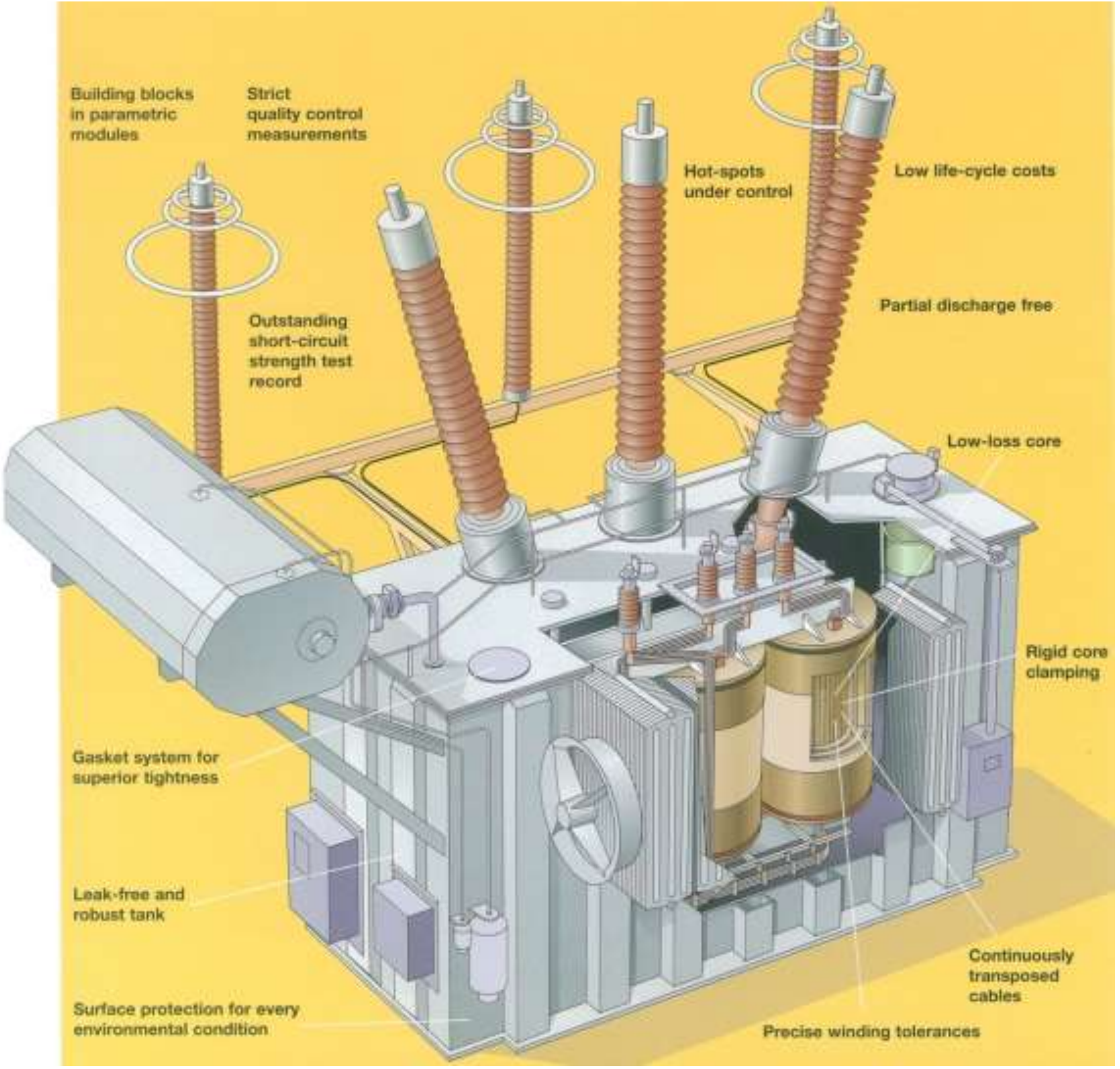
"A high pCPU/vCPU ratio"

Use Cases

High performance front-end fleets, web-servers, on-demand batch processing, distributed analytics, high performance science and engineering applications, ad serving, batch processing, MMO gaming, video encoding, and distributed analytics.


EC2 Management Console
Services
Edit
Anders Daneryd
Ireland
Help
EC2 Dashboard
Events
Tags
Reports
Limits
INSTANCES
Instances
Spot Requests
Reserved Instances
IMAGES
AMIs
Bundle Tasks
ELASTIC BLOCK STORE
Volumes
Snapshots
Launch Instance
Connect
Actions
Filter by tags and attributes or search by keyword
1 to 3 of 3
Name
Instance ID
Instance Type
Availability Zone
Instance State
marcusanderscomsolapparaten
i-01926143
m1.large
eu-west-1c
stopped
instance for parallel
i-f986fdbb
c3.8xlarge
eu-west-1c
running
instance for parallel (2)
i-b7a8f8f5
c3.8xlarge
eu-west-1c
running
Instances: i-f986fdbb (instance for parallel), i-b7a8f8f5 (instance for parallel (2))
Description
Status Checks
Monitoring
Tags
i-f986fdbb: ec2-54-78-5-216.eu-west-1.compute.amazonaws.com
i-b7a8f8f5: ec2-54-74-50-51.eu-west-1.compute.amazonaws.com
© 2008 - 2014, Amazon Web Services, Inc. or its affiliates. All rights reserved.
Privacy Policy
Terms of Use
Feedback
Cluster Sweep
Remote and Cloud Access
Run remote
Remote invoke command:
SSH
SSH command:
Putty
SSH directory:
C:\Program Files\PuTTY
Browse...
SSH key file:
C:\test3.ppk
Forward ports:
1718, 48246
Port host:
SSH user:
ubuntu
File transfer command:
SCP
SCP command:
Putty
SCP directory:
C:\Program Files\PuTTY
SCP key file:
C:\test3.ppk
SCP user:
ubuntu
Remote hosts
ec2-54-78-5-216.eu-west-1.compute.amazonaws.com
ec2-54-74-50-51.eu-west-1.compute.amazonaws.com
Remote OS:
Linux

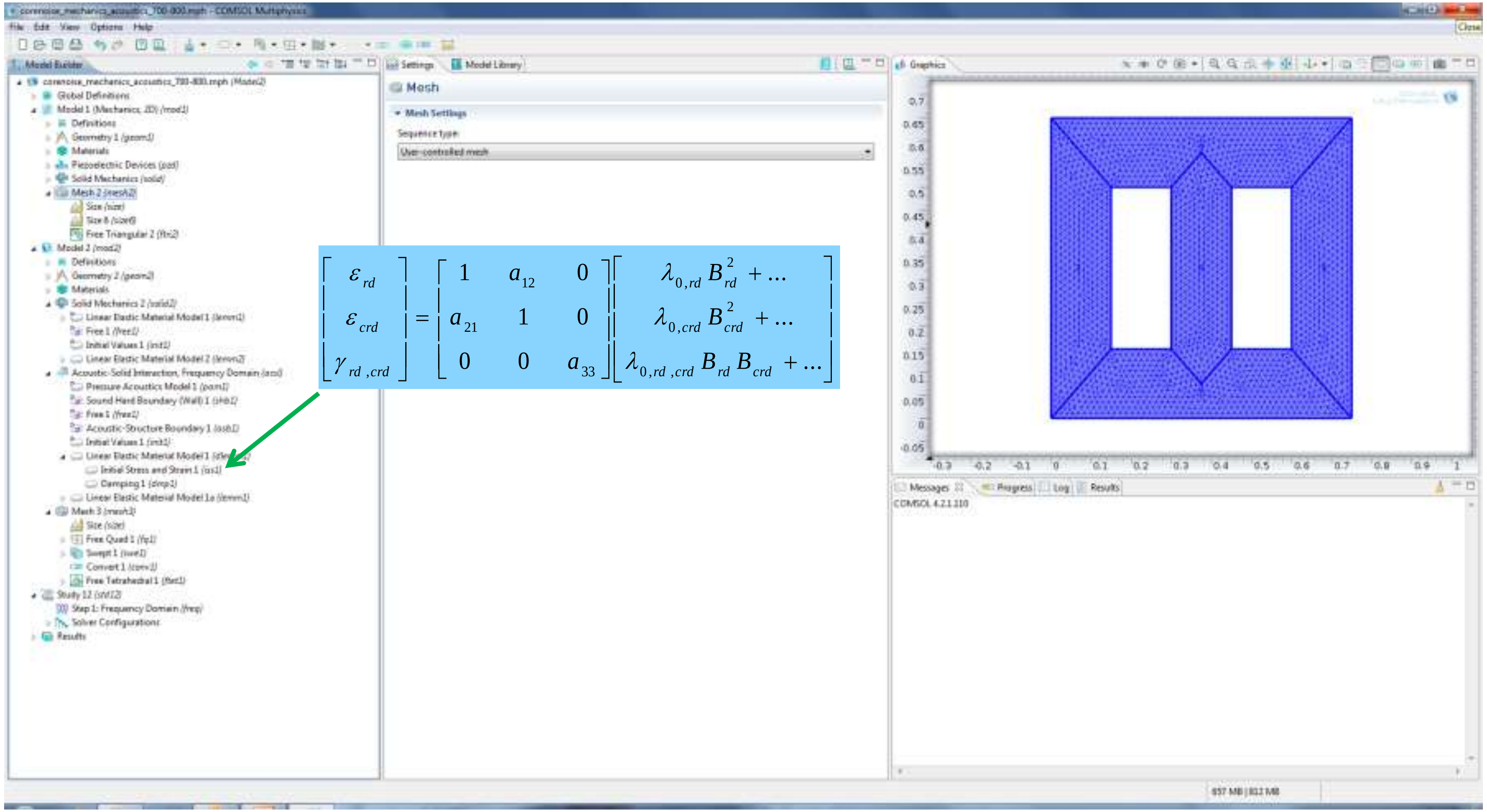
Transformer Acoustics @ ABB



- Load noise (windings)
- No-load noise (core) (User Presentation)
- Cooling (fans)

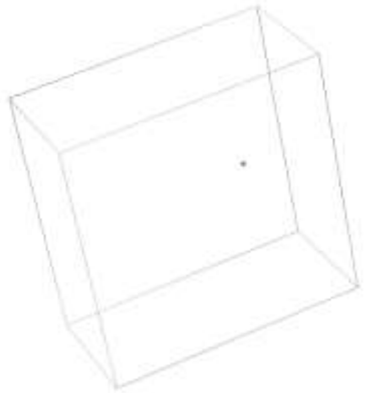
Core noise FE tool: winding voltage → acoustic power

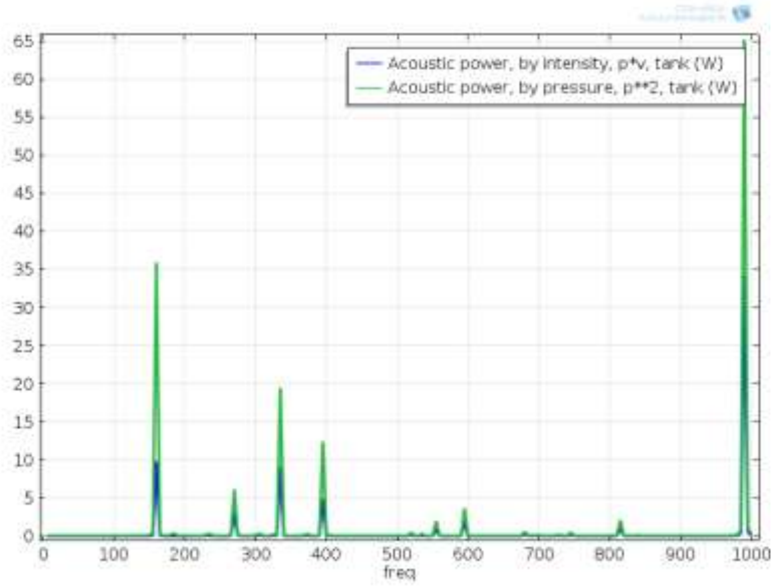
3 steps: **2D**: EM, time domain → Matlab for FFT → **3D**: mechanics & structural acoustics, frequency domain



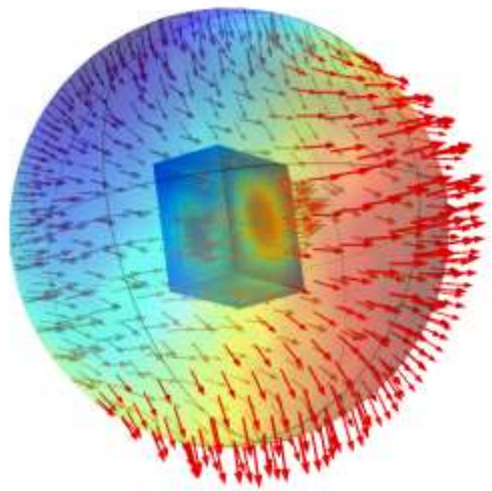
$$\begin{bmatrix} \varepsilon_{rd} \\ \varepsilon_{crd} \\ \gamma_{rd,crd} \end{bmatrix} = \begin{bmatrix} 1 & a_{12} & 0 \\ a_{21} & 1 & 0 \\ 0 & 0 & a_{33} \end{bmatrix} \begin{bmatrix} \lambda_{0,rd} B_{rd}^2 + \ldots \\ \lambda_{0,crd} B_{crd}^2 + \ldots \\ \lambda_{0,rd,crd} B_{rd} B_{crd} + \ldots \end{bmatrix}$$

The cloud model problem

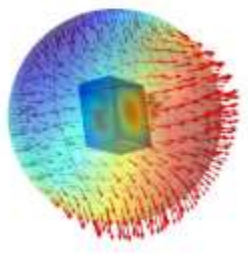


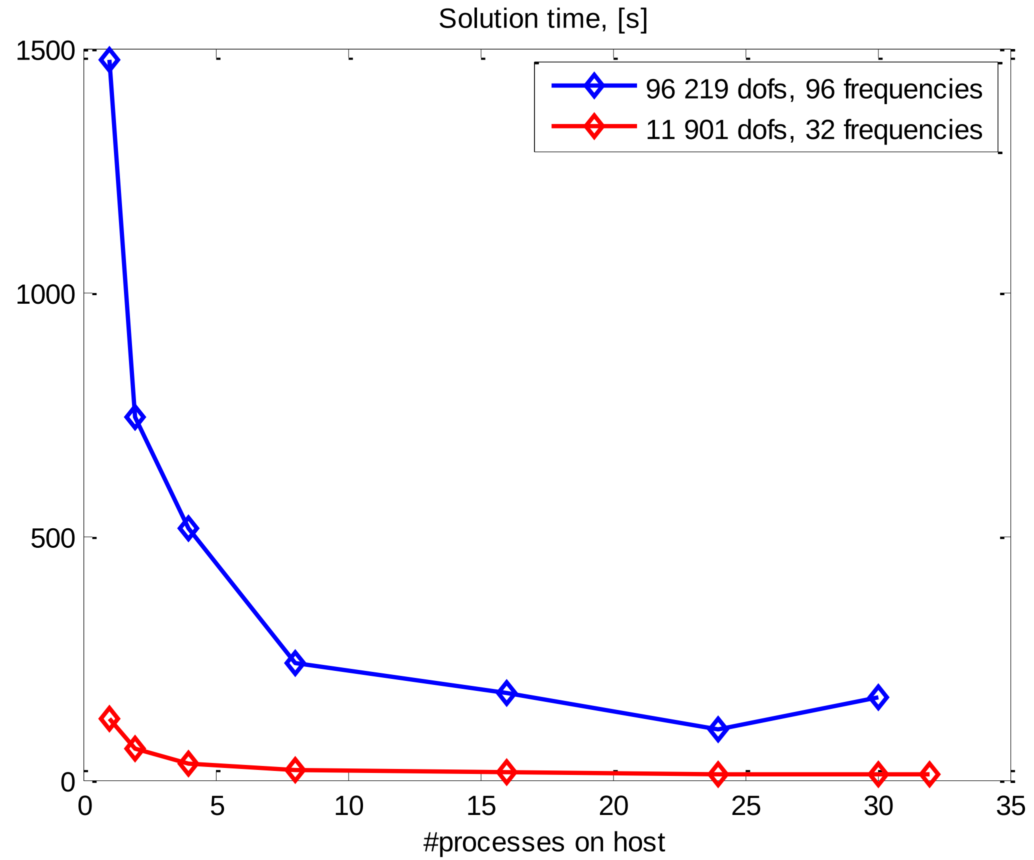


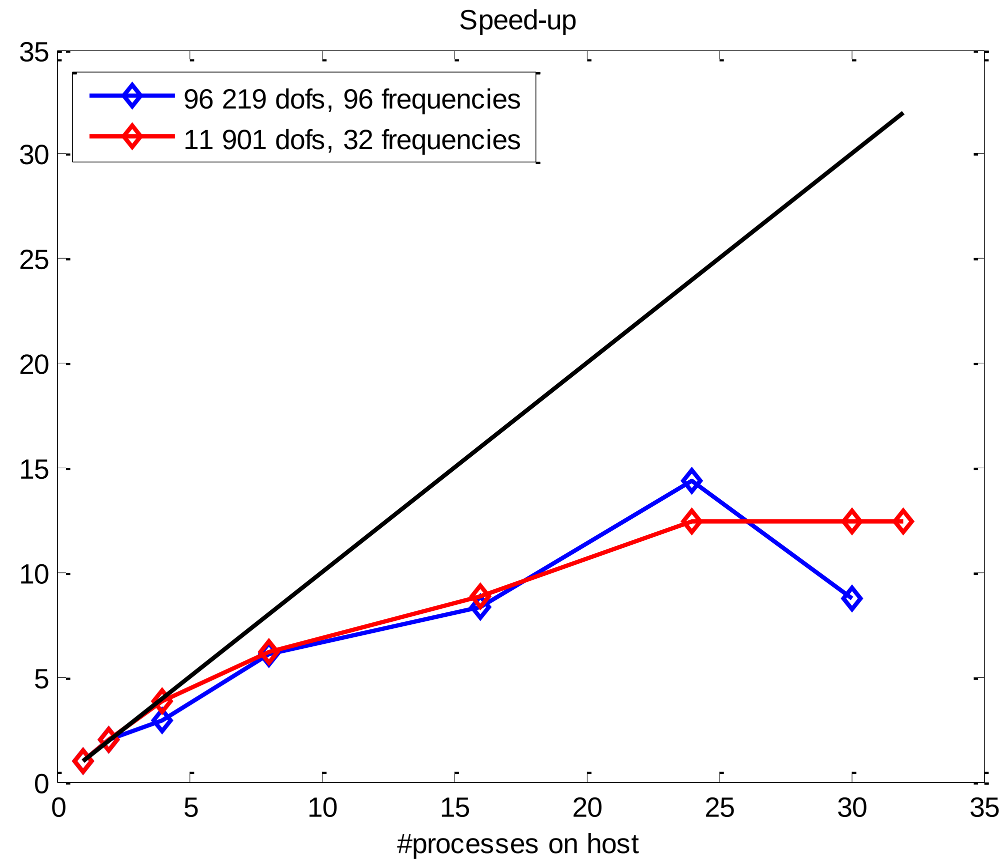
- Thin-walled box w mineral oil, ~1m side
- Point source excitation
- Frequency sweeps, <1000Hz
    - acoustic power,
    - radiation efficiency
    - directivity
- Details of oil-tank interaction – added mass *and* stiffness



Encouraging first results: one *c3.8xlarge* instance, frequency sweep by ”Cluster Computing” study node







Next steps

- *In depth analyses of performance bottlenecks and how to optimize model + COMSOL + AWS, and …*
- if *meaningful* - ”hundreds” of instances for transformer analysis, propagation of uncertainties
- Parallelization of ”non-trivial” tasks – e.g. direct solver, eigenvalues, …
- Towards petaflop …

THANK YOU FOR YOUR ATTENTION

Anders & Daniel

8 nodes/8 proc, 8 frequencies

C3.8xlarge

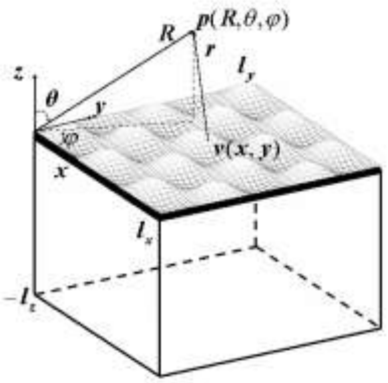
327 392 dofs

CPU: 8/32 => 25%
memory: 77%, 47.4GB/61.6GB


```
top - 07:58:27 up  2:11,  1 user,  load average: 8.35, 7.57, 4.72
Tasks: 229 total,   1 running, 228 sleeping,   0 stopped,   0 zombie
Cpu(s): 25.1%us,  0.4%sy,  0.0%ni, 74.5%id,  0.0%wa,  0.0%hi,  0.0%si,  0.0%st
Mem:  61598808k total, 47389644k used, 14209164k free,    30584k buffers
Swap:        0k total,        0k used,        0k free,   448540k cached

  PID USER      PR  NI  VIRT  RES  SHR S %CPU %MEM    TIME+  COMMAND
11710 ubuntu    20   0 10.4g 5.6g  41m S  100  9.5   8:44.41 comsollauncher
11711 ubuntu    20   0 10.4g 5.6g  41m S  100  9.5   8:45.50 comsollauncher
11713 ubuntu    20   0 10.4g 5.8g  41m S  100  9.9   8:46.48 comsollauncher
11715 ubuntu    20   0 10.5g 5.8g  40m S  100  9.8   8:44.72 comsollauncher
11708 ubuntu    20   0 10.4g 5.1g  42m S  100  8.7   8:45.01 comsollauncher
11709 ubuntu    20   0 10.5g 5.7g  42m S  100  9.7   8:45.46 comsollauncher
11712 ubuntu    20   0 10.4g 5.1g  41m S  100  8.7   8:44.06 comsollauncher
11714 ubuntu    20   0 10.5g 5.5g  40m S  100  9.4   8:44.30 comsollauncher
  795 syslog    20   0  247m 1516 1136 S    0  0.0   0:00.97 rsyslogd
30832 ubuntu    20   0 17464 1524 1072 R    0  0.0   0:05.36 top
    1 root      20   0 24332 2268 1340 S    0  0.0   0:01.31 init
    2 root      20   0     0    0    0 S    0  0.0   0:00.00 kthreadd
    3 root      20   0     0    0    0 S    0  0.0   0:00.02 ksoftirqd/0
    4 root      20   0     0    0    0 S    0  0.0   0:00.00 kworker/0:0
    5 root      20   0     0    0    0 S    0  0.0   0:00.01 kworker/u:0
    6 root      RT   0     0    0    0 S    0  0.0   0:00.00 migration/0
    7 root      RT   0     0    0    0 S    0  0.0   0:00.02 watchdog/0
    8 root      RT   0     0    0    0 S    0  0.0   0:00.00 migration/1
```

Motivation for our cloud model problem (2)



Fahy's approach for coupled system modal properties and forced response

$$p(x,t)=\sum_{i=0}^{i\to\infty} p_i(t)\psi_i(x) \qquad w(x_2,t)=\sum_{i=1}^{i\to\infty} w_i(t)\varphi_i(x_2)$$

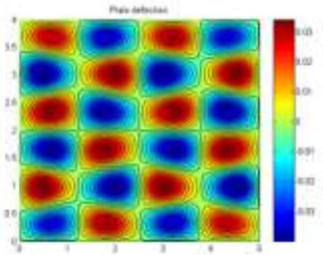
$$\ddot{p}_k+\Omega_k^2 p_k=\frac{\rho_0 c_0^2 S_p}{\Lambda_k}\sum_l C_{kl}\ddot{w}_l+\frac{\rho_0 c_0^2}{\Lambda_k}\dot{Q}_k=\sum_l E_{kl}\ddot{w}_l+\dot{Q}_k$$

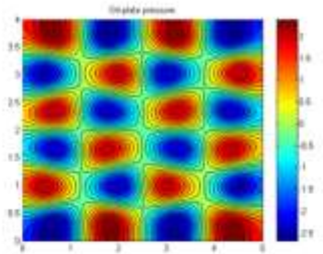
$$\ddot{w}_l+\omega_l^2 w_l=\frac{S_p}{\Lambda_l}\sum_k C_{lk}p_k+\frac{F_l}{\Lambda_l}=\sum_l D_{lk}p_k+F_l$$

$$\ddot{P}p+\omega^2 Ew=\dot{Q}$$
$$\ddot{W}w-Dp=F$$
$$\Leftrightarrow$$
$$\begin{bmatrix}\ddot{P} & \omega^2 E\\ -D & \ddot{W}\end{bmatrix}\begin{bmatrix}p_{1\to k}\\ w_{1\to l}\end{bmatrix}=\begin{bmatrix}\dot{Q}_{1\to k}\\ F_{1\to l}\end{bmatrix}$$

$$\det\{A_0+\omega^2 A_1\}=0\Rightarrow\omega_1^2,\omega_1^2,\ldots,\omega_{l+k}^2$$

$$A_0=\begin{bmatrix}\Omega_{1\to k}^2 & 0\\ -D & \omega_{1\to l}^2\end{bmatrix}\ ;\ A_1=\begin{bmatrix}-1 & E\\ 0 & -1\end{bmatrix}$$





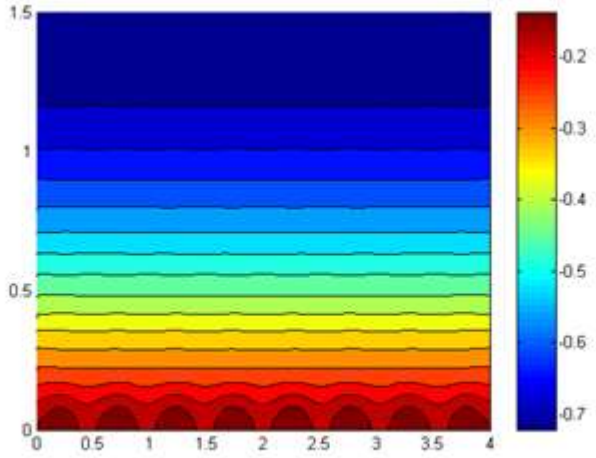


Fig. 4.16. Mode 16. Oil pressure. Plate at 0 in vertical direction. All contributions from uncoupled oil modes are included.

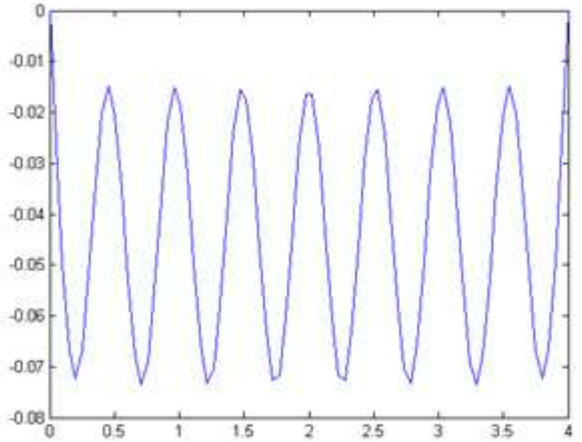
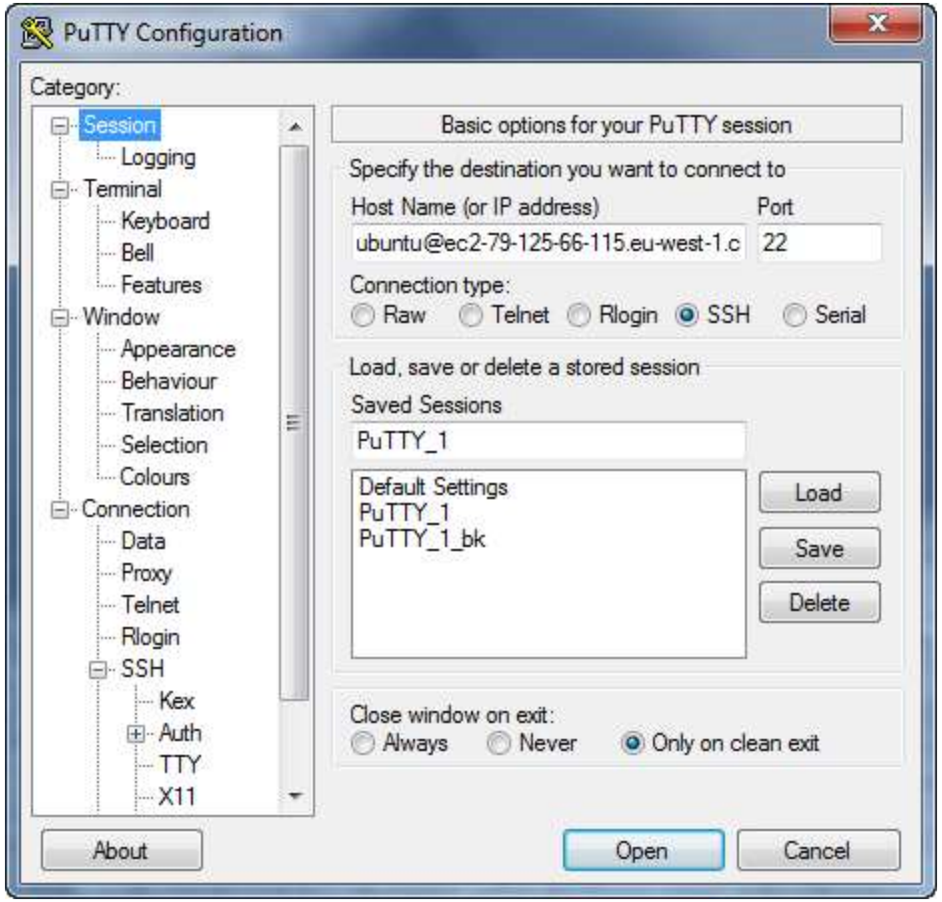
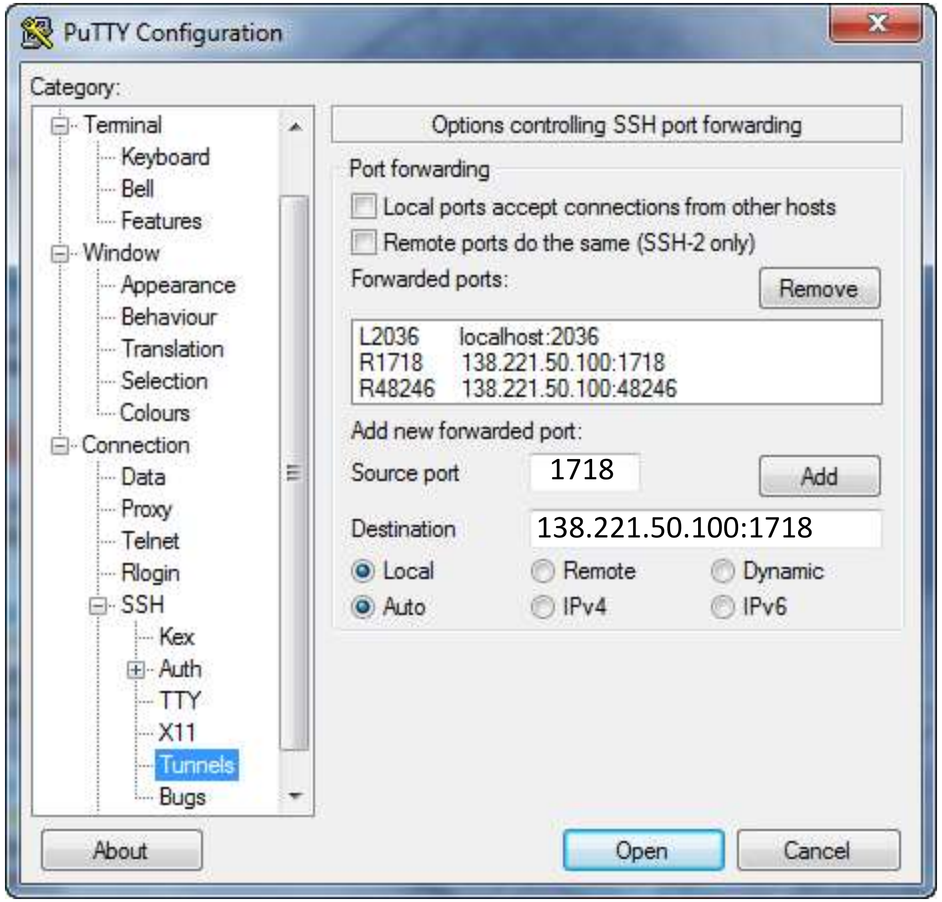


Fig. 4.14. Coupled mode no 16 at 196.6Hz. Plate deflection. All contributions from uncoupled plate modes are included.

Change DNS every new instance launch

Source port 1718 => Add => Source port 48246
”Destination” IP:port; ”Remote”
Source port 2036 => Add; ”Local”
”Destination” localhost:2036; ”Local”





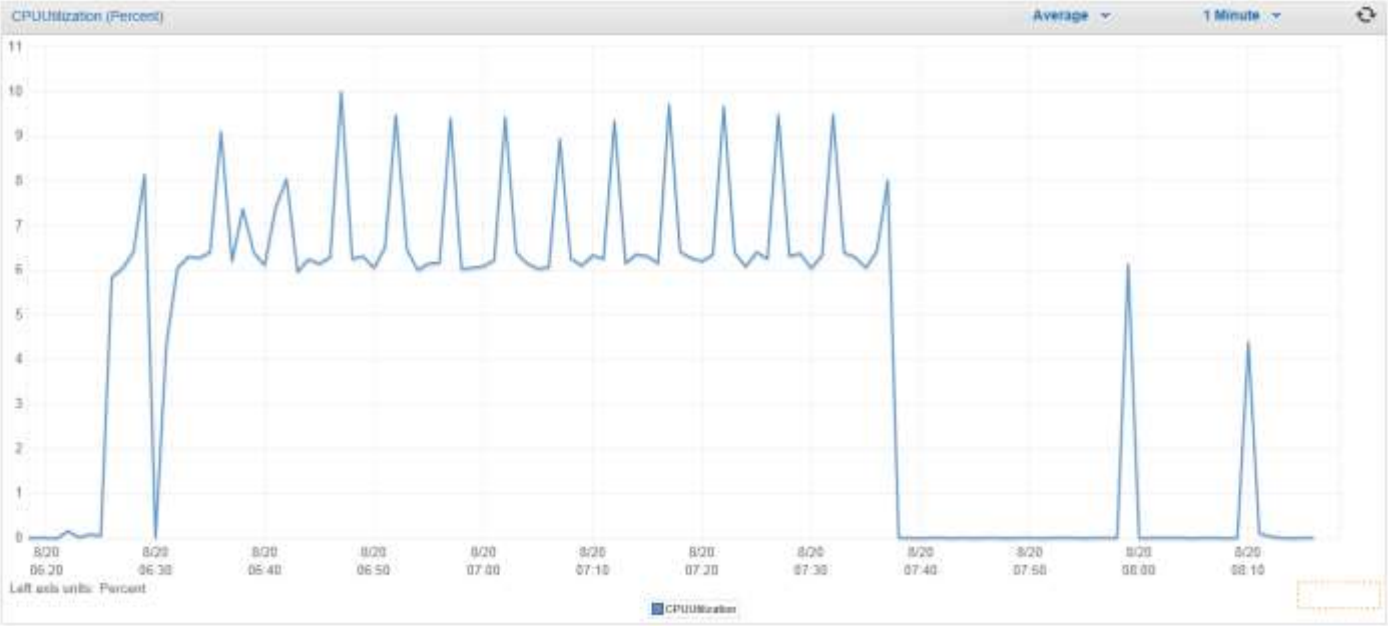
Messages × | Progress | Log | Accumulated Probe Table 3 × | External Process ×

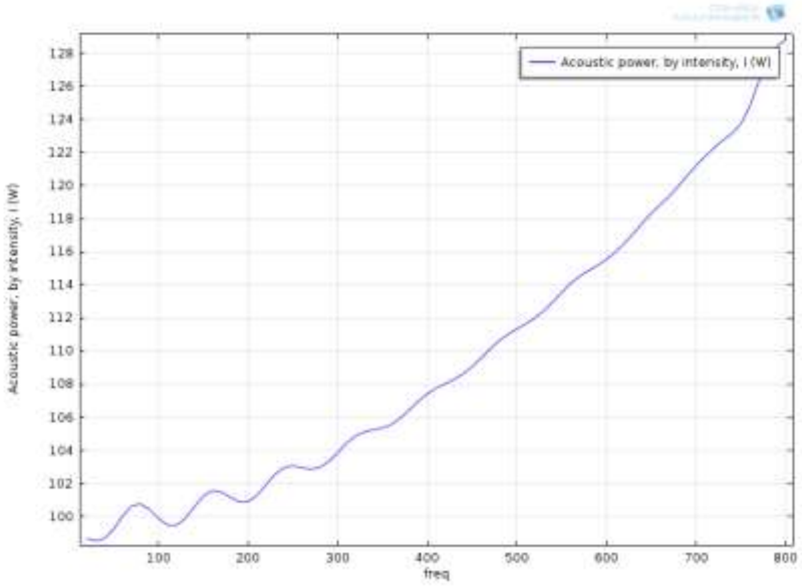
Name	Progress	Status	Paramete	Par	Filename	Host
External Process 1	100%	Done	frekvens	10	C:\Cloud\Comsol\Cambridge\models\clustersweep\results_2_frekvens_10.mph	ec2-54-78-5-216.eu-west-1.compute.amazonaws.com
External Process 2	100%	Done	frekvens	12	C:\Cloud\Comsol\Cambridge\models\clustersweep\results_2_frekvens_12.mph	ec2-54-74-50-51.eu-west-1.compute.amazonaws.com
External Process 3	100%	Done	frekvens	14	C:\Cloud\Comsol\Cambridge\models\clustersweep\results_2_frekvens_14.mph	ec2-54-78-5-216.eu-west-1.compute.amazonaws.com
External Process 4	100%	Done	frekvens	16	C:\Cloud\Comsol\Cambridge\models\clustersweep\results_2_frekvens_16.mph	ec2-54-74-50-51.eu-west-1.compute.amazonaws.com
External Process 5	100%	Done	frekvens	18	C:\Cloud\Comsol\Cambridge\models\clustersweep\results_2_frekvens_18.mph	ec2-54-78-5-216.eu-west-1.compute.amazonaws.com
External Process 6	100%	Done	frekvens	20	C:\Cloud\Comsol\Cambridge\models\clustersweep\results_2_frekvens_20.mph	ec2-54-74-50-51.eu-west-1.compute.amazonaws.com
External Process 7	100%	Done	frekvens	22	C:\Cloud\Comsol\Cambridge\models\clustersweep\results_2_frekvens_22.mph	ec2-54-78-5-216.eu-west-1.compute.amazonaws.com
External Process 8	100%	Done	frekvens	24	C:\Cloud\Comsol\Cambridge\models\clustersweep\results_2_frekvens_24.mph	ec2-54-74-50-51.eu-west-1.compute.amazonaws.com
External Process 9	100%	Done	frekvens	26	C:\Cloud\Comsol\Cambridge\models\clustersweep\results_2_frekvens_26.mph	ec2-54-78-5-216.eu-west-1.compute.amazonaws.com
External Process 10	100%	Done	frekvens	28	C:\Cloud\Comsol\Cambridge\models\clustersweep\results_2_frekvens_28.mph	ec2-54-74-50-51.eu-west-1.compute.amazonaws.com
External Process 11	100%	Done	frekvens	30	C:\Cloud\Comsol\Cambridge\models\clustersweep\results_2_frekvens_30.mph	ec2-54-78-5-216.eu-west-1.compute.amazonaws.com
External Process 12	100%	Done	frekvens	32	C:\Cloud\Comsol\Cambridge\models\clustersweep\results_2_frekvens_32.mph	ec2-54-74-50-51.eu-west-1.compute.amazonaws.com
External Process 13	100%	Done	frekvens	34	C:\Cloud\Comsol\Cambridge\models\clustersweep\results_2_frekvens_34.mph	ec2-54-78-5-216.eu-west-1.compute.amazonaws.com
External Process 14	100%	Done	frekvens	36	C:\Cloud\Comsol\Cambridge\models\clustersweep\results_2_frekvens_36.mph	ec2-54-74-50-51.eu-west-1.compute.amazonaws.com
External Process 15	100%	Done	frekvens	38	C:\Cloud\Comsol\Cambridge\models\clustersweep\results_2_frekvens_38.mph	ec2-54-78-5-216.eu-west-1.compute.amazonaws.com
External Process 16	100%	Done	frekvens	40	C:\Cloud\Comsol\Cambridge\models\clustersweep\results_2_frekvens_40.mph	ec2-54-74-50-51.eu-west-1.compute.amazonaws.com
External Process 17	100%	Done	frekvens	42	C:\Cloud\Comsol\Cambridge\models\clustersweep\results_2_frekvens_42.mph	ec2-54-74-50-51.eu-west-1.compute.amazonaws.com
External Process 18	100%	Done	frekvens	44	C:\Cloud\Comsol\Cambridge\models\clustersweep\results_2_frekvens_44.mph	ec2-54-78-5-216.eu-west-1.compute.amazonaws.com
External Process 19	100%	Done	frekvens	46	C:\Cloud\Comsol\Cambridge\models\clustersweep\results_2_frekvens_46.mph	ec2-54-78-5-216.eu-west-1.compute.amazonaws.com
External Process 20	100%	Done	frekvens	48	C:\Cloud\Comsol\Cambridge\models\clustersweep\results_2_frekvens_48.mph	ec2-54-78-5-216.eu-west-1.compute.amazonaws.com
External Process 21	100%	Done	frekvens	50	C:\Cloud\Comsol\Cambridge\models\clustersweep\results_2_frekvens_50.mph	ec2-54-78-5-216.eu-west-1.compute.amazonaws.com
External Process 22	100%	Done	frekvens	52	C:\Cloud\Comsol\Cambridge\models\clustersweep\results_2_frekvens_52.mph	ec2-54-78-5-216.eu-west-1.compute.amazonaws.com
External Process 23	100%	Done	frekvens	54	C:\Cloud\Comsol\Cambridge\models\clustersweep\results_2_frekvens_54.mph	ec2-54-78-5-216.eu-west-1.compute.amazonaws.com
External Process 24	100%	Done	frekvens	56	C:\Cloud\Comsol\Cambridge\models\clustersweep\results_2_frekvens_56.mph	ec2-54-78-5-216.eu-west-1.compute.amazonaws.com
External Process 25	100%	Done	frekvens	58	C:\Cloud\Comsol\Cambridge\models\clustersweep\results_2_frekvens_58.mph	ec2-54-74-50-51.eu-west-1.compute.amazonaws.com
External Process 26	100%	Done	frekvens	60	C:\Cloud\Comsol\Cambridge\models\clustersweep\results_2_frekvens_60.mph	ec2-54-74-50-51.eu-west-1.compute.amazonaws.com
External Process 27	100%	Done	frekvens	62	C:\Cloud\Comsol\Cambridge\models\clustersweep\results_2_frekvens_62.mph	ec2-54-74-50-51.eu-west-1.compute.amazonaws.com
External Process 28	100%	Done	frekvens	64	C:\Cloud\Comsol\Cambridge\models\clustersweep\results_2_frekvens_64.mph	ec2-54-74-50-51.eu-west-1.compute.amazonaws.com
External Process 29	100%	Done	frekvens	66	C:\Cloud\Comsol\Cambridge\models\clustersweep\results_2_frekvens_66.mph	ec2-54-74-50-51.eu-west-1.compute.amazonaws.com
External Process 30	100%	Done	frekvens	68	C:\Cloud\Comsol\Cambridge\models\clustersweep\results_2_frekvens_68.mph	ec2-54-74-50-51.eu-west-1.compute.amazonaws.com
External Process 31	100%	Done	frekvens	70	C:\Cloud\Comsol\Cambridge\models\clustersweep\results_2_frekvens_70.mph	ec2-54-74-50-51.eu-west-1.compute.amazonaws.com
External Process 32	100%	Done	frekvens	72	C:\Cloud\Comsol\Cambridge\models\clustersweep\results_2_frekvens_72.mph	ec2-54-78-5-216.eu-west-1.compute.amazonaws.com

ABB_point_source_1.mph: (20, 10, 2*frmax), frmax = 400Hz

C3.8xlarge

95946 dofs; solution time 3965s; Physical memory: 2.38 GB ,Virtual memory: 11.32 GB; 113MB



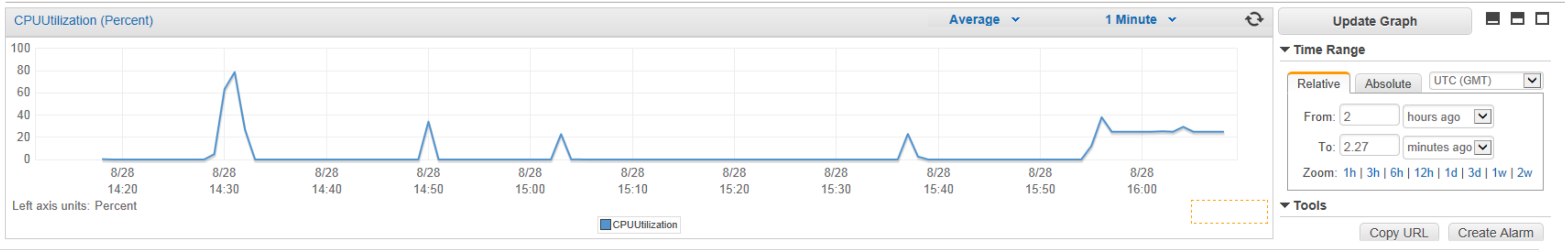


ABB_point_source_2_parallel.mph: 32 frequencies

C3.8xlarge

95 946 dofs

#processes	Time, s	Run #
1	1478	7
2	745	6
4	515	2
8	241	1
16	178	3
24	103	5
30	168	2
32	-	8

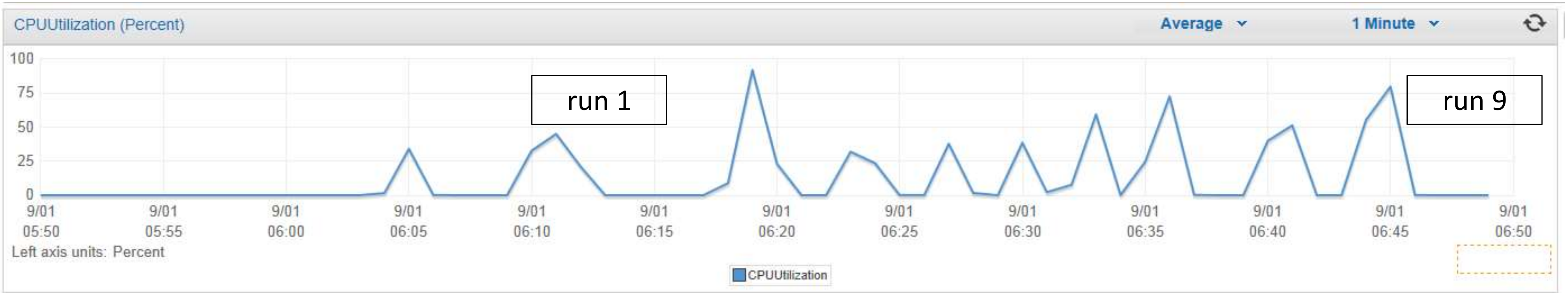


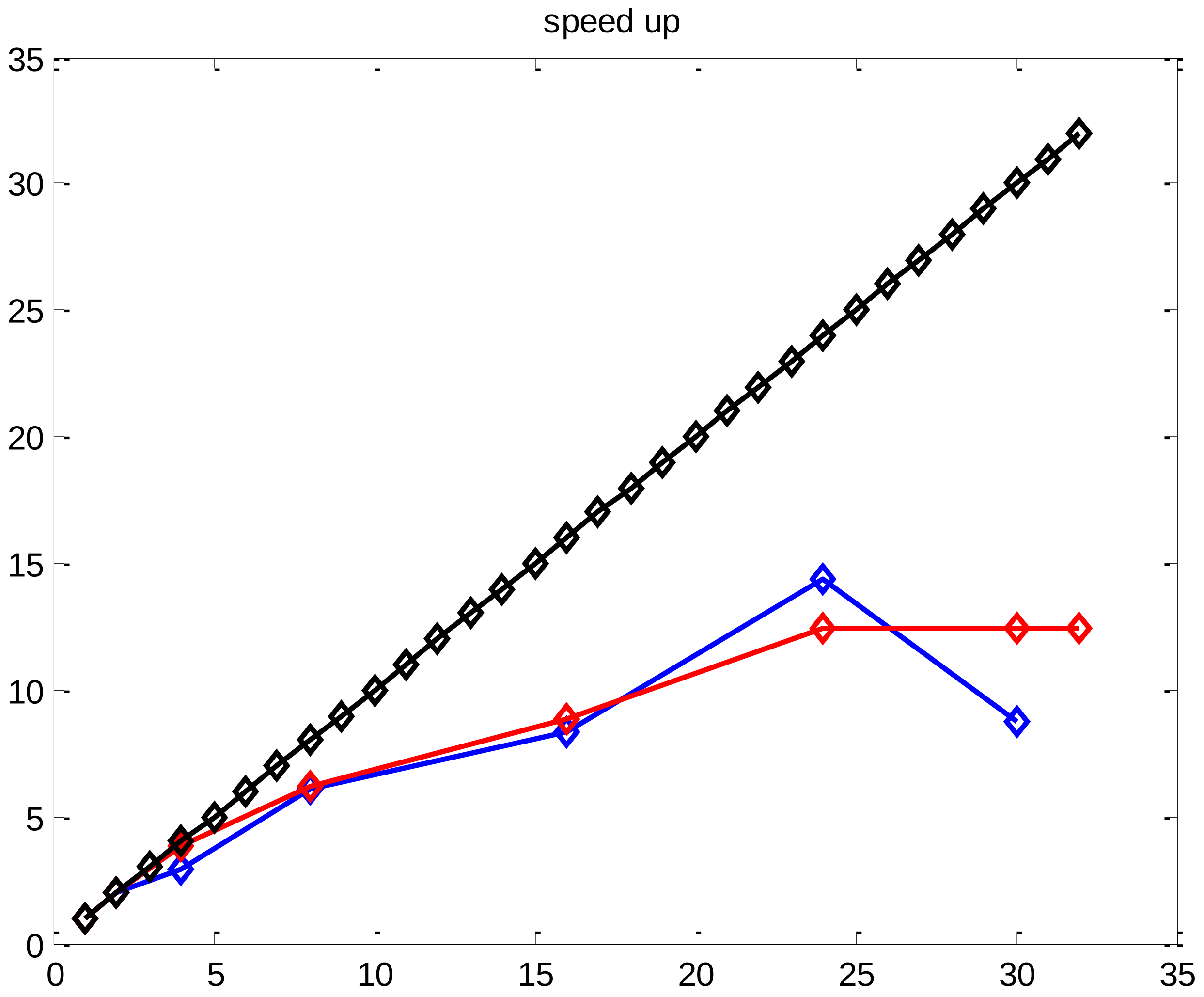
ABB_point_source_2_parallel.mph: 96 frequencies

C3.8xlarge

11 889 dofs

#processes	Time, s	Run #
1	124	1
2	63	3
4	32	4
8	20	5
16	14	6
24	10	7
30	10	2
32	10	9




speed up
0
5
10
15
20
25
30
35
0
5
10
15
20
25
30
35