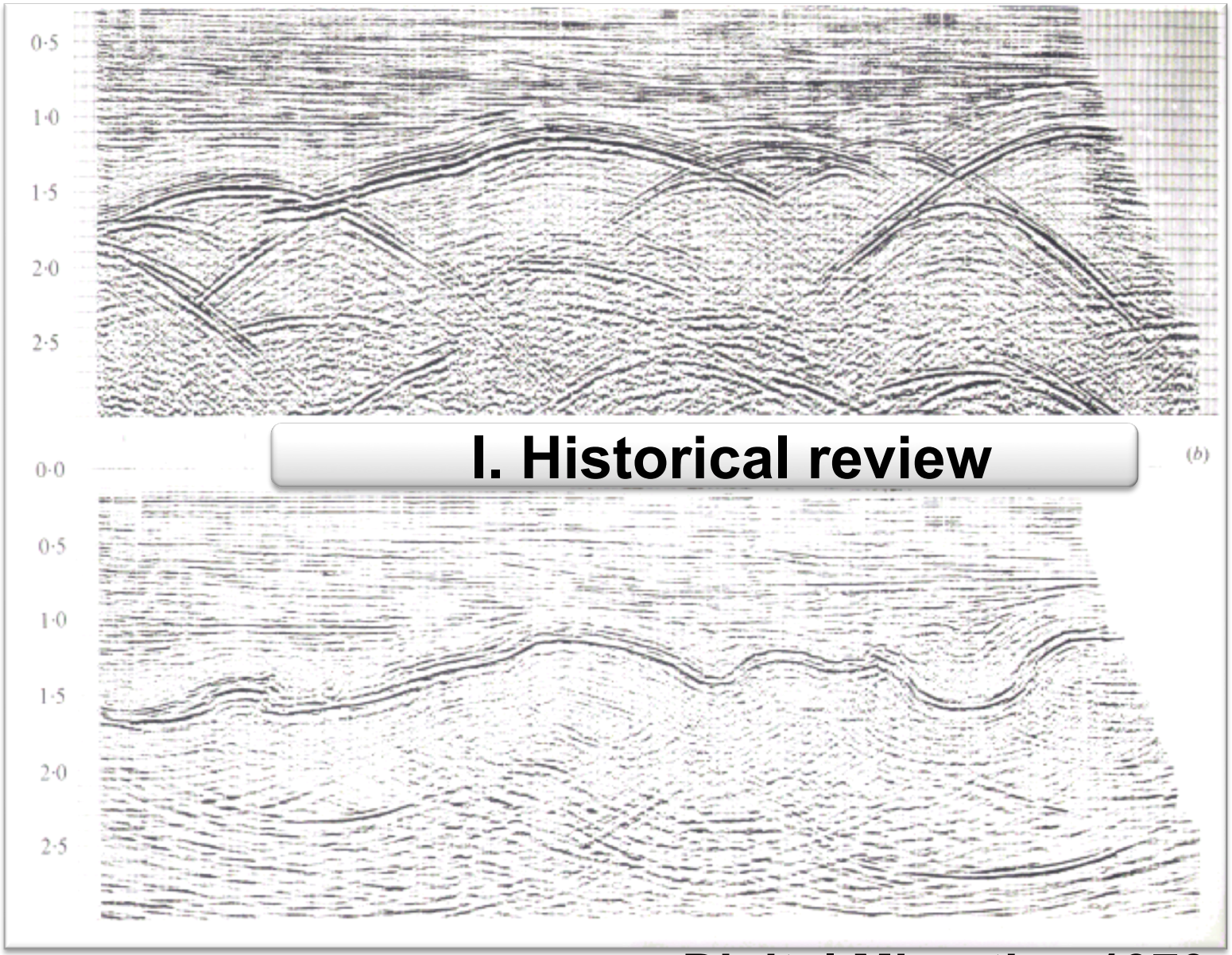
High performance computing in geophysics: horizon 2020, perspectives and challenges.

I. Historical review

II. HPC evolution what is changing

III. HPC 2020 for O&G Upstream

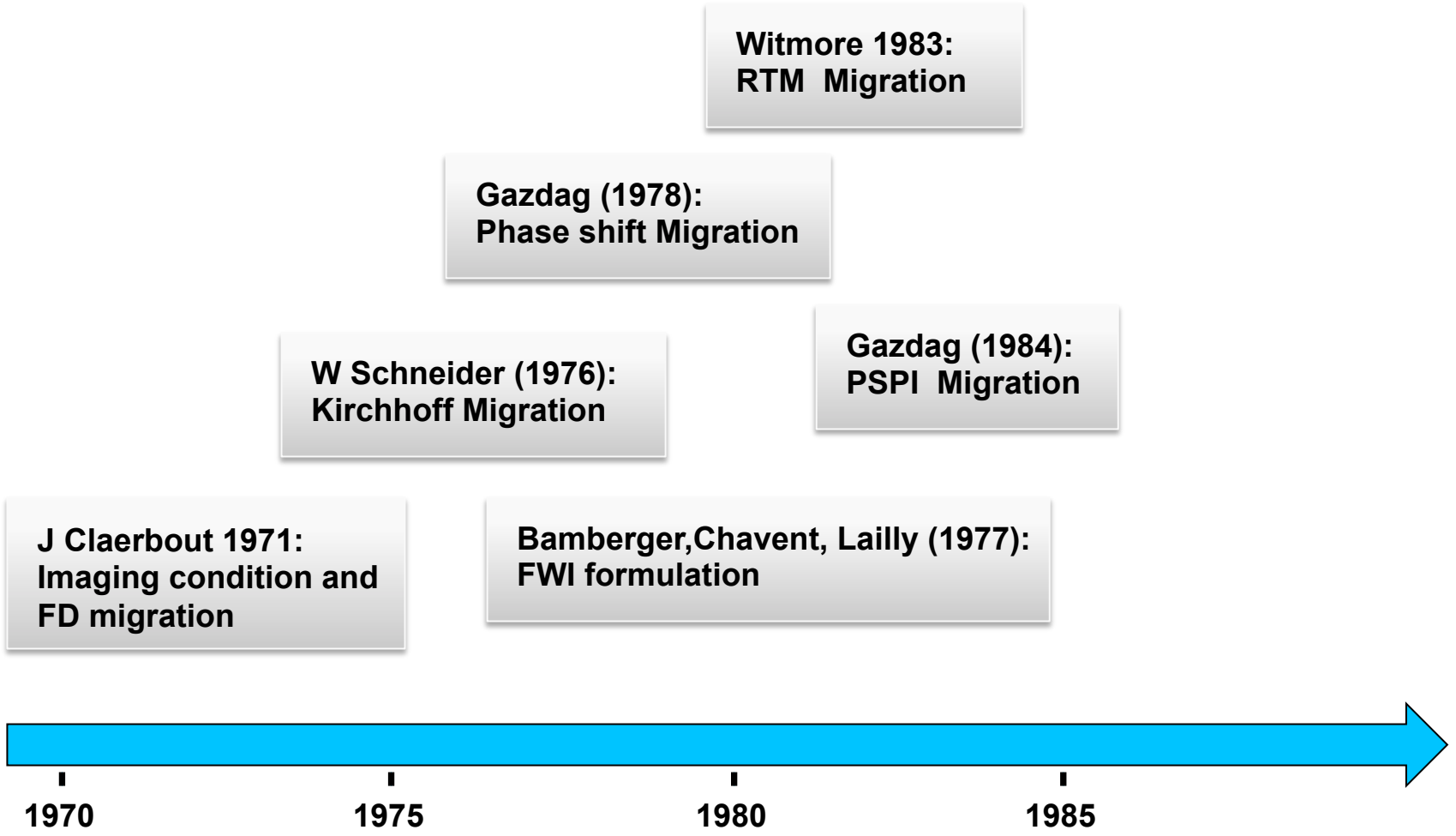
TOTAL



I. Historical review

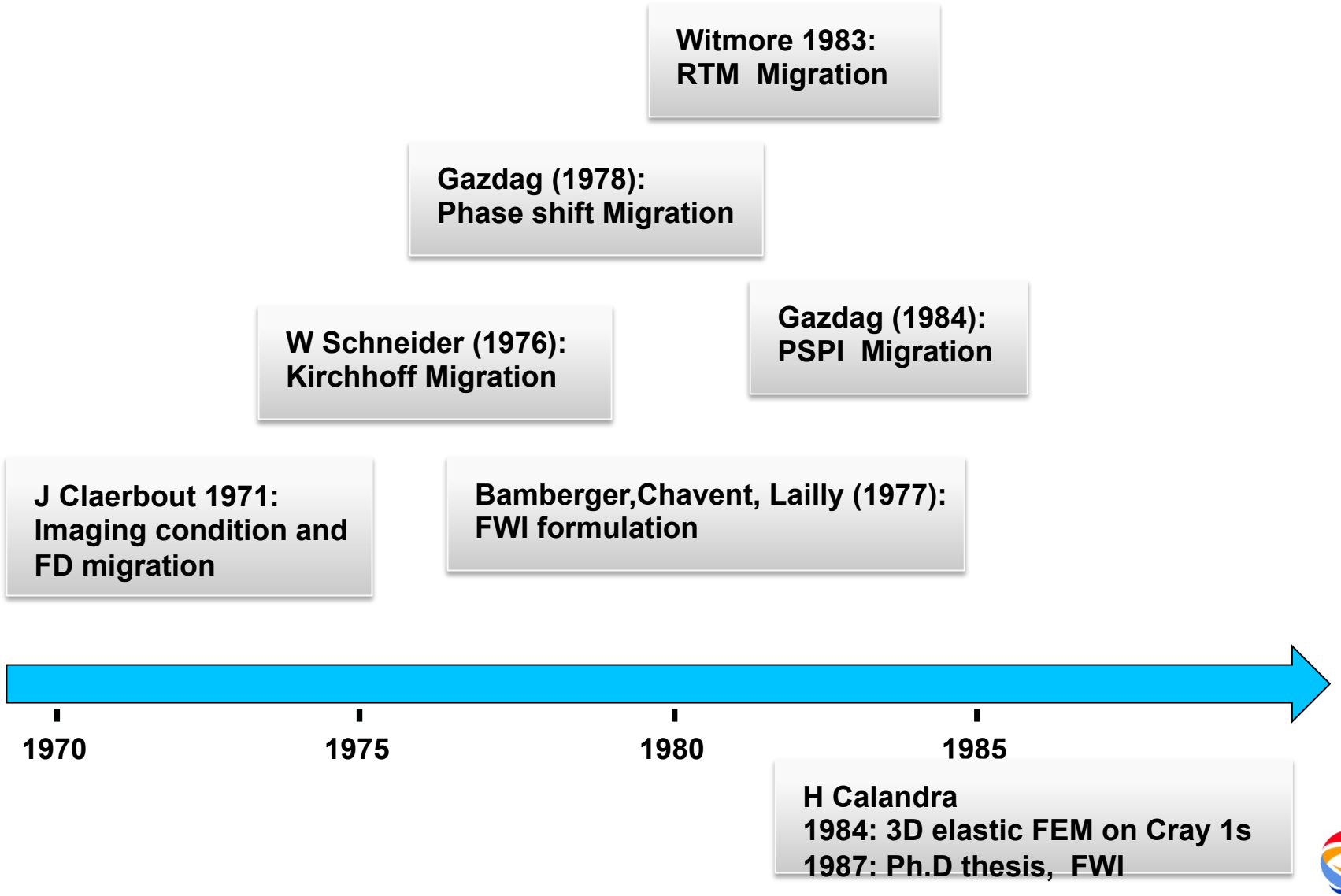
Digital Migration 1970

Some key dates…



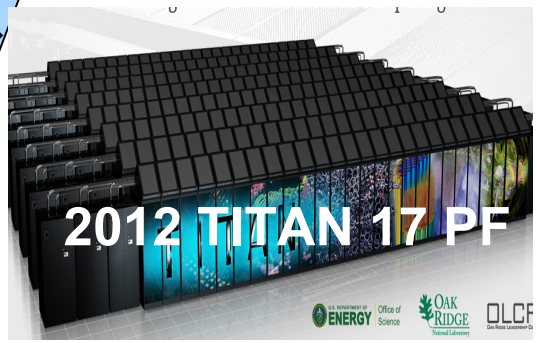
TOTAL

Some key dates…



Some key evolutions

3D TTI reverse time migration
3D TTI FWI
3D Elastic modeling



3D WE Prestack Depth Migration

3D Post stackDepth Migration
3D Kirchhoff prestack depth migration
3D prestack time migration

2D Post stack RTM Migration
2D Phase Shift migration...
2D prestack time migration

2014...

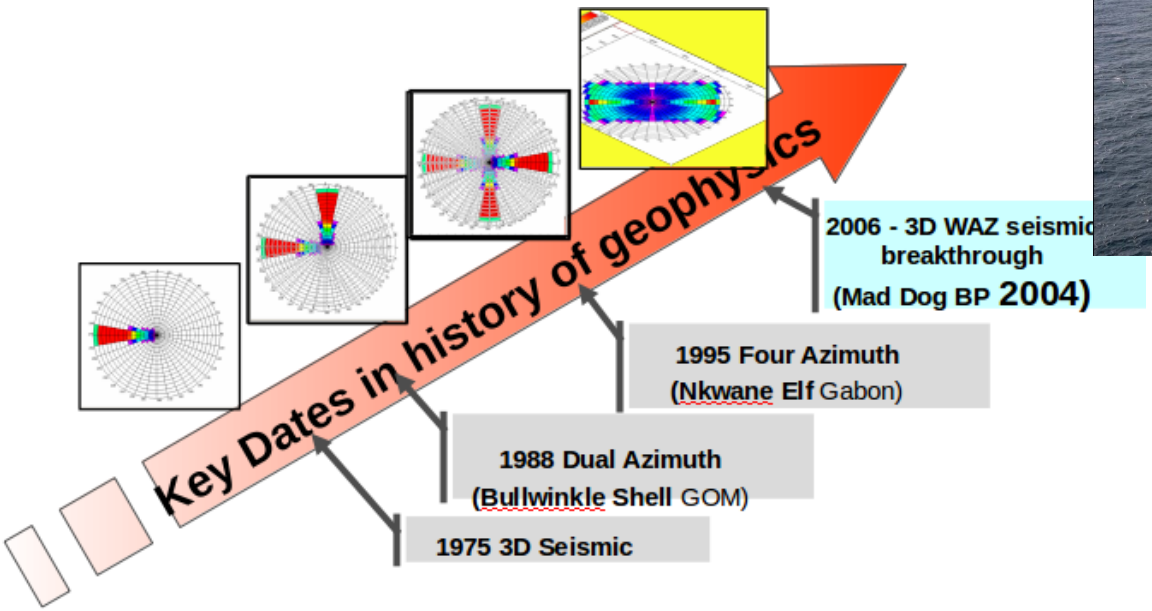
1980

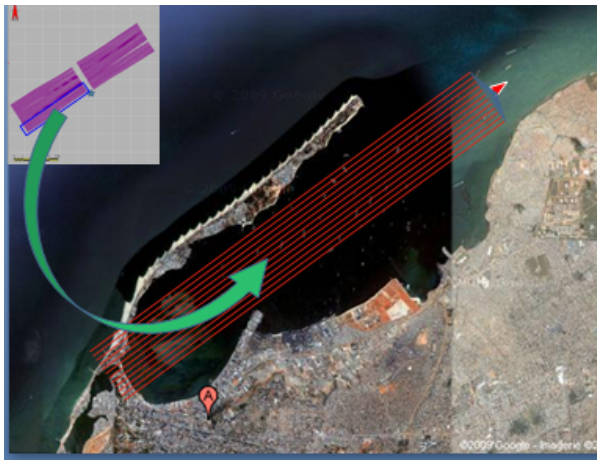
$34x10^7$ speed up

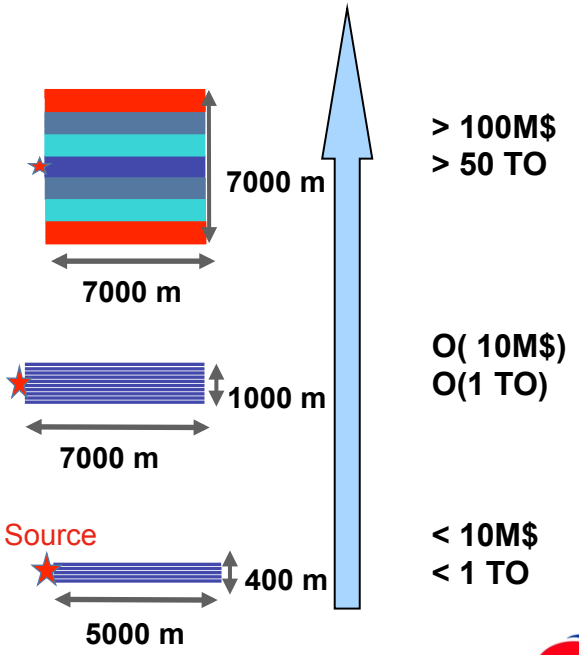
TOTAL

Seismic acquisition key contributor to seismic depth imaging progress

Seismic acquisition

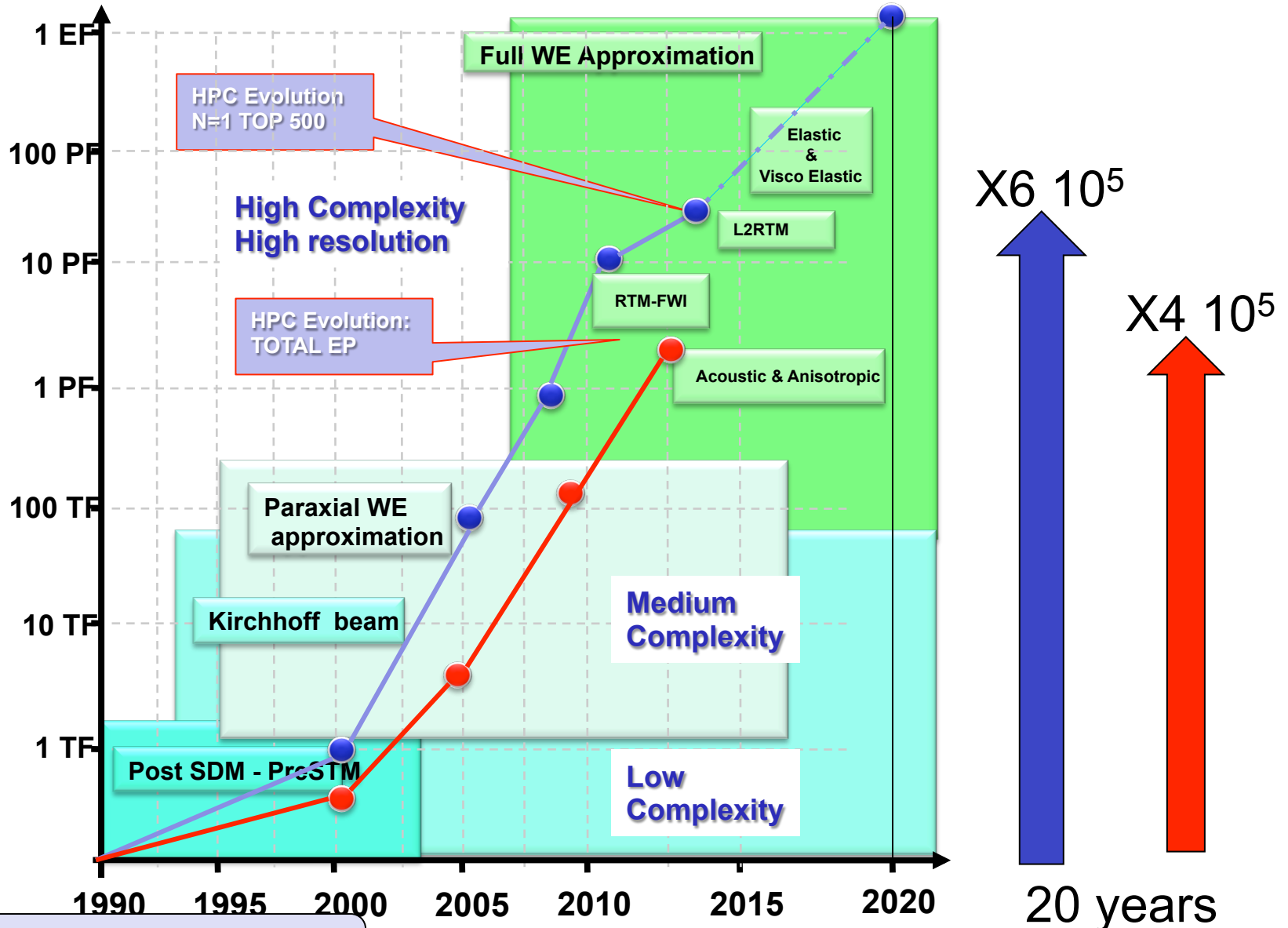






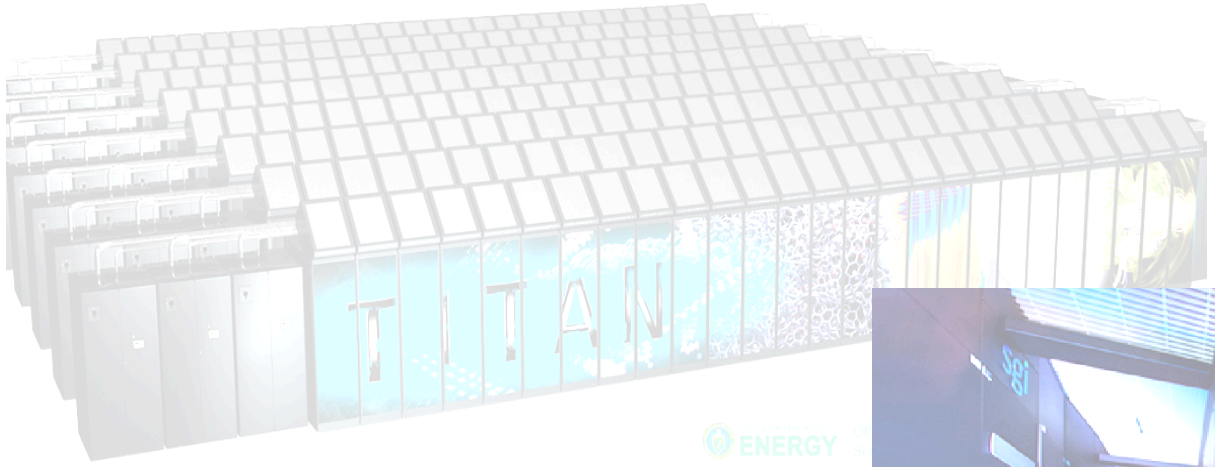
TOTAL

HPC and Seismic depth imaging evolution

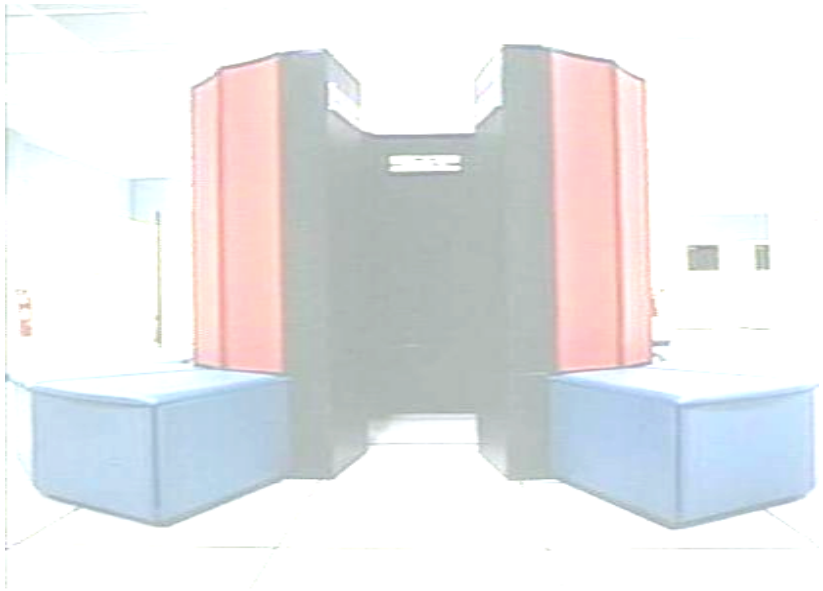


1 TF = 10^{12} operations / s
1 PF = 10^{15} operations / s
1 EF = 10^{18} operations / s

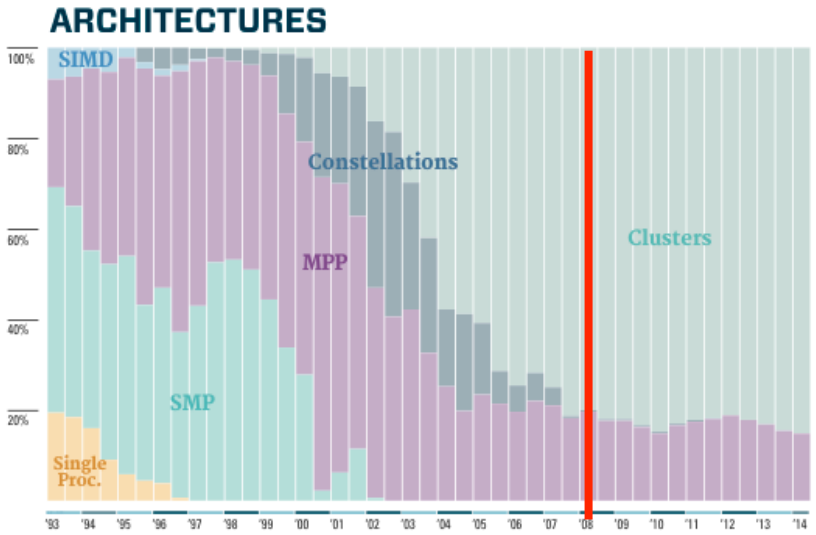
TOTAL



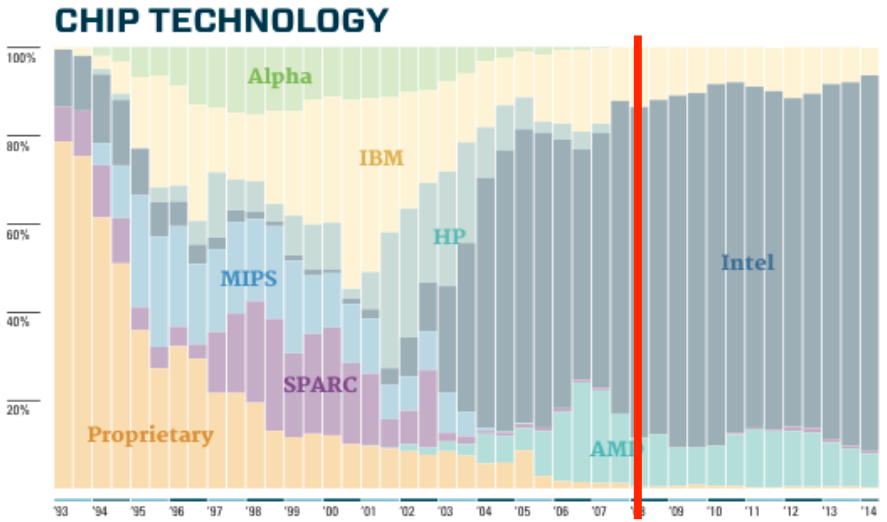
II. HPC evolution what is changing

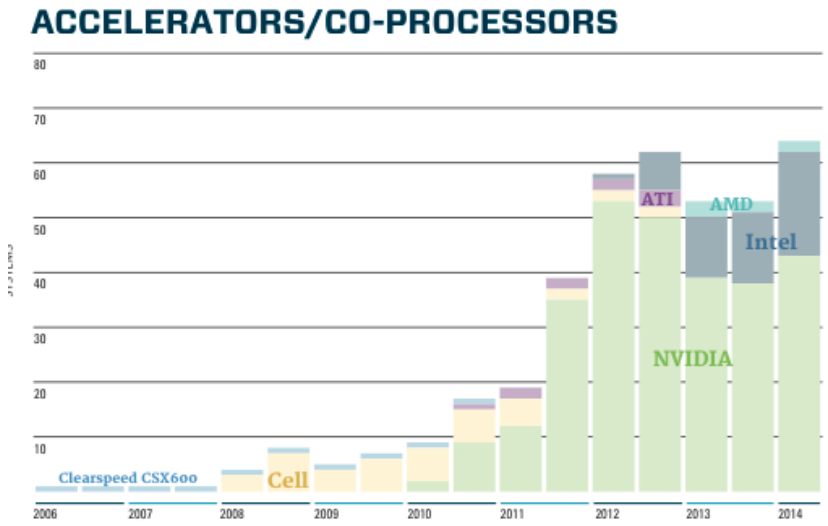


HPC in 2014



Since 2008 a stable ratio between MPP and clusters distribution….



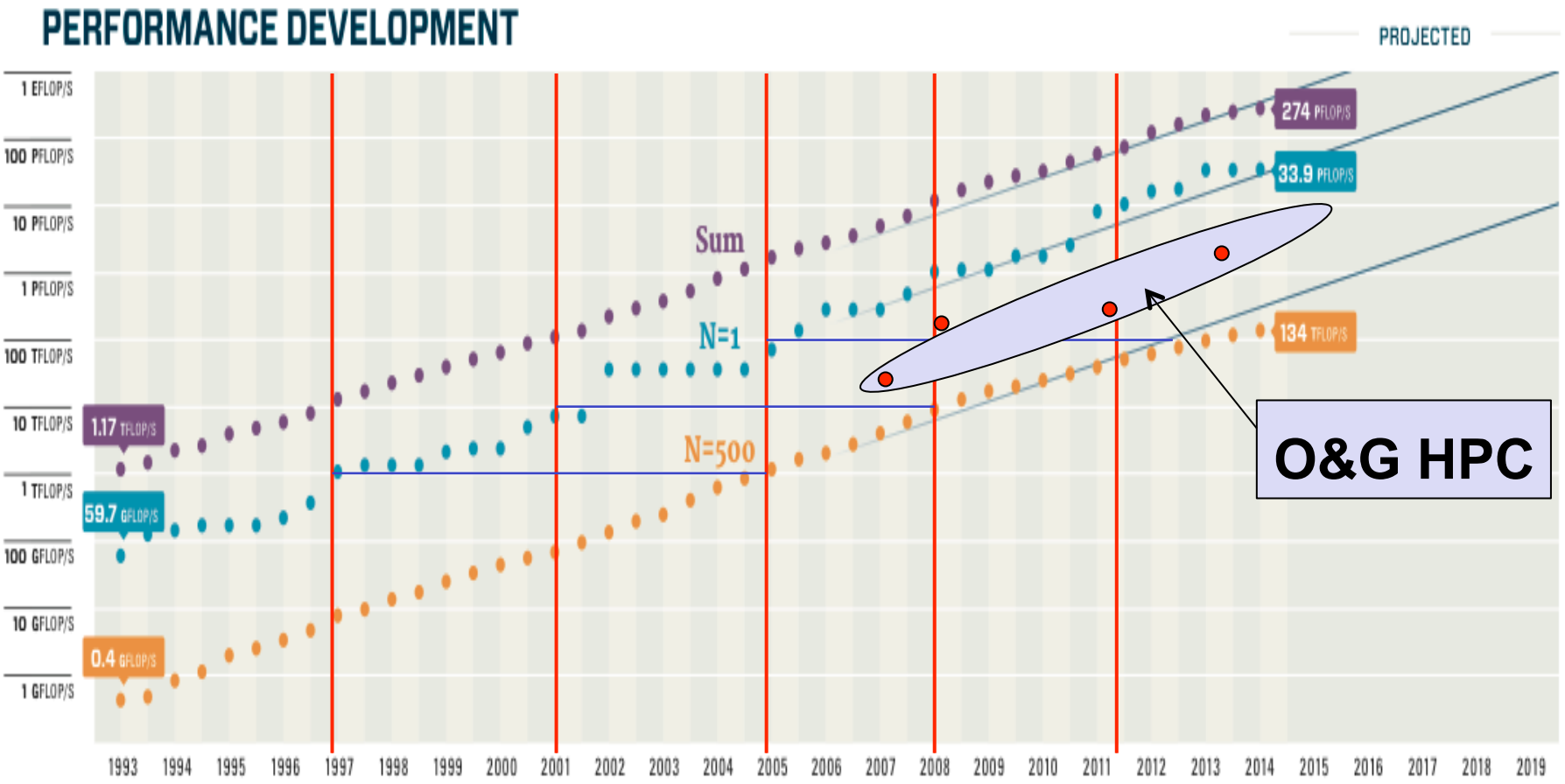


…Intel is the main CPU provider (>75%) …

…Nvidia is the main hybrid solution provider …. … Intel Phi processor stable/progressing…

TOTAL

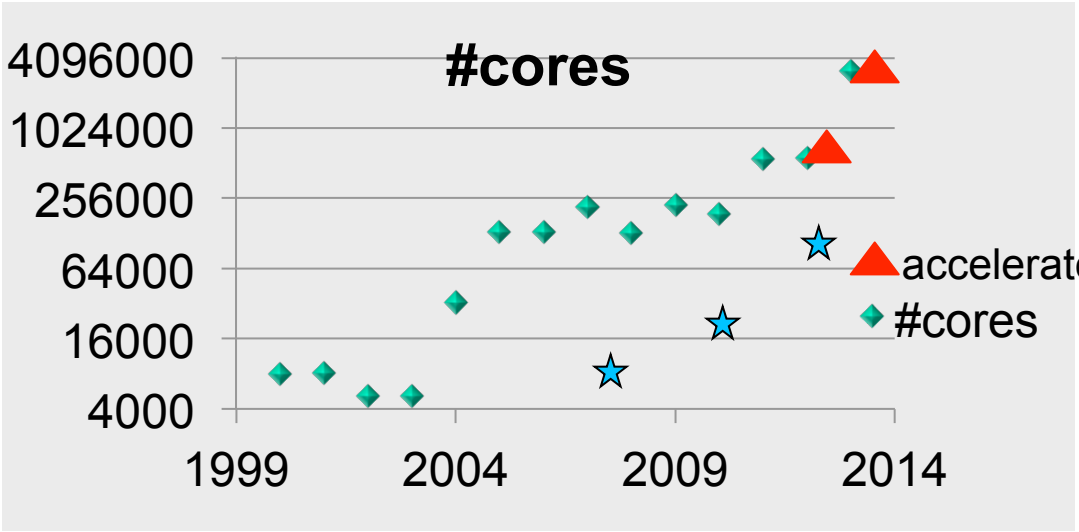
HPC evolution



X10 every 3-4 years

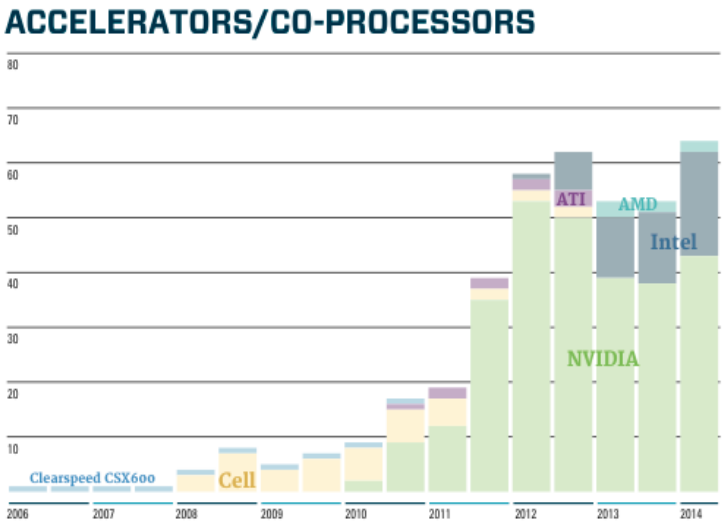
TOTAL

More cores and heterogenous systems?



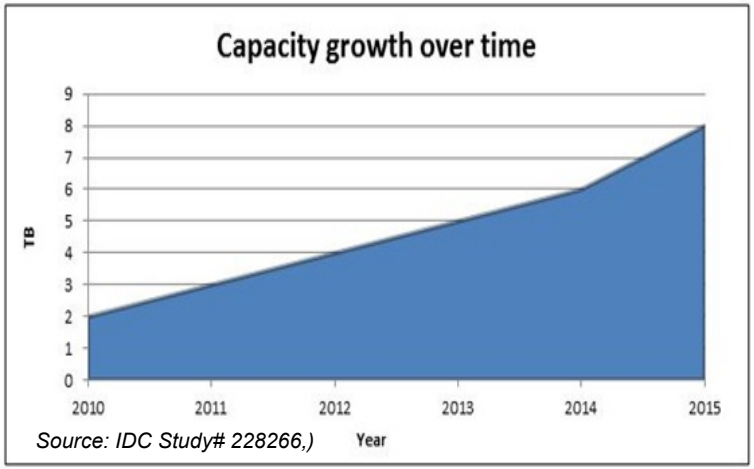
Moore's Law is still valid → more and more cores

GPUs, manycore technology is already dominating top10…
and very popular in O&G…

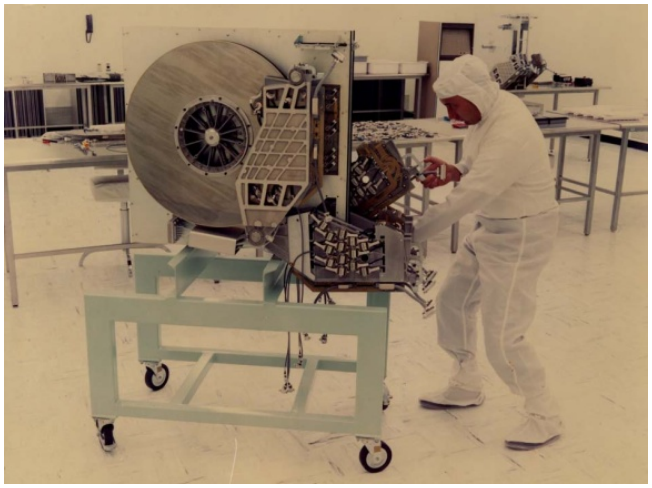


TOTAL

More data more data storage capacity



Source: IDC Study# 228266,)



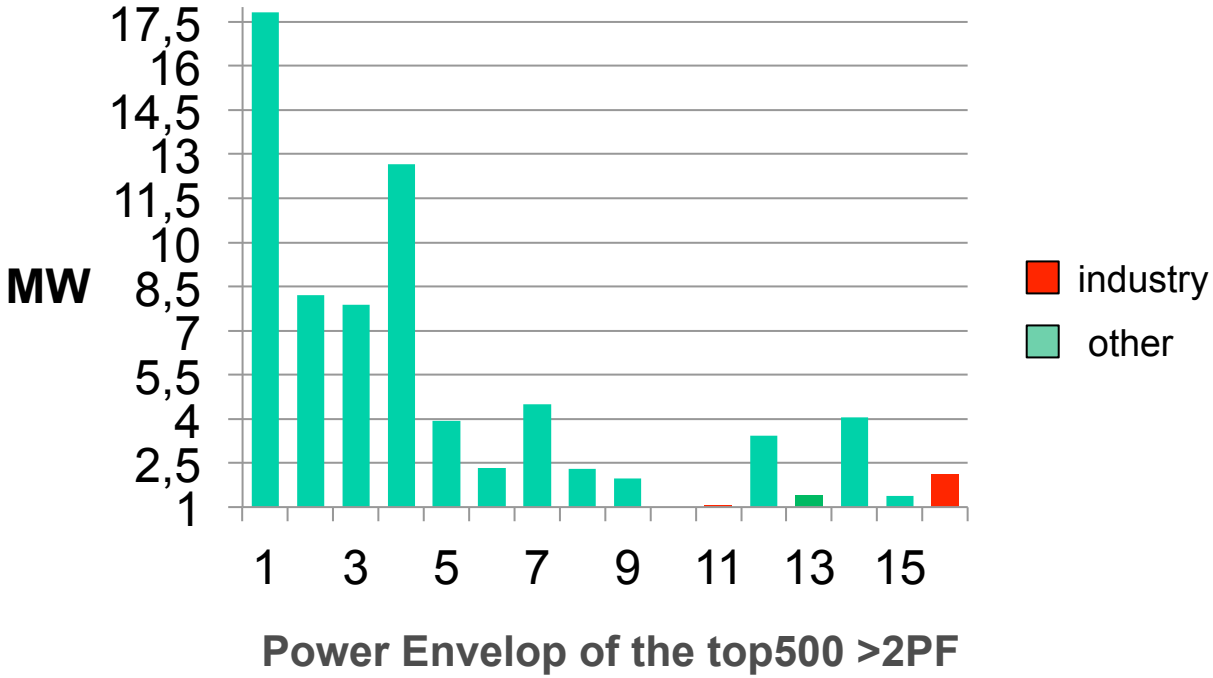
1979 250 MB HDD

Multi PetaBytes fast storage in O&G data center

New technology storage: SSD, NVRAM

TOTAL

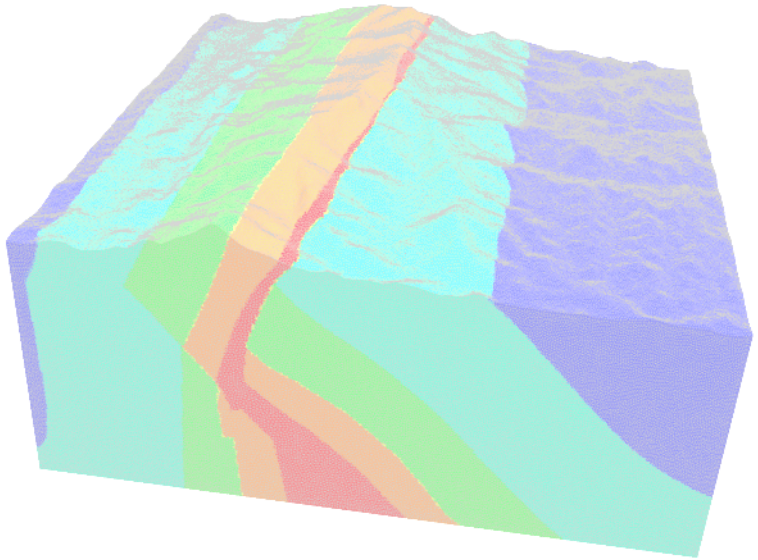
HPC what is changing

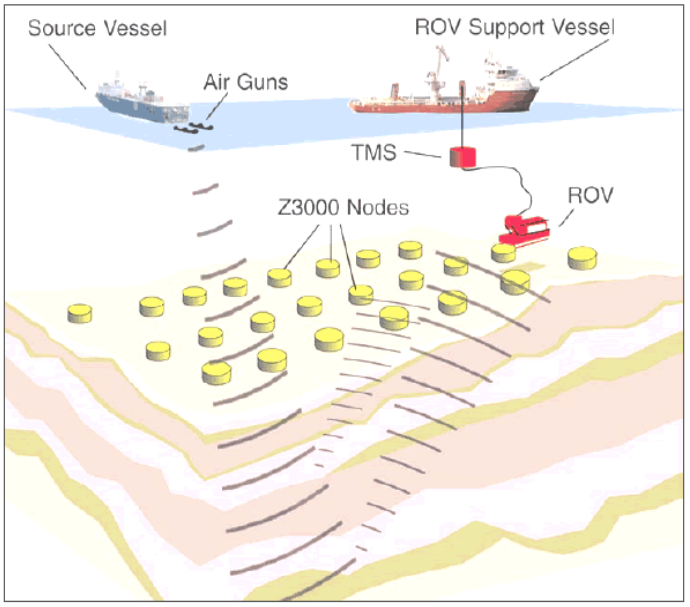


Power Envelop of the top500 >2PF

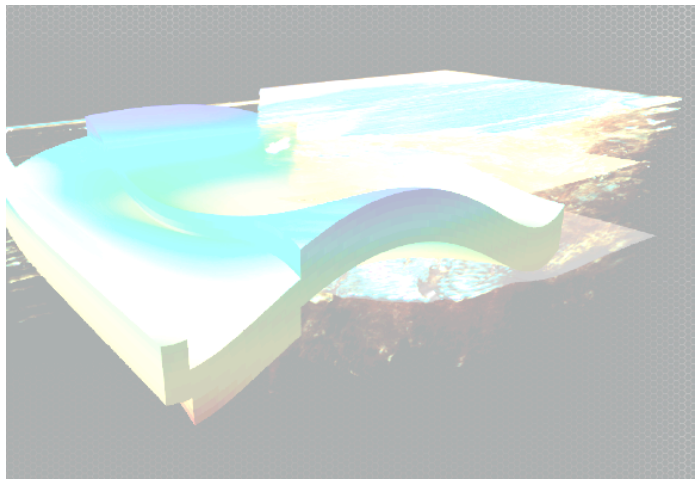
Power envelop is becoming a key parameter
➔Green 500
➔Impact on datacenter design
➔Impact on system management
➔Impact on software design ?

TOTAL



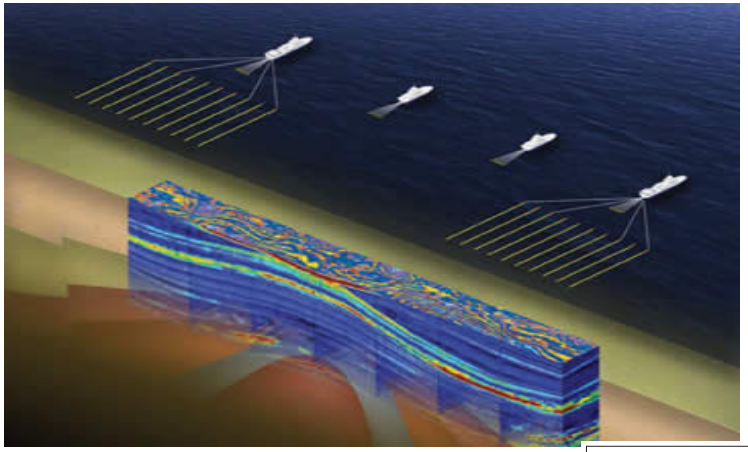


III. HPC perspectives for O&G Upstream



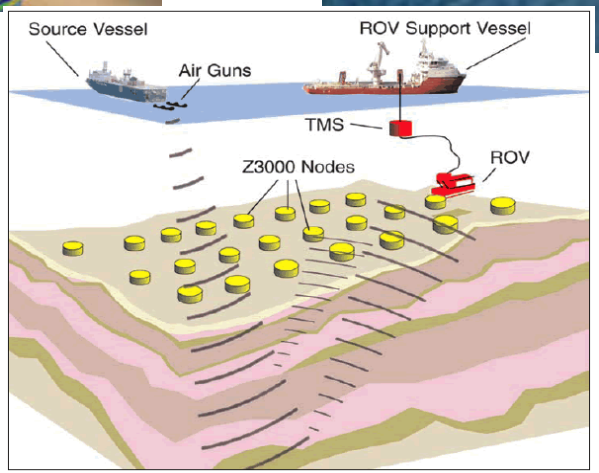
TOTAL

Computing effort driven by data acquisition

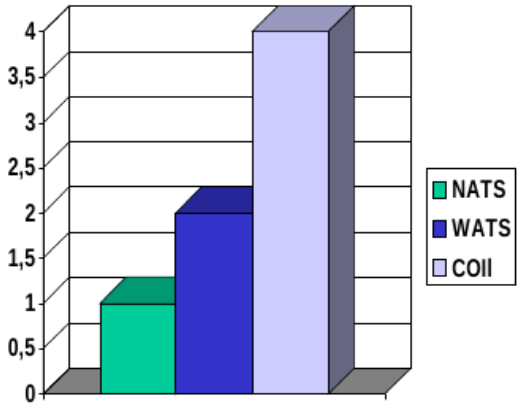


Wide Azimuth acquisition

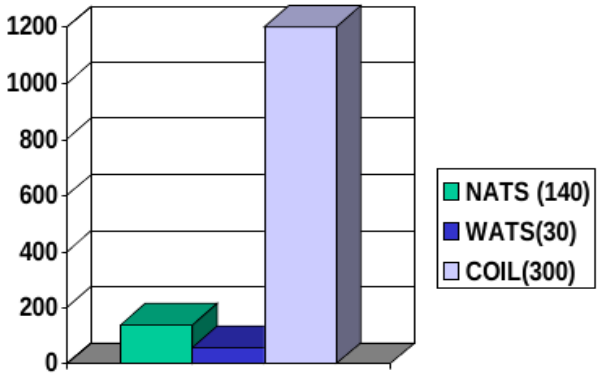
Coil acquisition



Node acquisition



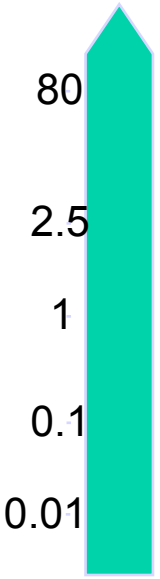
Computing effort per shot profile



Computing effort per km²

TOTAL

Computing requirement driven by numerical methods and algorithms



Elastic WE

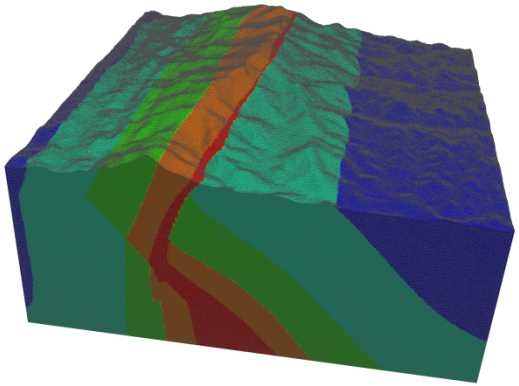
TTI WE

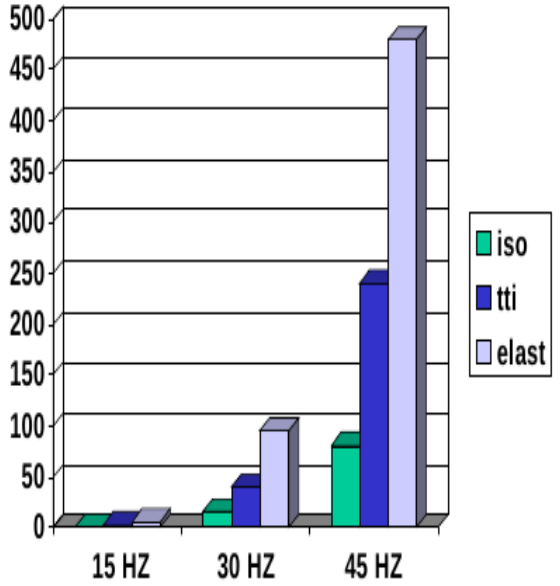
Acoustic WE

One Way

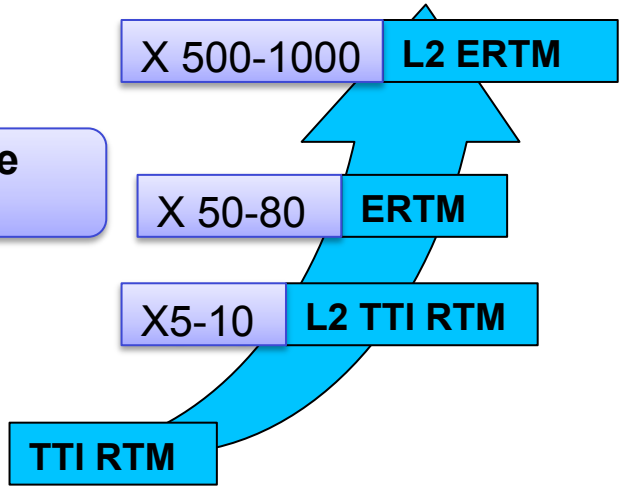
Kirchhoff

More physics but more CPU demanding algorithms





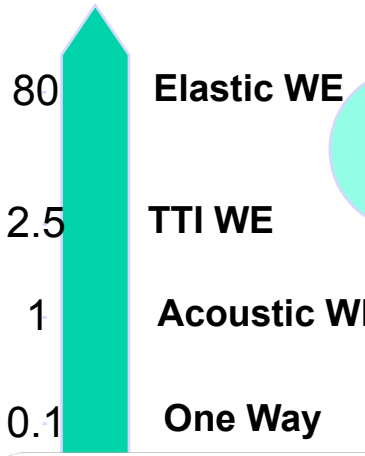
More accurate algorithms



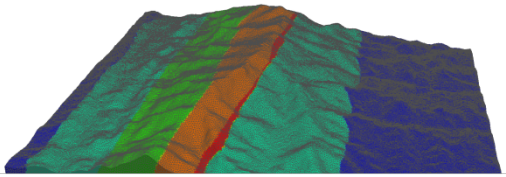
Computing effort grows linearly with the number of shot to process and exponentially O(N^4) with seismic bandwidth…

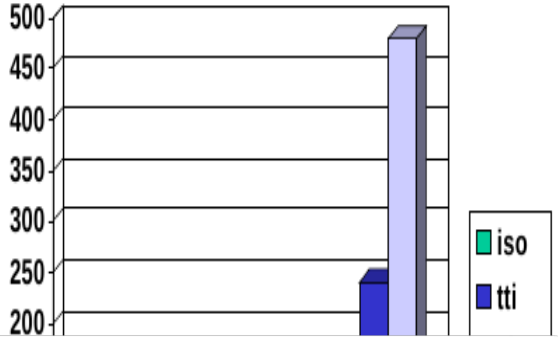
TOTAL

Computing requirement driven by numerical methods and algorithms



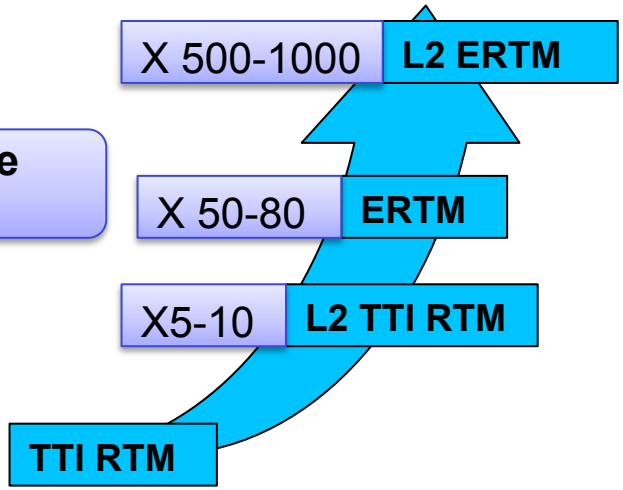
More physics but more CPU demanding algorithms





Seismic imaging will still be the main HPC driver in O&G Upstream. But new players are coming…

15 HZ 30 HZ 45 HZ



More accurate algorithms

Computing effort grows linearly with the number of shot to process and exponentially $O(N^4)$ with seismic bandwidth...

TOTAL

HPC challenges in O&G Upstream: reservoir simulation

Accelerate development studies

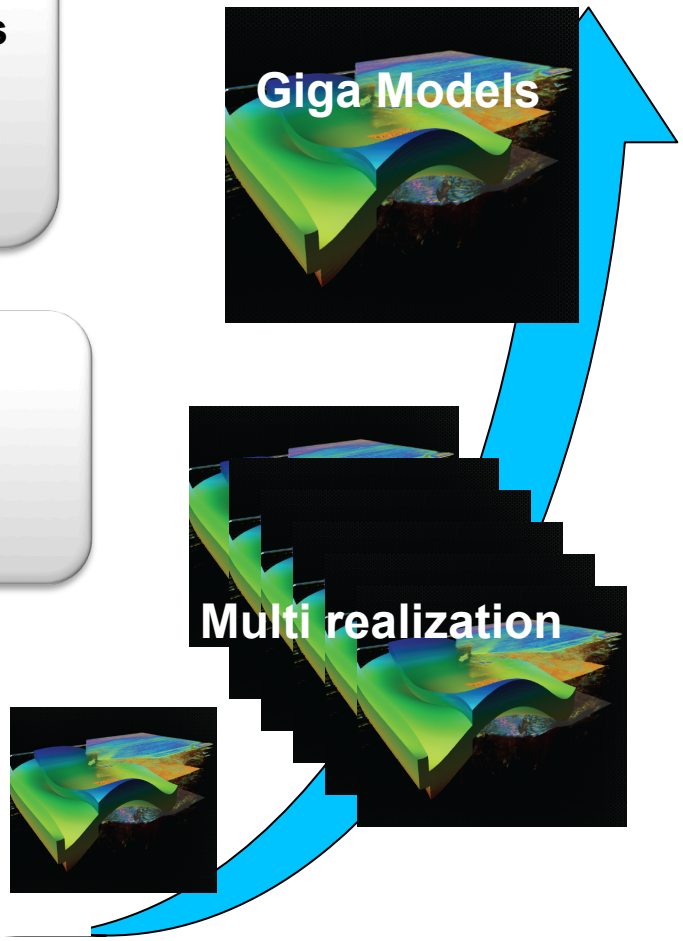
- Faster reservoir simulation runs: hours instead of days
- No upscaling between geological model and dynamic model
- Improved reservoir-to-surface coupling

Forecast more accurately

- Incorporate HR seismic (incl. 4D) & geologyModel complex physics (EOR, heavy oil, non conventional)
- Develop multi-realization and multi-scenario approach

Foster R&D to prepare for the future

- Develop new solvers, taking advantage of future HPC hardware
- Flow Assurance: multi-phase flow in wells and pipes
- Digital Rock Physics: pore imaging, pore flow simulations
- Molecular Dynamics: many potential applications (non conventional, etc.)



~ X 100 Computing capabilities

TOTAL

HPC challenges for O&G Upstream

- **Seismic acquisition: order of magnitude**
  - more data: multi-component data, dense data, 4D acquisition…
- **Seismic depth imaging methods : 1-3 orders of magnitude**
  - more iterations, more physics, more complex approximations
  - More interactivity, more workflow control, more data integration
- **Reservoir simulation: 1-2 orders of magnitude**
  - bigger model, multi resolution, uncertainties…, more interactions with data, 4D data…

TOTAL

HPC challenges for O&G Upstream

➢ **Exaflop system for O&G ? New perspectives**

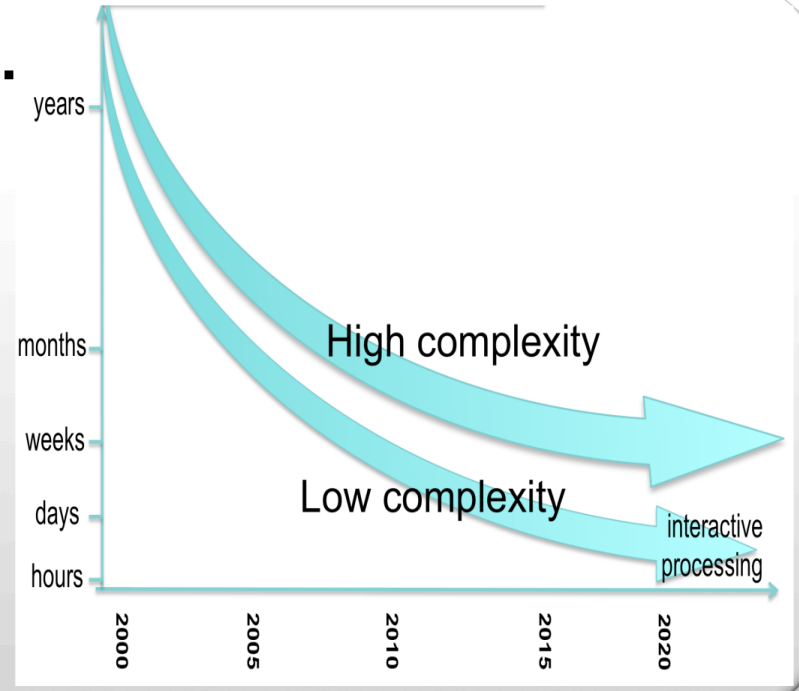
➢ **From week to hours, minutes…**

➔ **Many-simulations technologies**

- **Uncertainty analysis**
- **Global optimization**

➔**Integration of disciplines**

- **Bridge between physical scales**
- **Geological scenario exploration**
  - **Interactivity**



TOTAL

HPC challenges for O&G Upstream

- Exaflop system for O&G ? Still some challenging questions

More cores, more compute nodes

- Questions:
  - Design of compute node
    - Hybrid: CPU, CPU-GPUS, manycore?
    - Mix of them ?
    - local storage vs. global file system?
  - Interconnect topology?
  - Reliability…

TOTAL

HPC challenges for O&G Upstream

- Exaflop system for O&G ? Still some challenging questions

More cores, more compute nodes

Xtreme //

- At node level
- At inter-node level
- What programming languages ?
  - at node level: OpenMP, OpenACC,Cuda,Opencl
  - at internode level: MPI, PGAS(CAF, XMP…?)
- Actual codes are quite conservatives: MPI+…..
- Portability issues

TOTAL

HPC challenges for O&G Upstream

- Exaflop system for O&G ? Still some challenging questions

More DATA !

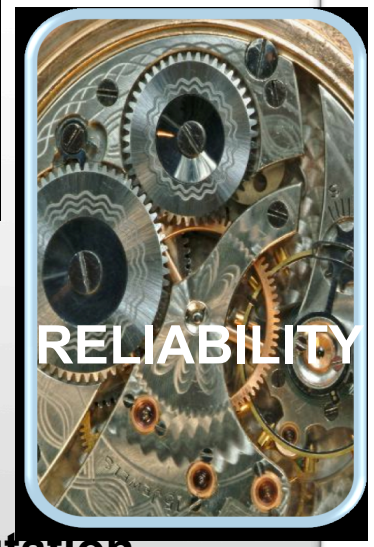
- Input data …
- Intermediate data.

- High Bandwidth file system storage
- Hierarchical file system from local to global FS: Increase data locality (NVRAM, SSD?) and reduce data movement
- More interaction and data control during the program execution:
  - In Situ data access: Visualization, parameters control (chkpt/ restart)

HPC challenges for O&G Upstream

- Exaflop system for O&G ? Still some interesting questions

- Power Envelop
  - Direct impact on data center design
  - 10MW system ~ 10 $M/year



➔ Need to optimize at all level:
- ➔ Hardware and system level
  - ➔ Adapt CPU frequency,
  - ➔ Cooling,
  - ➔ Minimize data movement: Optimize data locality,
- ➔ System level: monitoring and system management
- ➔ Application level: more interaction during the computation, visualization, fault tolerance…

TOTAL

HPC Challenges for O&G Upstream

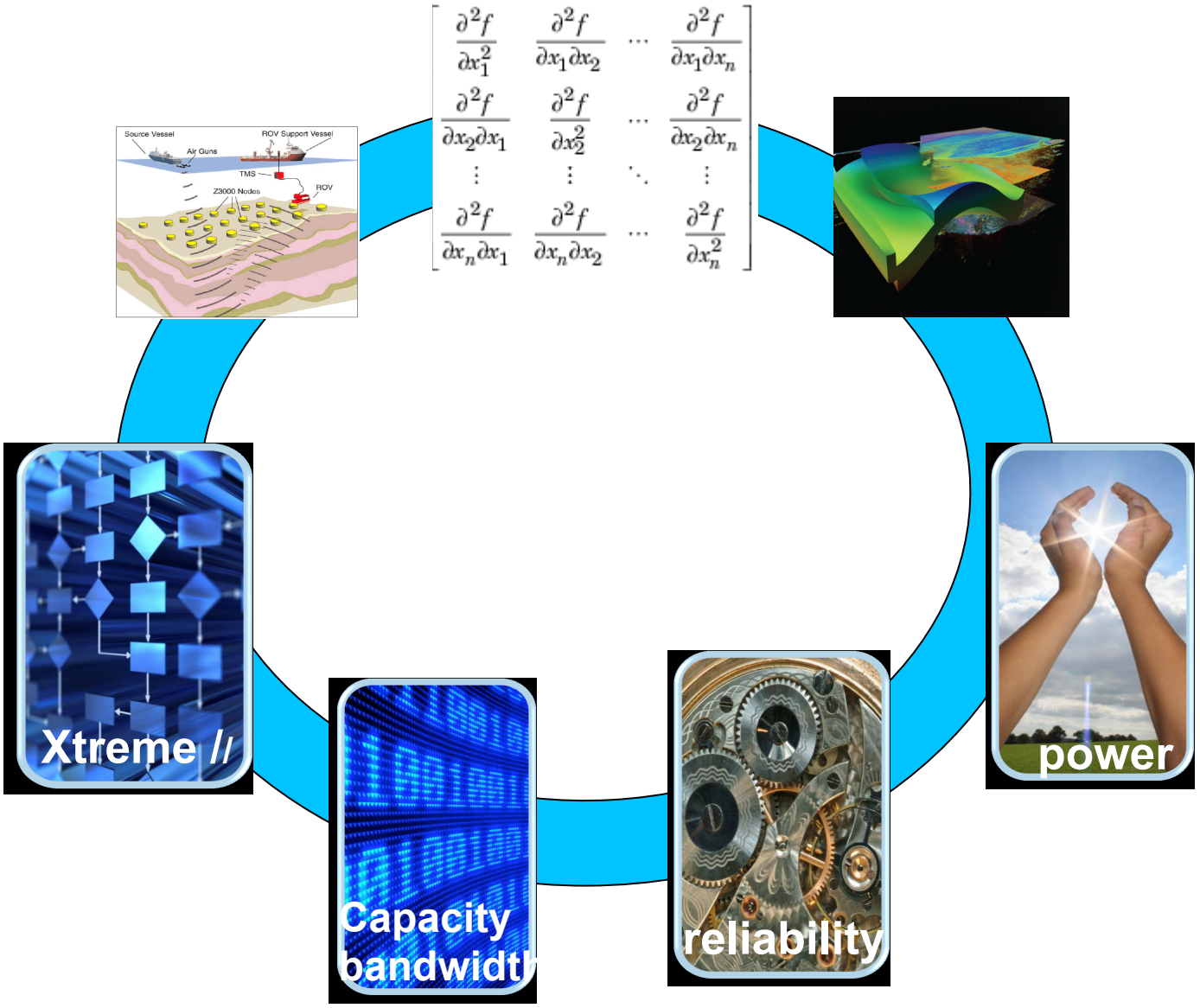
Different algorithms different architectures ?

- **Seismic Imaging:**
  - 1 shot/node (100's GB, >> 10 TF): embarrassingly parallel
  - Local fast storage or distributed file system and fast global file system
  - Fast interconnect : collective communications, post-processing…
  - Should be well designed for "Lattice Boltzmann" type algorithms

- **Reservoir simulation**
  - Need more scalability.
  - Fault tolerance: check pointing mechanism
  - More interaction with the code during processing…

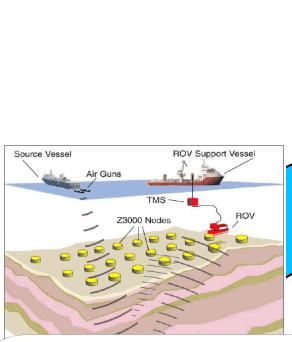
TOTAL

Conclusion

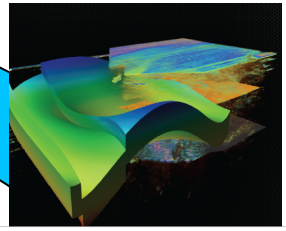


TOTAL

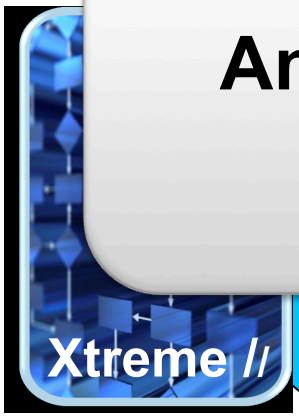
Conclusion

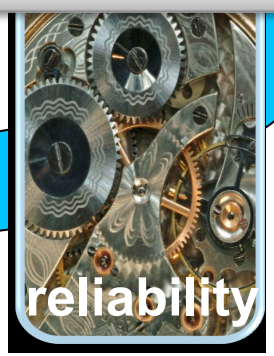


$$\begin{bmatrix} \frac{\partial^2 f}{\partial x_1^2} & \frac{\partial^2 f}{\partial x_1 \partial x_2} & \cdots & \frac{\partial^2 f}{\partial x_1 \partial x_n} \\ \frac{\partial^2 f}{\partial x_2 \partial x_1} & \frac{\partial^2 f}{\partial x_2^2} & \cdots & \frac{\partial^2 f}{\partial x_2 \partial x_n} \\ \vdots & \vdots & \ddots & \vdots \\ \frac{\partial^2 f}{\partial x_n \partial x_1} & \frac{\partial^2 f}{\partial x_n \partial x_2} & \cdots & \frac{\partial^2 f}{\partial x_n^2} \end{bmatrix}$$



And STILL many questions . . .





TOTAL

Thank You