Introduction to Numerical Techniques for Acoustics

Master 2 Acoustical Engineering
Numerical Techniques for Acoustics - Session 1

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Monday 16 September 2019 - ENSTA

Jack Dongara at CEMRACS 2016

CEMRACS 2016

Numerical challenges in parallel scientific computing

July 18th - August 26th

Algorithms for future emerging technologies

Jack Dongarra
University of Tennessee
Oak Ridge National Lab
University of Manchester

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http ://smai.emath.fr/cemracs/cemracs16/images/inria-0716.pdf

M. Massot and L. Series, Cours X02 master AMS 2018

Méthodes numériques avancées et HPC pour la simulation de phénomènes complexes

Introduction aux archictectures des calculateurs

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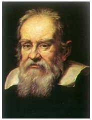
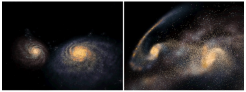
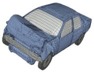
Simulation: The Third Pillar of Science

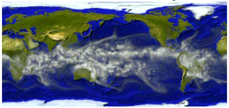


- Traditional scientific and engineering paradigm:
  1) Do theory or paper design.
  2) Perform experiments or build system.
- Limitations:
  - Too difficult -- build large wind tunnels.
  - Too expensive -- build a throw-away passenger jet.
  - Too slow -- wait for climate or galactic evolution.
  - Too dangerous -- weapons, drug design, climate experimentation.

- Computational science paradigm:
  3) Use high performance computer systems to simulate the phenomenon
     - Base on known physical laws and efficient numerical methods.

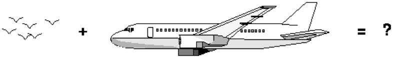


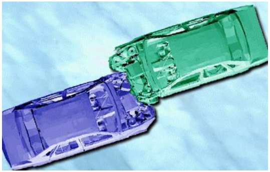


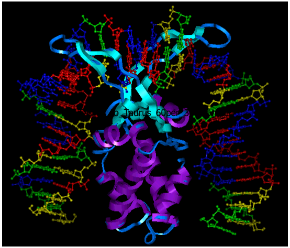


Why Turn to Simulation?

- **When the problem is too . . .**
  - Complex
  - Large / small
  - Expensive
  - Dangerous
- **to do any other way.**

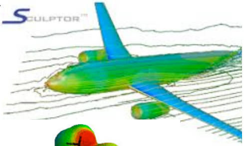


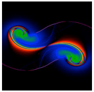


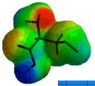


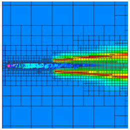
Wide Range of Applications that Depend on HPC is Incredibly Broad and Diverse

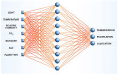
- Airplane wing design,
- Quantum chemistry,
- Geophysical flows,
- Noise reduction,
- Diffusion of solid bodies in a liquid,
- Adaptive mesh refinement,
- Computational materials research,
- Deep learning in neural networks,
- Stochastic simulation,
- Massively parallel data mining,
- …



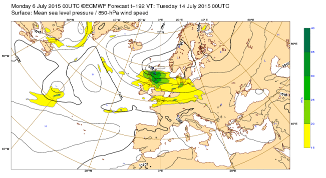


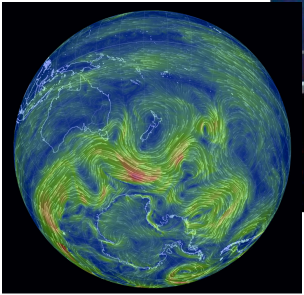






Supercomputers Touch Everyone with Weather Forecasting





Computational Science Fuses Three Distinct Elements:

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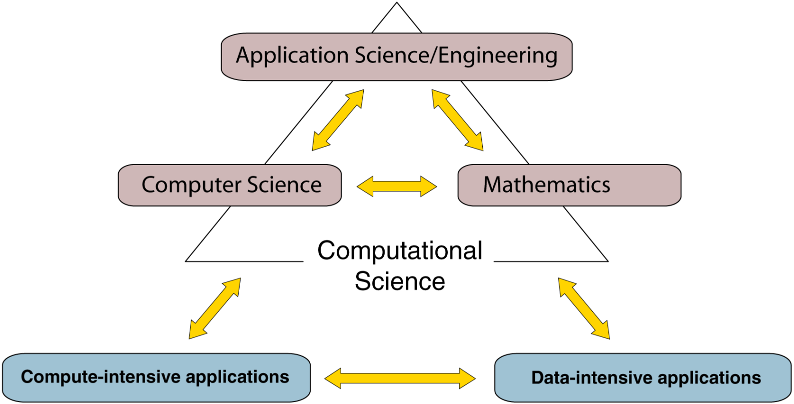


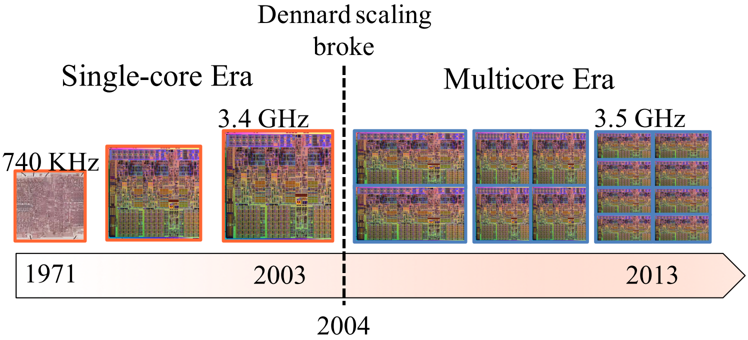
Look at the Fastest Computers

- **Strategic importance of supercomputing**
  - **Essential for scientific discovery**
  - **Critical for national security**
  - **Fundamental contributor to the economy and competitiveness through use in engineering and manufacturing**
- **Supercomputers are *the tool for solving the most challenging problems through simulations***

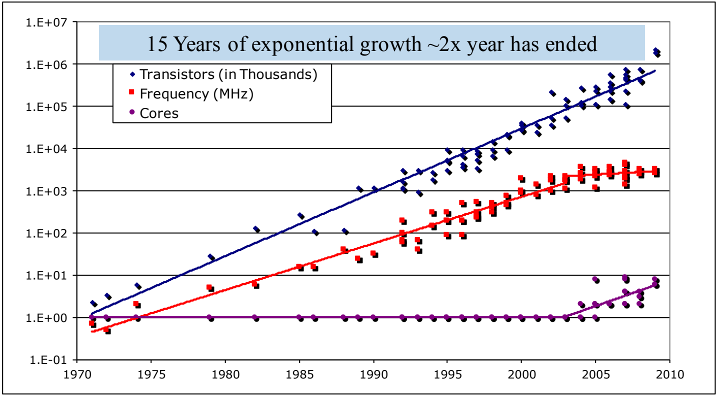
Dennard Scaling Over

Evolution of processors

The primary reason cited for the breakdown is that at small sizes, current leakage poses greater challenges, and also causes the chip to heat up, which creates a threat of thermal runaway and therefore further increases energy costs.

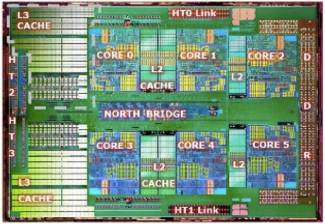


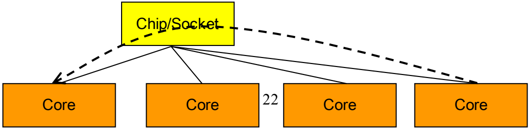
But Clock Frequency Scaling Replaced by Scaling Cores / Chip



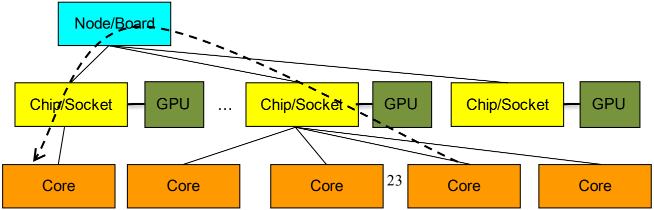
Data from Kunle Olukotun, Lance Hammond, Herb Sutter, Burton Smith, Chris Batten, and Krste Asanoviç
Slide from Kathy Yelick

Example of typical parallel machine



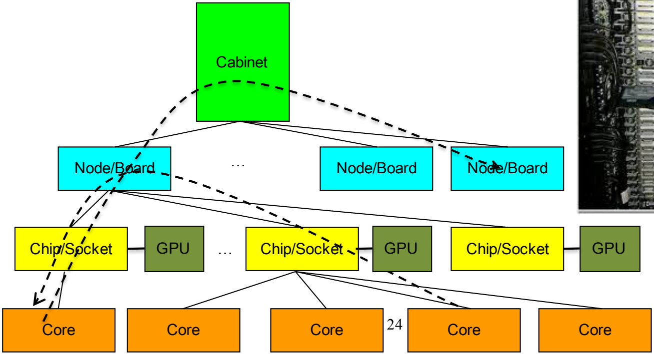


Example of typical parallel machine

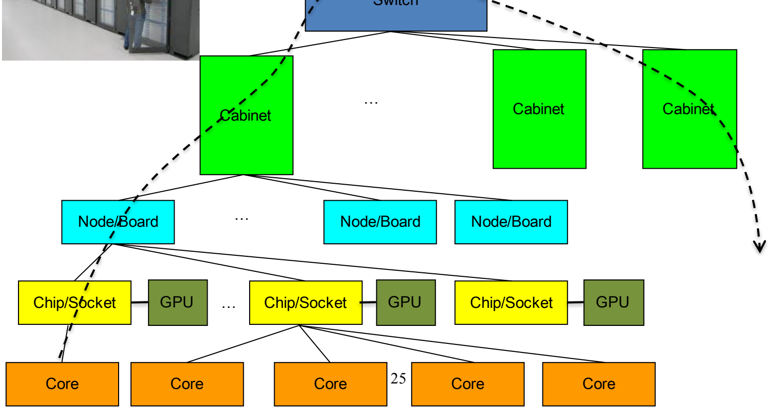


Example of typical parallel machine

Shared memory programming between processes on a board and
a combination of shared memory and distributed memory programming
between nodes and cabinets



Example of typical parallel machine

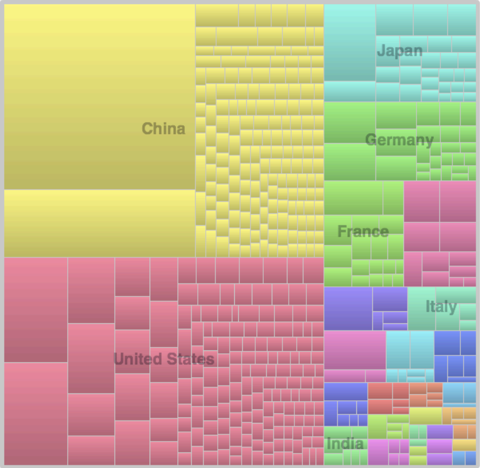


ICL UT

State of Supercomputing Today

- Pflops (> 10^{15} Flop/s) computing fully established with 95 systems.
- Three technology architecture possibilities or "swim lanes" are thriving.
  - Commodity (e.g. Intel)
  - Commodity + accelerator (e.g. GPUs) (93 systems)
  - Lightweight cores (e.g. ShenWei, ARM, Intel's Knights Landing)
- Interest in supercomputing is now worldwide, and growing in many new markets (around 50% of Top500 computers are used in industry).
- Exascale (10^{18} Flop/s) projects exist in many countries and regions.
- Intel processors have largest share, 91% followed by AMD, 3%.

Countries Share



COUNTRY	NUMBER OF SUPERCOMPUTERS
China	**167**
United States	165
Japan	29
Germany	26
France	18
Britain	12
India	9
Russia	7
South Korea	7
Poland	6
other	54

China has 1/3 of the systems, while the number of systems in the US has fallen to the lowest point since the TOP500 list was created.

June 2016: The TOP 10 Systems

Rank	Site	Computer	Country	Cores	Rmax [Pflops]	% of Peak	Power [MW]	GFlops/ Watt
1	National Super Computer Center in Wuxi	Sunway TaihuLight, SW26010 (260C) + Custom	China	10,649,000	93.0	74	15.4	6.04
2	National Super Computer Center in Guangzhou	Tianhe-2 NUDT, Xeon (12C) + IntelXeon Phi (57c) + Custom	China	3,120,000	33.9	62	17.8	1.91
3	DOE / OS Oak Ridge Nat Lab	Titan, Cray XK7, AMD (16C) + Nvidia Kepler GPU (14c) + Custom	USA	560,640	17.6	65	8.21	2.14
4	DOE / NNSA L Livermore Nat Lab	Sequoia, BlueGene/Q (16C) + custom	USA	1,572,864	17.2	85	7.89	2.18
5	RIKEN Advanced Inst for Comp Sci	K computer Fujitsu SPARC64 VIIIfx (8C) + Custom	Japan	705,024	10.5	93	12.7	.827
6	DOE / OS Argonne Nat Lab	Mira, BlueGene/Q (16C) + Custom	USA	786,432	8.16	85	3.95	2.07
7	DOE / NNSA / Los Alamos & Sandia	Trinity, Cray XC40,Xeon (16C) + Custom	USA	301,056	8.10	80	4.23	1.92
8	Swiss CSCS	Piz Daint, Cray XC30, Xeon (8C) + Nvidia Kepler (14c) + Custom	Swiss	115,984	6.27	81	2.33	2.69
9	HLRS Stuttgart	Hazel Hen, Cray XC40, Xeon (12C) + Custom	Germany	185,088	5.64	76	3.62	1.56
10	KAUST	Shaheen II, Cray XC40, Xeon (16C) + Custom	Saudi Arabia	196,608	5.54	77	2.83	1.96
500	Internet company	Inspur Intel (8C) + Nnvidia	China	5440	.286	71		


神威
太湖之光
SHENWEI
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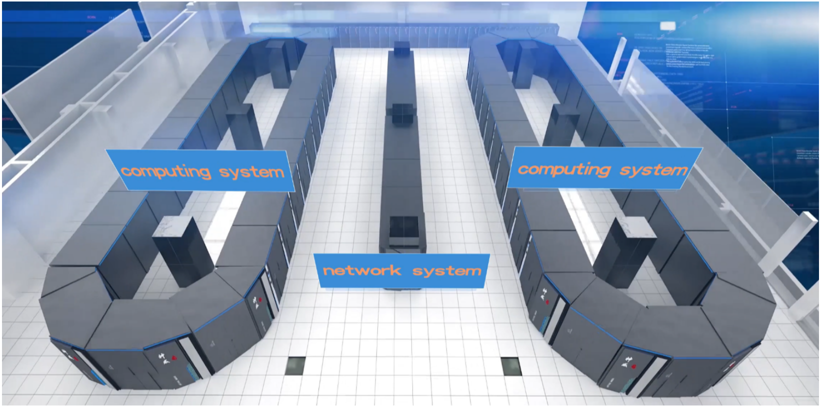

computing system
computing system
network system

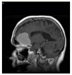
Industrial Use of Supercomputers

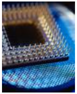
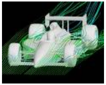
- **Of the 500 Fastest Supercomputer**
  - **Worldwide, Industrial Use is ~48%**

- Aerospace
- Automotive
- Biology
- CFD
- Database
- Defense
- Digital Content Creation
- Digital Media
- Electronics
- Energy
- Environment
- Finance
- Gaming
- Geophysics
- Image Proc./Rendering
- Information Processing Service
- Information Service
- Life Science
- Media
- Medicine
- Pharmaceutics
- Research
- Retail
- Semiconductor
- Telecomm
- Weather and Climate Research
- Weather Forecasting







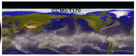









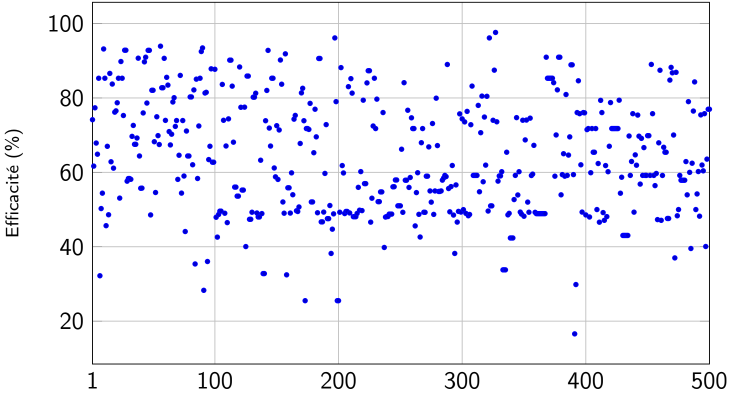




TOP 500 performances for dense matrix inversion

Puissance maximale (Linpack)

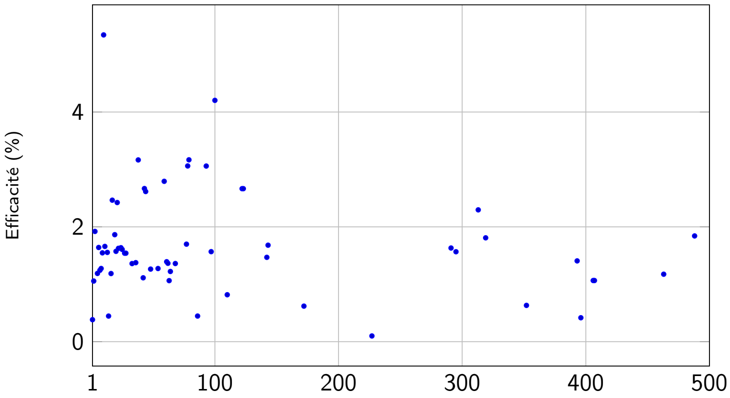
Efficacité du bench Linpack



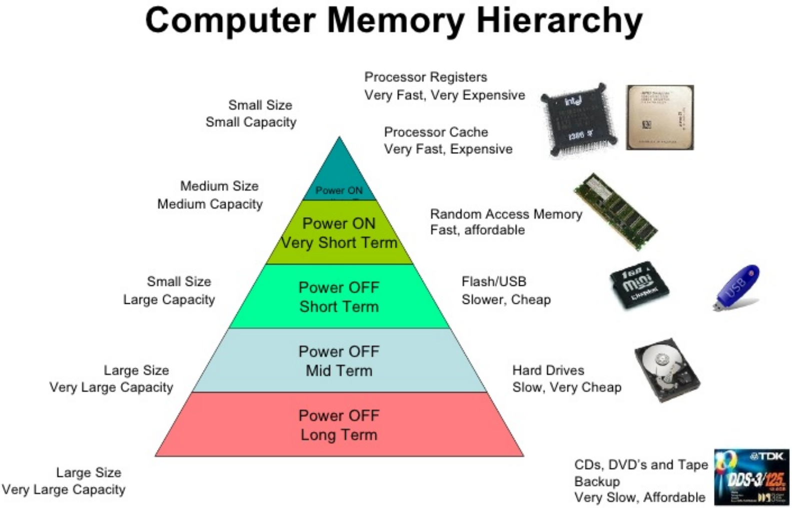
TOP 500 performances for sparse matrix-vector product

Puissance maximale (HPCG)

Efficacité du bench Linpack



Memory bottleneck



Numerical approximation for a simple addition

Matlab code :

```
a = 1000000.;
b = 999999.5;
c = 0.1;
d = (a - b) + c;
e = (a + c) - b;
fprintf("d = %16.15f\n", d);
fprintf("e = %16.15f\n", e);
```

Output :

d = 0.600000000000000

e = 0.599999999976717

Numerical approximation propagation (float)

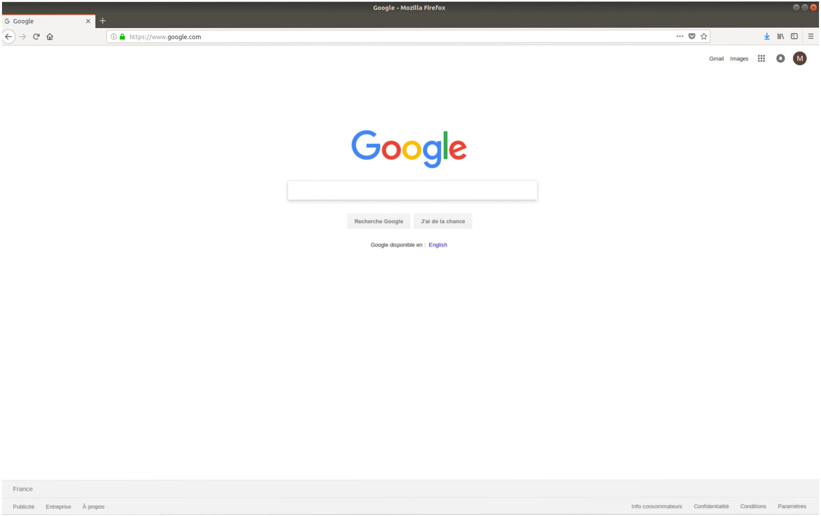
Matlab code :

```
u0 = 0.01;
for n=1:15
  u1 = 101*u0 - 1;
  u0 = u1;
  fprintf("u1 = %16.15e
      \n", u1);
end
```

Output :

u1 = 1.000000000000001e-02
u1 = 1.000000000000090e-02
u1 = 1.000000000009060e-02
u1 = 1.000000000915091e-02
u1 = 1.000000092424203e-02
u1 = 1.000009334844454e-02
u1 = 1.000942819289841e-02
u1 = 1.095224748273904e-02
u1 = 1.061769957566432e-01
u1 = 9.723876571420963e+00
u1 = 9.811115337135172e+02
u1 = 9.909126490506524e+04
u1 = 1.000821675541159e+07
u1 = 1.010829891296571e+09
u1 = 1.020938190199536e+11

Code generation



Home page of *www.google.com*

Code generation

A (small) part of the source. **But what does this code do ?**

Inadapted physical/mathematical model

For room acoustic simulation, **linear wave equation ?**

To keep in mind !

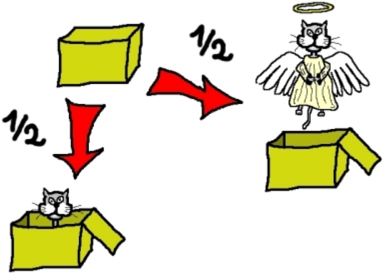
Usual question : Is my simulation the most efficient ?

But first :

- What is the reliability of my code ?
- What is the reliability of my numerical model ?
- What is the reliability of my math/phys model ?

Finally, what is the reliability of my result ?

Answer



Schrodinger's rules !

Numerical sciences are not as deterministic as we think...

To remove indeterminacy, two ways :

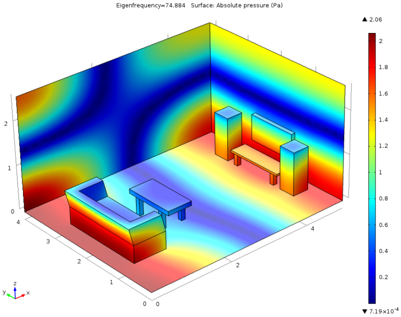
- Follow the course *Experimental techniques in acoustics*,
- Compare several numerical methods/softwares output.

Numerical technics for acoustics

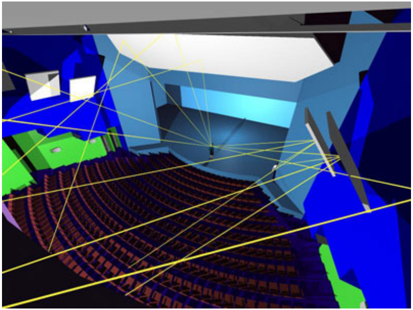
As for others science, a very large range of applications :

- Room propagation (building, archeology, ...)
- Musical instrument (directivity, manufacturing, ...)
- Vibro-acoustic (structural mechanics, resonance, ...)
- Aero/submarin acoustic (sonar detection, aircraft landing, ...)
- Audio spatialization (HRTF design, 3D reverberation, ...)
- Medical imaging (echography)
- Transducers (directivity, response, ...)
- Environment and urbanism (City sound propagation,
- Inverse problem (detection, identification, ...)
- ...

Room acoustic

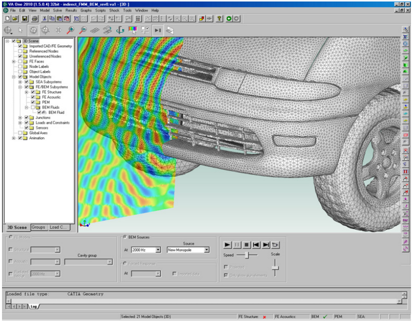


Eigen frequencies finding, *Comsol*.

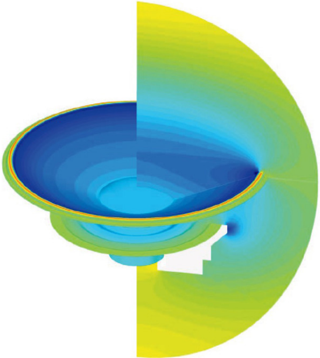


Ray-tracing, *Odeon*.

Vibro-acoustic

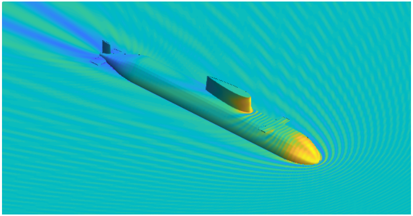


Acoustic pressure, *VAone*.

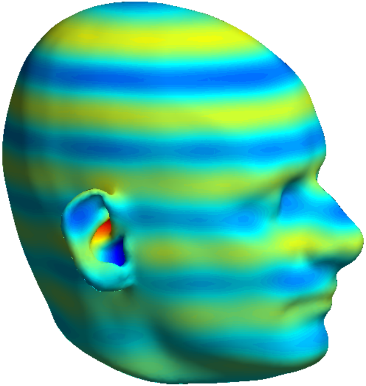


Acoustic velociy, *Actran*.

Scattering



Sonar detection, *Gypsilab*.



HRTF computation, *Gypsilab*.

A decision algorithm for engineers

IF Experimentation

- is real **return**
- is numerical **then**

If Sofware

- is commercial **return**
- is home-made **then**

If langage

- high level (matlab, python, julia, ...) **See you next months !**
- low level (C, C++, fortran, ...) **See you next years !**

Few references

- Allaire, G. (2005). *Analyse numérique et optimisation : Une introduction a la modélisation mathématique et a la simulation numérique*. Ecole polytechnique.
- Dongarra, J. (2016). *Algorithms for future emerging technologies*. http ://smai.emath.fr/cemracs/cemracs16/images/inria-0716.pdf
- Massot, M. & Series Laurent (2018). *Méthodes numériques avancées et HPC pour la simulation de phénomènes complexes*. http ://www.cmap.polytechnique.fr/~massot/Personal_web_page_of_Marc_Massot/CoursAMS.html
- Terrasse, I., & Abboud, T. (2007). *Modélisation des phénomenes de propagation d'ondes*. Ecole Polytechnique.