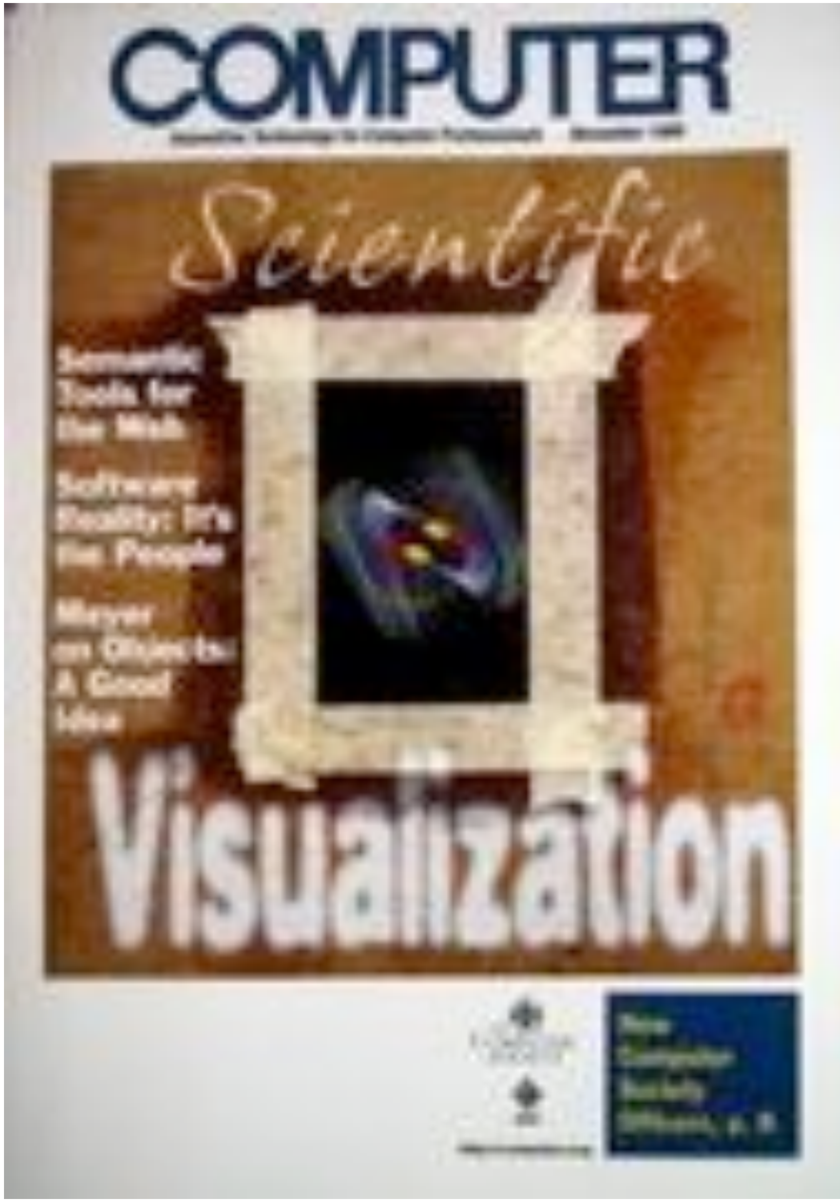
HPC Tutorial:
Colliding Black Holes on LONI

Yaakoub El Khamra
yye00@cct.lsu.edu
Center for Computation & Technology
Louisiana State University


COMPUTER
Scientific
Semantic Tools for the Web
Software Reality: It's the People
Meyer on Objects: A Good Idea
Visualization


iMode and the Wireless Internet
The Perils of Data Misreporting
The Myths of Diminishing Firms
Security by Obscurity
COMMUNICATIONS
of the ACM
November 2003
Volume 46, Number 11
BLUEPRINT FOR THE FUTURE OF
HIGH-PERFORMANCE NETWORKING
MEASURING PRODUCTIVITY IN THE SOFTWARE INDUSTRY
GREAT PRINCIPLES OF COMPUTING

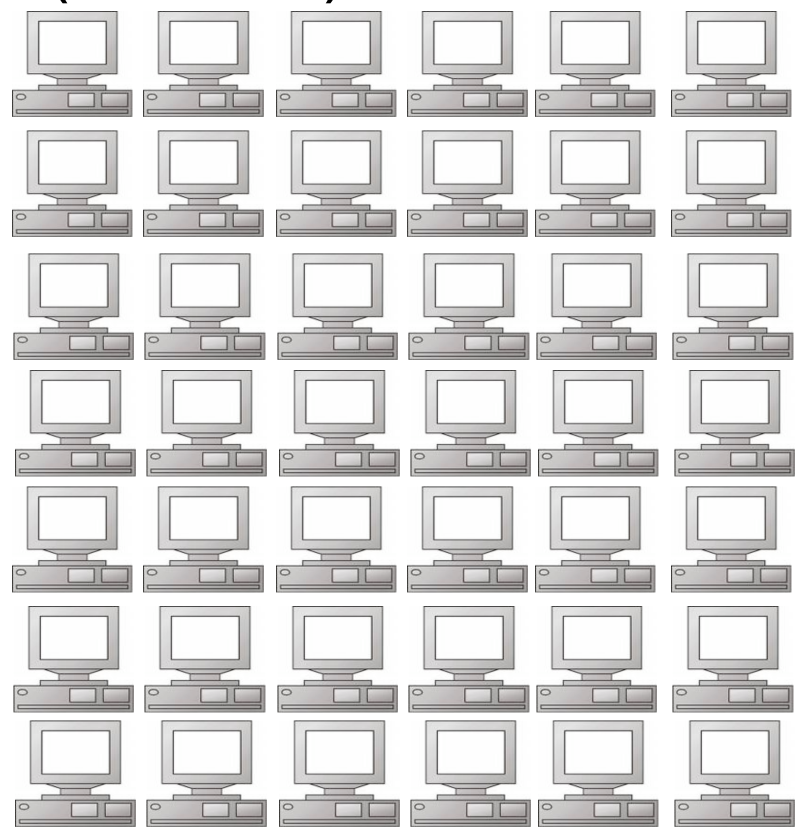
What is HPC

- HPC: High Performance Computing
- Extremely fast computing, millions of millions of operations per second

In other words...

- Traditional computing

- Supercomputing (cluster)



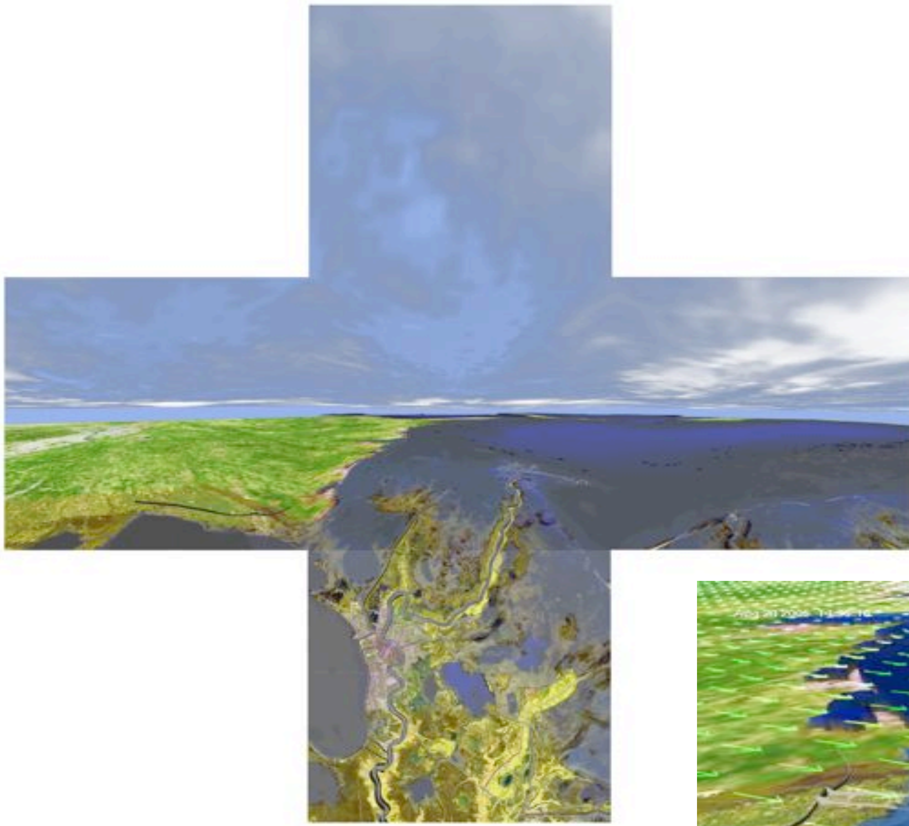
Why HPC

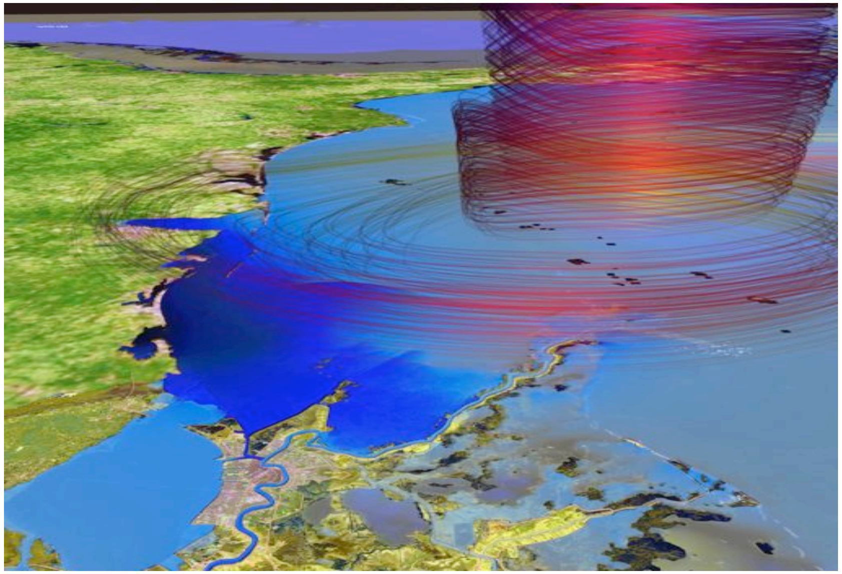
- Problems are too big, you run out of memory
- Problems take too long to solve, you can't wait for years
- Too many problems to solve, you can't wait forever

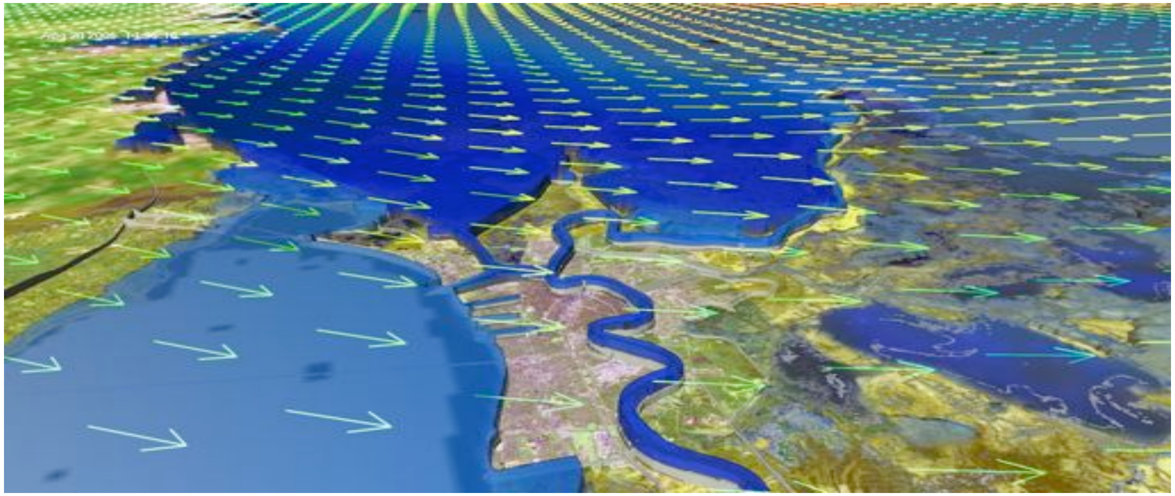
Applications

- Weather simulations, hurricanes
- Computational Fluid Dynamics
- Oil reservoir simulation
- Computational biology
- Astrophysics, numerical relativity (we will be doing this today)
- Many others...

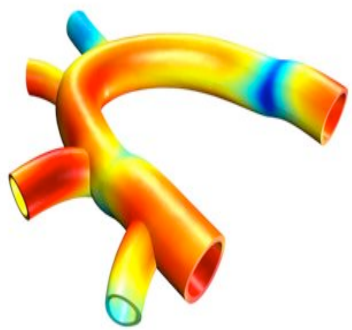
Hurricane Katrina

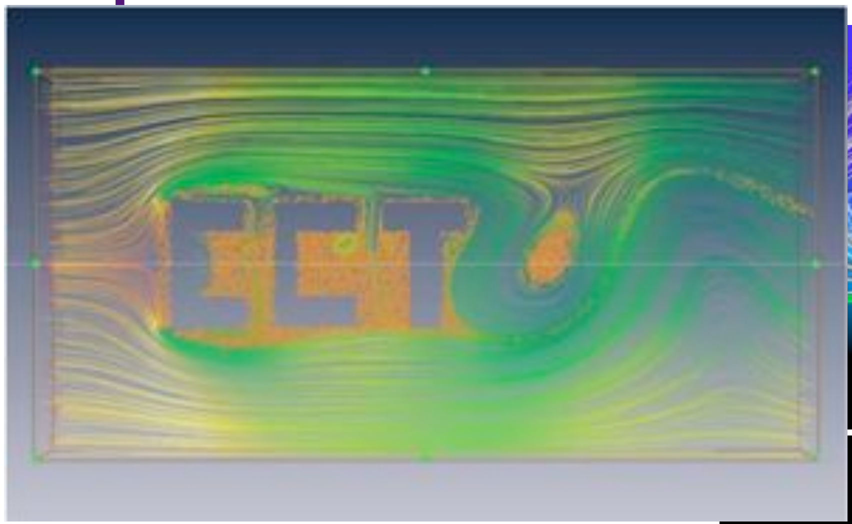


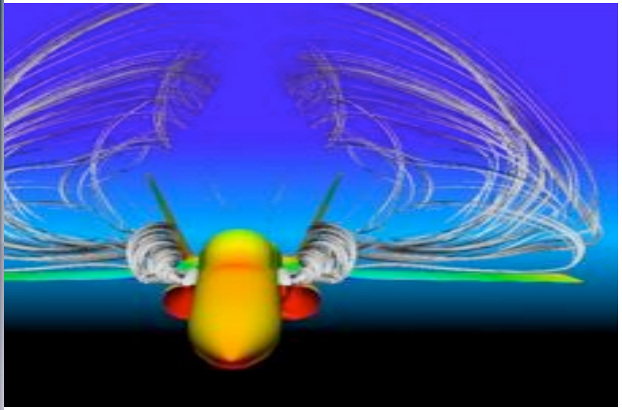


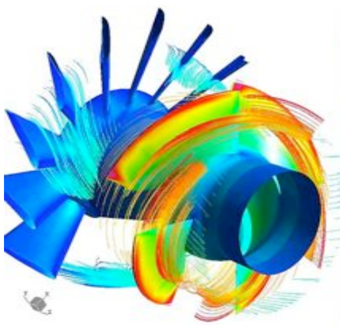


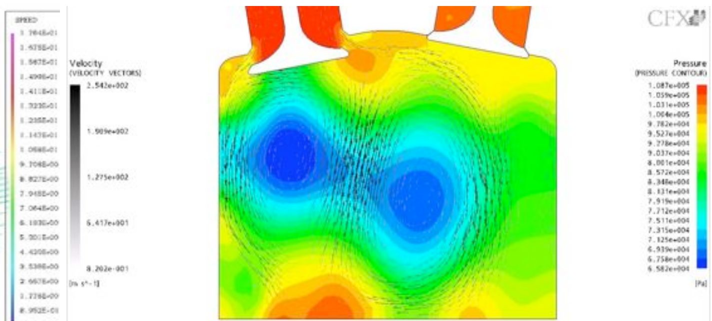
Computational Fluid Dynamics

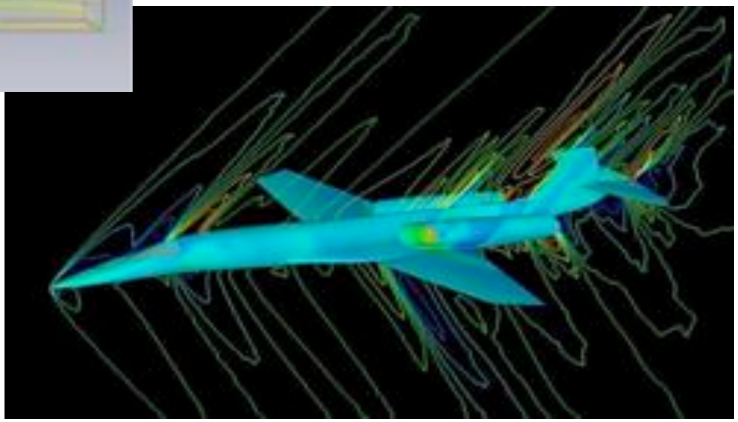


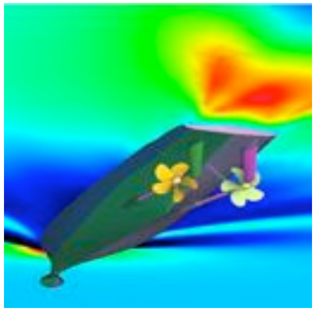


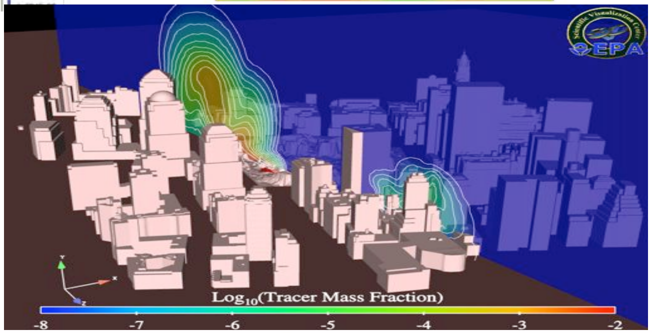


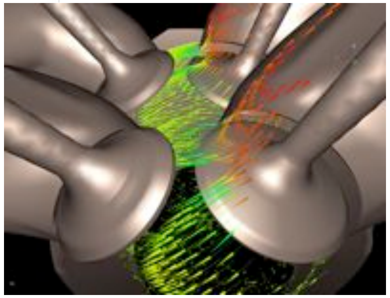


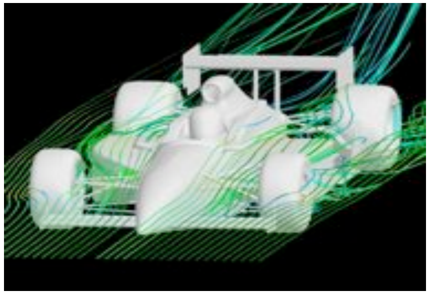




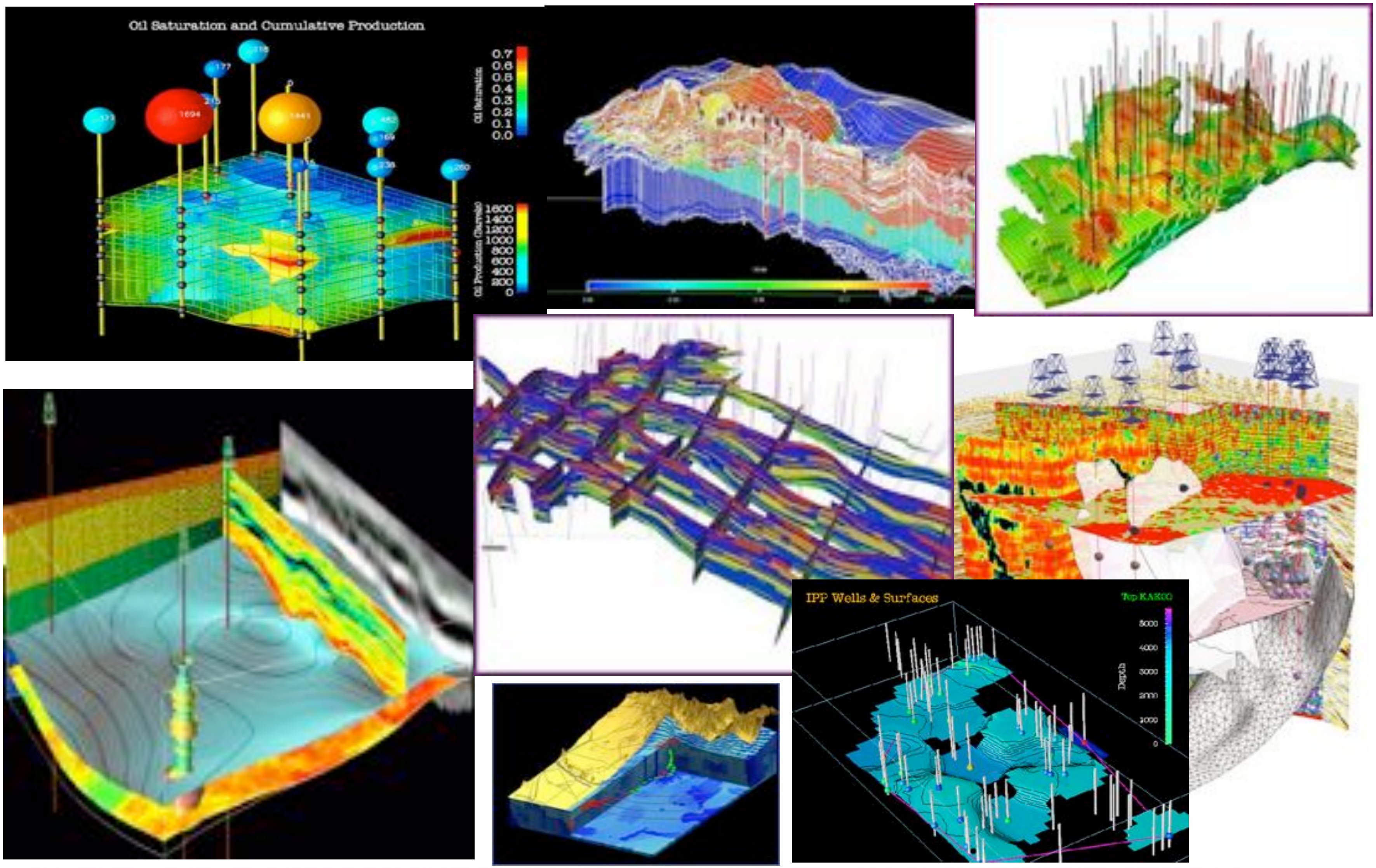




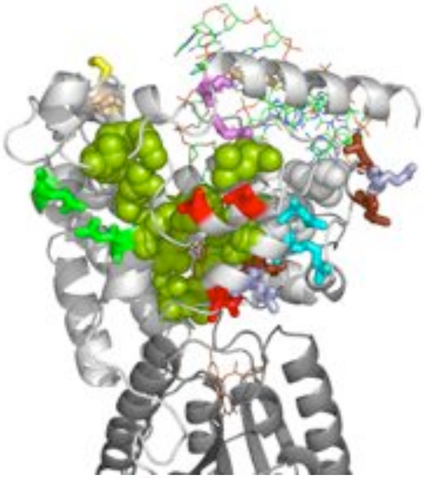


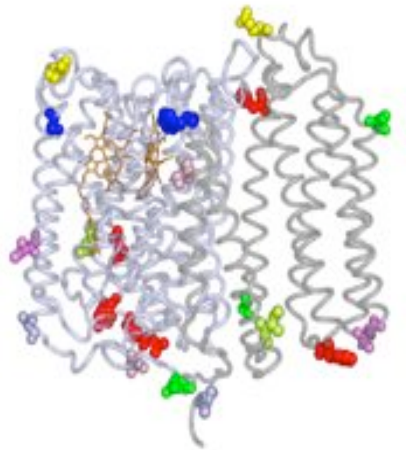


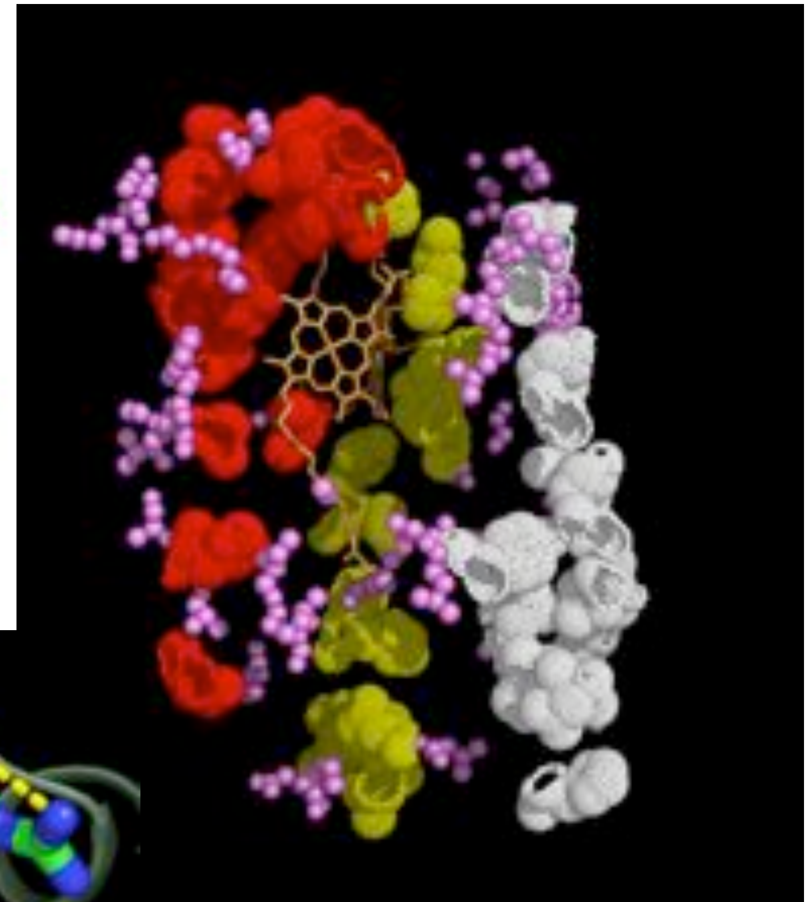
Reservoir Simulation

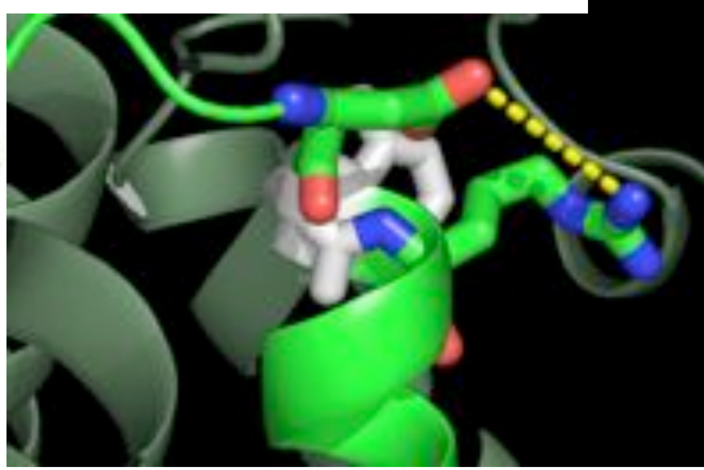


Computational Biology

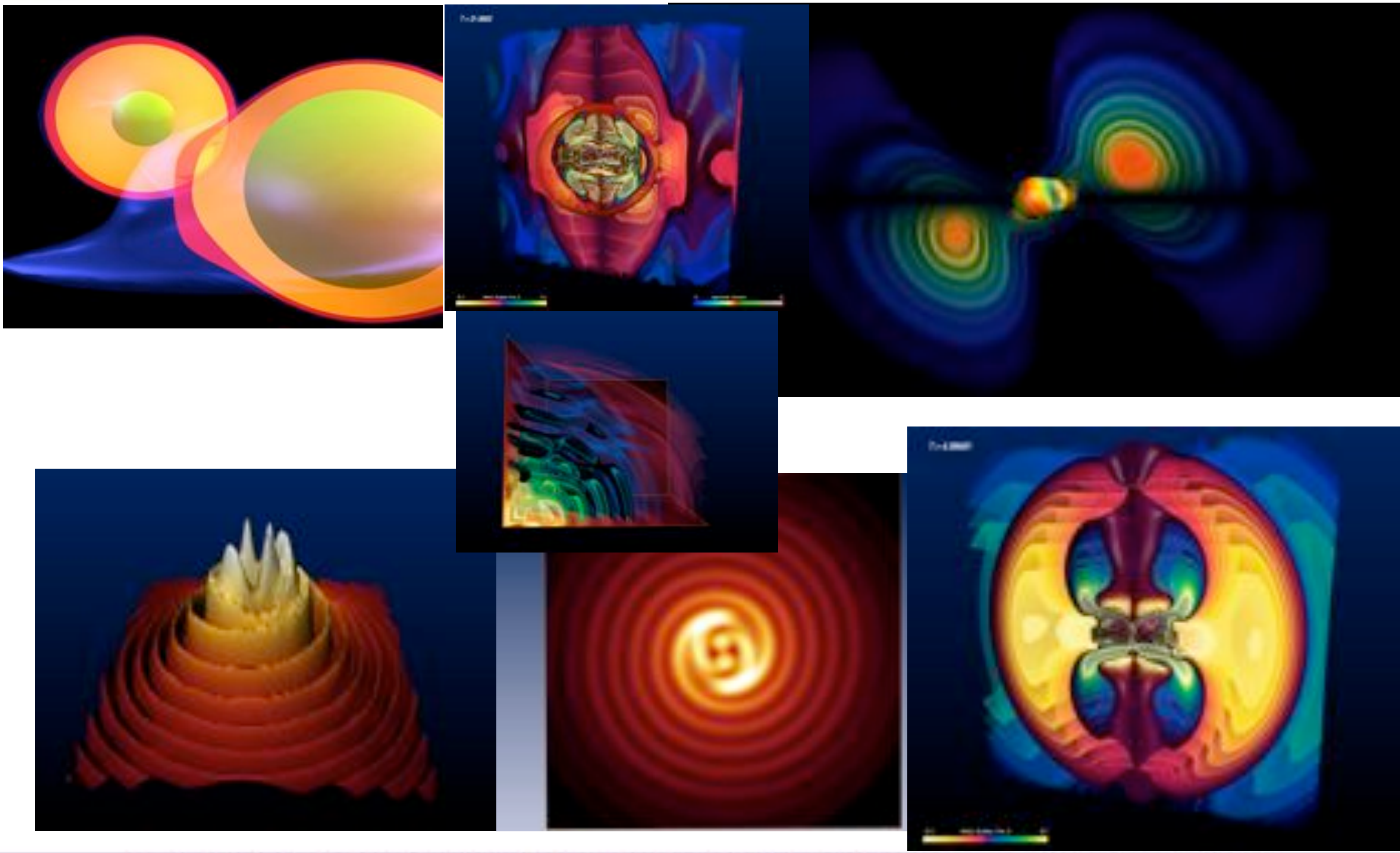






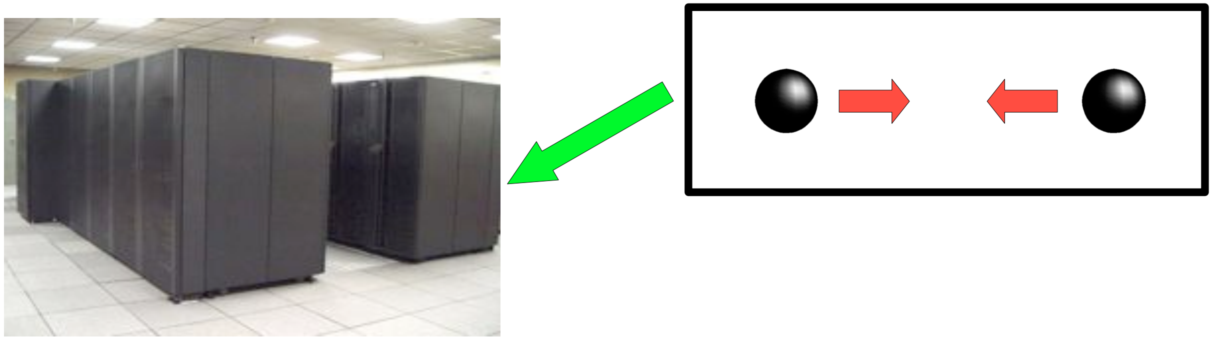


Astrophysics, Numrel



Our tutorial today

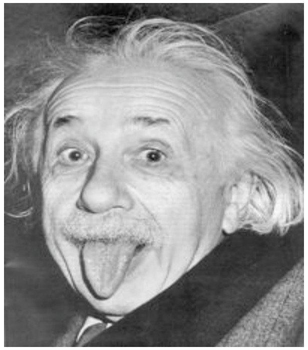
- We will use a supercomputer to simulate colliding black holes
- We need to use a supercomputer because the problem is large and the equations are difficult



Why use a supercomputer?

Einstein Equations

$$
\begin{aligned}
\partial_t \phi &= -\frac{1}{6}\alpha K + \beta^k \partial_k \phi + \frac{1}{6}\partial_k \beta^k \\
\partial_t \tilde{\gamma}_{ij} &= -2\alpha \tilde{A}_{ij} + \beta^k \partial_k \tilde{\gamma}_{ij} + \tilde{\gamma}_{ik}\partial_j \beta^k + \tilde{\gamma}_{jk}\partial_i \beta^k - \frac{2}{3}\tilde{\gamma}_{ij}\partial_k \beta^k \\
\partial_t K &= -D^i D_i \alpha + \alpha(\tilde{A}_{ij}\tilde{A}^{ij} + \frac{1}{3}K^2) + \beta^i \partial_i K \\
\partial_t \tilde{A}_{ij} &= e^{-4\phi}[-D_i D_j \alpha + \alpha R_{ij}]^{TF} + \alpha(K\tilde{A}_{ij} - 2\tilde{A}_{ik}\tilde{A}^k{}_j) \\
&\quad + \tilde{A}_{kj}\partial_i \beta^k + \tilde{A}_{ki}\partial_j \beta^k - \frac{2}{3}\tilde{A}_{ij}\partial_k \beta^k \\
\partial_t \Gamma^i &= -2\partial_j \alpha \tilde{A}^{ij} + 2\alpha(\tilde{\Gamma}^i_{jk}\tilde{A}^{kj} - \frac{2}{3}\tilde{\gamma}^{ij}\partial_j K + 6\tilde{A}^{ij}\partial_j \phi) \\
&\quad - \partial_j(\beta^k \partial_k \tilde{\gamma}^{ij} - \tilde{\gamma}^{kj}\partial_k \beta^i - \tilde{\gamma}^{ki}\partial_k \beta^j + \frac{2}{3}\tilde{\gamma}^{ij}\partial_k \beta^k),
\end{aligned}
$$



Black Hole Collisions

- A black hole is an object whose gravitational pull inside a certain radius is so strong that nothing, not even light can escape it
- Black hole collisions are the strongest sources of gravitational waves
- Gravitational waves will provide a revolutionary new view on the universe in 5-10 years when we will start seeing them with LIGO
- We have to understand black hole collisions theoretically in order to make sense of the gravitational wave observations

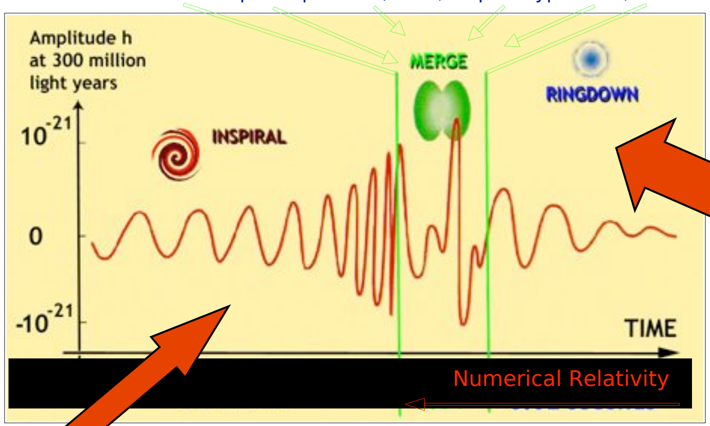
Black holes are cool!

Observations

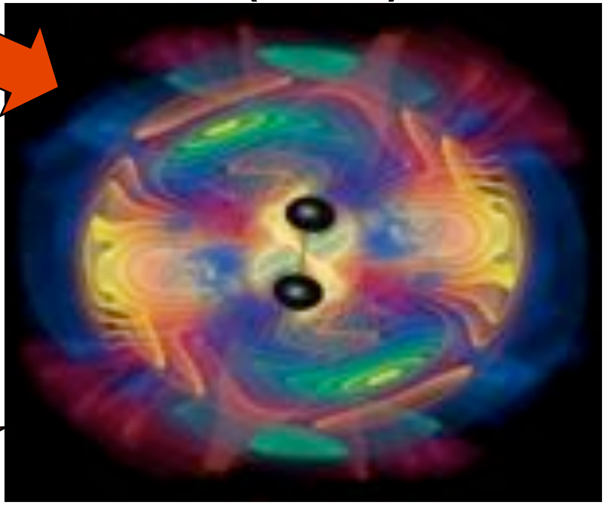
(LIGO)

Analysis & Insight

Teraflop Computation, AMR, Elliptic-Hyperbolic, ???



Models (LSU)



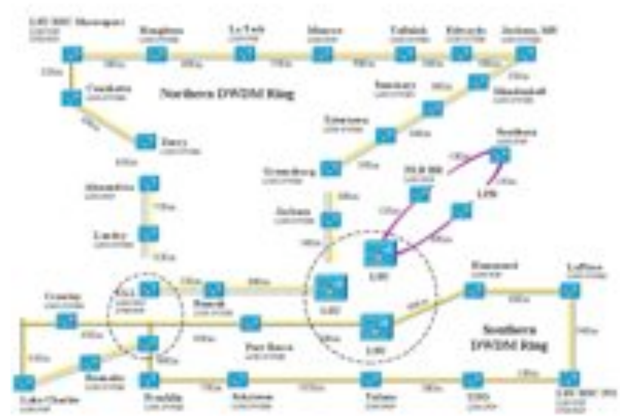
This “Gravitational Wave Detector” is in Livingston Parish

A note about the hardware

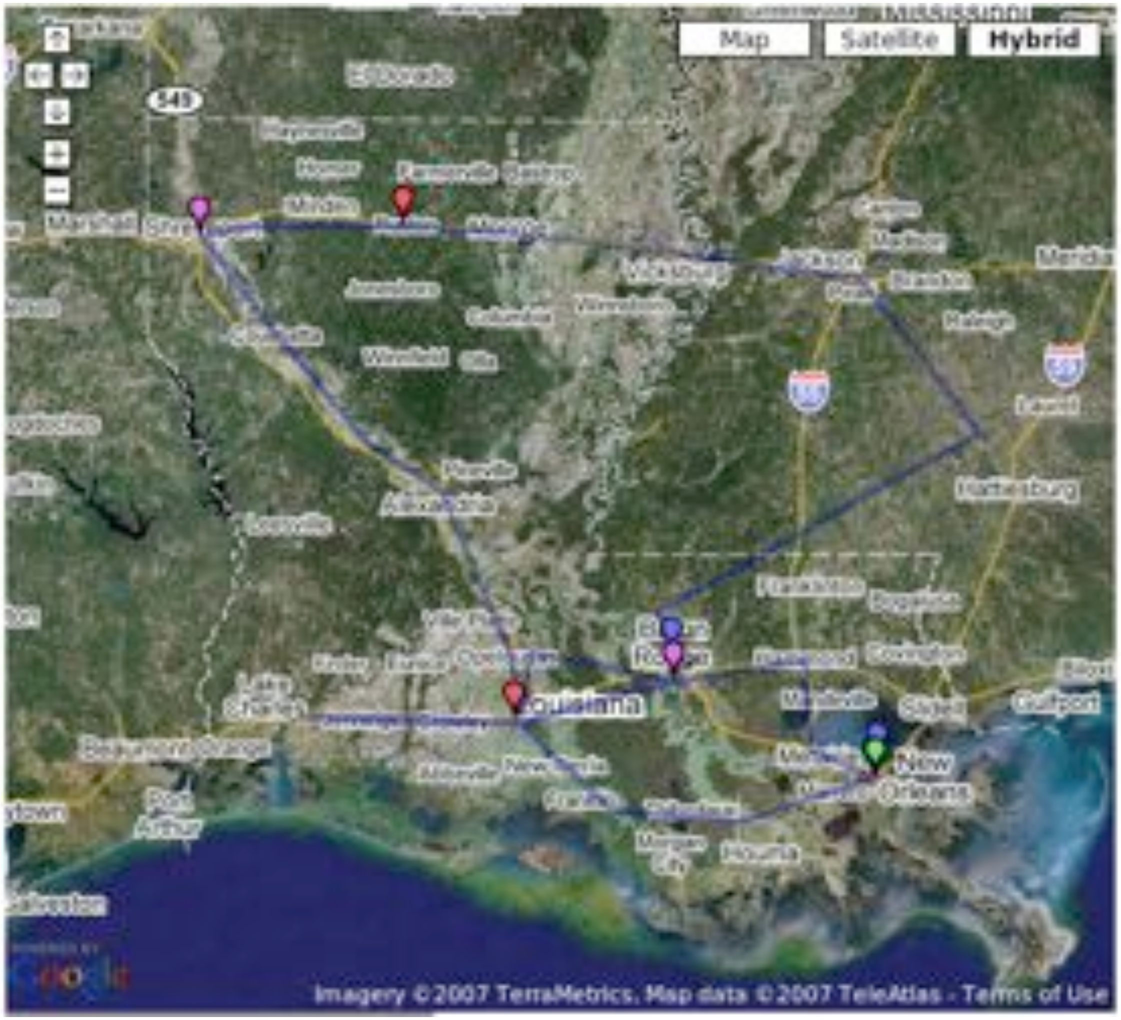
- 1 Interactive (head) Node (p575) [zeke.loni.org]
  - 8 IBM Power5 1.9 GHz processors
  - 16 GB RAM
  - 1 IBM High Performance (Federation) Switch network interface
  - 4 1Gb Ethernet network interfaces
  - AIX 5.3
- 13 Parallel Computing Nodes (p575)
  - 8 IBM Power5 1.9 GHz processors
  - 16 GB RAM
  - 1 IBM High Performance (Federation) Switch network interface
  - 4 1Gb Ethernet network interfaces
  - AIX 5.3

Yet more hardware...

- Zeke is one of 5 identical machines
- These machines are located at universities across Louisiana
- They are connected by a network of fiber optics, hence the name LONI: Louisiana Optical Network Initiative
- There are also 6 5-Teraflop Dell clusters and 1 50-Teraflop Dell cluster

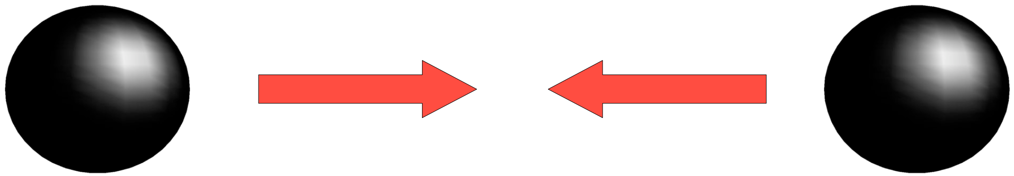


Geographically Speaking...



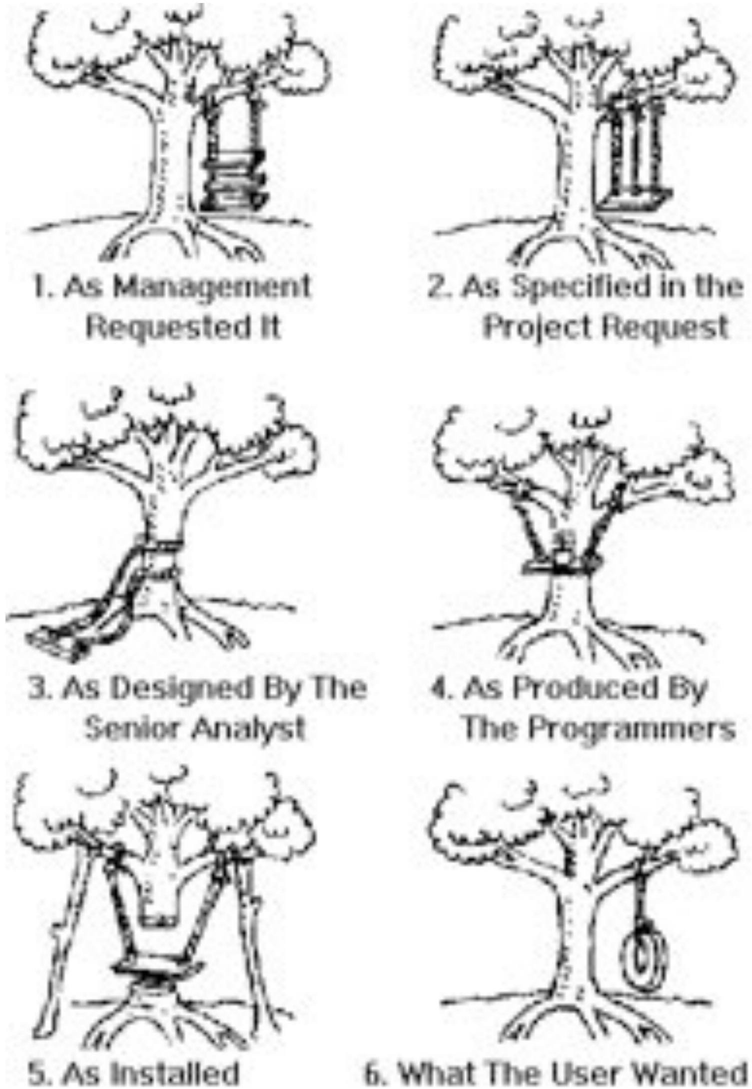
Enough of hardware

- We have the hardware covered, what about the software?
- We need software, instructions we give to the machine to tell it what to do
- In our case, how to solve the Einstein equations for 2 colliding black holes



Writing code is sometimes complicated

- You have to tell thousands of processors how to work together, talk to each other etc...
- You have to orchestrate communication of thousands of processors
- You need to solve the Einstein equations!!

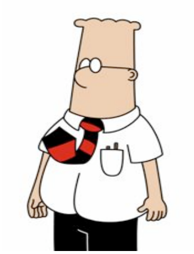


Hence Cactus

- To solve these and other problems, we have Cactus
- Cactus is a framework for scientific computing
- Simplifies code development
- Allows easier collaboration
- It solves the Einstein equations!
- Easy to use, so we will use it today!

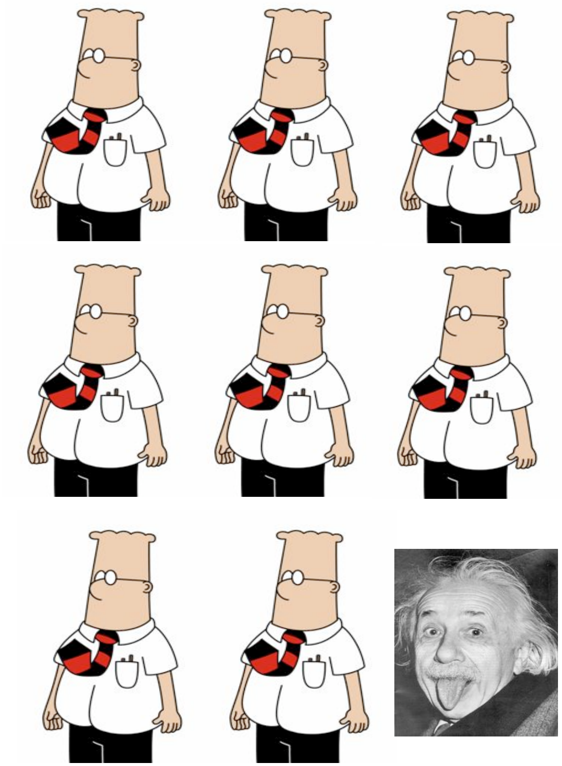
In more detail

- Without Cactus



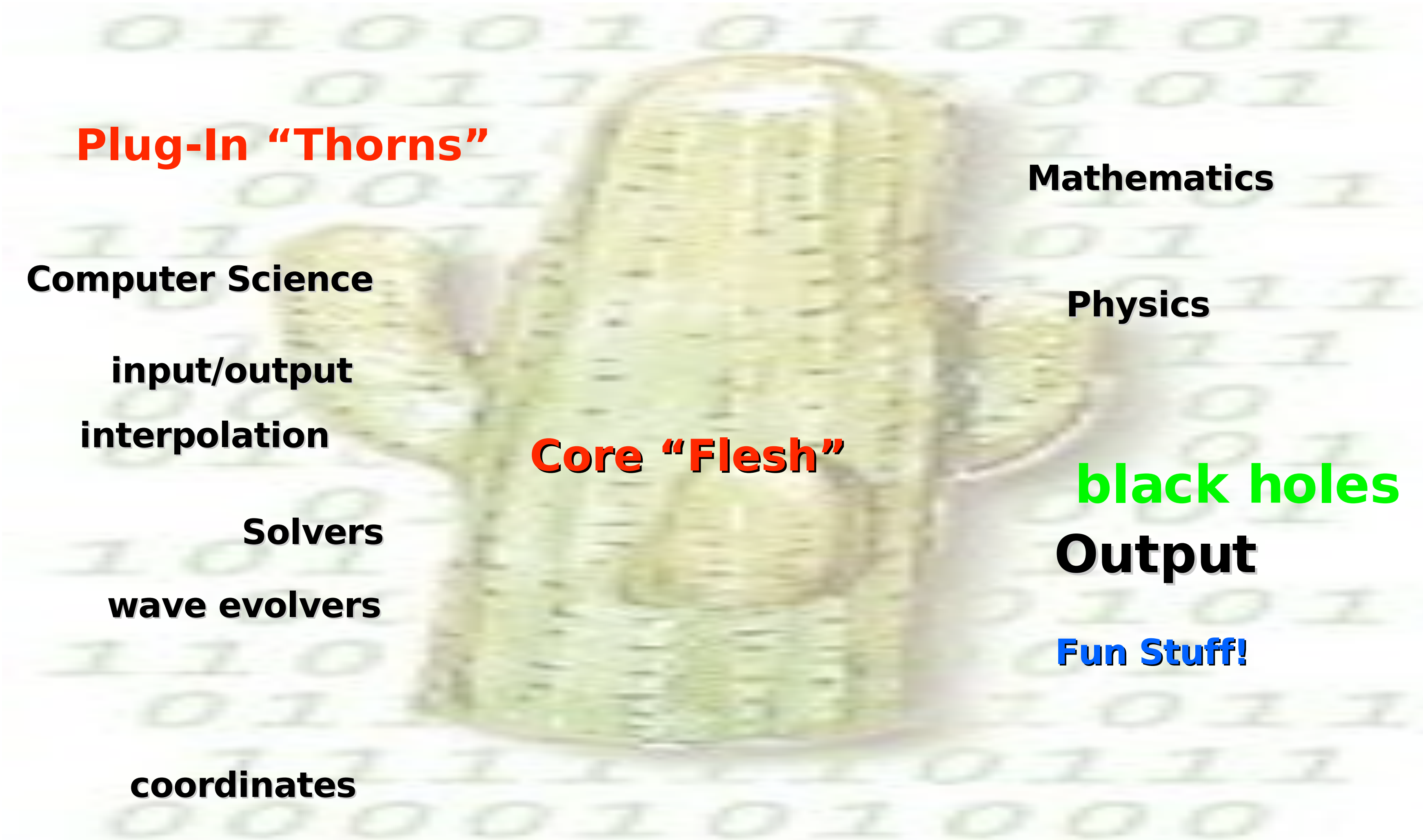
You write everything!

- With Cactus



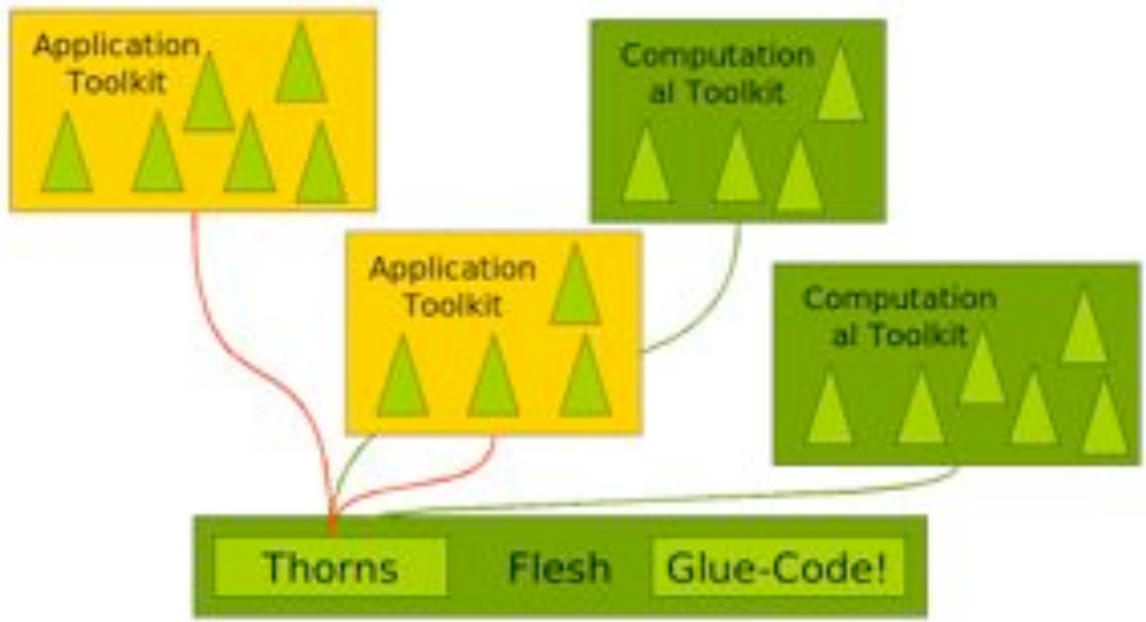
Cactus Developers and Community wrote a lot of the code, and will help you with yours

Cactus: Structure



Cactus Goals

- Portable
- Modular
- Easy to use



Let's Try Cactus

- Typical problem that CCT physicists solve on a daily basis: black hole collisions
- We will run a simulation on LONI machines: Louisiana Optical Network Initiative machines
- The machines we are running on are IBM p5

This particular simulation

- Head-on collision of two black holes
- Small size problem due to time restrictions
- We will see Ψ_4 which is a measure of the gravitational wave
- We use symmetries so you will only see one octant of the domain
- The black holes will merge and emit gravitational waves

Hands-on Section

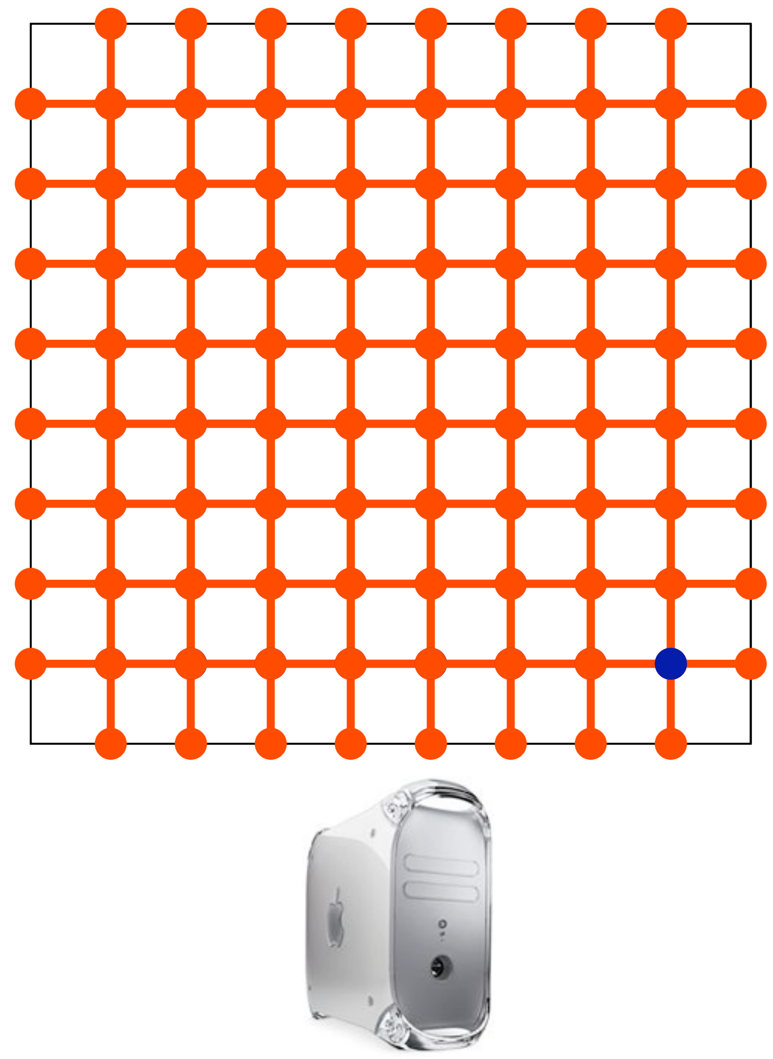
Please refer to your cheat sheets

More about Cactus

- Variables: A quantity which represents some component of a physical system and varies over time and space
  - E.g. temperature (T): different value at each point in the room at any given time, T(t,x,y,z)
- Parameters: External controls to Cactus that you want to change (possibly at runtime)
  - E.g. The speed of a car in an air flow simulation around a car

While we wait: Variables

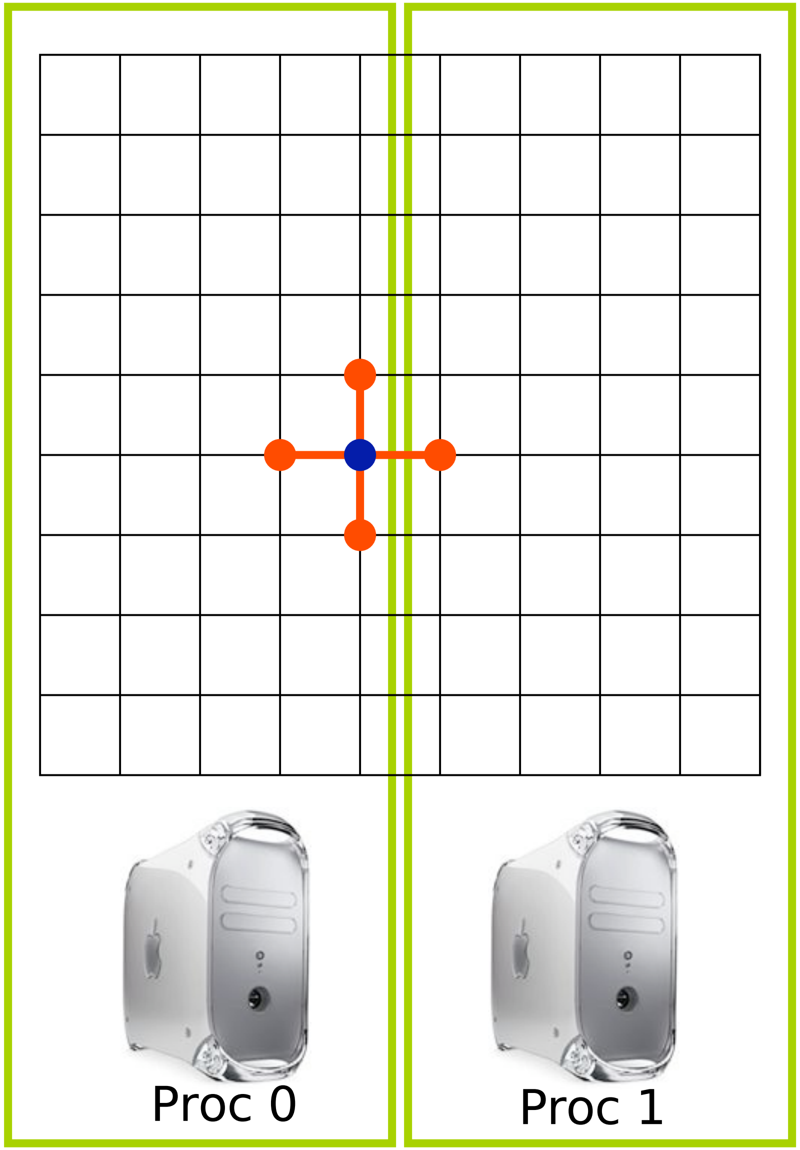
- We solve the Einstein equations with a divide and conquer approach
- The physical domain is divided into smaller, discrete pieces
- Every processor gets some of those pieces



Proc 0

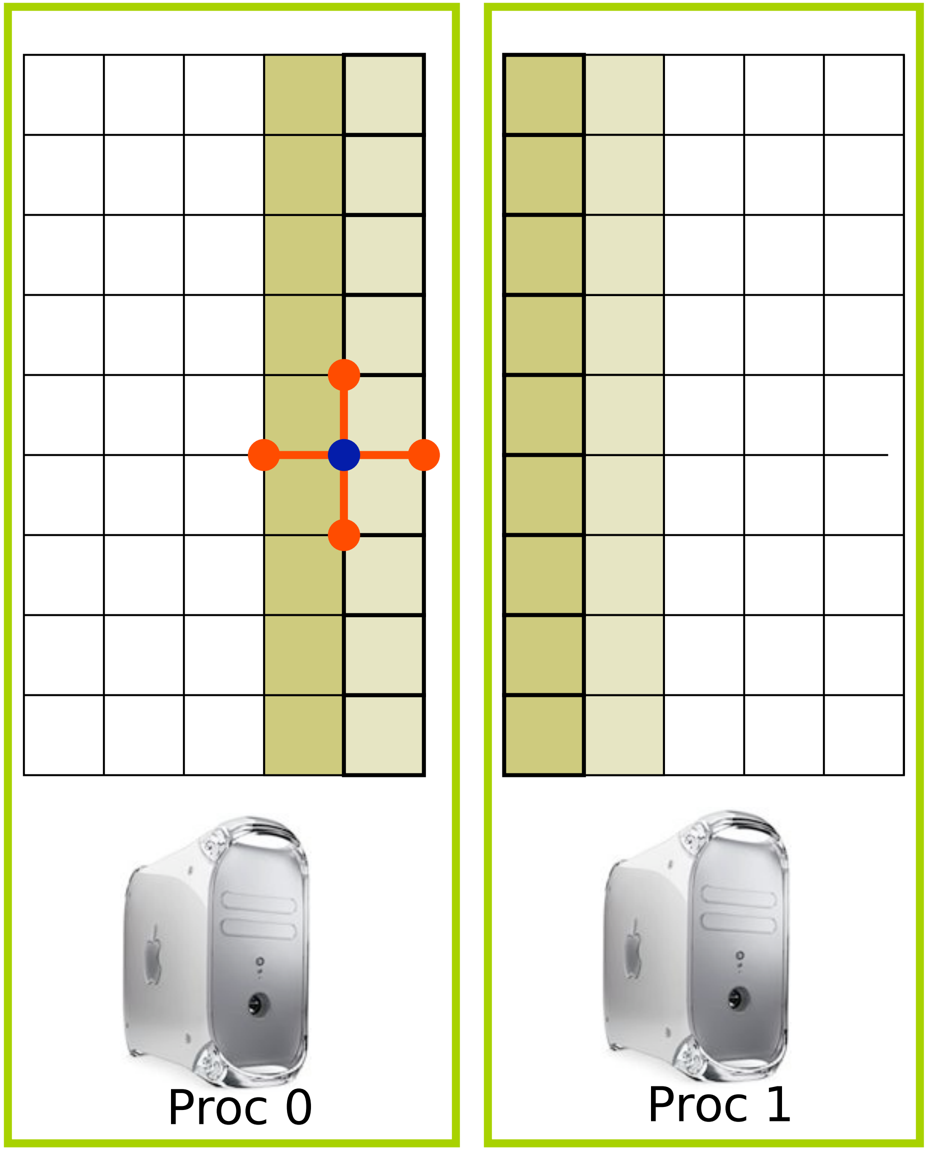
While we wait...

- Every processor has a chunk of the problem
- Every processor works on its own chunk until it requires information from other processors



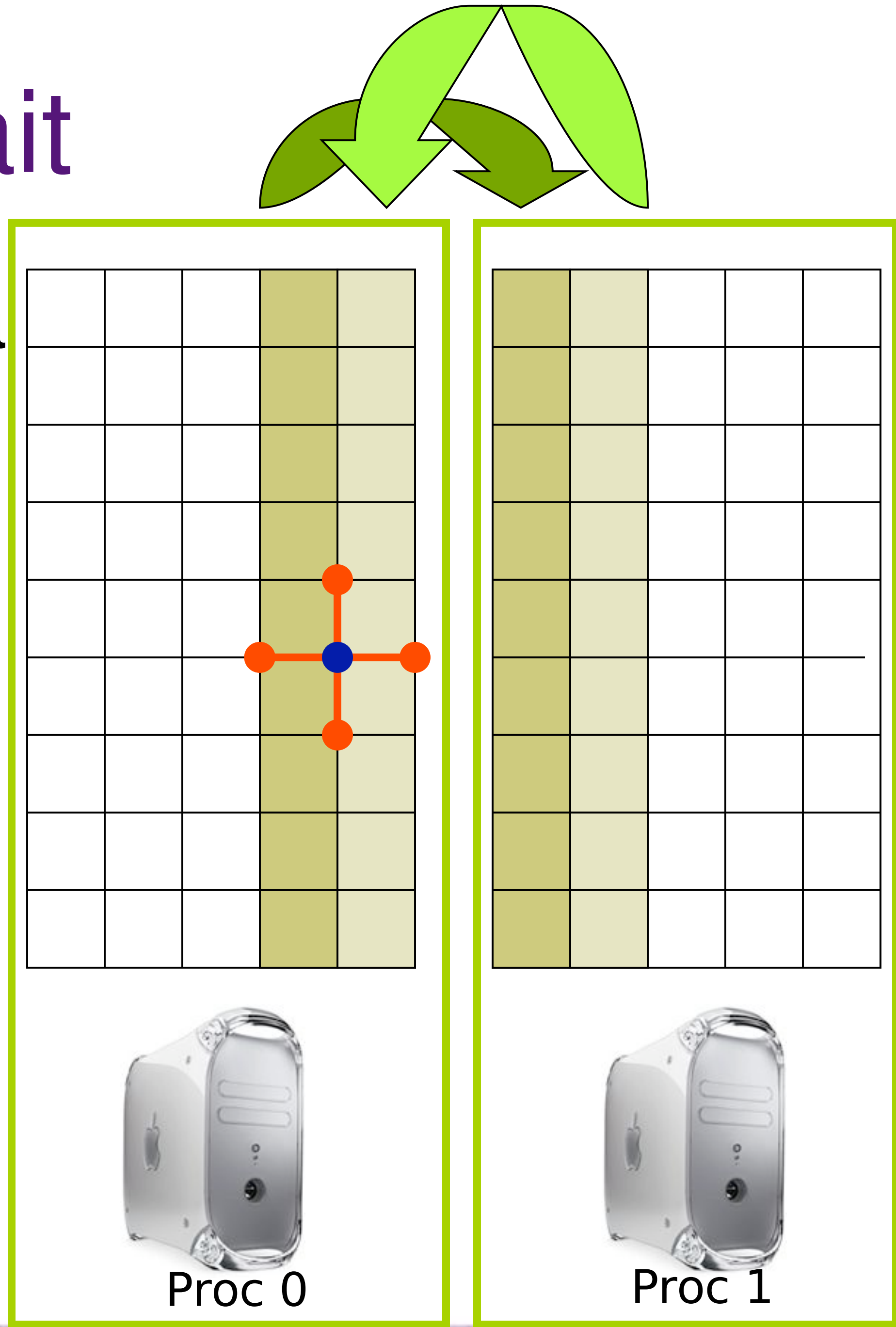
While we wait...

- Cactus allows us to add a ghost-zone, or halo to the chunk
- This alloaws every processor to use data from other neighboring processors



While we wait

- Once new fresh data is required, the ghost-zones (or halos) are synchronized
- Wash, rinse and repeat...



Remember the “Fun Stuff”?

More Fun Stuff

Back to work now...

Let's check on our black holes

Questions???