Open Source Visualization of Scientific Data

8 August 2011

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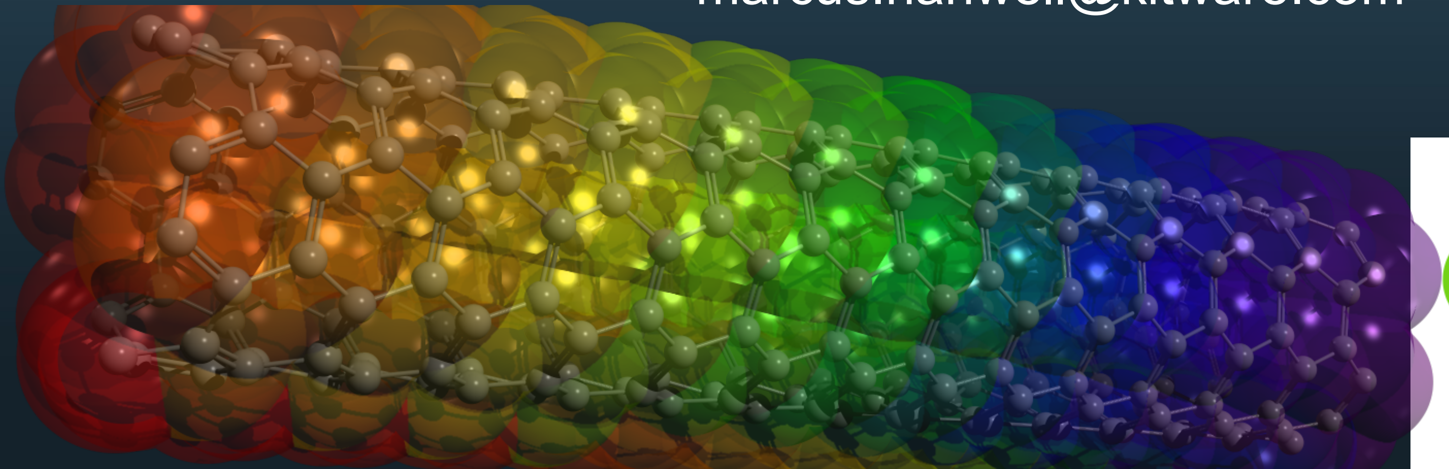


Outline

- Background
- Why is open science important?
- Opening up chemistry over the last four years
- The Visualization Toolkit (VTK)
- ParaView – a client-server Qt based VTK GUI
- New frontiers – web, mobile and tablets
- Future directions

My Background

- Ph.D. (Physics) – University of Sheffield
- Google Summer of Code – Avogadro
- Postdoc (Chemistry) – University of Pittsburgh
- R&D engineer – Kitware, Inc
- Passionate about physics, chemistry, and the growing need to improve computational tools
- See the need for powerful open source, cross platform frameworks and applications
- Develop(ed): Gentoo, KDE, Kalzium, Avogadro, Open Babel, VTK, ParaView, Titan, CMake

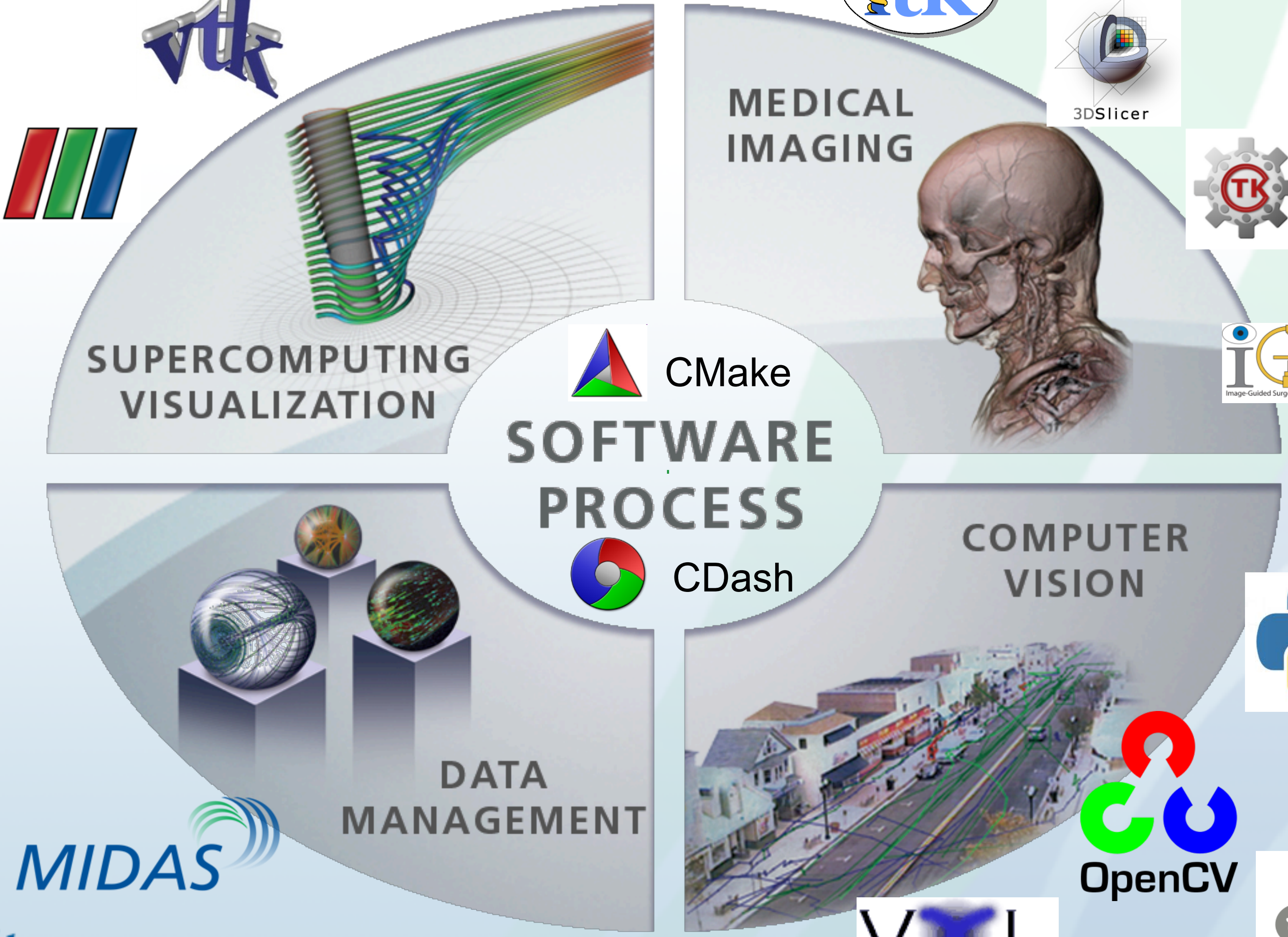
Kitware

- Founded in 1998: 5 former GE Research employees
- 95 employees: 42% PhD
- Privately held, profitable from creation, no debt
- Rapidly Growing: >30% in 2010, 7M web-visitors/quarter
- Offices
  - Albany, NY
  - **Carrboro, NC**
  - Lyon, France
  - Bangalore, India

2006 National
Tibbetts Award
Presented to
Loki Incorporated
In Recognition of your
Outstanding Contributions to the
SBIR Program
Roland Tibbetts and Small Business Technology Council
SBTC
Championing Small Business Technology Companies

- 2011 Small Business Administration's Tibbetts Award
- HPCWire Readers and Editor's Choice
- Inc's 5000 List: 2008 to 2010

Kitware: Core Technologies



SUPERCOMPUTING VISUALIZATION

MEDICAL IMAGING

CMake

SOFTWARE PROCESS

CDash

DATA MANAGEMENT

COMPUTER VISION

vtk

itk

3DSlicer

IGSTK Image-Guided Surgery Toolkit

OpenCV

VXL

MIDAS

Kitware

Desktop summit

What Is “Open Science”?

“Open science is the idea that scientific knowledge of all kinds should be openly shared as early as is practical in the discovery process.”

openscience.org

What Is The Problem?

"…when the journal system was developed in the 17th and 18th centuries it was an excellent example of open science. The journals are perhaps the most open system for the dissemination of knowledge that can be constructed — if you're working with 17th century technology. But, of course, today we can do a lot better."

openscience.org

Opening Up Chemistry

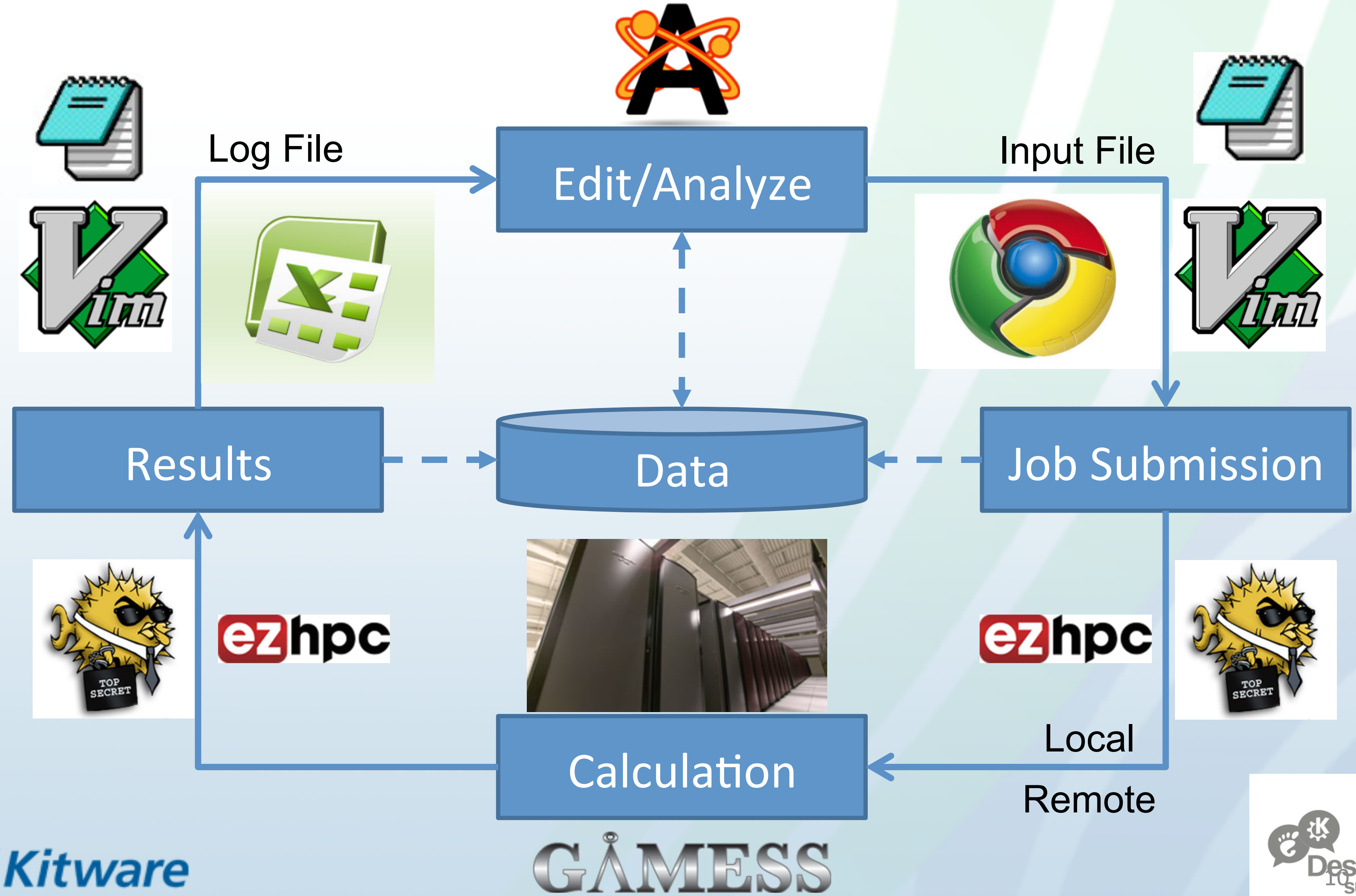
- Computational chemistry is currently one of the more closed sciences
- Lots of black box proprietary codes
  - Only a few have access to the code
  - Publishing results from black box codes
  - Many file formats in use, little agreement
- More papers should be including data
- Growing need for open standards

Movements for Open Chemistry

- Formed an “unorganization” – Blue Obelisk
  - Published first article in 2005
  - Open data, open standards and open source
  - Meet at ACS and other conferences when possible
  - Follow-up article currently in press

- Quixote collaboration more recently
  - Provide meaningful data storage and exchange
  - Principally targeting computational chemistry

Typical Chemistry Workflow



Log File

Edit/Analyze

Input File

Results

Data

Job Submission

Local

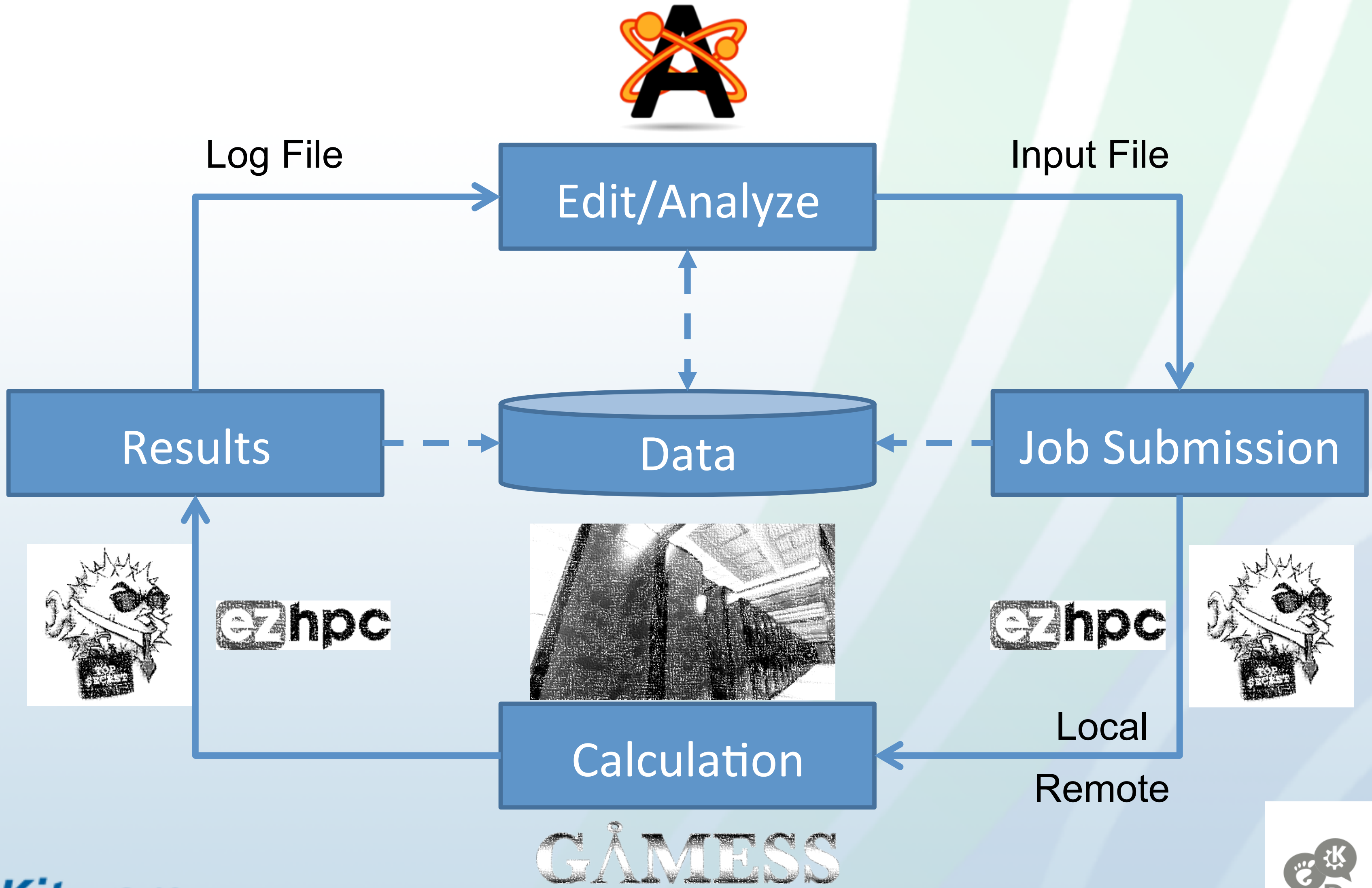
Remote

Calculation

Problem: Pretty Complex/Manual

- Most steps require user intervention
- Obtain starting structure (previous work, databases)
- Edit structure
- Write input file
- Move input file to cluster
- Submit to queue
- Wait for completion
- Retrieve input file
- Analyze output file
- Extract the relevant data, change formats
- Store results
- Repeat

Improved Chemistry Workflow



Log File

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Job Submission

ezhpc

ezhpc

Calculation

Local

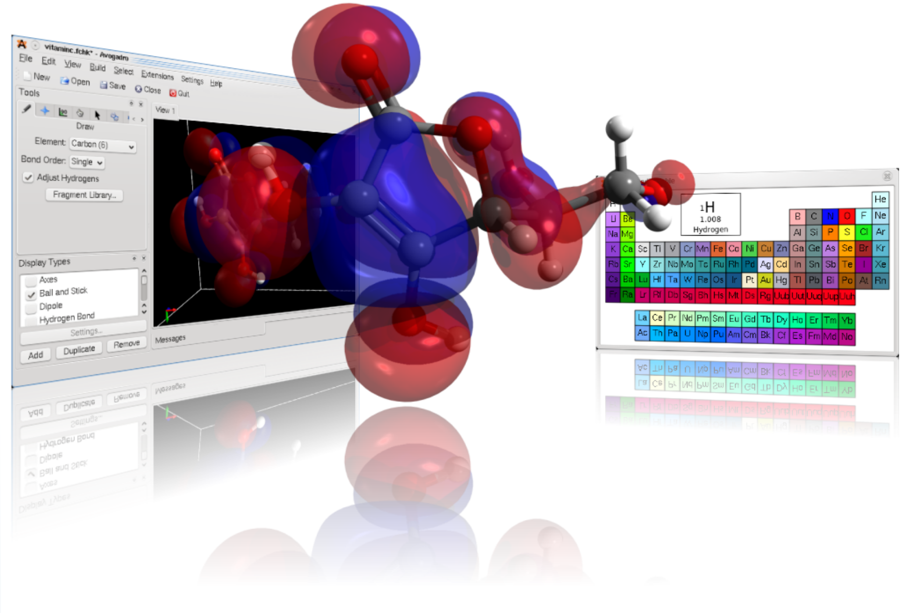
Remote

GAMESS

Kitware

Desktop summit

Avogadro



Element: Carbon (6)
Bond Order: Single
☑ Adjust Hydrogens
☑ Ball and Stick

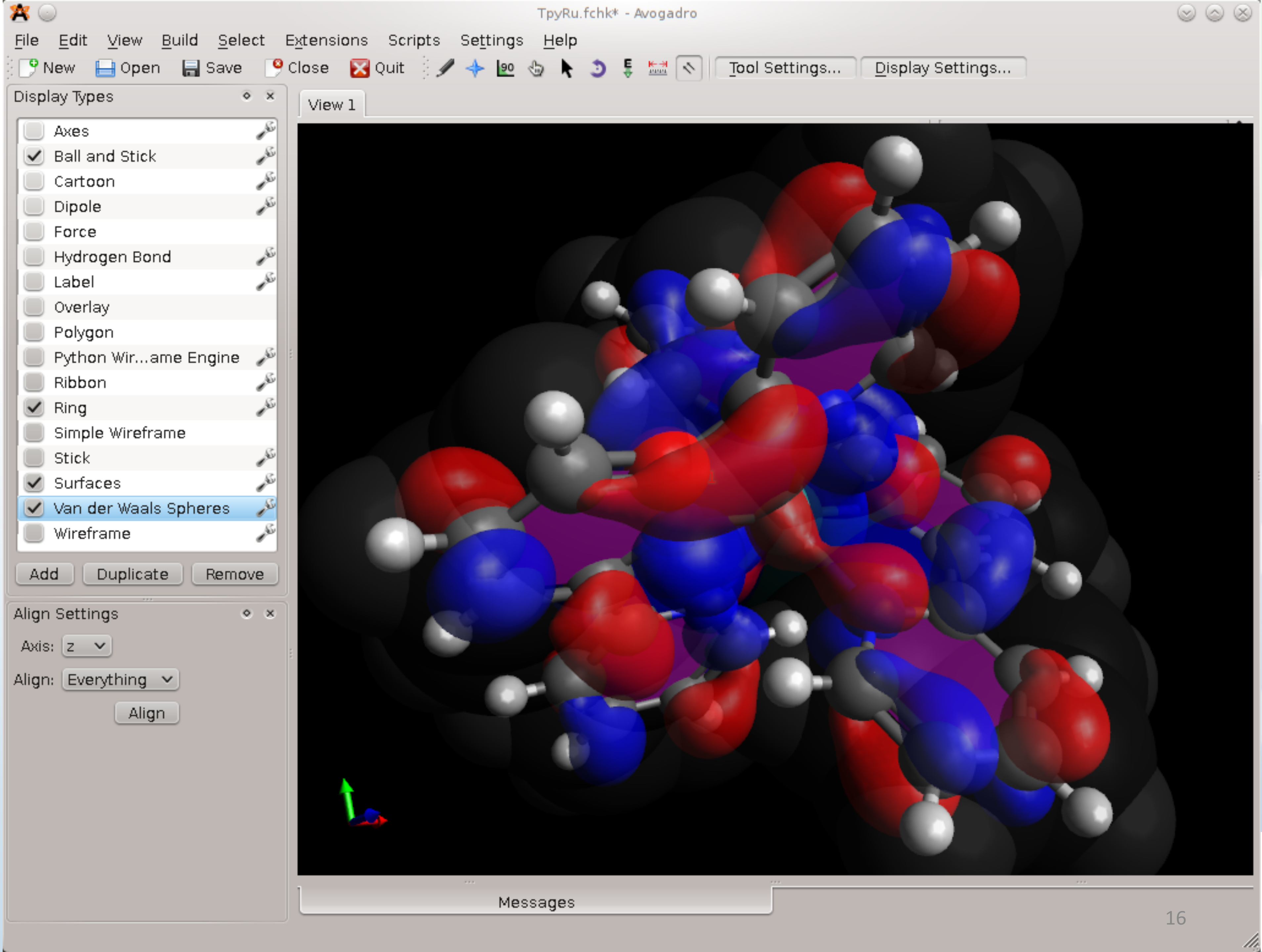
- Project began 2006
- Split into library and application (plugin based)
- One of very few open source **editors**
- Designed to be extensible from the start
- Generate input & read output from many codes
- An active and growing community
- Chemistry needs a free, open framework

Avogadro’s Roots

- Avogadro projected started in 2006
- First funded work in 2007 by Marcus Hanwell
  - Google Summer of Code student
  - Final year of Ph.D. spent the summer coding
  - Funded as part of KDE project – Kalzium editor
- Built on several other open source projects
  - Qt, Eigen, Open Babel, Blue Obelisk Data Repository
- Also uses open standards, e.g. OpenGL
- Cross platform, open source stack

Avogadro Vital Statistics

- Supports Linux, Windows and Mac OS X
- Contributions from over 20 developers
- Over 180,000 downloads over 4 years
- Translated into 19 languages
- Used by Kalzium for molecular editor
- Featured by Trolltech/Nokia,
  - Qt in use
  - Qt ambassador program



Display Types

- ☐ Axes
- ☑ Ball and Stick
- ☐ Cartoon
- ☐ Dipole
- ☐ Force
- ☐ Hydrogen Bond
- ☐ Label
- ☐ Overlay
- ☐ Polygon
- ☐ Python Wir...ame Engine
- ☐ Ribbon
- ☑ Ring
- ☐ Simple Wireframe
- ☐ Stick
- ☑ Surfaces
- ☑ Van der Waals Spheres
- ☐ Wireframe

Align Settings

Axis: z

Align: Everything

Desktop Database

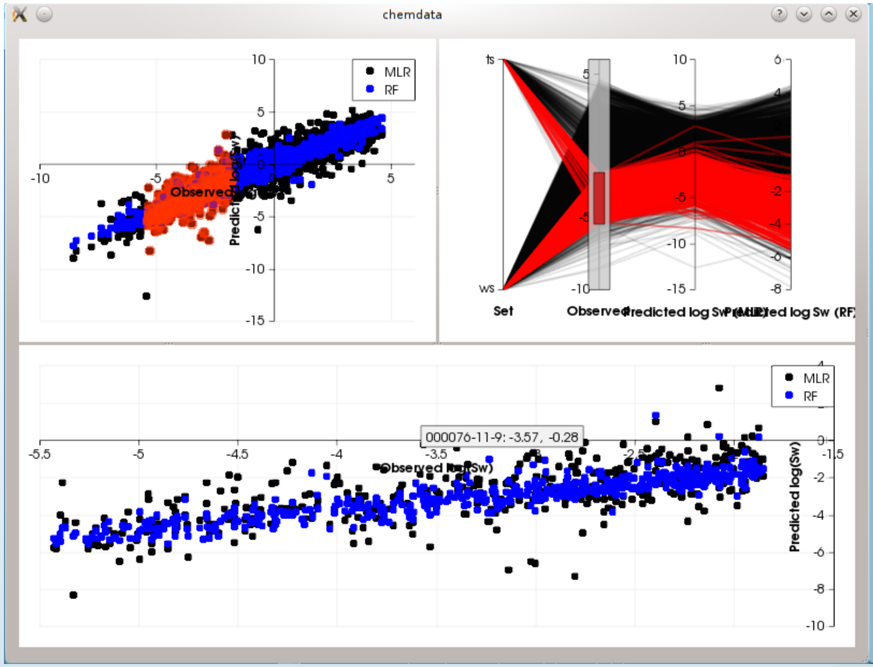
mongoDB

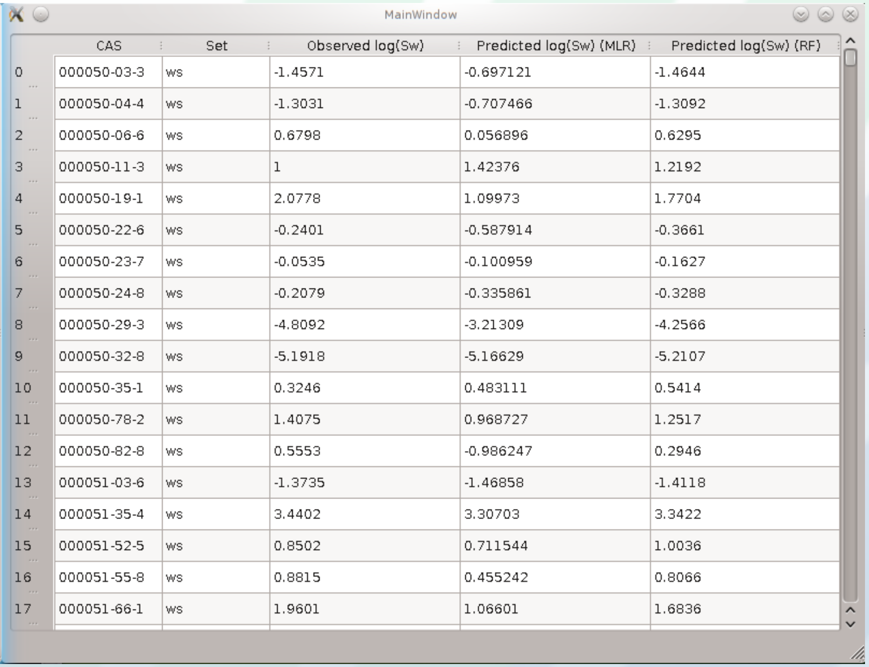
- Use of “document store” NoSQL
  - Doesn’t force too much structure
    - Some entries have experimental data available
    - Some have computational jobs
  - Employ a “pile of stuff” approach
    - Can store both source and derived data
    - Calculate identifiers, QSAR properties, etc
- MongoDB is a scalable, open solution
  - Proven scaling with large web applications

Chemistry Data Explorer

- Qt application
- Connects to local or remote database
- Uses VTK for visual data exploration
- Can ingest new data
  - Uses Open Babel to generate descriptors
  - Standard InChi, SMILES, molecular weight
  - More could be added
    - All derived from files stored in the database

Chemistry Data Explorer



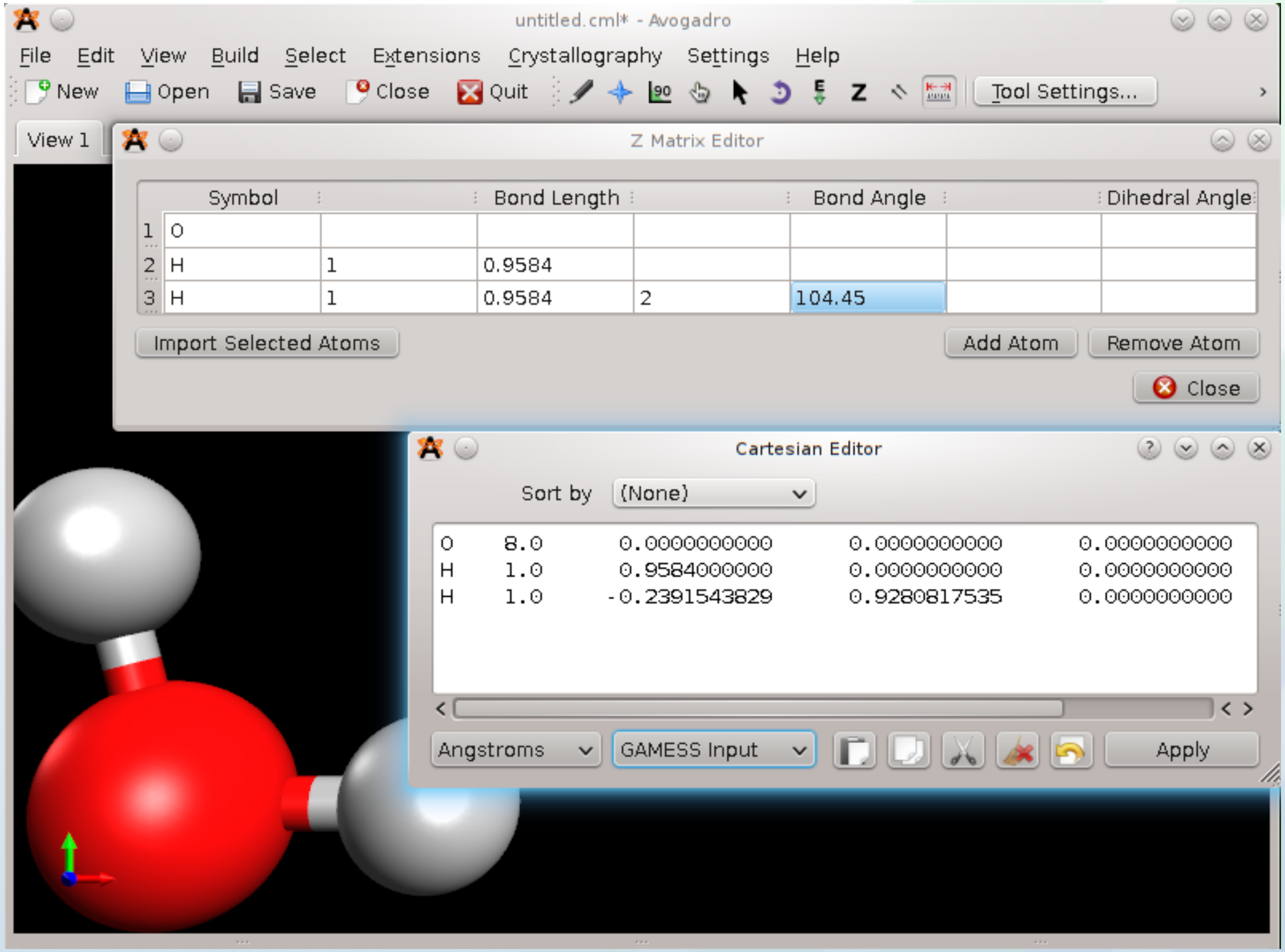


	CAS	Set	Observed log(Sw)	Predicted log(Sw) (MLR)	Predicted log(Sw) (RF)
0	000050-03-3	ws	-1.4571	-0.697121	-1.4644
1	000050-04-4	ws	-1.3031	-0.707466	-1.3092
2	000050-06-6	ws	0.6798	0.056896	0.6295
3	000050-11-3	ws	1	1.42376	1.2192
4	000050-19-1	ws	2.0778	1.09973	1.7704
5	000050-22-6	ws	-0.2401	-0.587914	-0.3661
6	000050-23-7	ws	-0.0535	-0.100959	-0.1627
7	000050-24-8	ws	-0.2079	-0.335861	-0.3288
8	000050-29-3	ws	-4.8092	-3.21309	-4.2566
9	000050-32-8	ws	-5.1918	-5.16629	-5.2107
10	000050-35-1	ws	0.3246	0.483111	0.5414
11	000050-78-2	ws	1.4075	0.968727	1.2517
12	000050-82-8	ws	0.5553	-0.986247	0.2946
13	000051-03-6	ws	-1.3735	-1.46858	-1.4118
14	000051-35-4	ws	3.4402	3.30703	3.3422
15	000051-52-5	ws	0.8502	0.711544	1.0036
16	000051-55-8	ws	0.8815	0.455242	0.8066
17	000051-66-1	ws	1.9601	1.06601	1.6836

Database Interaction on the Web

- Avogadro directly accesses some (read-only) public databases:
  - PDB, NIH “fetch by name”
  - More could be added
- ChemData follows this approach
- Quixote aims to support both public and private sharing models – open framework

Z-Matrix/Cartesian Molecule Editor



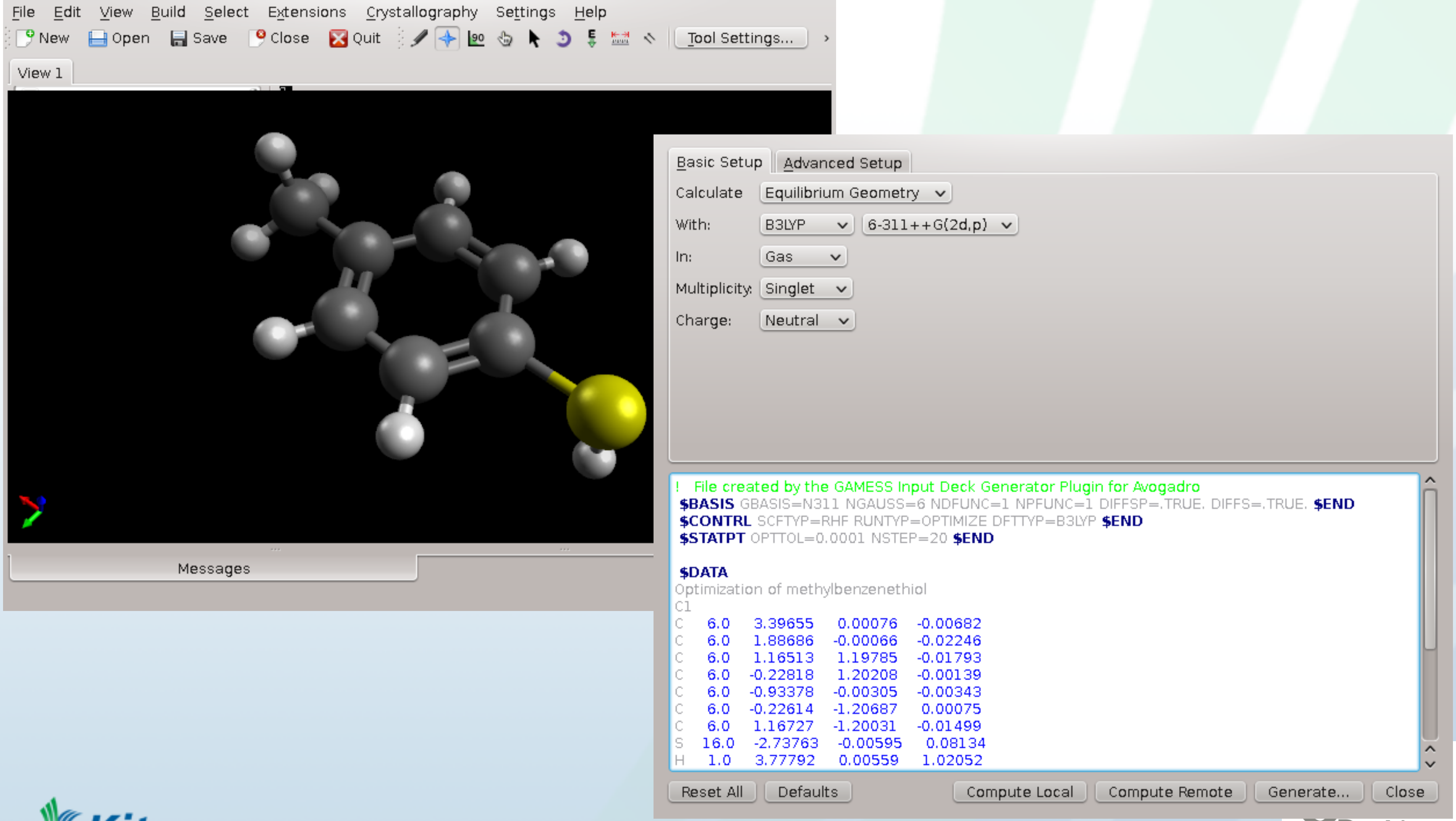
	Symbol		Bond Length		Bond Angle		Dihedral Angle
1	O						
2	H	1	0.9584				
3	H	1	0.9584	2	104.45		

Sort by (None)

```
O     8.0     0.0000000000    0.0000000000    0.0000000000
H     1.0     0.9584000000    0.0000000000    0.0000000000
H     1.0    -0.2391543829    0.9280817535    0.0000000000
```

Angstroms | GAMESS Input

Avogadro → GAMESS



Calculate: Equilibrium Geometry

With: B3LYP 6-311++G(2d,p)

In: Gas

Multiplicity: Singlet

Charge: Neutral

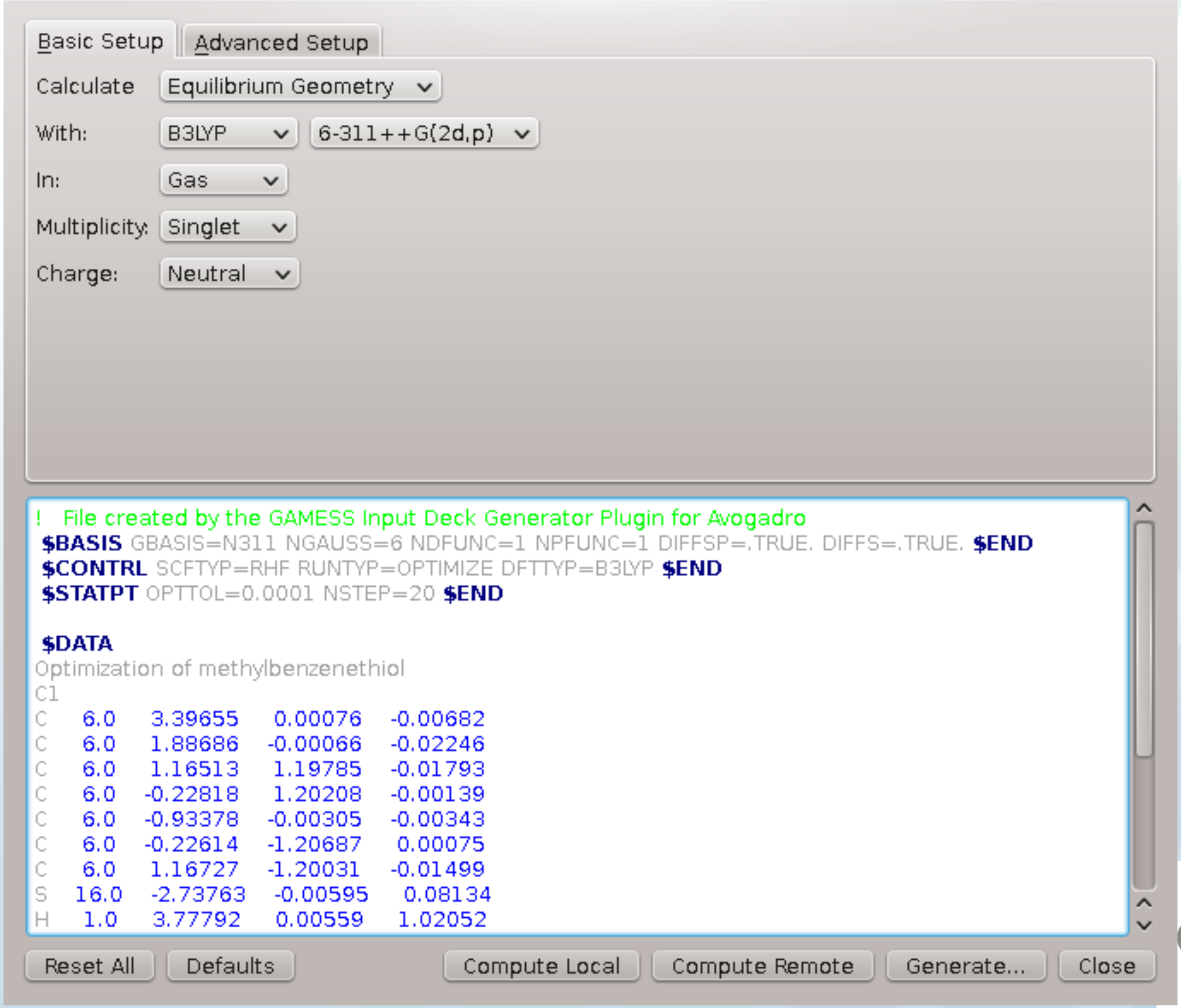
```
!   File created by the GAMESS Input Deck Generator Plugin for Avogadro
 $BASIS GBASIS=N311 NGAUSS=6 NDFUNC=1 NPFUNC=1 DIFFSP=.TRUE. DIFFS=.TRUE. $END
 $CONTRL SCFTYP=RHF RUNTYP=OPTIMIZE DFTTYP=B3LYP $END
 $STATPT OPTTOL=0.0001 NSTEP=20 $END

 $DATA
Optimization of methylbenzenethiol
C1
C     6.0     3.39655    0.00076    -0.00682
C     6.0     1.88686   -0.00066    -0.02246
C     6.0     1.16513    1.19785    -0.01793
C     6.0    -0.22818    1.20208    -0.00139
C     6.0    -0.93378   -0.00305    -0.00343
C     6.0    -0.22614   -1.20687     0.00075
C     6.0     1.16727   -1.20031    -0.01499
S    16.0    -2.73763   -0.00595     0.08134
H     1.0     3.77792    0.00559     1.02052
```

Calling Stand Alone Programs

- Many already supported:
  - GAMESS, GAMESS-UK, Molpro, Q-Chem, MOPAC, NWChem, Gaussian, Dalton
  - Easy to add more
- Some codes writing Avogadro based custom applications,
  - Q-Chem, Molpro…
- DLPOLY author approached me:
  - Open sourced DLPOLY2, want a GUI

GAMESS Input Generation



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H     1.0    3.77792    0.00559    1.02052
```

OpenQube – Quantum Data

- Reads in key quantum data
  - – Basis set used in calculation
  - – Eigenvectors for molecular orbitals
  - – Density matrix for electron density
  - – Standard geometry
- Multithreaded calculation
  - – Produce regular grids of scalar data
  - – Molecular orbitals, electron density…

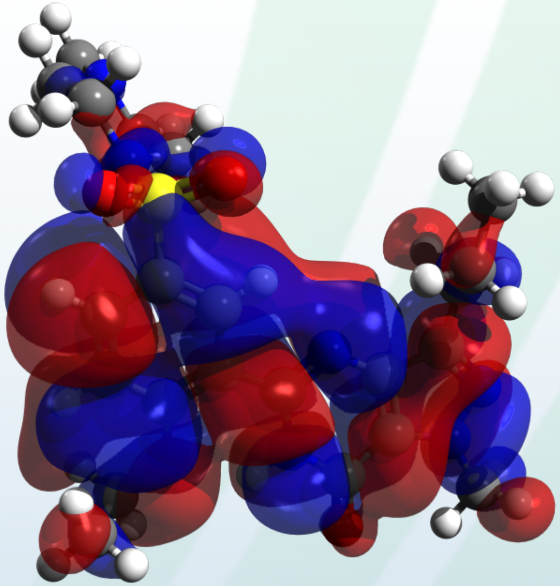
Molecular Orbitals and Electron Density

- Quantum files store basis sets and matrices

$$GTO = ce^{-\alpha r^2}$$

$$\phi_i = \sum_{\mu} c_{\mu i} \phi_{\mu}$$

$$\rho(r) = \sum_{\mu} \sum_{\nu} P_{\mu\nu} \phi_{\mu} \phi_{\nu}$$

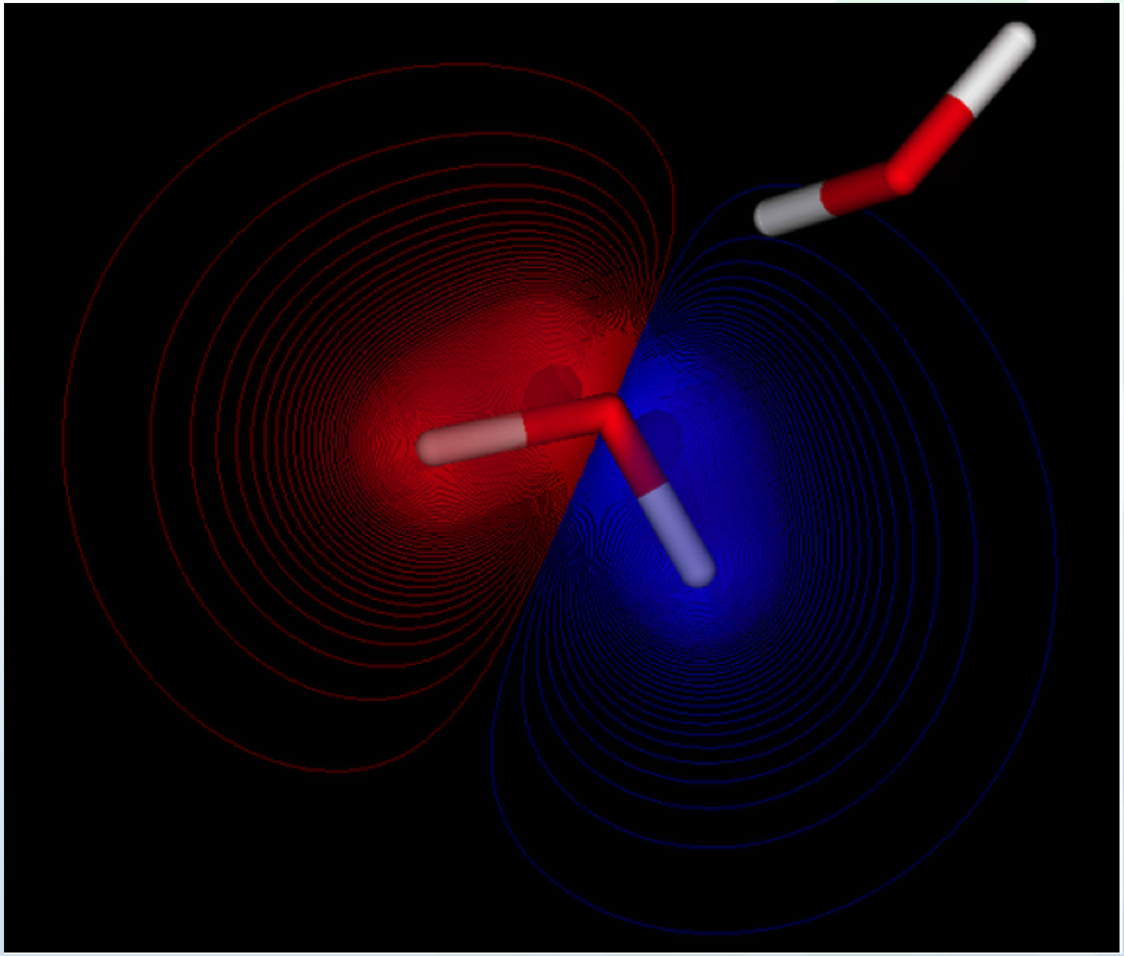


- Using these equations, and the supplied matrices – calculate cubes

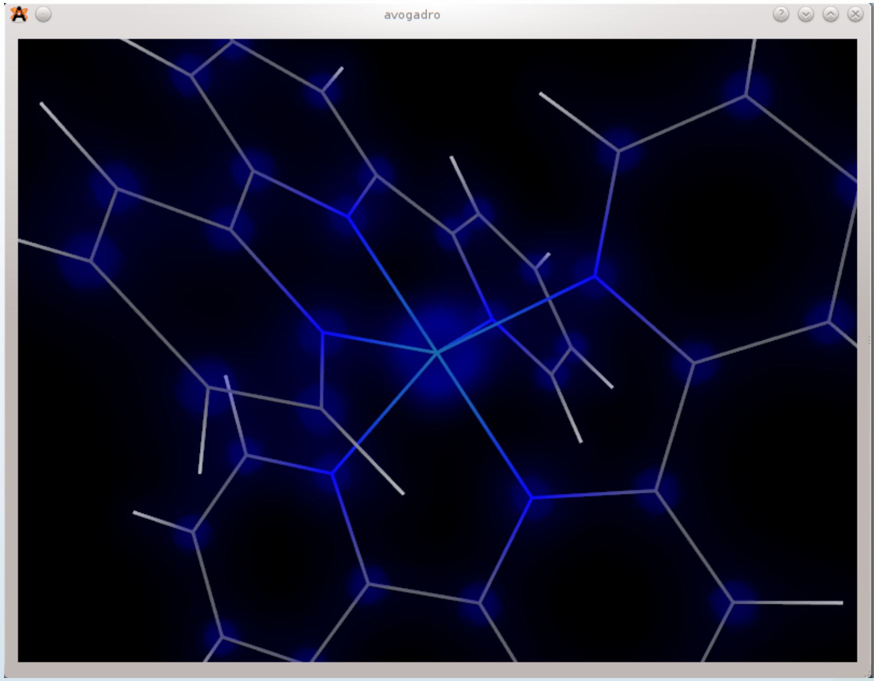
Advanced Visualization: VTK

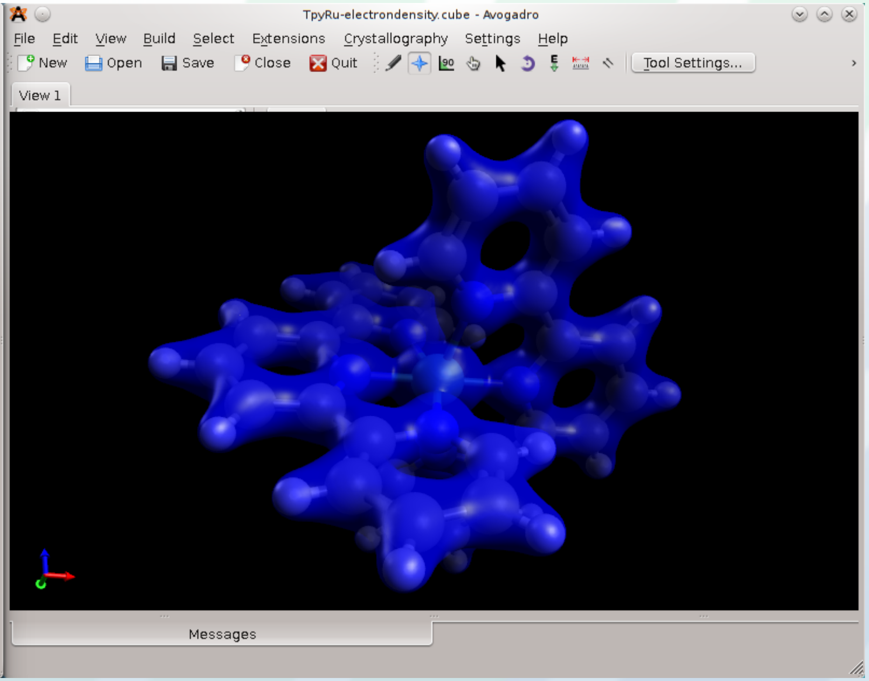
- New Avogadro plugin:
  - Takes volumetric data from Avogadro
  - Uses GPU accelerated rendering in VTK
- Widespread excitement from many in the chemistry community
- Several groups interested in collaborating
- Google Summer of Code project
- Leverage significant capabilities in VTK

Volume Rendered With Contours

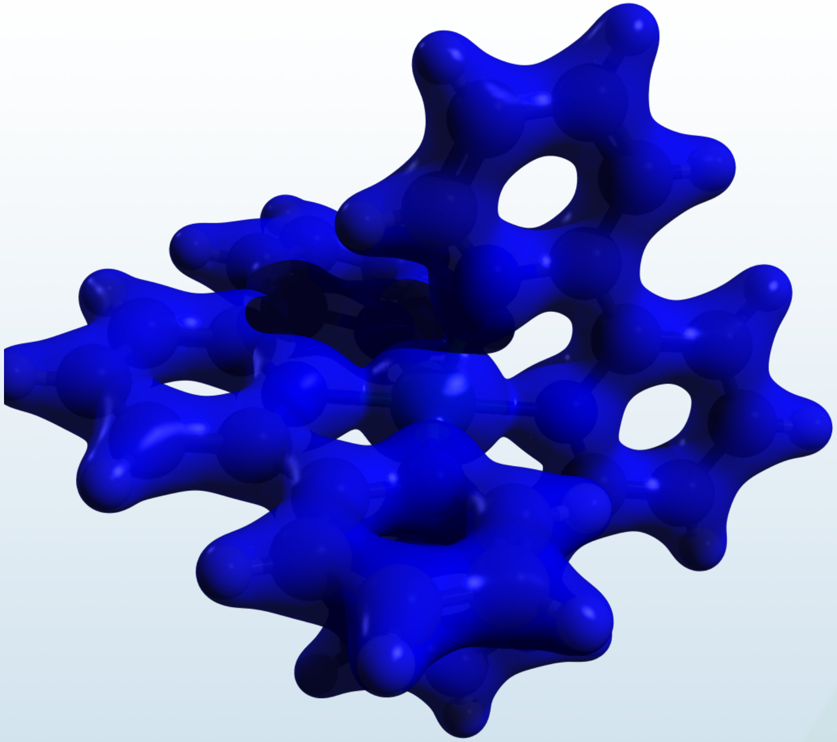


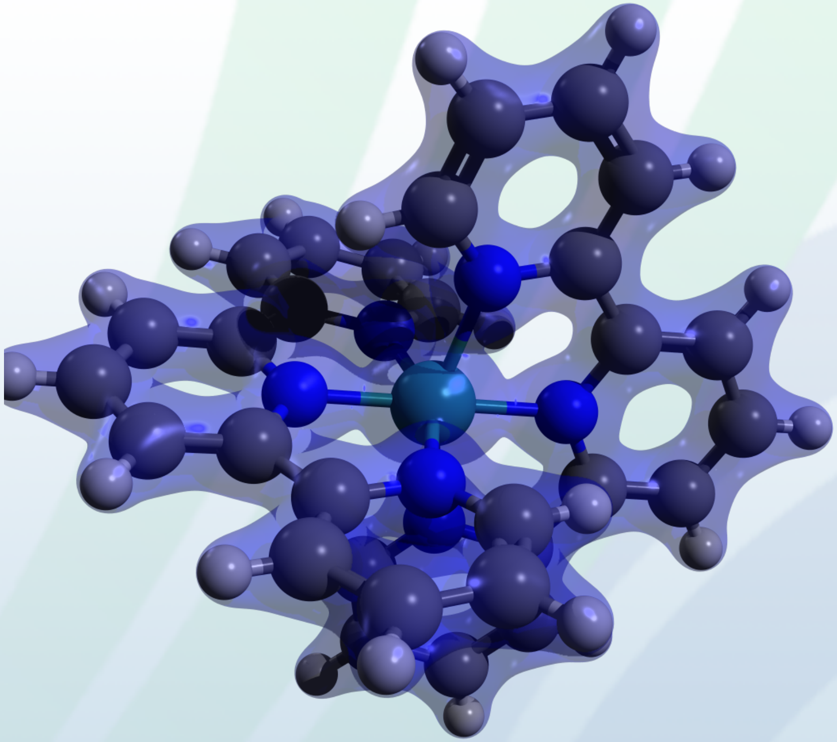
Electron Density Volume Render





Electron Density Ray Tracing





VTK: The Toolkit

- Collection of C++ libraries
  - Leveraged by many applications
  - Divided into logical areas, e.g.
    - Filtering – data processing in visualization pipeline
    - InfoVis – informatics visualization
    - Widgets – 3D interaction widgets
    - VolumeRendering – 3D volume rendering
- Cross platform, using OpenGL
- Wrapped in Python, Tcl and Java

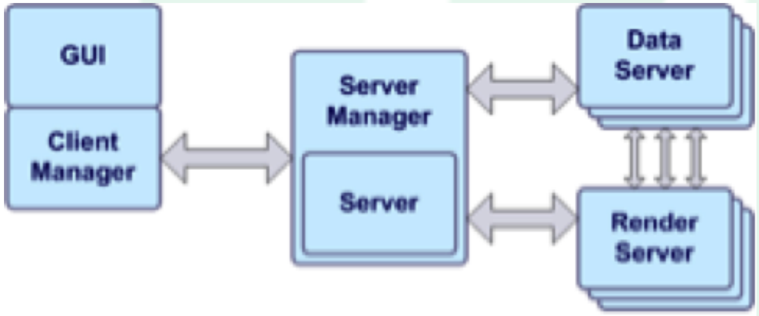
VTK Development Team

- From Ohloh: **Very large, active development team:** Over the past twelve months, **100 developers** contributed new code to VTK. This is one of the largest open-source teams in the world, and is in the **top 2%** of all project teams on Ohloh.

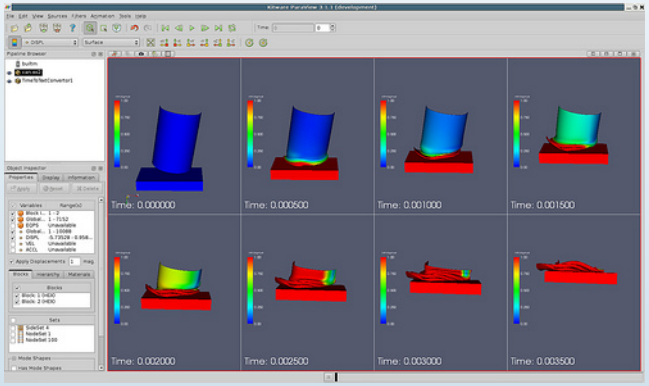
PITTSBURGH SUPERCOMPUTING CENTER
CSCS
Swiss National Supercomputing Centre
Los Alamos NATIONAL LABORATORY EST. 1943
CD-adapco
eDF
ARL
U.S. Army Research Laboratory
GE
TU Delft
Delft University of Technology
Kitware
THE UNIVERSITY of NORTH CAROLINA at CHAPEL HILL
Sandia National Laboratories
INDIANA UNIVERSITY
SCI
www.sci.utah.edu
GEORGETOWN UNIVERSITY
1789
cea
JOHNS HOPKINS UNIVERSITY
MIT
Massachusetts Institute of Technology
Rensselaer
RENSSELAER POLYTECHNIC INSTITUTE 1824

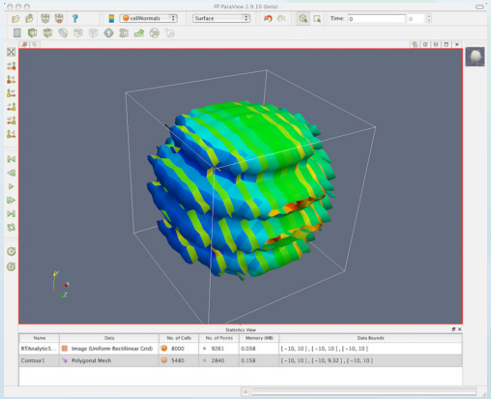
and many others...

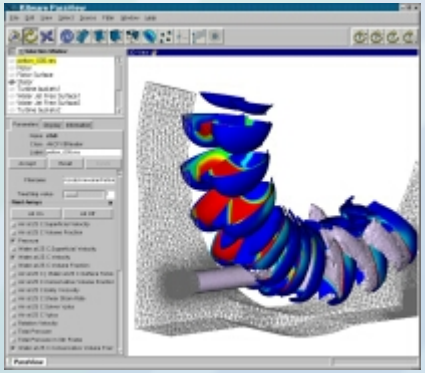
ParaView



- Parallel visualization application
- Open source, BSD licensed
- Turn-key application wrapper around VTK
- Parallel data processing **and** rendering





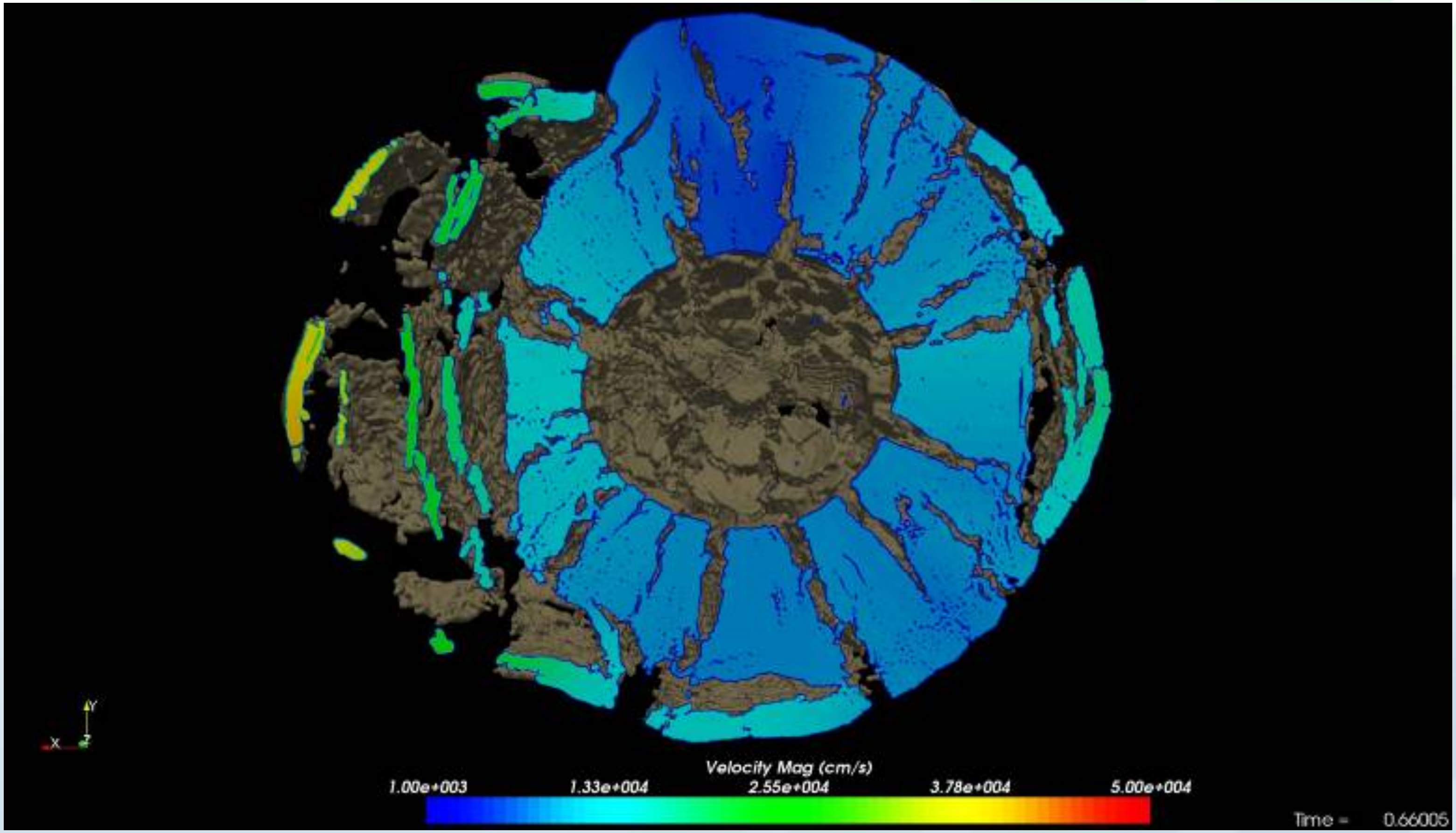


Large Data Visualization

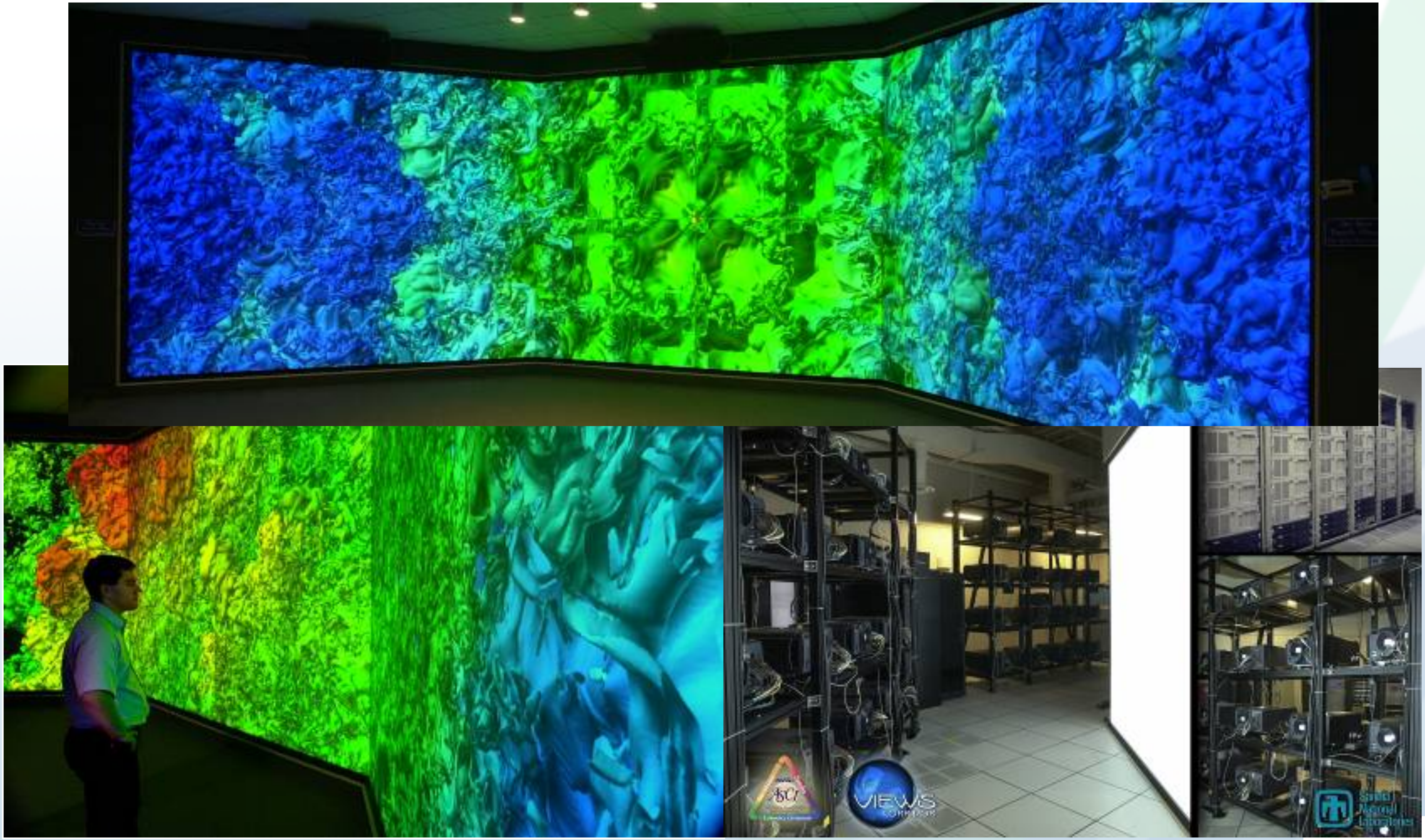
- BlueGene/L at LLNL
  - 65,536 compute nodes (32 bit PPC)
  - 1,024 I/O nodes (32 bit PPC)
  - 512 MB of RAM per node

- Sandia Red Storm
  - 12,960 compute nodes (AMD Opteron dual)
  - 640 service and I/O nodes
  - 40 TB of DDR RAM per node

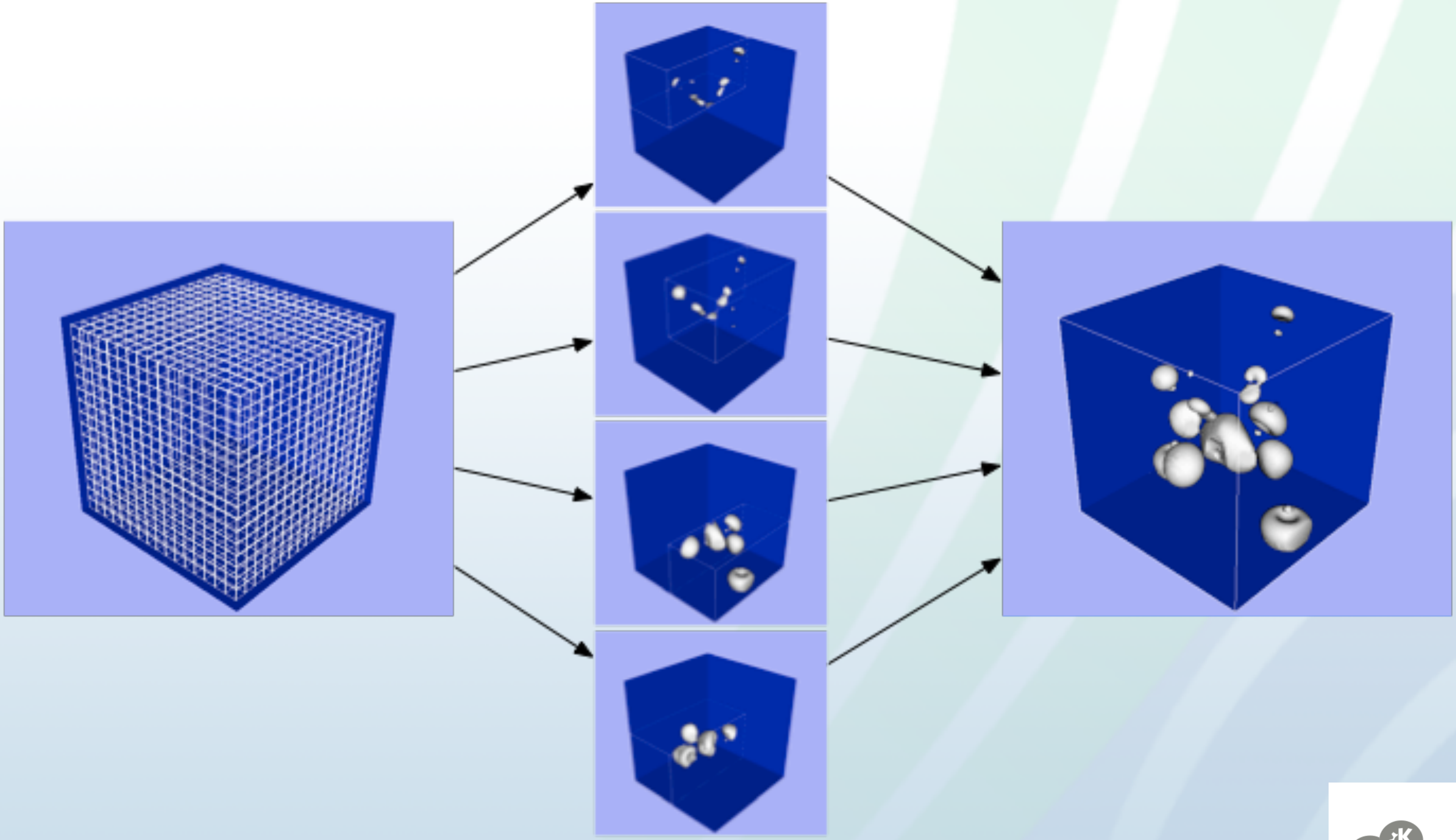
1 Billion Cell Asteroid Simulation



Tiled Displays

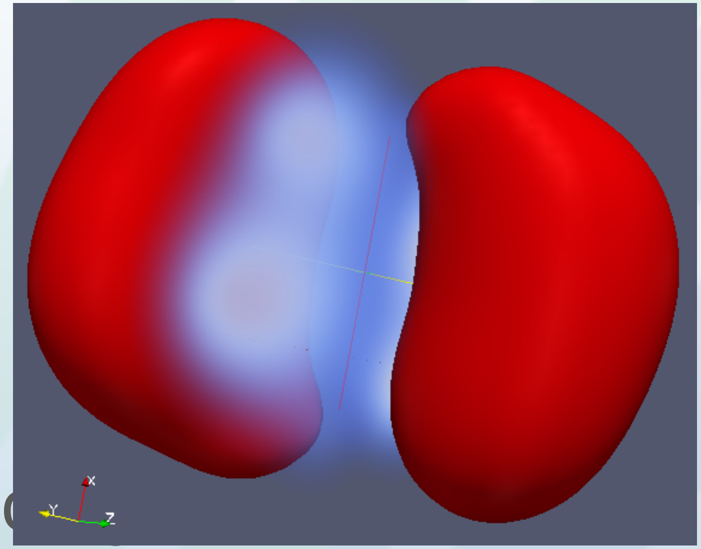


Parallel Processing/Rendering



3D Chemistry Visualization

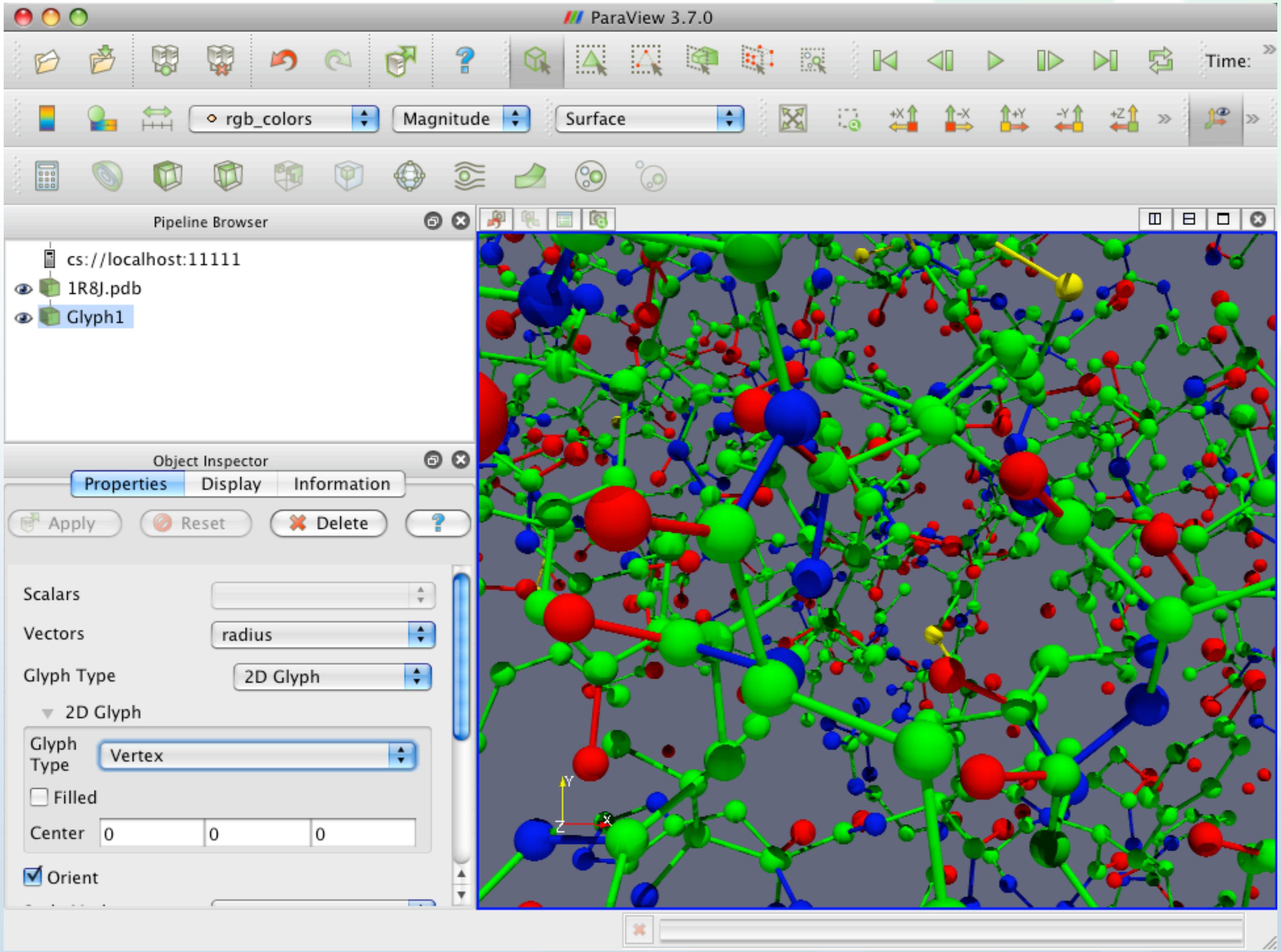
- Some existing features specific to chemistry
  - Gaussian cube, PDB, and a few others
- Excellent handling of volumetric data:
  - Marching cubes
  - Volume rendering
  - Contouring
- Advanced rendering:
  - Point sprites
  - Manta – real time ray trac



Titan: VTK and Informatics

- Led by Sandia National Laboratories
- Substantial expansion of VTK:
  - Informatics & analysis
- Actively developed, growing feature set
- Improved 2D rendering and API
- Database connectivity, client-server, pipeline based approach
- Uses web technologies such as ProtoViz
- Scalable, interactive infoviz

Manta: Real Time Ray Tracing



rgb_colors | Magnitude | Surface

cs://localhost:11111
1R8J.pdb
Glyph1

Scalars
Vectors radius
Glyph Type 2D Glyph
2D Glyph
Glyph Type Vertex
□ Filled
Center 0 0 0
☑ Orient

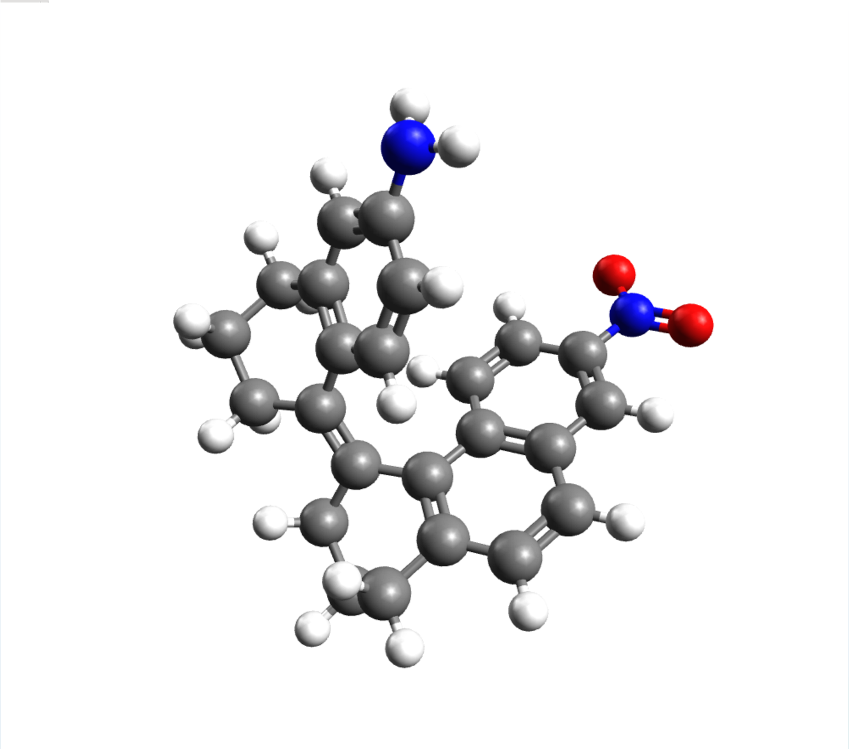
New Frontiers

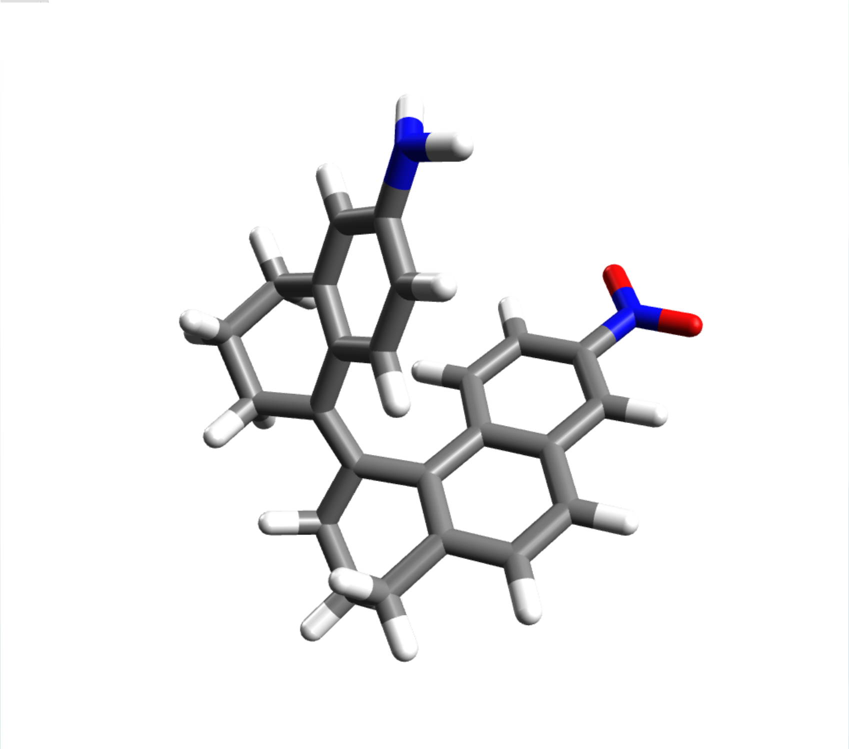
- New work porting VTK
  - – Use C++ as the common core
    - iOS port in the early stages
    - Android port
  - – Use OpenGL ES 2.0 – new rendering code
- Also ParaViewWeb – delivering over web
  - – Use image delivery and rendering on server
  - – Also using WebGL for rendering (optionally)

Future Directions

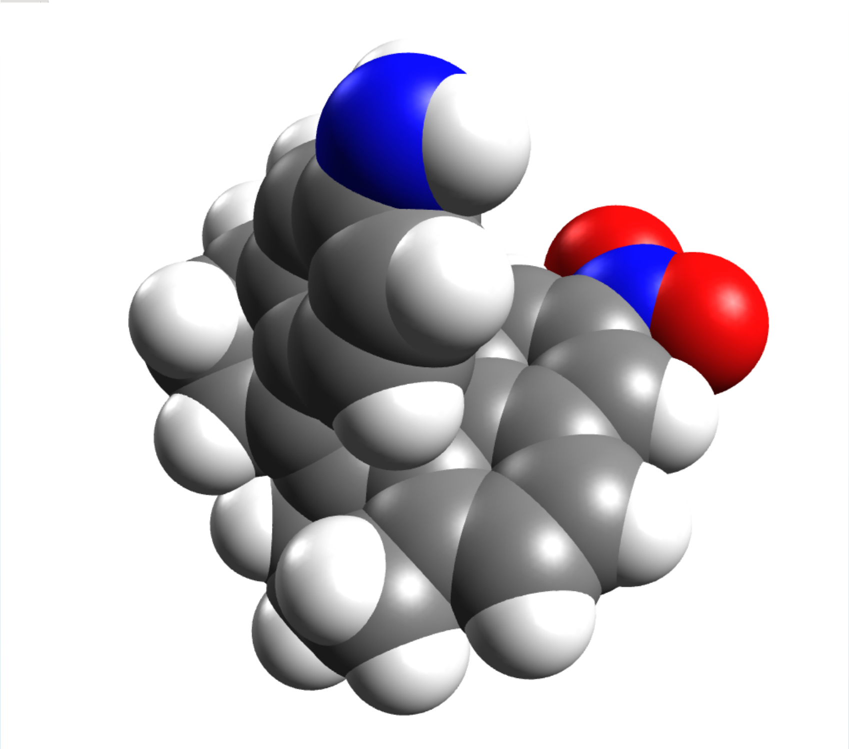
- VTK modularization (in progress)
  - Developing more agile build systems
  - Automating more with CMake
- Using Git more fully to improve stability
  - Use of master and next
  - Topic branches - merge when ready
- Code review using Gerrit
  - Integration with continuous integration
  - Test before merge

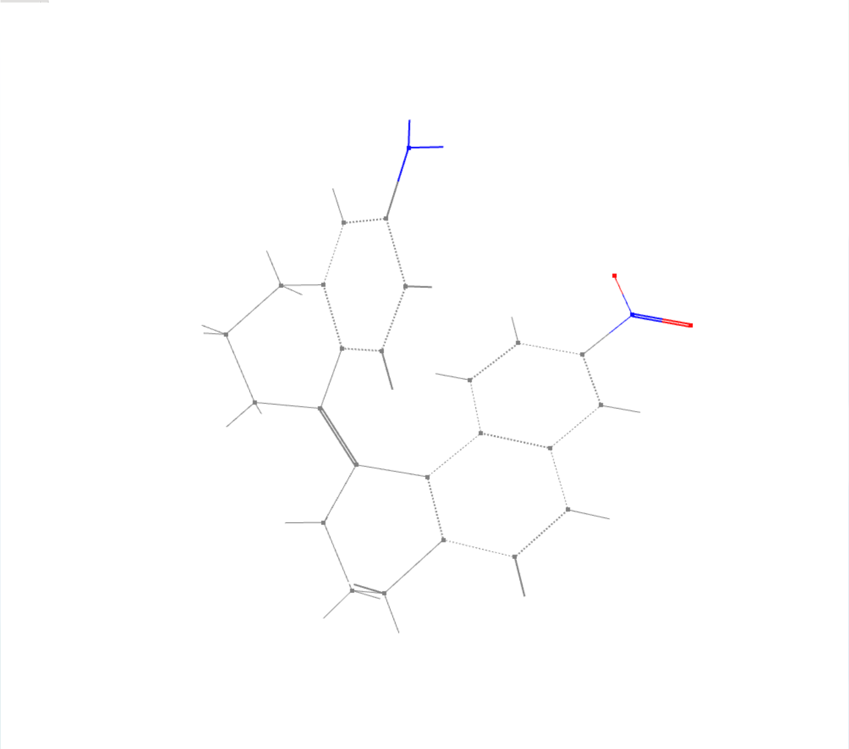
Standard Representations



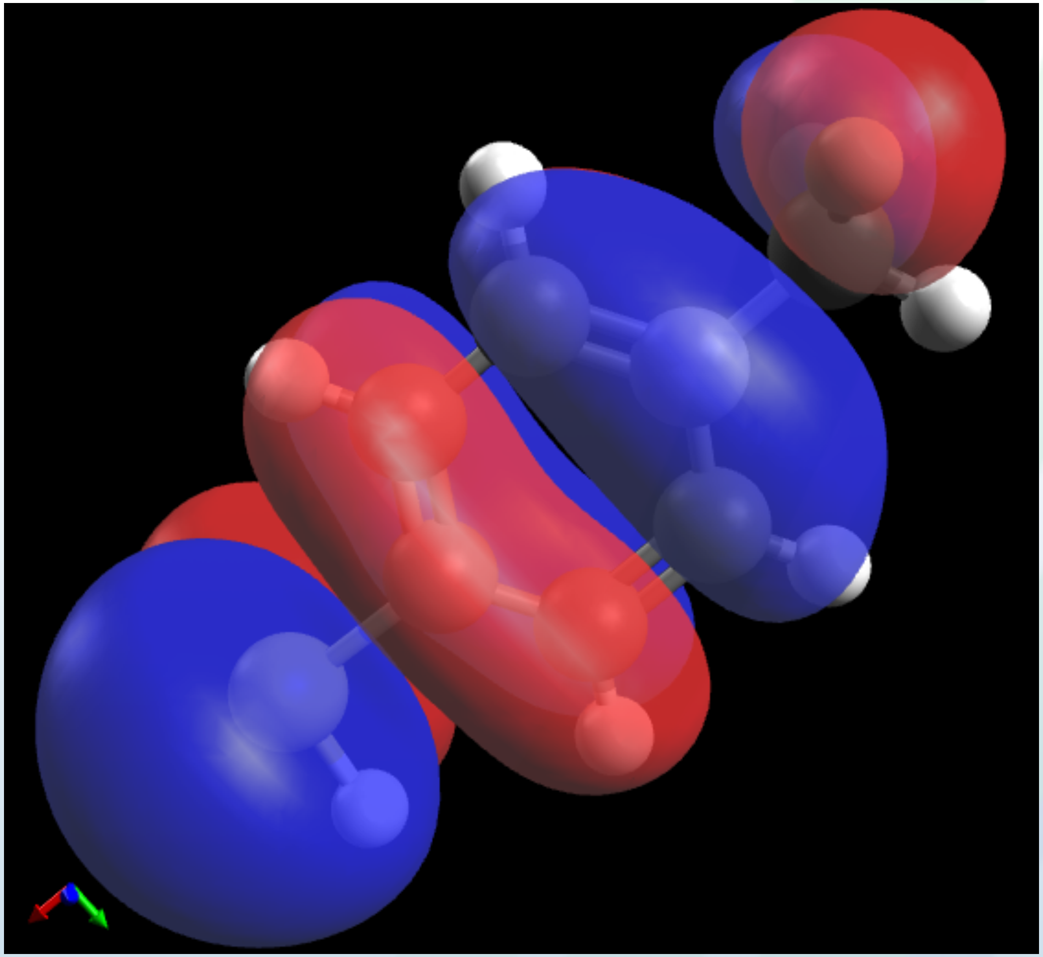


Standard Representations

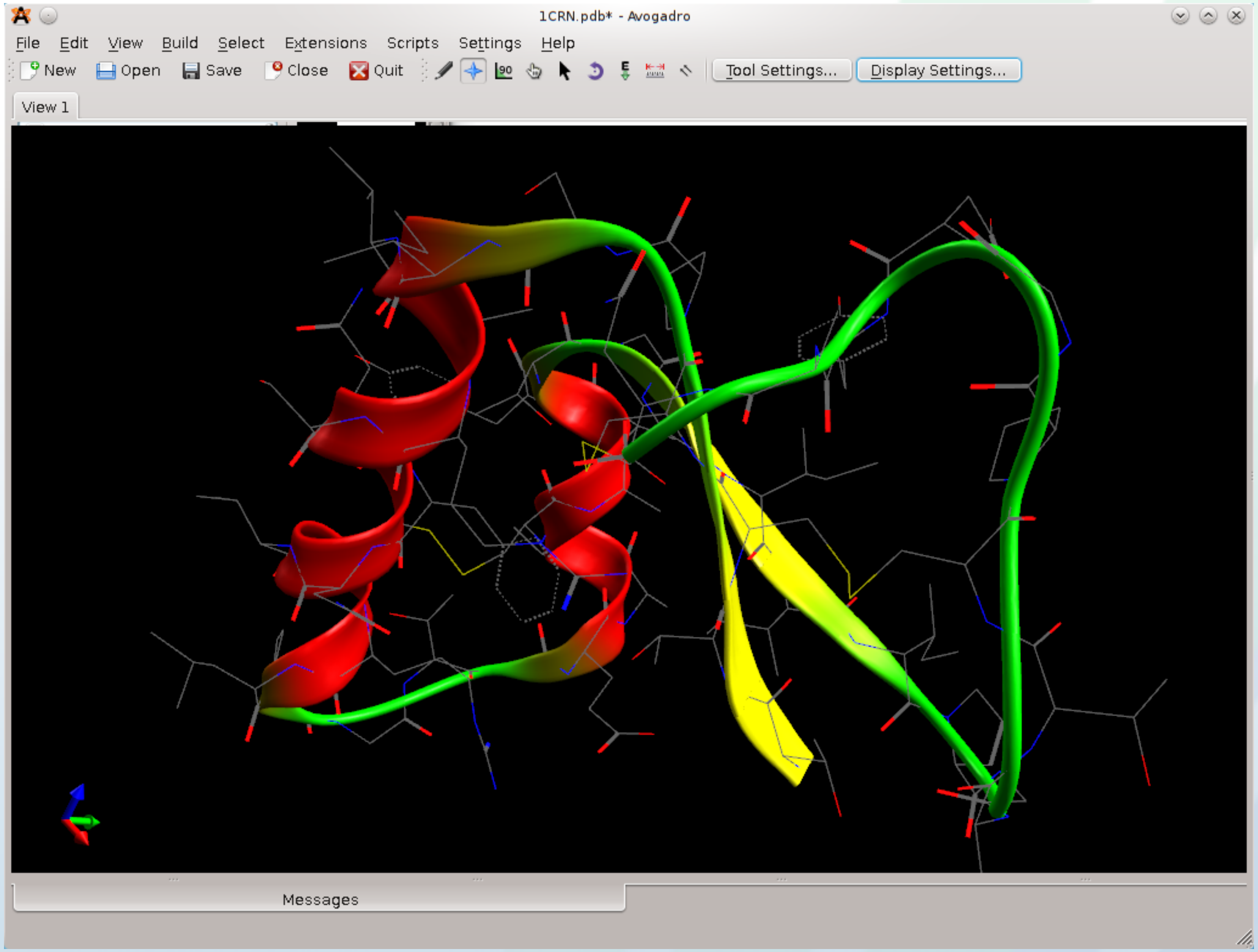




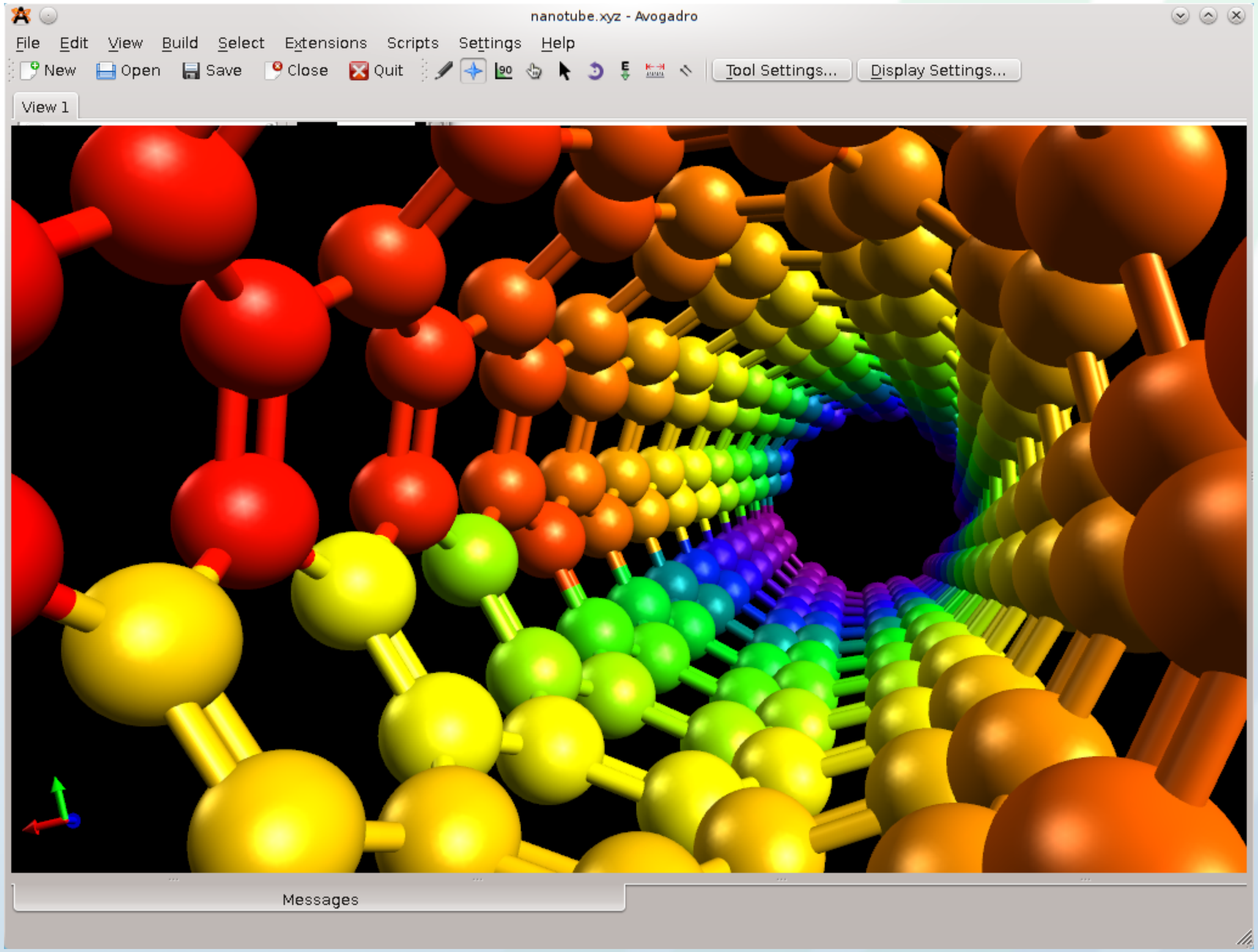
Volumetric Data: Molecular Orbitals



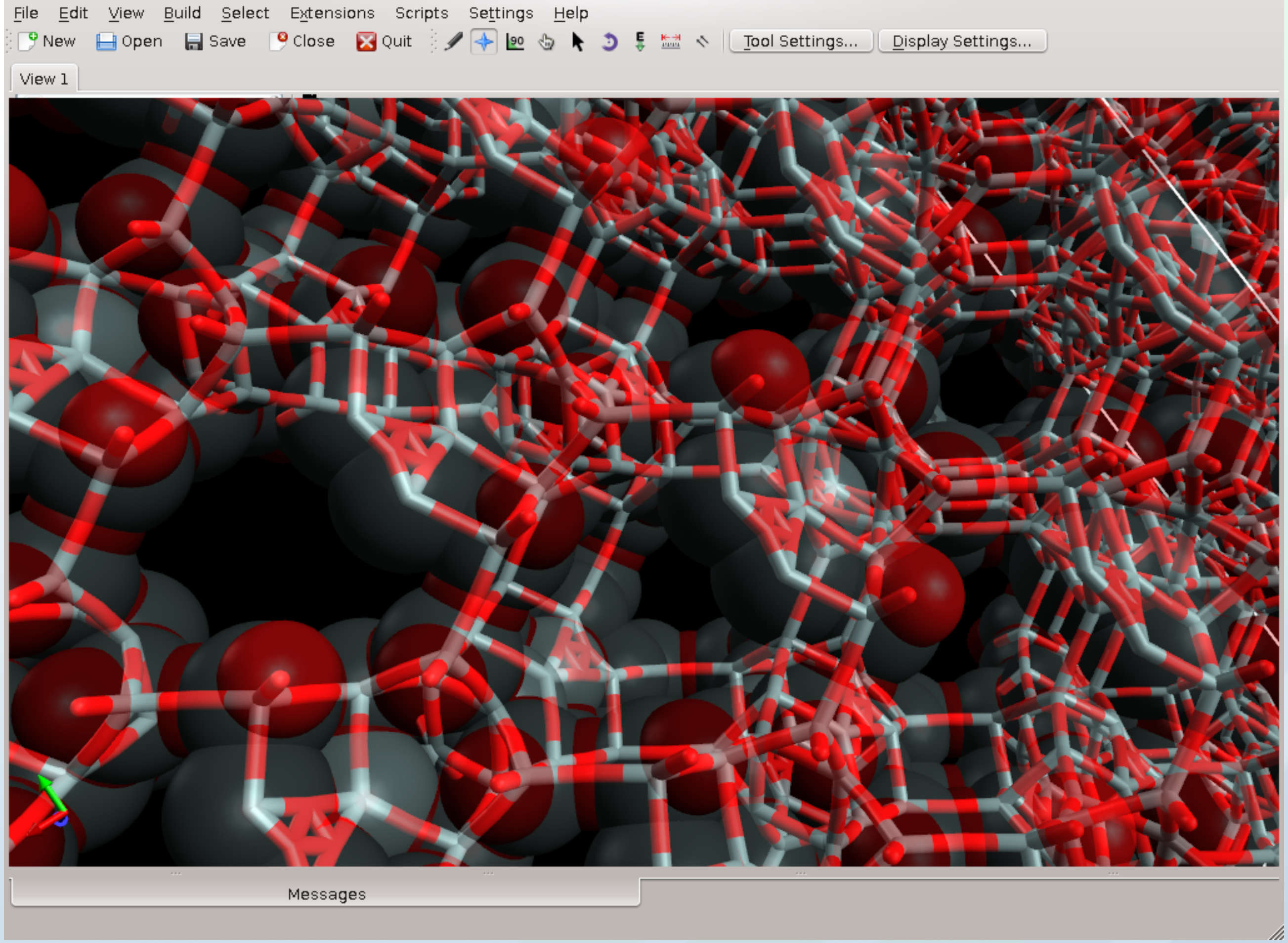
Biomolecules


1CRN.pdb* - Avogadro
File Edit View Build Select Extensions Scripts Settings Help
New Open Save Close Quit
Tool Settings... Display Settings...
View 1
Messages

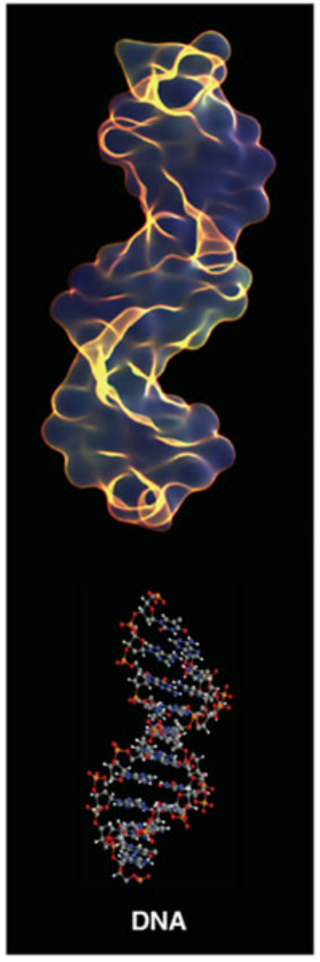
Nanomaterials

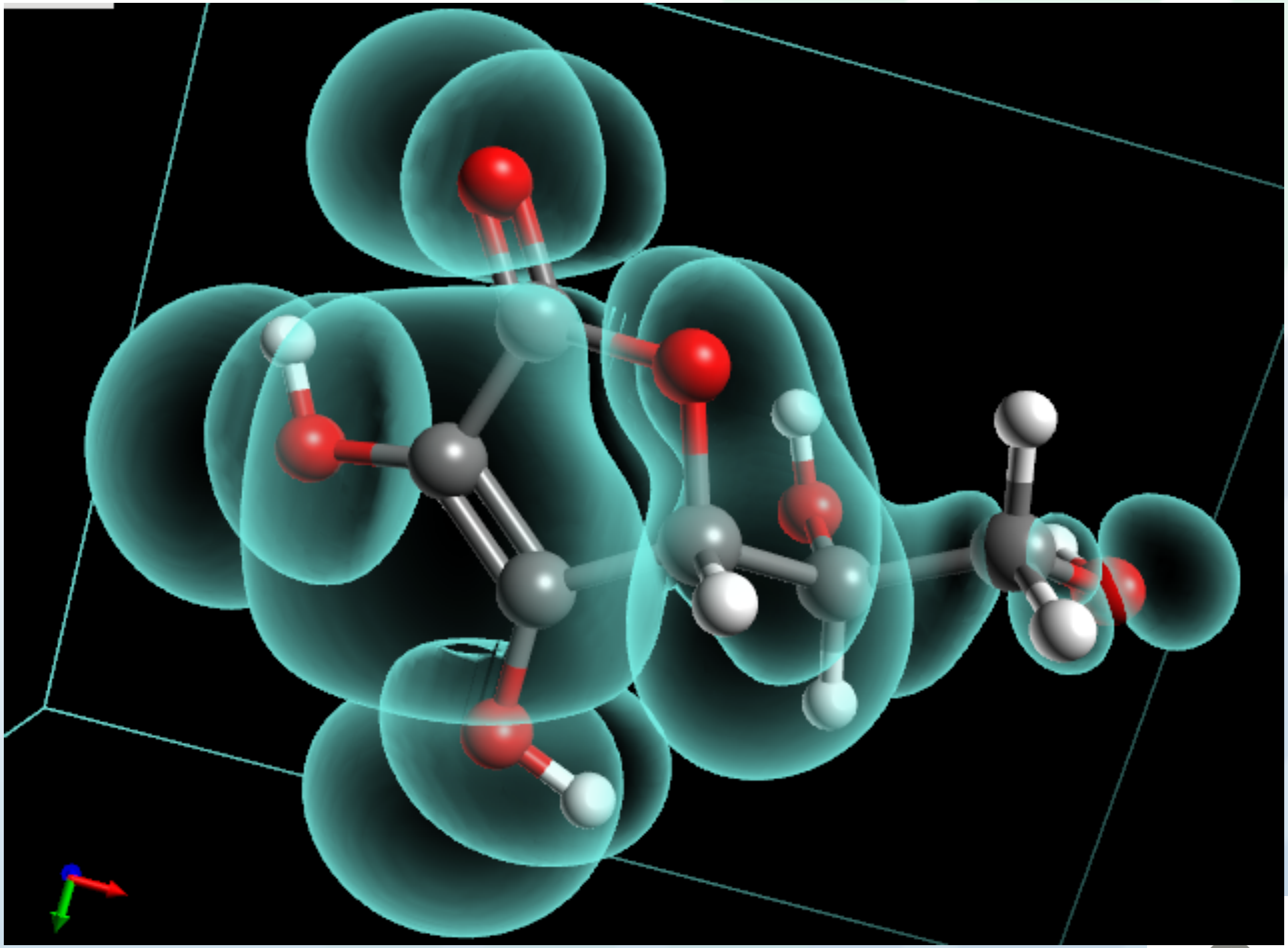

nanotube.xyz - Avogadro
File Edit View Build Select Extensions Scripts Settings Help
New Open Save Close Quit
Tool Settings... Display Settings...
View 1
Messages

Periodic Systems

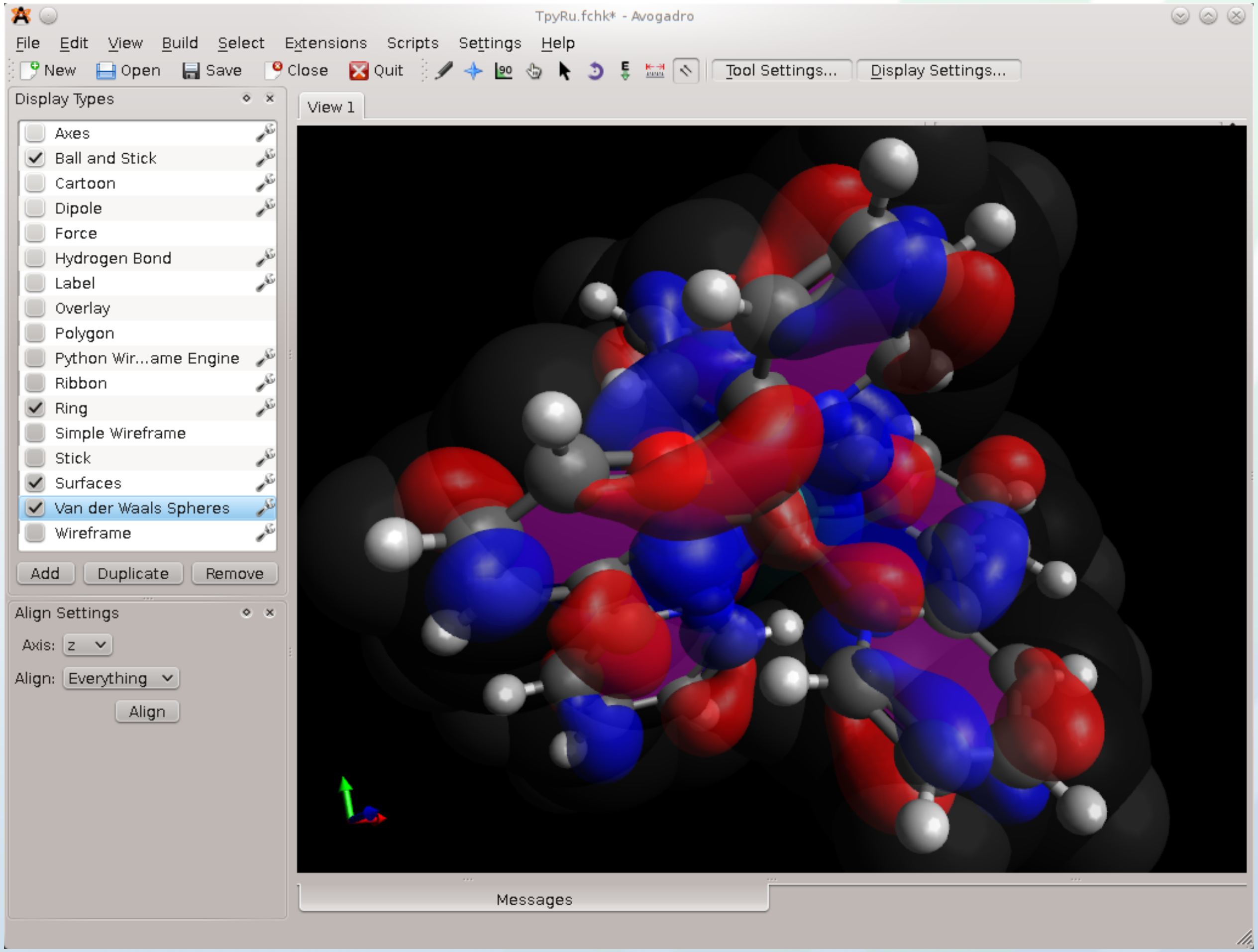


Simplified Views

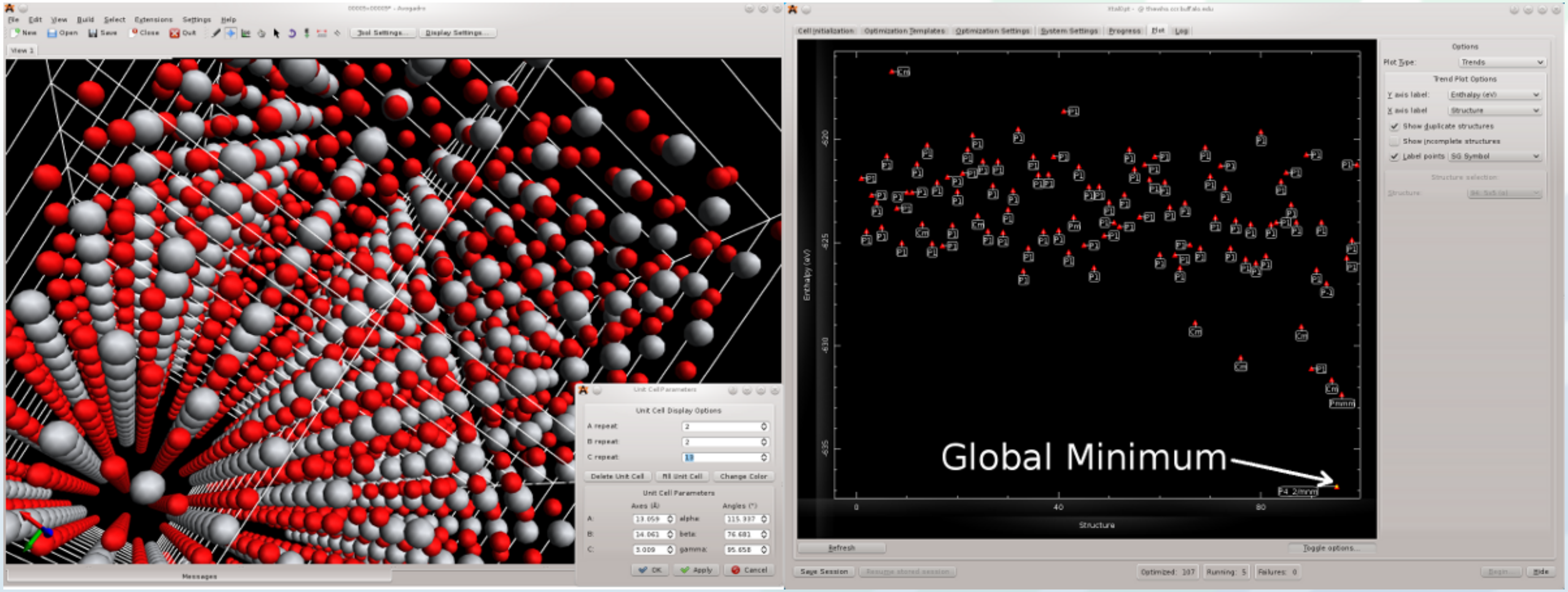




Hybrid Views: CPK + MO + Ball & Stick



Linked Views of Live Data


File Edit View Build Select Extensions Settings Help
New Open Save Close Quit
Tool Settings... Display Settings...
View 1
Messages
Cell Initialization Optimization Templates Optimization Settings System Settings Progress Plot Log
Enthalpy (eV)
-620
-625
-630
-635
0
40
80
Structure
Global Minimum
P4_2/mnm
Pmmn
Cm
P1
Refresh
Toggle options...
Save Session
Resume stored session
Begin...
Hide

Unit Cell Parameters

Unit Cell Display Options

A repeat: 2

B repeat: 2

C repeat: 10

Delete Unit Cell | Fill Unit Cell | Change Color

Unit Cell Parameters

	Axes (Å)		Angles (°)
A:	13.059	alpha:	115.337
B:	14.061	beta:	76.681
C:	5.009	gamma:	95.658

OK | Apply | Cancel

Options

Plot Type: Trends

Trend Plot Options

Y axis label: Enthalpy (eV)

X axis label: Structure

☑ Show duplicate structures

☐ Show incomplete structures

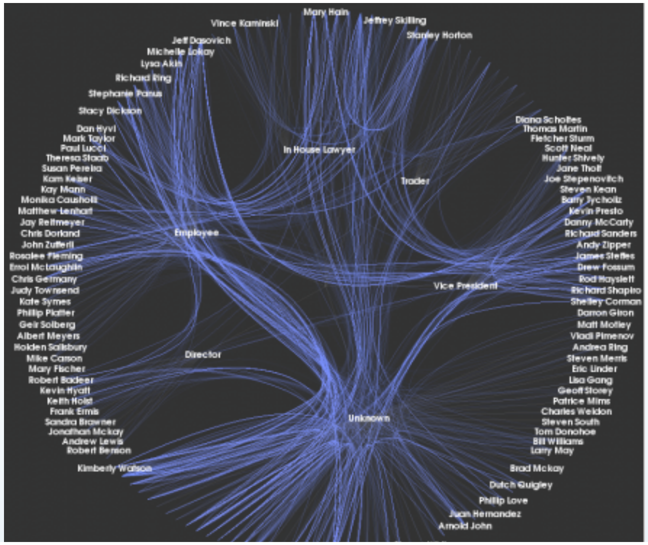
☑ Label points: SG Symbol

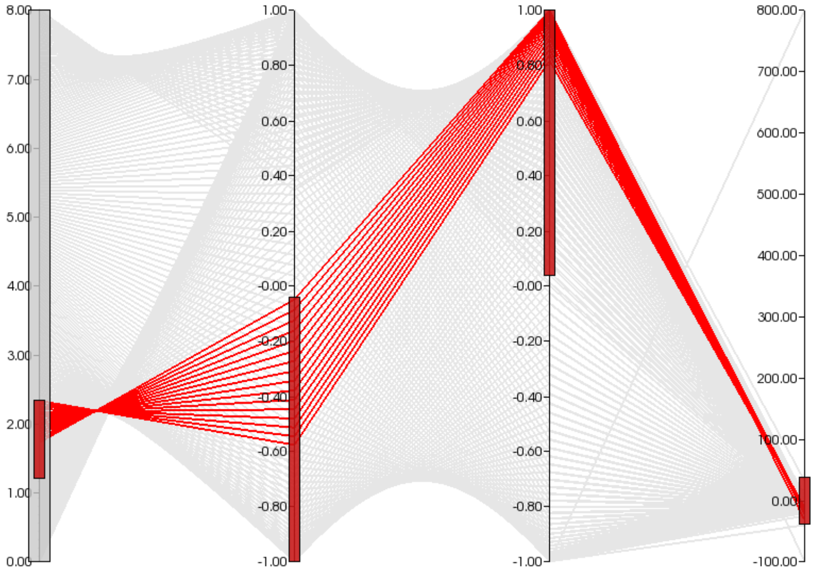
Structure selection:

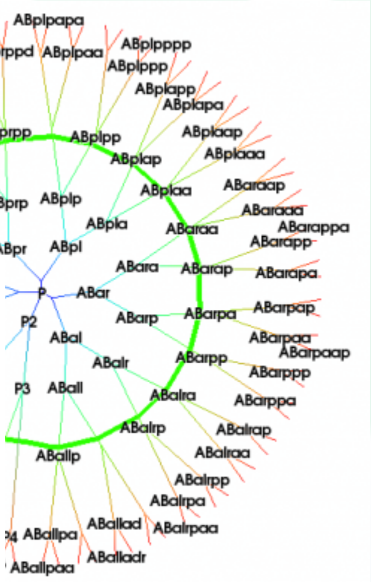
Structure: 94: 5x5 (s)

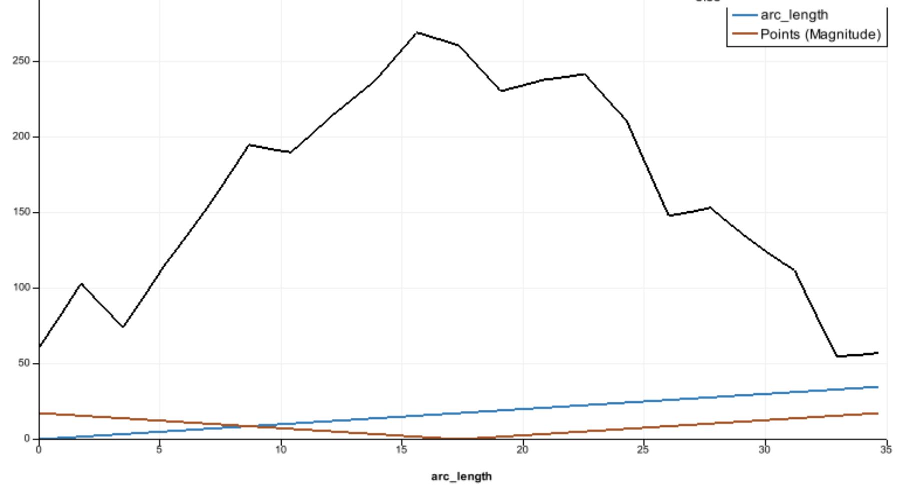
Optimized: 107 | Running: 5 | Failures: 0

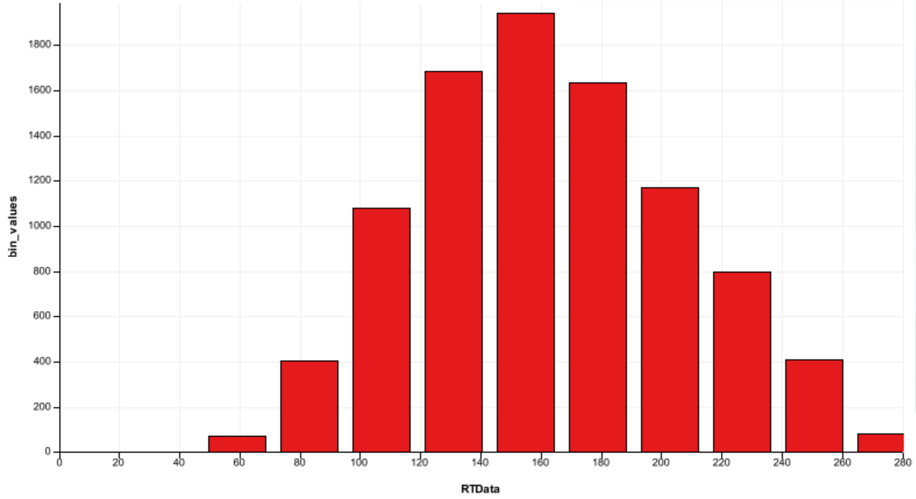
2D: Graphs and Charts



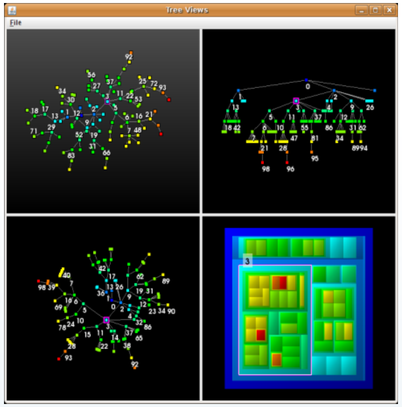


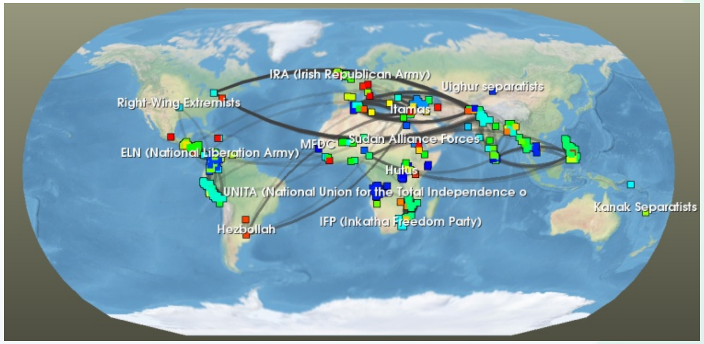


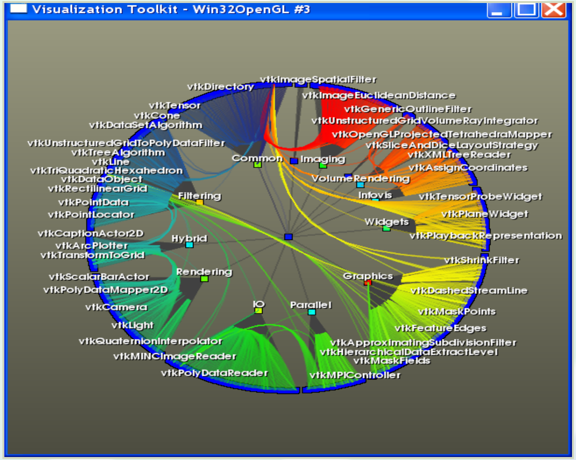


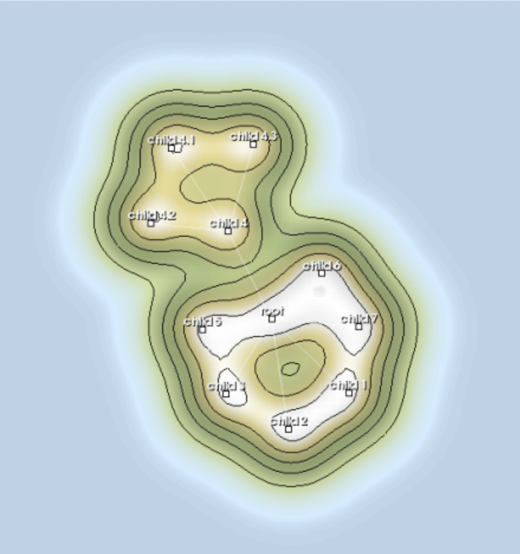


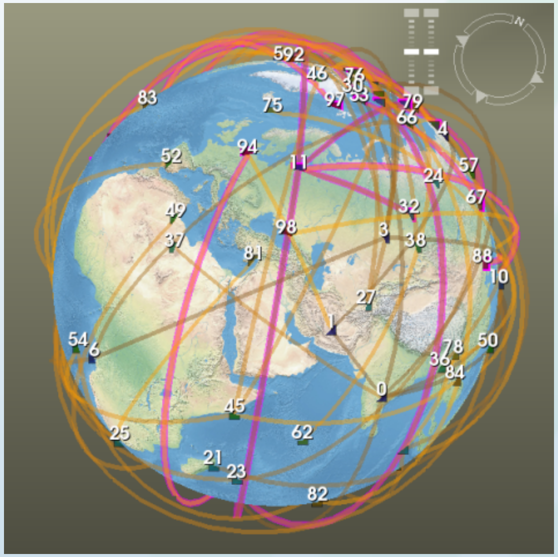
Informatics

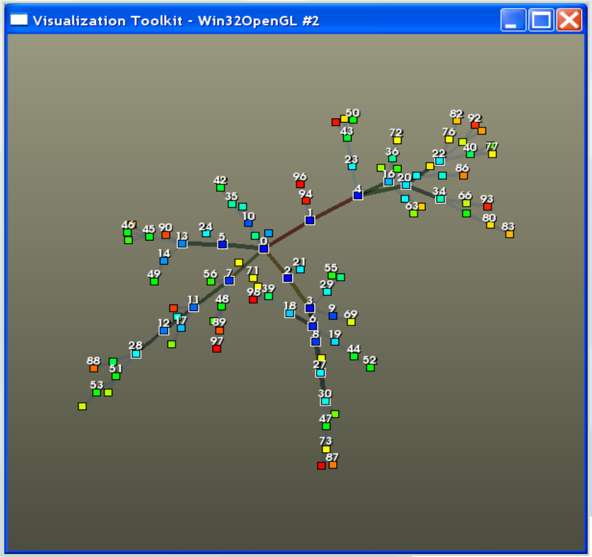



IRA (Irish Republican Army)
Uighur separatists
Right-Wing Extremists
Hamas
Sudan Alliance Forces
MFDC
ELN (National Liberation Army)
Hutus
UNITA (National Union for the total Independence o
Hezbollah
IFP (Inkatha Freedom Party)
Kanak Separatists

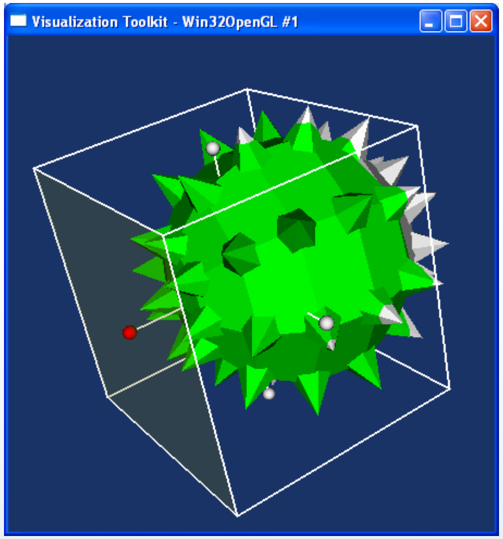


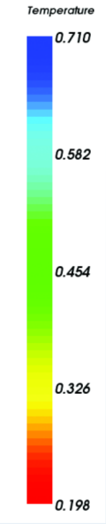


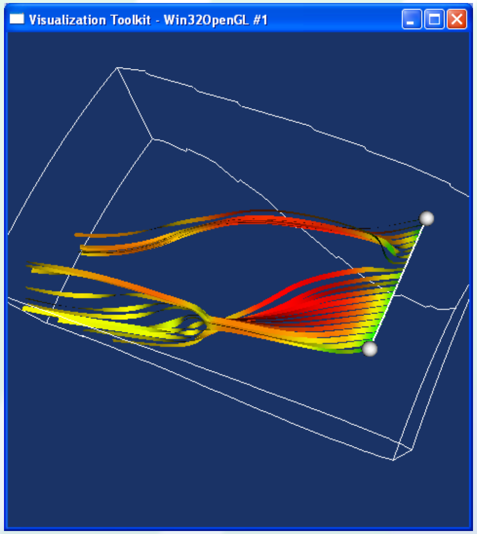


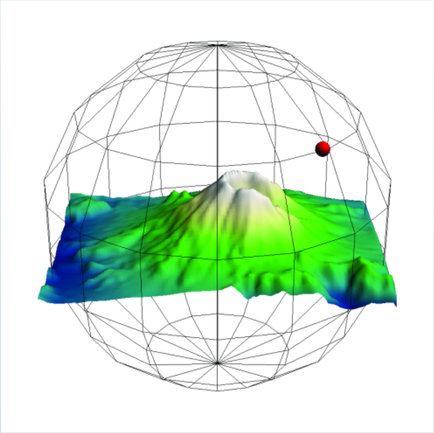


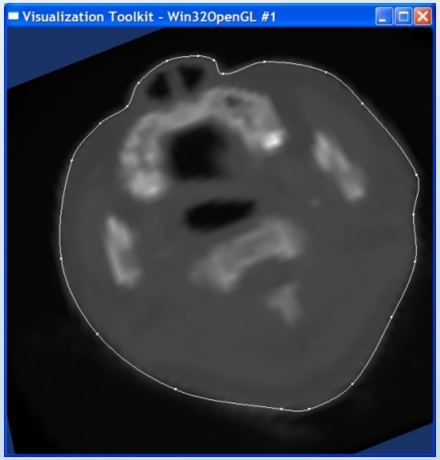
3D Interaction Widgets


Visualization Toolkit - Win32OpenGL #1


Temperature


Visualization Toolkit - Win32OpenGL #1




Visualization Toolkit - Win32OpenGL #1