Introduction to Python and VTK

Scientific Visualization Workshop 2014

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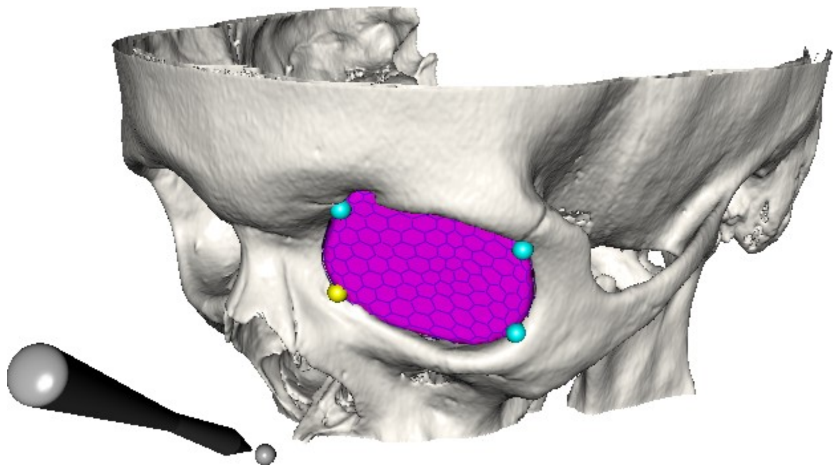
About me

- PhD student in Computerized Image Analysis
- Develop methods and tools for interactive analysis of medical 3D (volume) images



python™

History

- The Python programming language was developed in the late 1980s by a Dutch computer programmer named Guido Van Rossum (who now is the *Benevolent Dictator for Life* of the language)
- First version released in 1991
- Named after the Monty Python comedy group, not the snake...

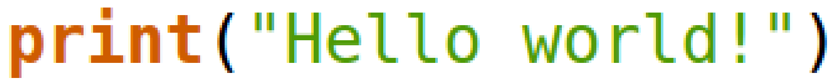
Key features

- General-purpose, high-level programming language
- Clear, readable syntax (similar to pseudocode)
- Dynamically AND strongly typed (see explanation here)
- Multi-paradigm: you can write code that is (fully or partially) procedural, object-oriented, or functional
- No compiling*
- Has extensive standard libraries and a rich selection of third-party modules
- Good for rapid prototyping

* some compiling is performed in the background to transform source code to byte code (*.pyc files)

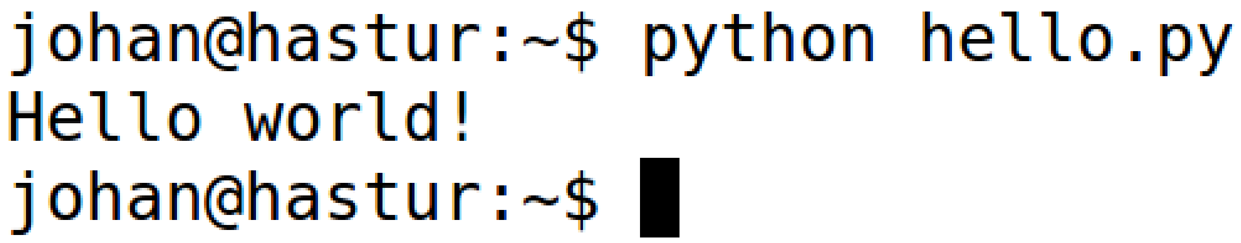
Running a Python program

- Suppose that we have a program hello.py containing this single line of code:



```
print("Hello world!")
```

- To run this program, just open a terminal, navigate to the directory of the file, and type



```
johan@hastur:~$ python hello.py
Hello world!
johan@hastur:~$ █
```

Built-in numeric types

- Integers (int): 1, 2, 3
- Floats (float): 0.1, 3.141592 (64-bit by default)
- Complex: 0+1j, 1.1+3.5j
- Booleans: True, False

Container types

- Strings (str): ”python”, ”foo”
- Lists (list): [1, 2, 3], [0.5, ”bar”, True], [[0, 1, 0], [1, 0, 0]]
- Tuples (tuple): (1, 2, 3)
- Dictionaries (dict): {”key0”: 1.5, ”key1”: 3.0}
- Strings and tuples are immutable (i.e., cannot be modified after creation), whereas lists and dictonaries are mutable (can be modified)
- Lists, tuples and dictionaries can contain mixed types

Control flow

- No switch-statement, but otherwise all the familiar control-flow statements are there. Examples:

```
numbers = [0, 1, 2, 3, 4]
for number in numbers:
    print(number)

for i in xrange(0, len(numbers)):
    print(numbers[i])

i = 0
while i < 10:
    print(i)
    i += 1
```

Functions

- Functions are defined like this:

```python
def fibonacci(n):
    if n == 0 or n == 1:
        return n
    else:
        return fibonacci(n - 1) + fibonacci(n - 2)

if __name__ == "__main__":
    print(fibonacci(10))
```

Whitespace-sensitive syntax

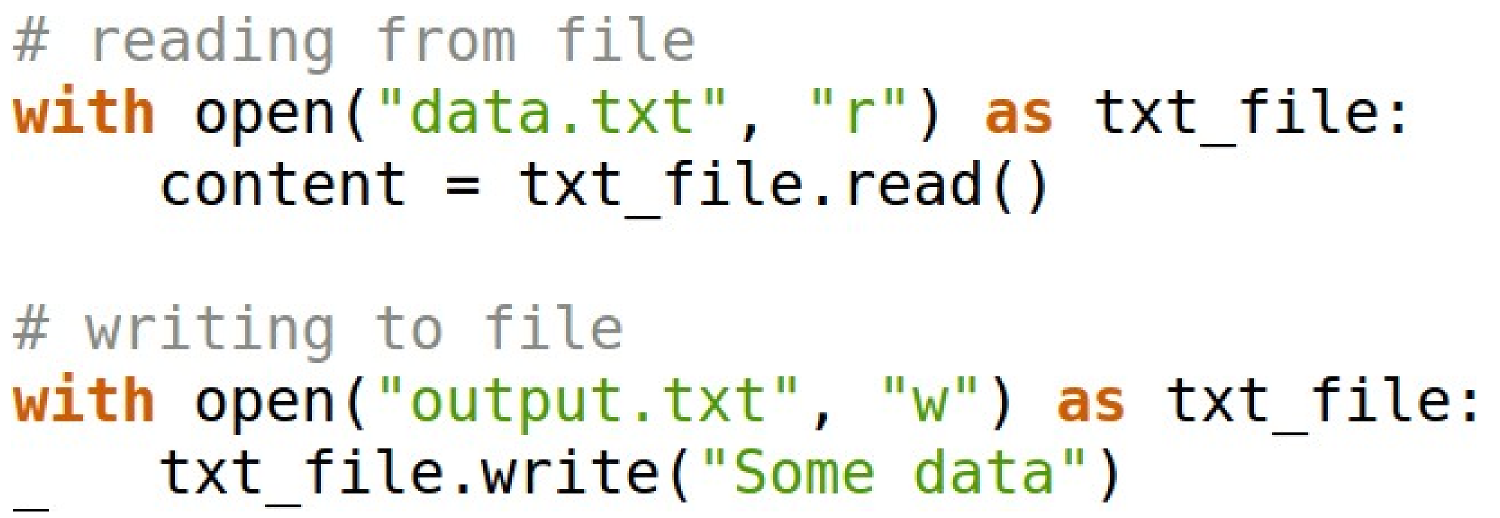
- Python uses ”:” and whitespace indentation to delimit code blocks, e.g., define where a function or control-flow statement starts and stops
- Controversial design choice...
- Forces you to write readable (or at least well-indented) code

```python
def fibonacci(n):
    if n == 0 or n == 1:
        return n
    else:
        return fibonacci(n - 1) + fibonacci(n - 2)

if __name__ == "__main__":
    print(fibonacci(10))
```

File I/O

- Using the **with** statement (available since Python 2.5), reading or writing to file is really simple:



```
# reading from file
with open("data.txt", "r") as txt_file:
    content = txt_file.read()

# writing to file
with open("output.txt", "w") as txt_file:
_   txt_file.write("Some data")
```

Classes

- Python supports object-oriented programming

```
import math

class Sphere:

    def __init__(self, center=[0.0, 0.0, 0.0], radius=1.0):
        self.center = center
        self.radius = radius

    def compute_volume(self):
        return (4.0 / 3.0) * math.pi * math.pow(self.radius, 3)

sphere = Sphere()
print(sphere.compute_volume())
```

(unlike Java or C++, getters and setters are normally not used in Python)

Modules

- Every *.py file is a **module**
- Related functions and classes should be grouped into modules
- You can then use the **import** statement to import the module (or some selected part of it) into your script
- Related modules can be grouped into a **package** (good if you plan to distribute your code)

The Python standard library

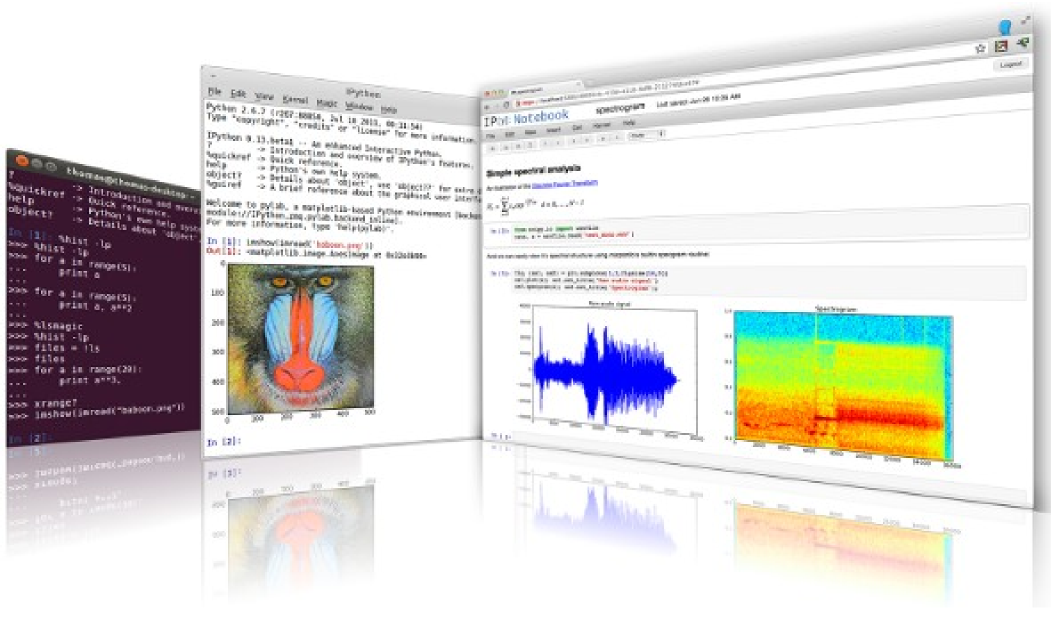
- Provides modules for file and directory access, mathematics, testing, GUI programming, networking, etc
- Read more about it on http://docs.python.org/2/library/index.html
- Some useful modules from the standard library are
  - **math** (mathematical functions and constants)
  - **os** (operating system functionality)
  - **sys** (system-specific parameters and functions)

Python versions (2.x vs. 3.x)

- The Python 3.x branch is a revision of the language and offers many improvements over Python 2.x
- However, Python 3.x is not backward-compatible, and many existing packages (e.g., VTK) for Python 2.x have not yet been ported to Python 3.x
- Python 2.x is still more widely used
- See http://wiki.python.org/moin/Python2orPython3 for more info
- In this workshop we will use Python 2.6 or 2.7

Text editors, IDEs, and interactive shells

- You can write your Python code in a text editor like Vim or Emacs, or use an IDE (see this list for options)
- The standard Python shell is great for trying out language features
- For a more powerful interactive computing environment, have a look at IPython



Style guide for Python code (PEP8)

- To simplify the life for Python programmers, some of the language developers sat down and wrote a style guide for Python code: PEP8
- The guidelines in PEP8 are just recommendations: you are free to break them and define your own coding style guide (but please be consistent)

When you need more speed

- NumPy & SciPy
- Cython (supports parallel processing via OpenMP)
- PyCUDA
- PyOpenCL

Other useful packages

- Graphics programming and visualization
  - PyOpenGL, VTK, Mayavi
- GUI programming
  - PyQt/PySide, wxPython, Tkinter
- Image analysis and processing
  - ITK, Pillow
- Computer vision
  - OpenCV
- Plotting
  - Matplotlib

Python tutorials

- If you are new to Python, start with:

  https://docs.python.org/2/tutorial/

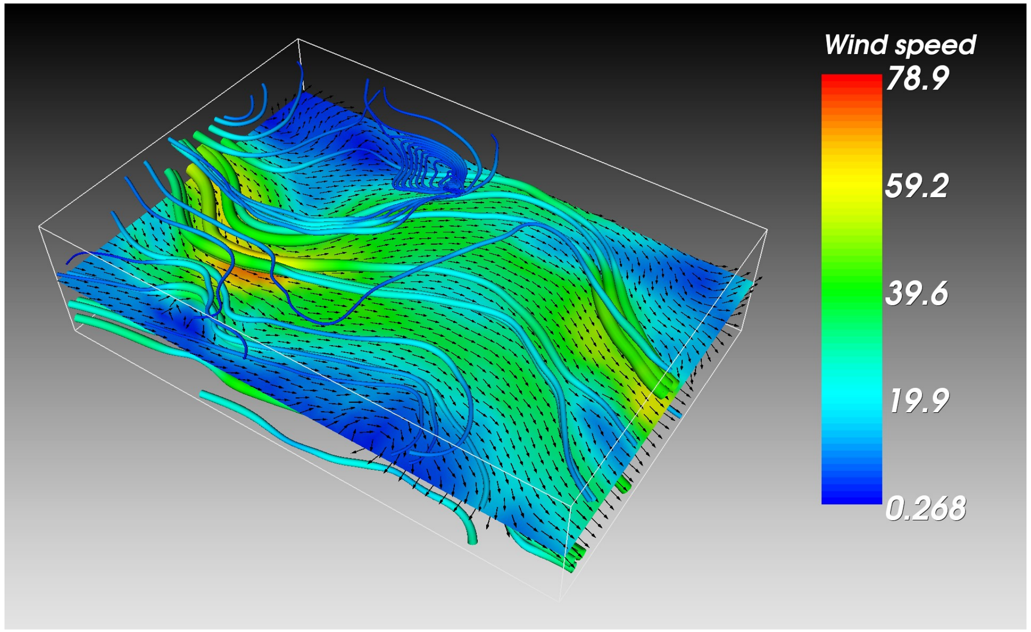
- Zed Shaw's *”Learning Python The Hard Way”* is also a good (but more demanding) tutorial:

  http://learnpythonthehardway.org/book/

vtk

The Visualization Toolkit (VTK)

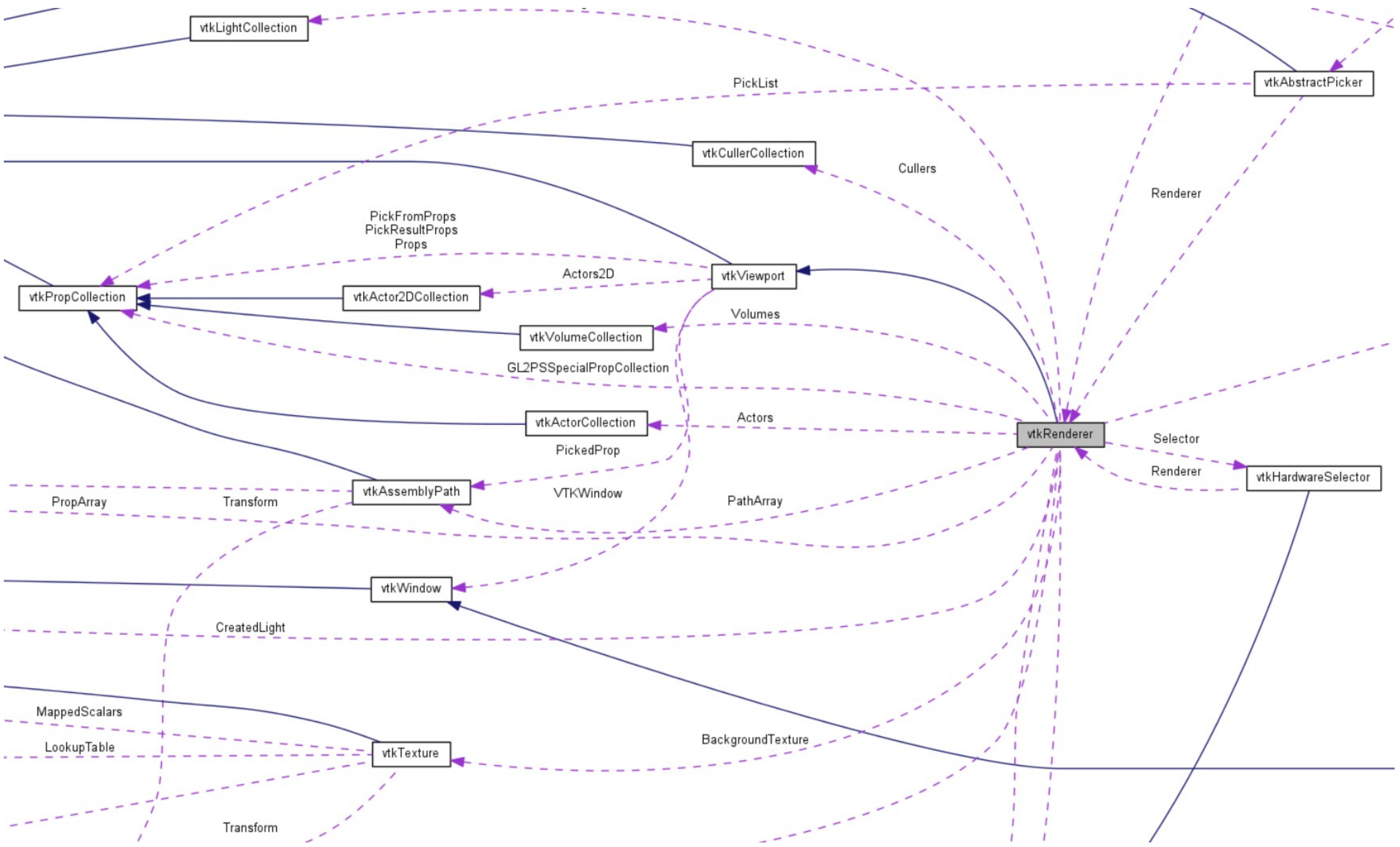
- Open source, freely available C++ toolkit for
  - scientific visualization
  - 3D computer graphics
  - mesh and image processing
- Managed by Kitware Inc.



VTK

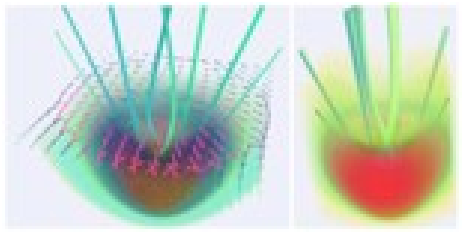
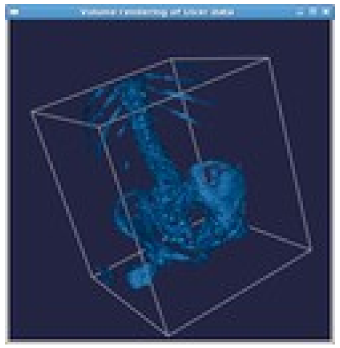
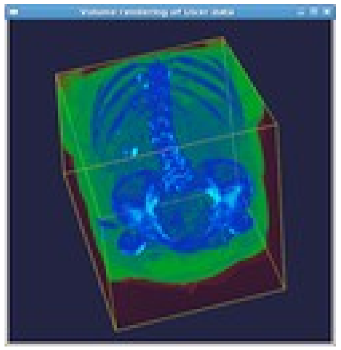
- Object-oriented design
- High level of abstraction (compared to graphics APIs like OpenGL or Direct3D)
- Provides bindings to Tcl/Tk, Python, and Java
- GUI bindings: Qt, wxWidgets, Tkinter, etc

Heavily object-oriented
(and a bit over-designed...)

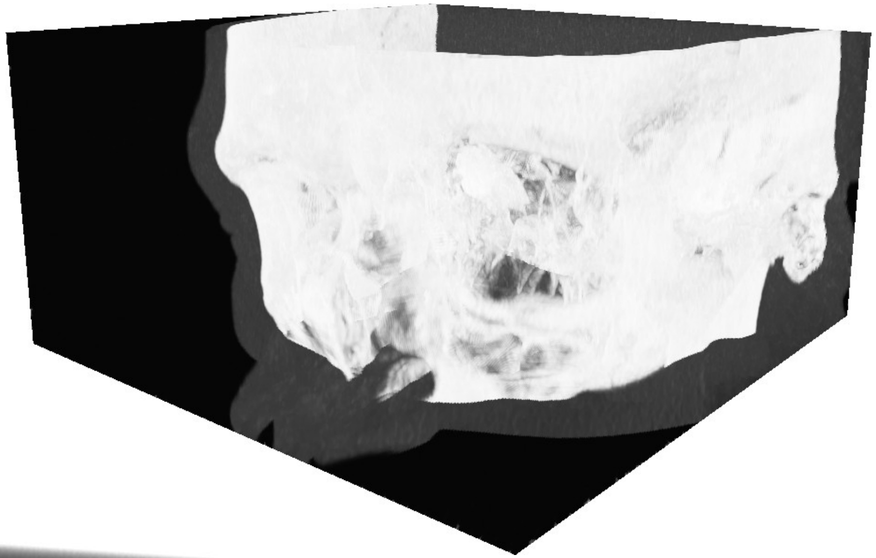


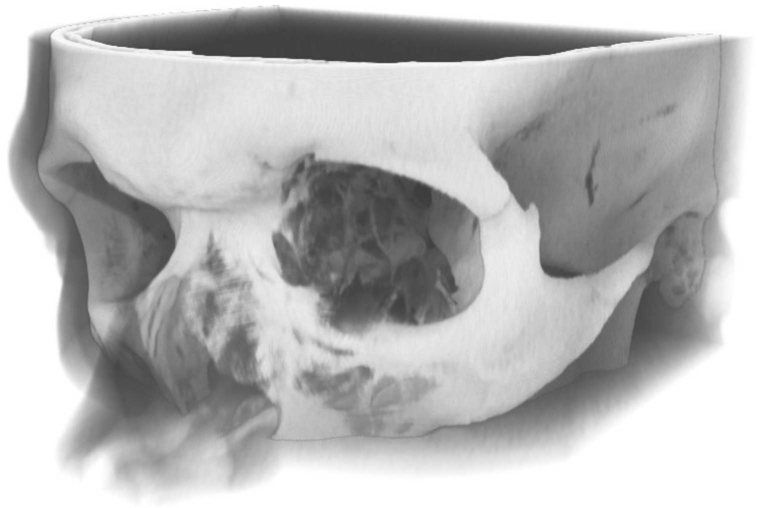
Some examples of what you can do with VTK

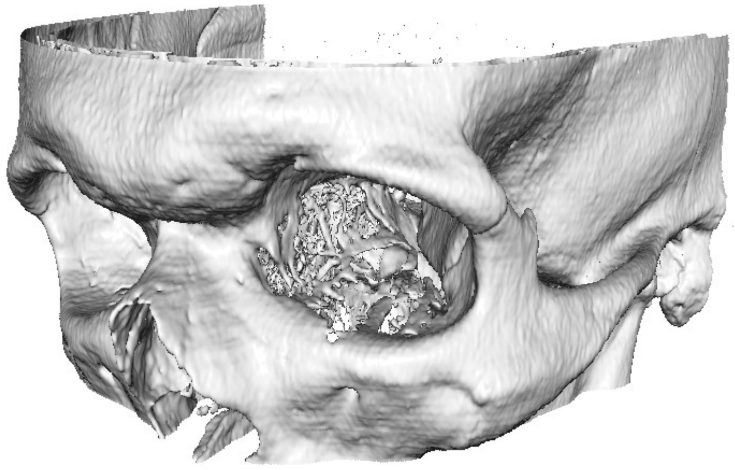
- Create visualizations of
  - scalar, vector, and tensor fields
  - volume data (e.g., 3D CT or MRI scans)
- Mesh and polygon processing
- Image analysis (2D and 3D images)
- Isosurface extraction
- Implementing your own algorithms

Volume rendering



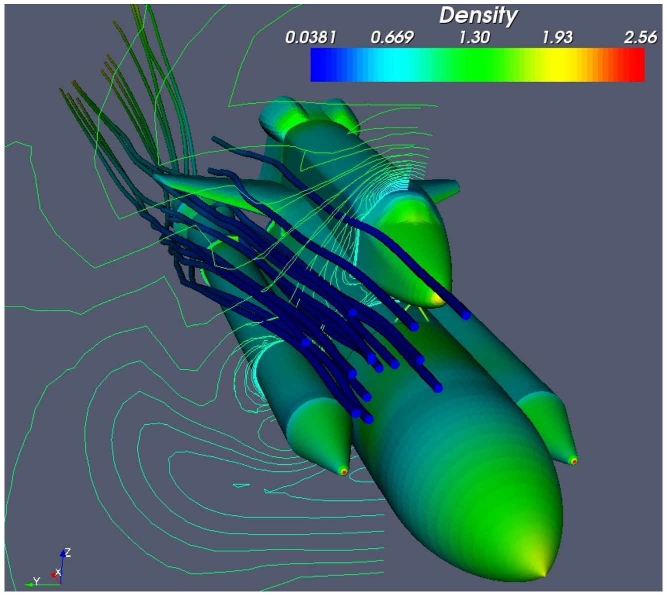




Rendering graphical 3D models (imported from .stl, .ply, .obj, etc)

Rendering performance

- VTK has decent rendering performance and is good for rapid prototyping of 3D visualization tools
- Not suitable for rendering large realistic 3D scenes with lots of dynamic content (i.e., games)

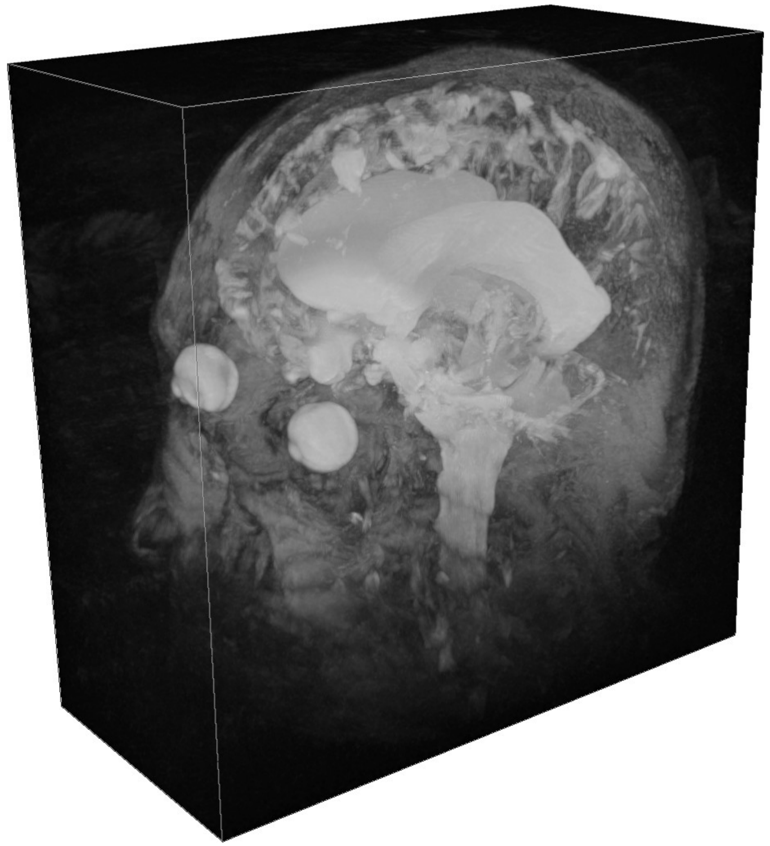


✓ ✗

The visualization pipeline

```
# vtk DataFile Version 3.0
vtk output
BINARY
DATASET STRUCTURED_POINTS
DIMENSIONS 256 256 124
SPACING 0.9 0.9 0.9
ORIGIN 0 0 0
CELL_DATA 7998075
POINT_DATA 8126464
COLOR_SCALARS ImageFile 1
^D^E^C^G^D^B^D^B^B^C^D^E^D^E^C^C
^D^C^C^C^C^E^D^C^A^B^B^B^F^A^C^E
^D^D^E^A^A^C^B^B^E^B^A^A^E^B^E^E
^A^C^C^G^C^D^F^B^D^E^@^G^C^D^D^C
^D^C^F^C^B^E^E^E^B^C^C^B^C^B^C^B
^C^C^F^E^F^C^D^A^A^C^F^D^D^E^E^B
```

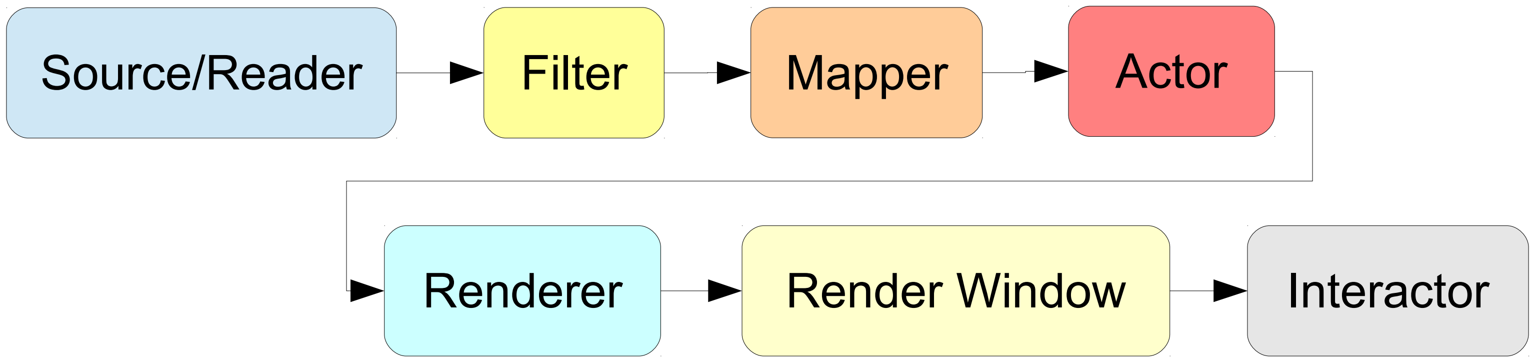
Input data



Visualization

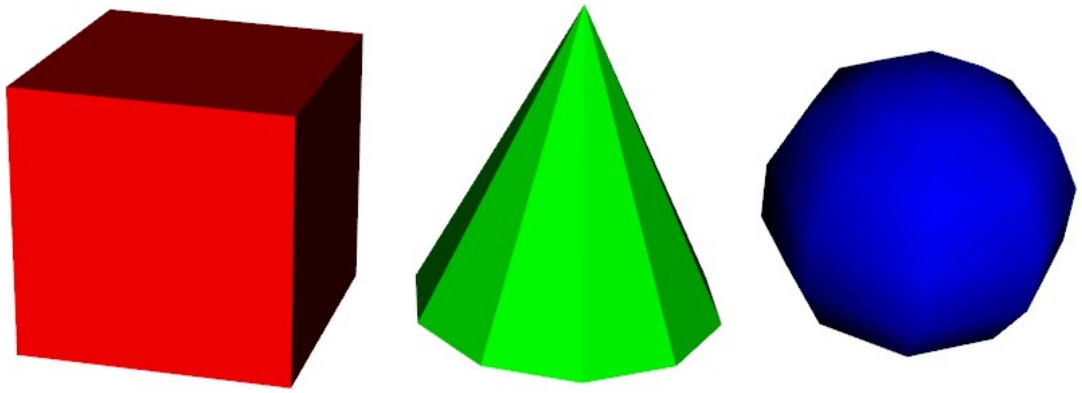
The visualization pipeline

- To visualize your data in VTK, you normally set up a pipeline like this:



Sources

- VTK provides various source classes that can be used to construct simple geometric objects like spheres, cubes, cones, cylinders, etc...
- Examples: **vtkSphereSource**, **vtkCubeSource**, **vtkConeSource**



source/reader → filter → mapper → actor → renderer → renderWindow → interactor

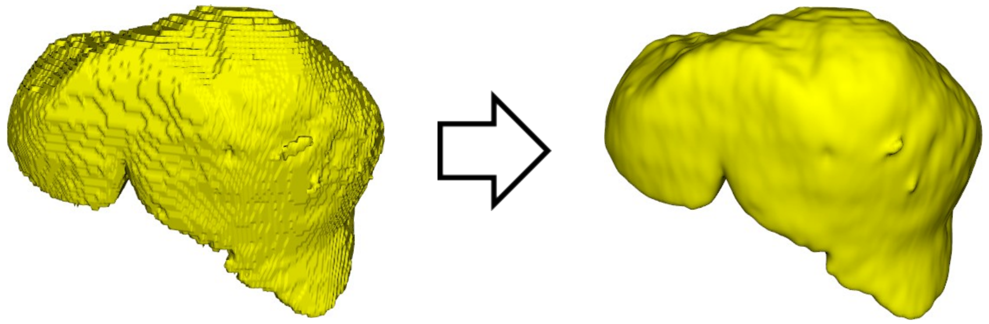
Readers

- Reads data from file
- You can use, e.g., **vtkStructuredPointsReader** to read a volumetric image from a .vtk file
- or **vtkSTLReader** to load a 3D polygon model from a .stl file
- If VTK cannot read your data, write your own reader!

source/reader → filter → mapper → actor → renderer → renderWindow → interactor

Filters

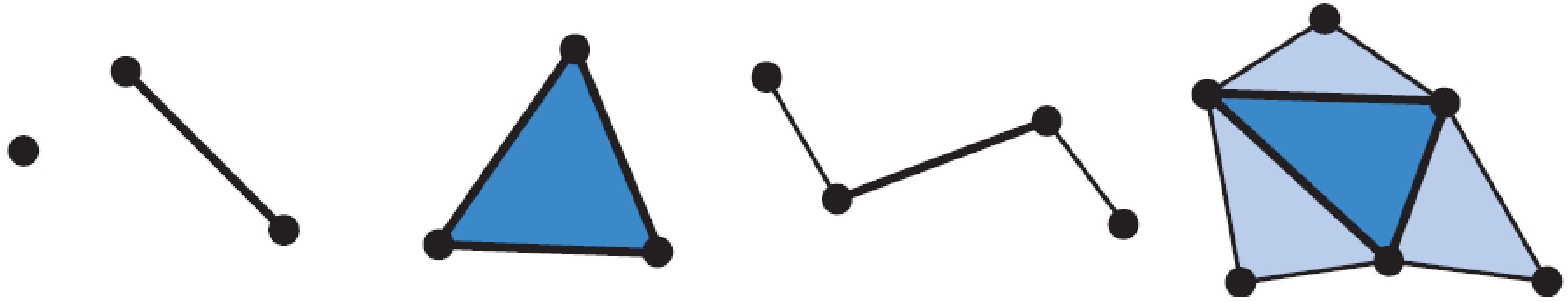
- Takes data as input, modifies it in some way, and returns the modified data
- Can be used to (for example)
  - select data of a particular size, strength, intensity, etc
  - process 2D/3D images or polygon meshes
  - generate geometric objects from data



source/reader → filter → mapper → actor → renderer → renderWindow → interactor

Mappers

- Maps data to graphics primitives (points, lines, or triangles) that can be displayed by the renderer
- The mapper you will use most in the labs is **vtkPolyDataMapper**
- **vtkPolyDataMapper** maps polygonal data (**vtkPolyData**) to graphics primitives

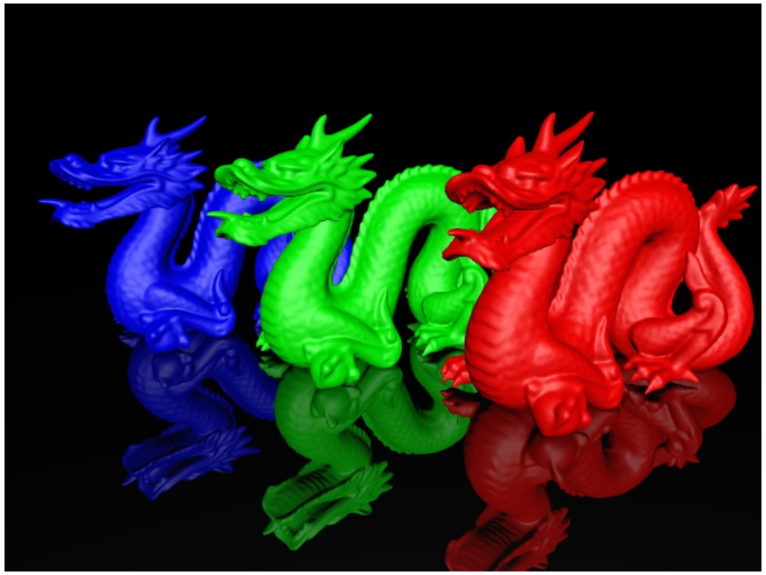


source/reader → filter → mapper → actor → renderer → renderWindow → interactor

Image source: http://www.realtimerendering.com

Actors

- **vtkActor** represents an object (geometry and properties) in a rendering scene
- Has position, scale, orientation, various rendering properties, textures, etc. Keeps a reference to the mapper.



source/reader → filter → mapper → actor → renderer → renderWindow → interactor

Rendering

- The process of converting 3D graphics primitives (points, lines, triangles, etc), a specification for lights and materials, and a camera view into an 2D image that can be displayed on the screen

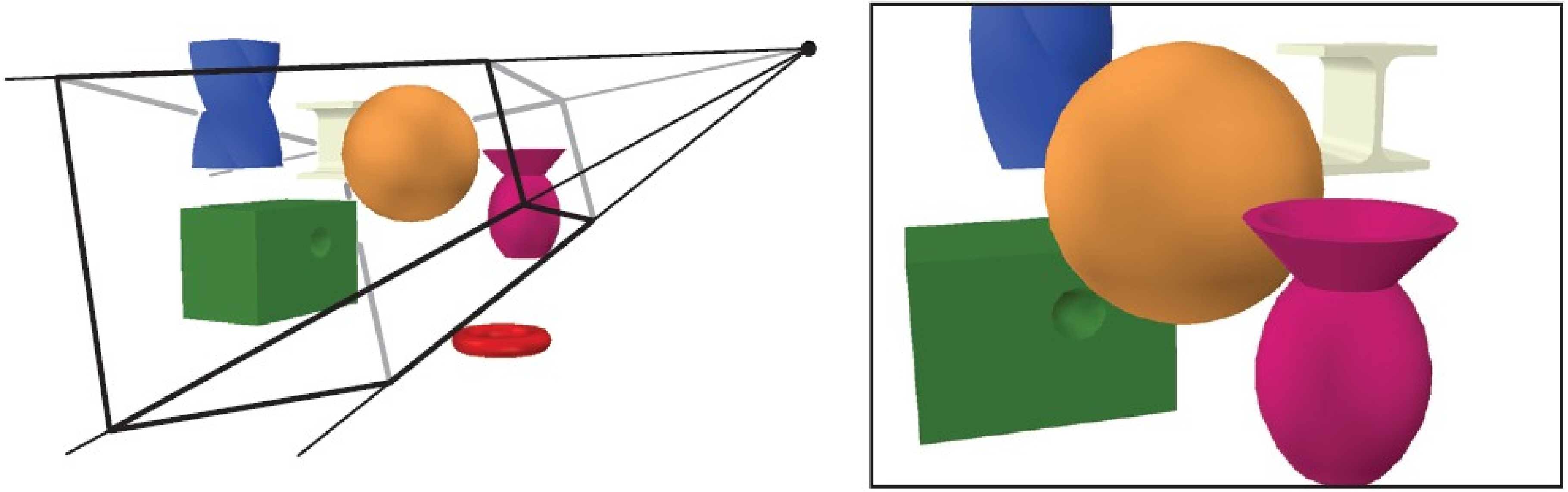
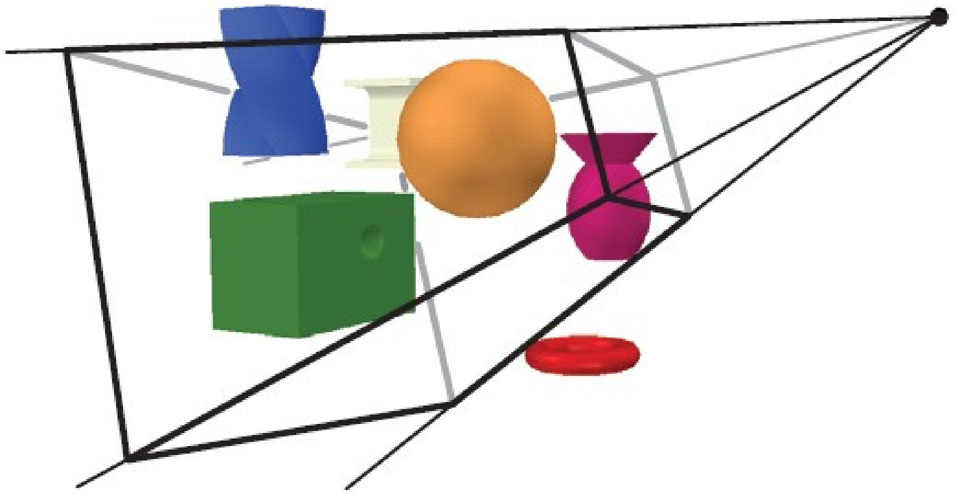
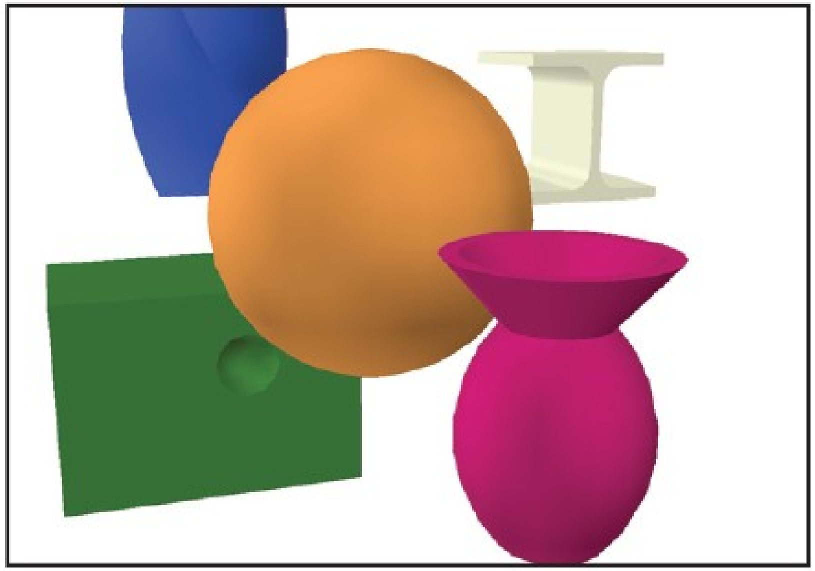


Image source: http://www.realtimerendering.com

Renderer

- **vtkRenderer** controls the rendering process for actors and scenes
- Under the hood, VTK uses OpenGL for rendering



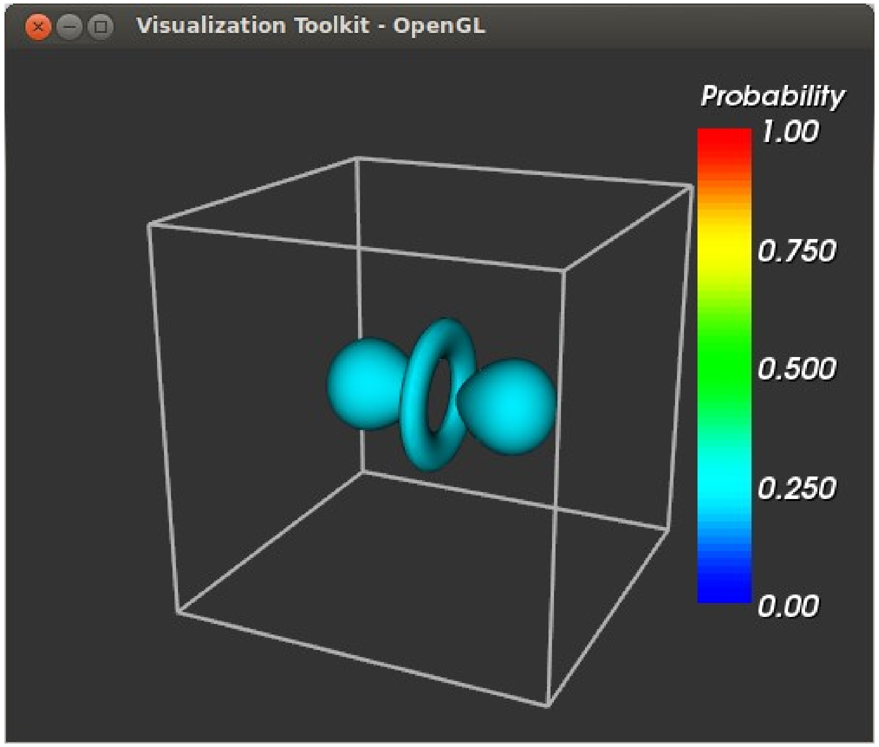


source/reader → filter → mapper → actor → renderer → renderWindow → interactor

Image source: http://www.realtimerendering.com

Render window

- The **vtkRenderWindow** class creates a window for renderers to draw into



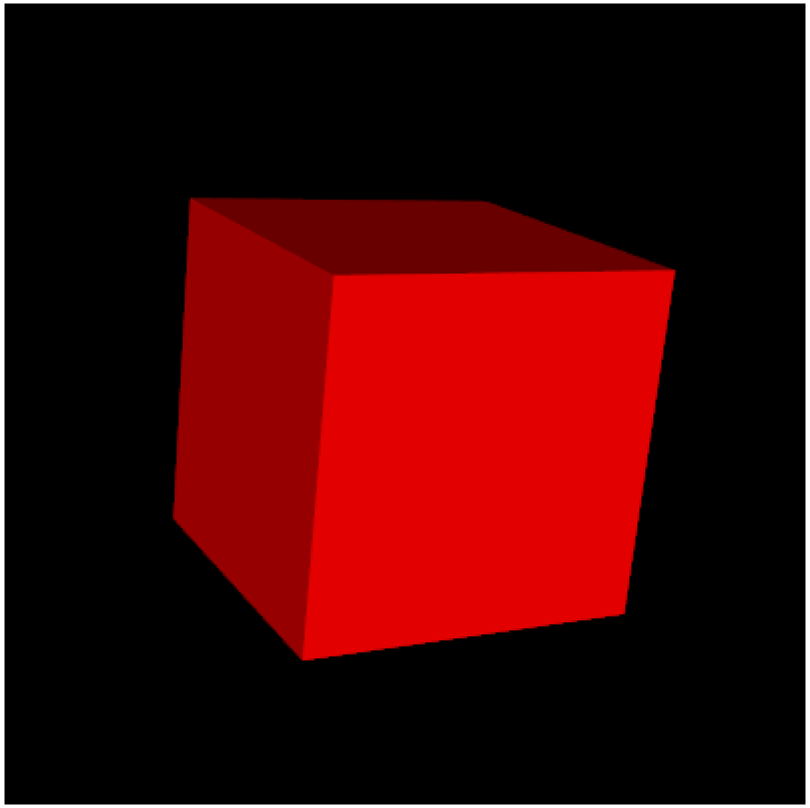
source/reader → filter → mapper → actor → renderer → renderWindow → interactor

Interactors

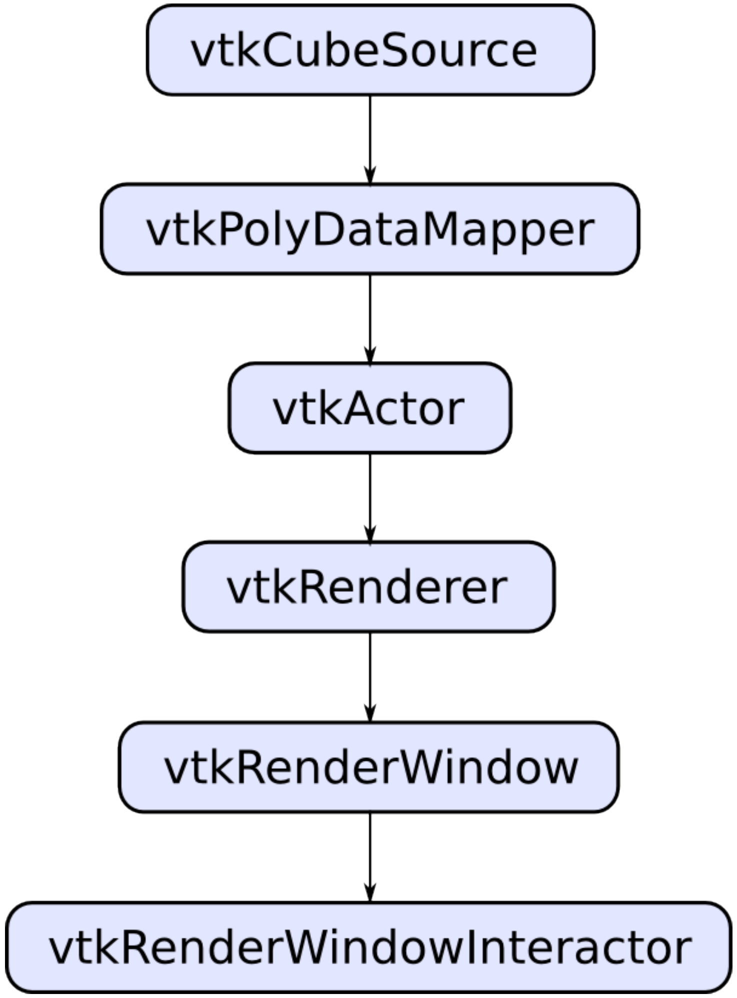
- The **vtkRenderWindowInteractor** class provides platform-independent window interaction via the mouse and keyboard
- Allows you to rotate/zoom/pan the camera, select and manipulate actors, etc
- Also handles time events

source/reader → filter → mapper → actor → renderer → renderWindow → interactor

Example 1:
Rendering a cube



Pipeline for the cube example



Source

```
import vtk

# Generate polygon data for a cube
cube = vtk.vtkCubeSource()
```

source/reader → filter → mapper → actor → renderer → renderWindow → interactor

Mapper

```
# Create a mapper for the cube data
cube_mapper = vtk.vtkPolyDataMapper()
cube_mapper.SetInput(cube.GetOutput())
```

source/reader → filter → mapper → actor → renderer → renderWindow → interactor

Actor

```
# Connect the mapper to an actor
cube_actor = vtk.vtkActor()
cube_actor.SetMapper(cube_mapper)
cube_actor.GetProperty().SetColor(1.0, 0.0, 0.0)
```

source/reader → filter → mapper → actor →
renderer → renderWindow → interactor

Renderer

```
# Create a renderer and add the cube actor to it
renderer = vtk.vtkRenderer()
renderer.SetBackground(0.0, 0.0, 0.0)
renderer.AddActor(cube_actor)
```

source/reader → filter → mapper → actor → renderer → renderWindow → interactor

Render window

```
# Create a render window
render_window = vtk.vtkRenderWindow()
render_window.SetWindowName("Simple VTK scene")
render_window.SetSize(400, 400)
render_window.AddRenderer(renderer)
```

source/reader → filter → mapper → actor → renderer → renderWindow → interactor

Interactor

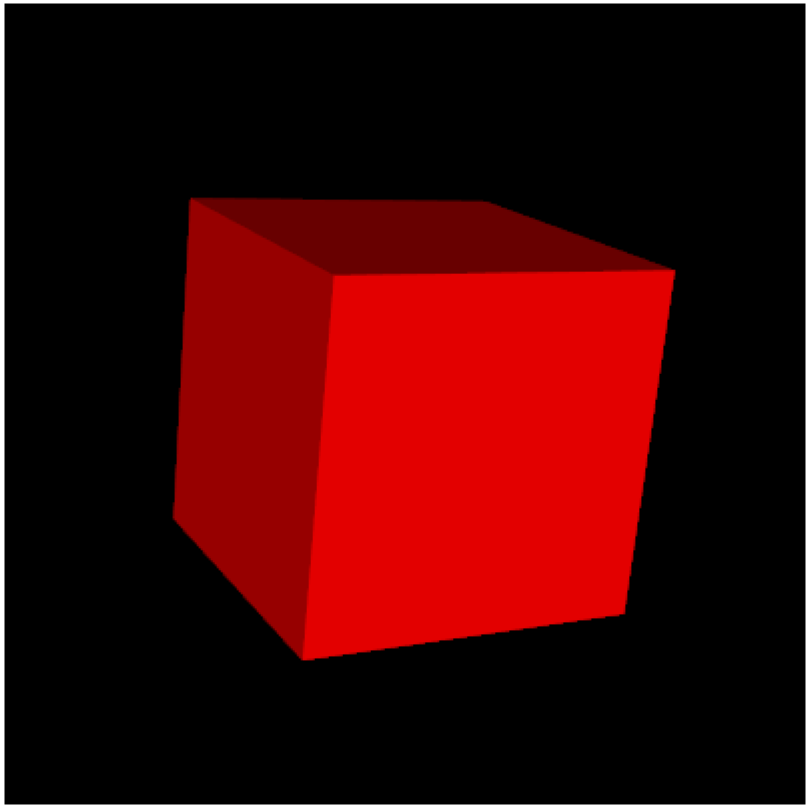
```
# Create an interactor
interactor = vtk.vtkRenderWindowInteractor()
interactor.SetRenderWindow(render_window)

# Initialize the interactor and start the
# rendering loop
interactor.Initialize()
render_window.Render()
interactor.Start()
```

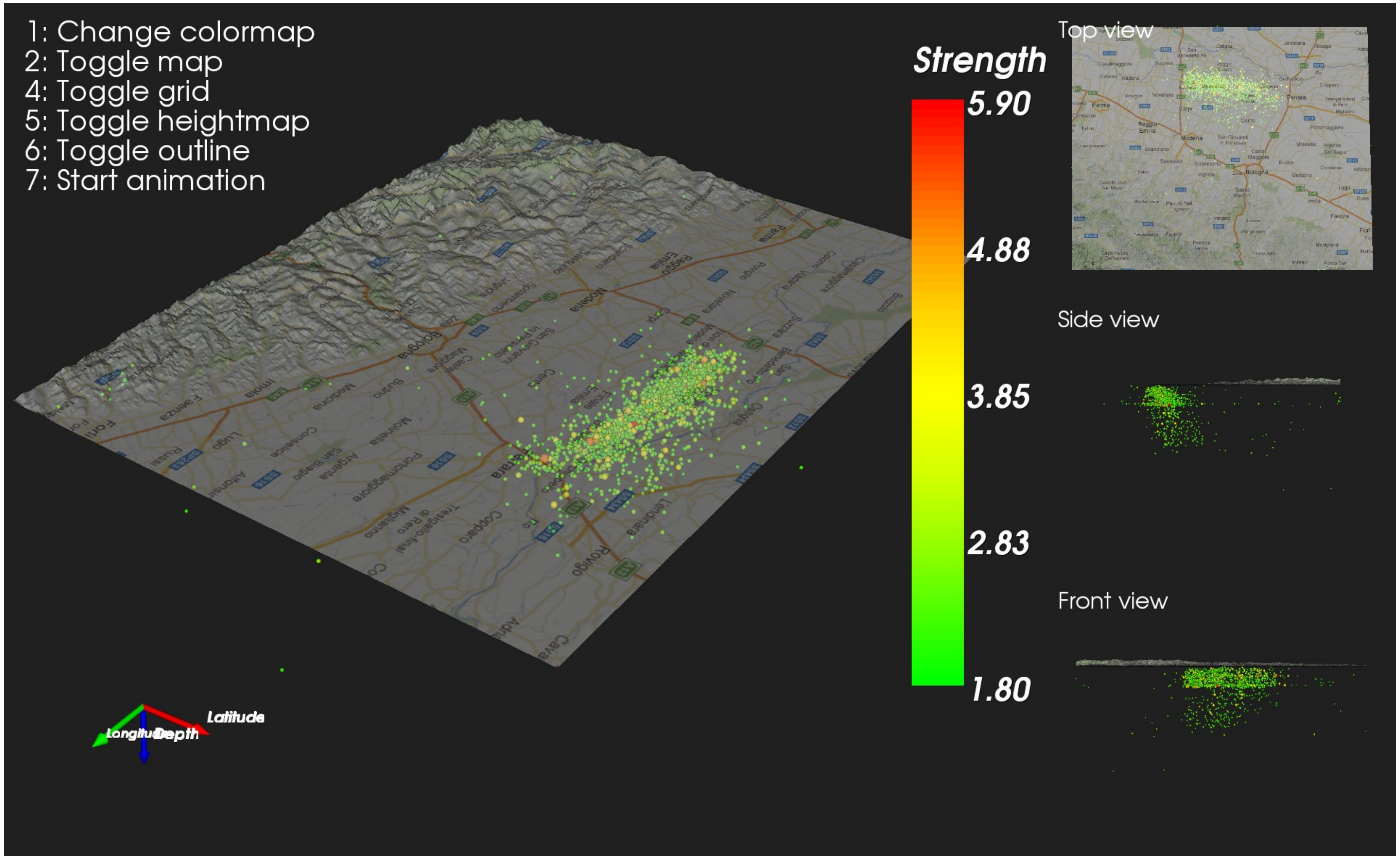
source/reader → filter → mapper → actor → renderer → renderWindow → interactor

Source code – cube.py

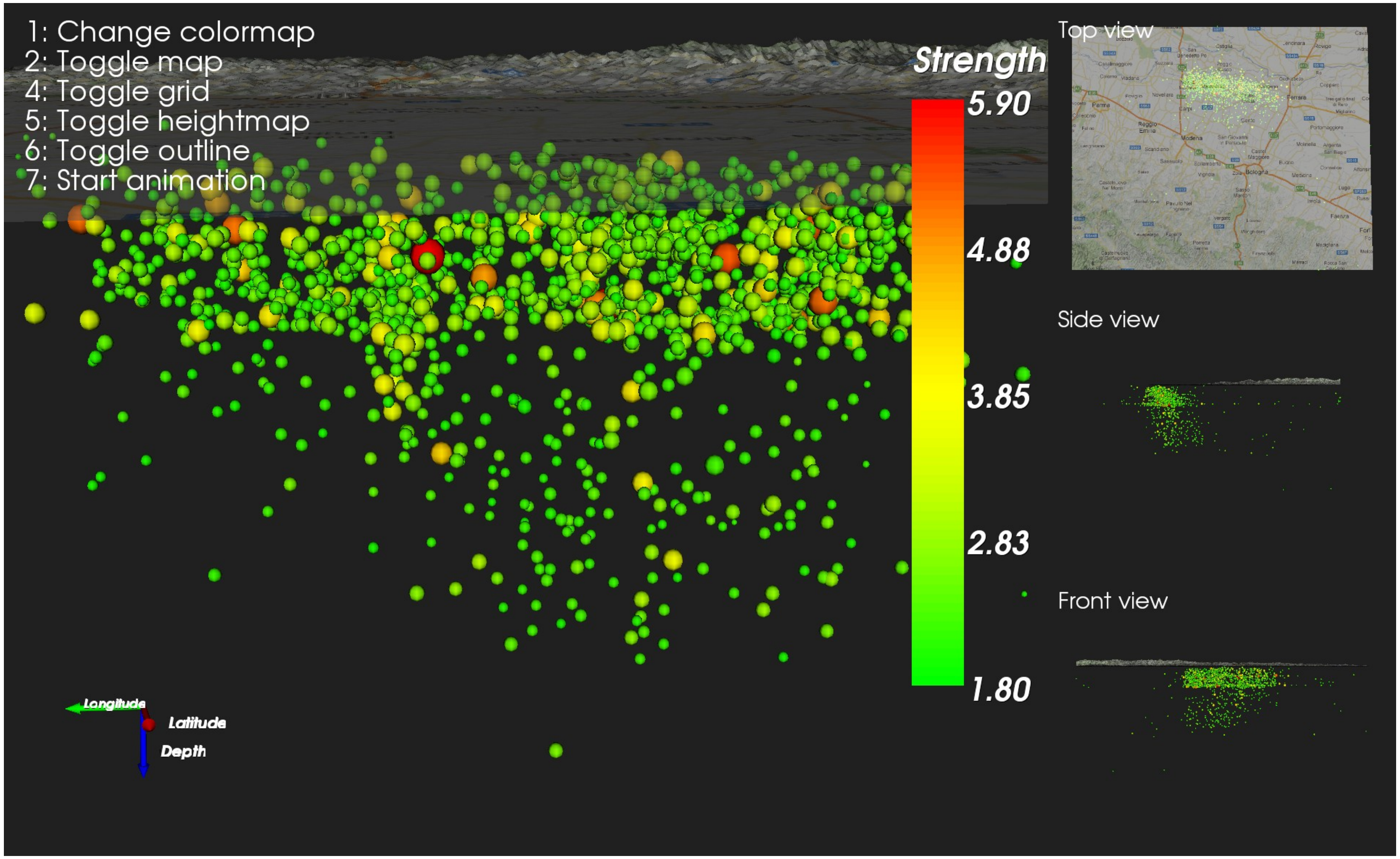
- Included in the .ZIP file containing the source code and datasets for Lab 1
- You can download it from the course webpage



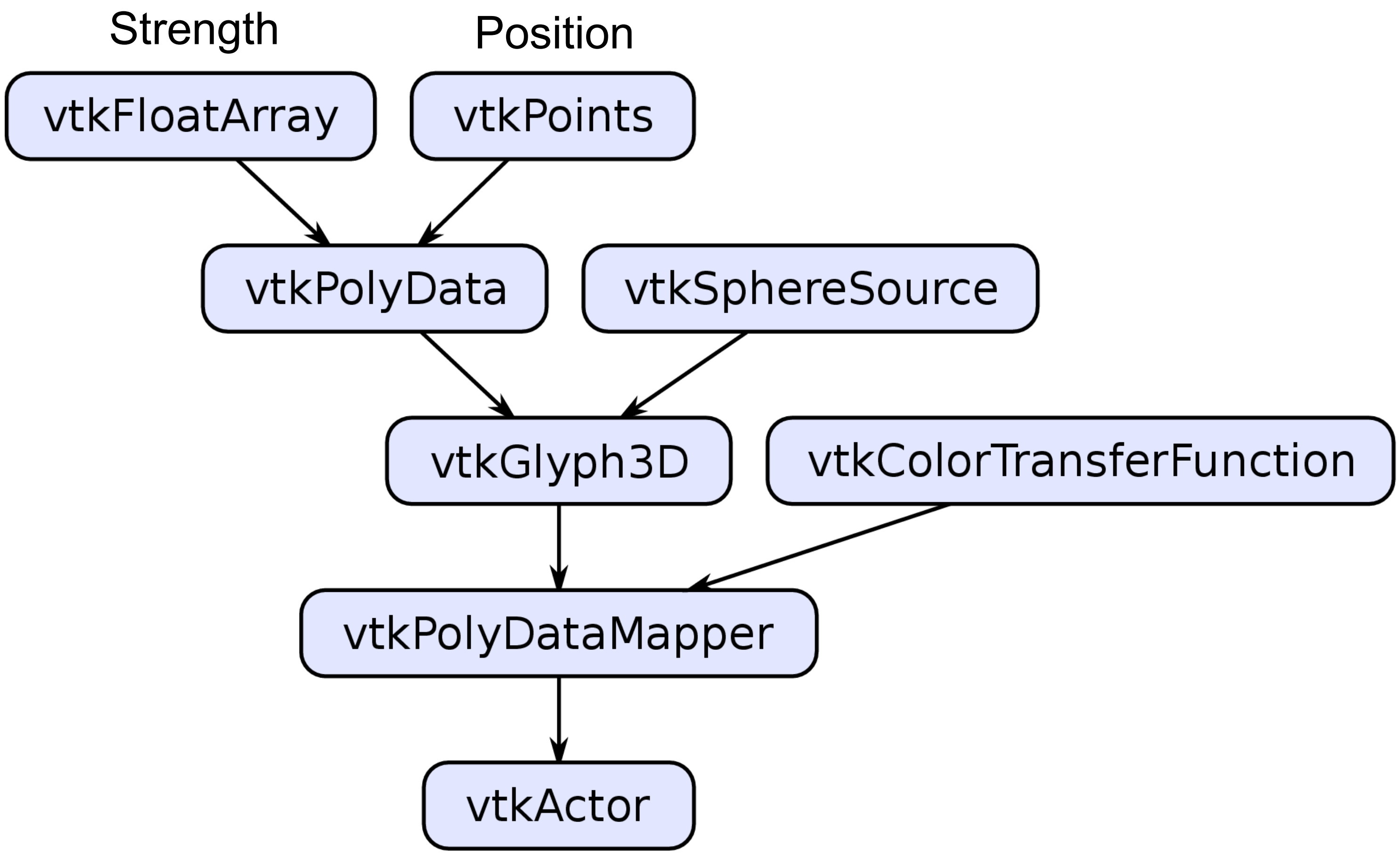
Example 2: Earthquake data



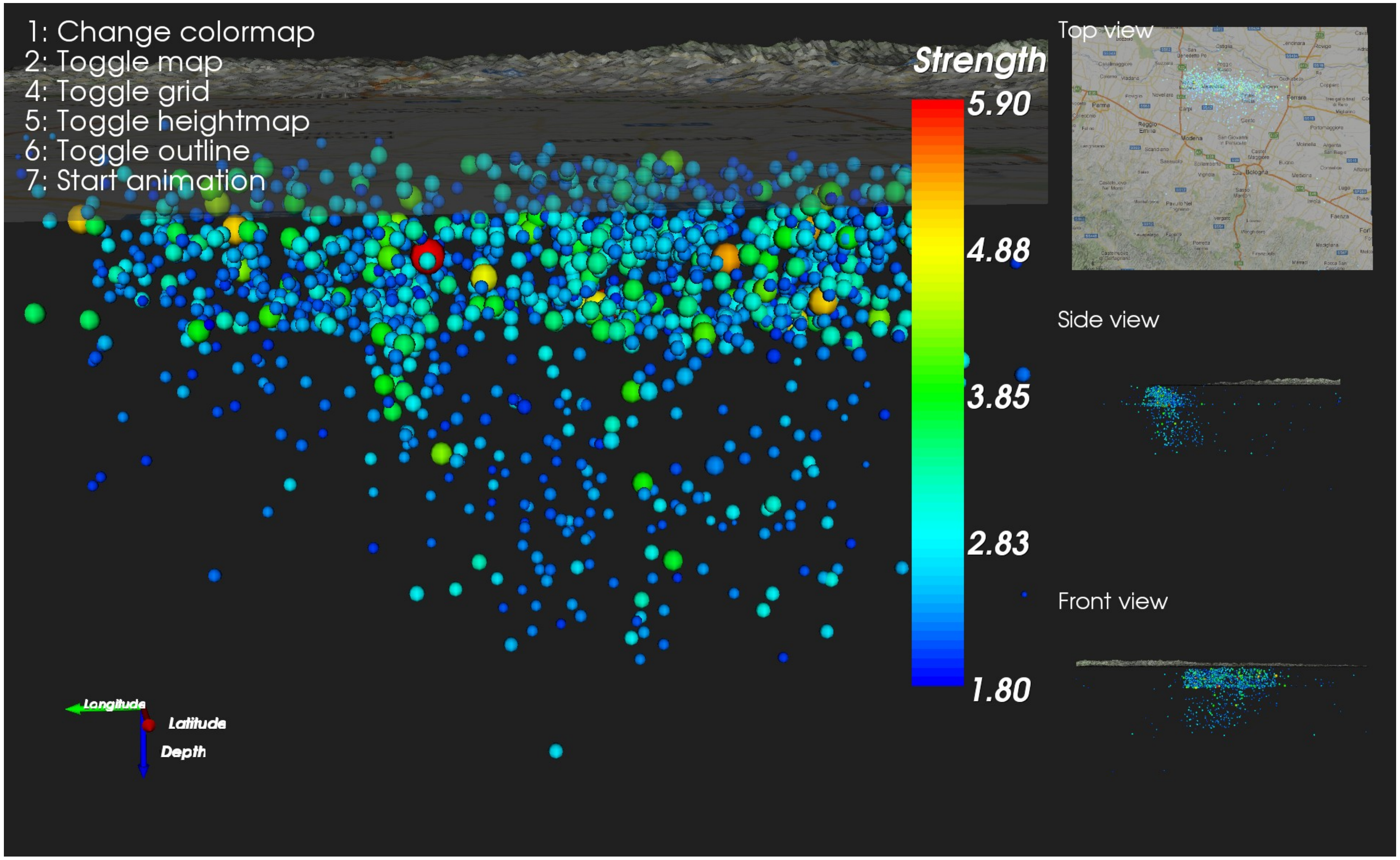
Visualizing the quakes with sphere glyphs



Sphere glyphs

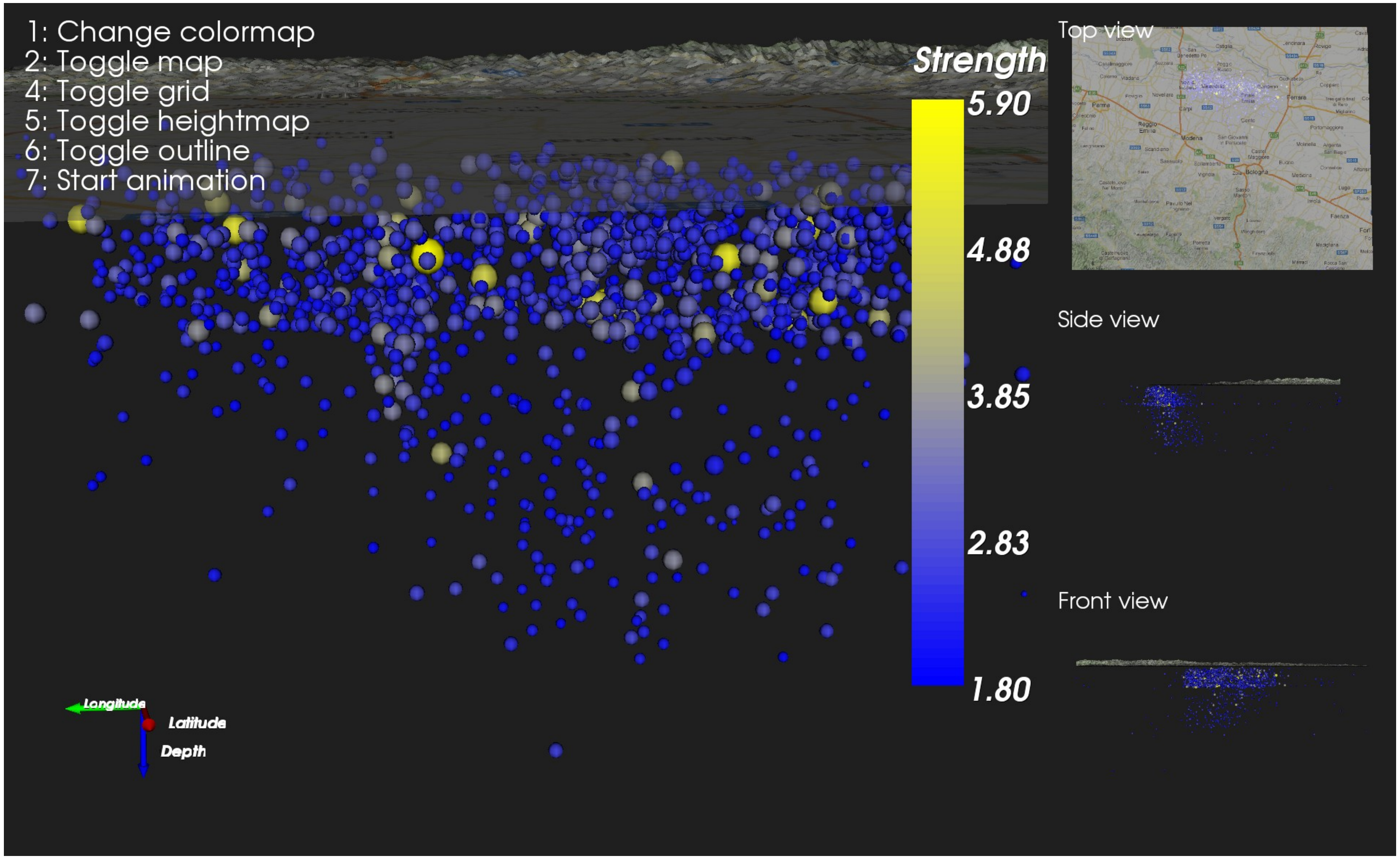


Colormaps

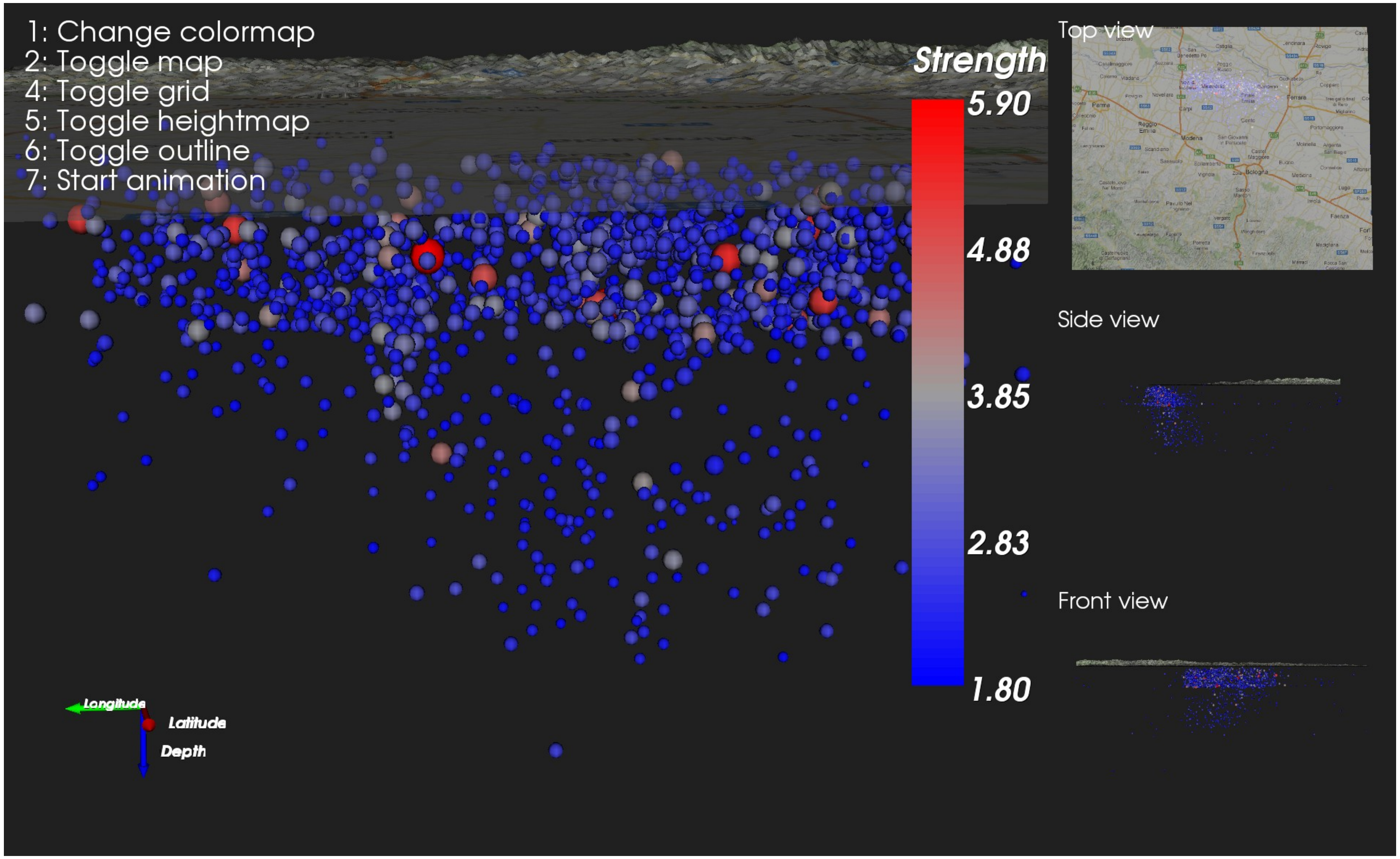


See this paper for a discussion on why the "rainbow" colormap is a poor choice for most applications

Colormaps


1: Change colormap
2: Toggle map
4: Toggle grid
5: Toggle heightmap
6: Toggle outline
7: Start animation
Strength
5.90
4.88
3.85
2.83
1.80
Top view
Side view
Front view
Longitude
Latitude
Depth

Colormaps



1: Change colormap
2: Toggle map
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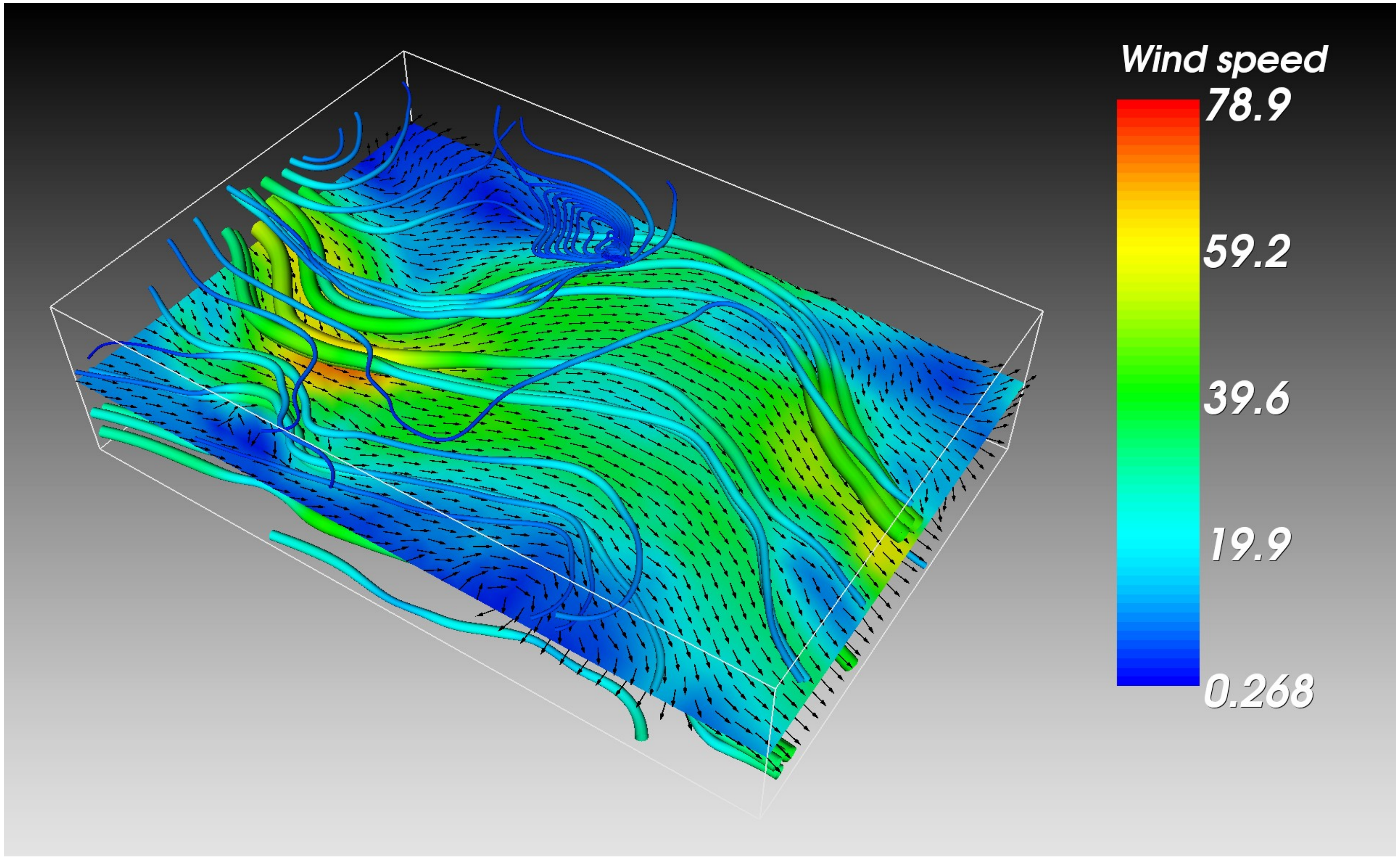
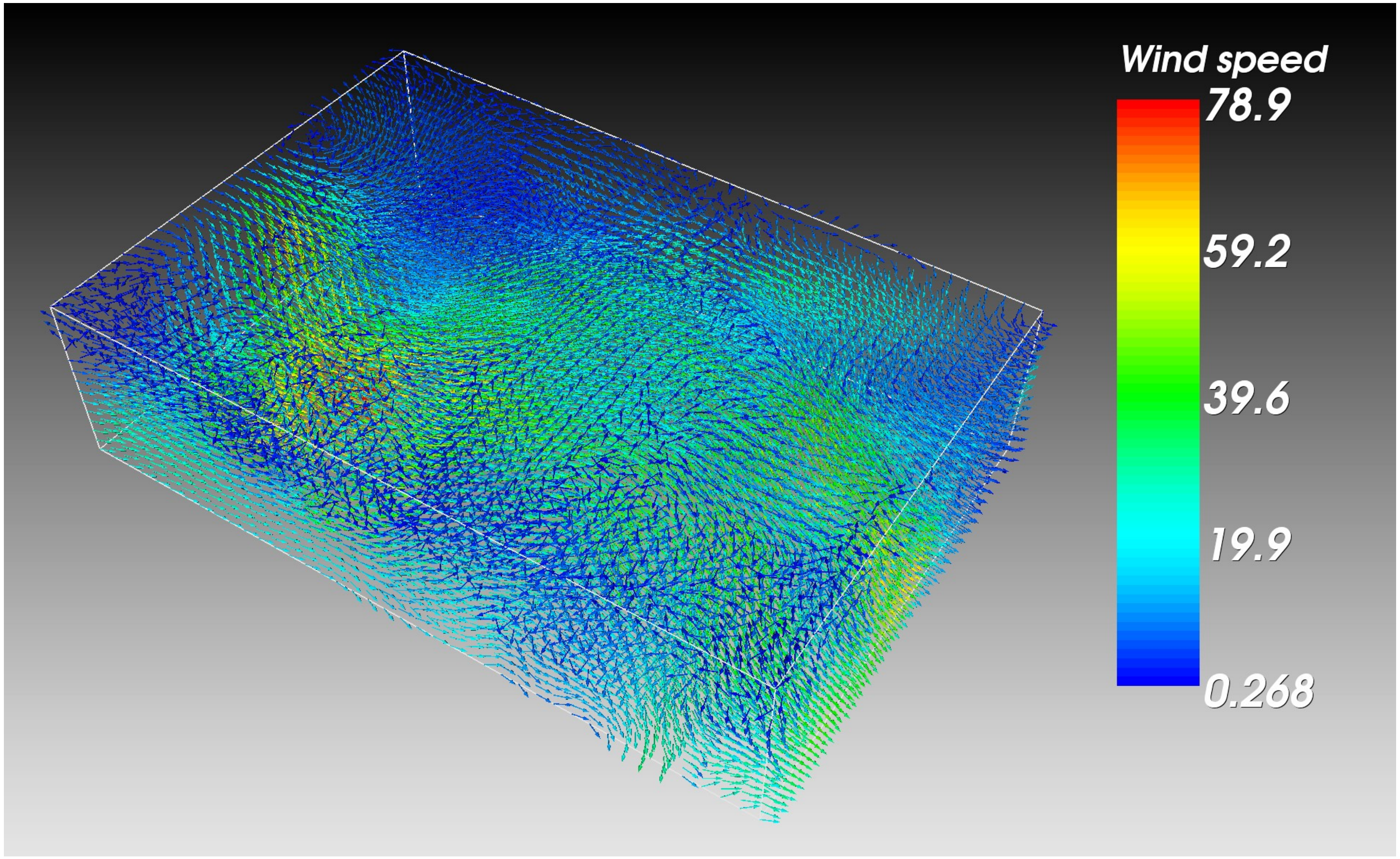
5: Toggle heightmap
6: Toggle outline
7: Start animation
Strength
5.90
4.88
3.85
2.83
1.80
Top view
Side view
Front view
Longitude
Latitude
Depth

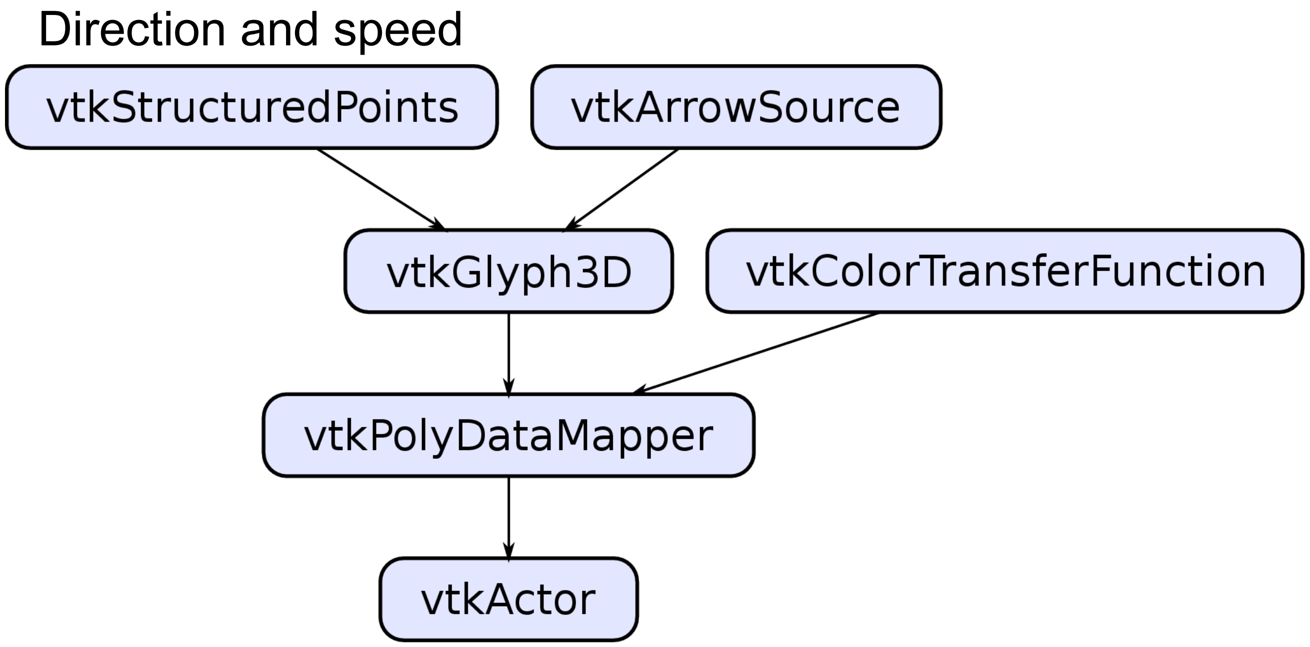
Example 2:
Air currents



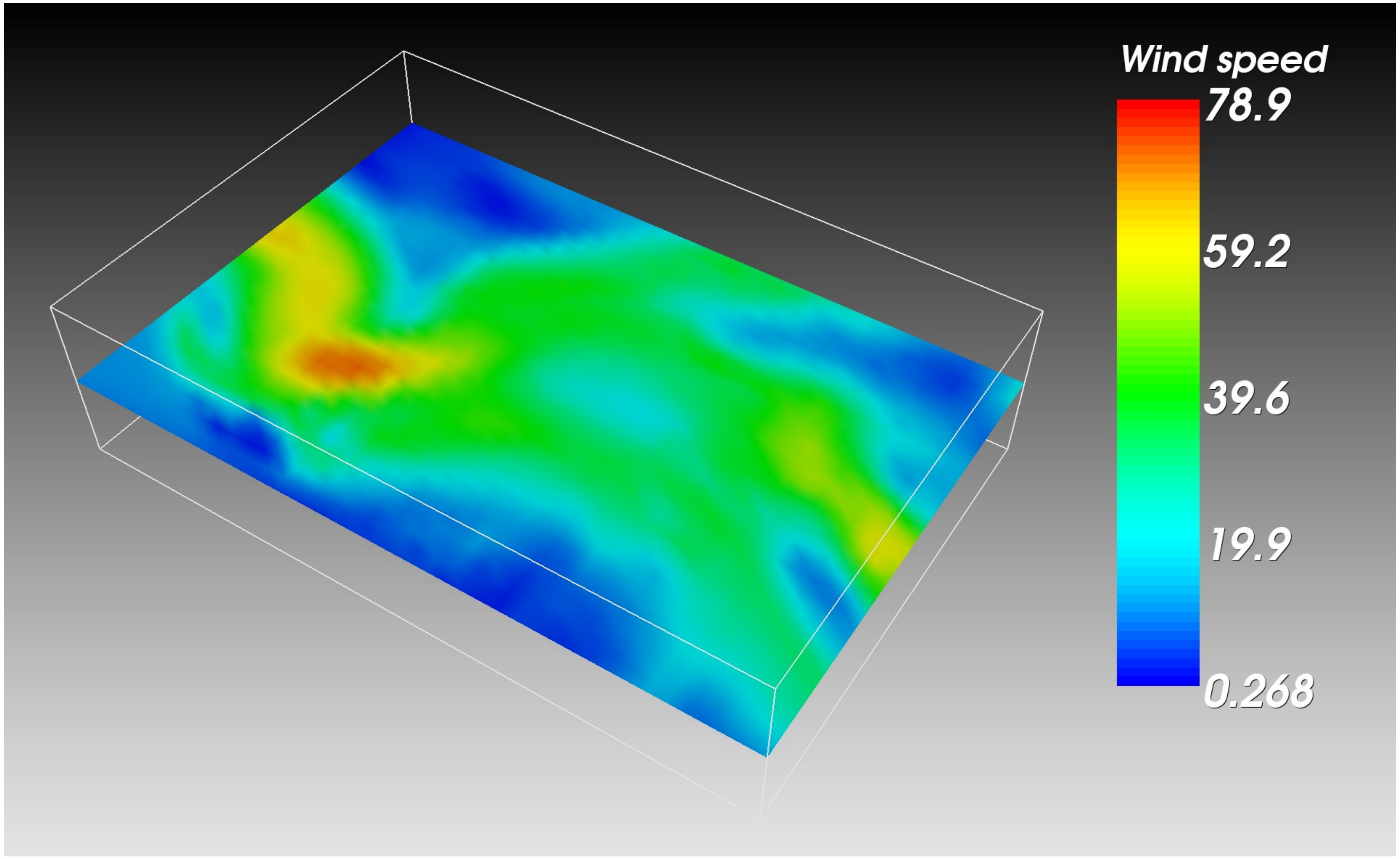
Arrow glyphs, first try



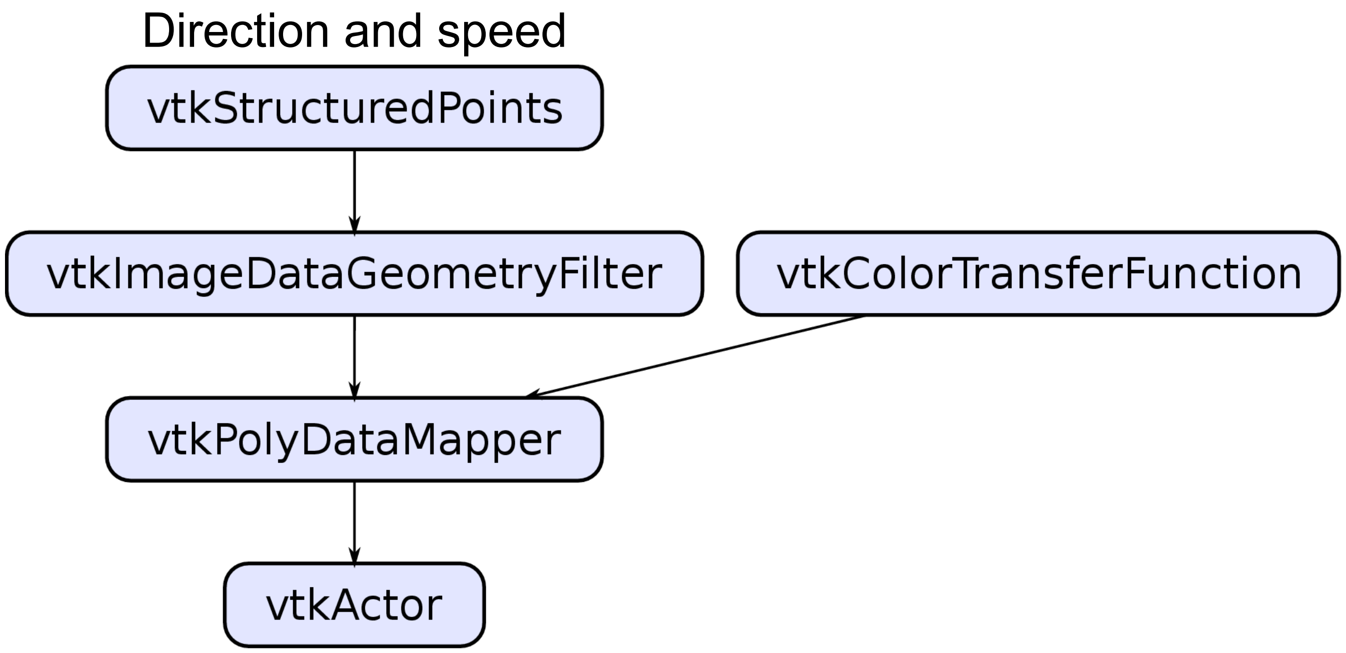
Arrow glyphs, first try



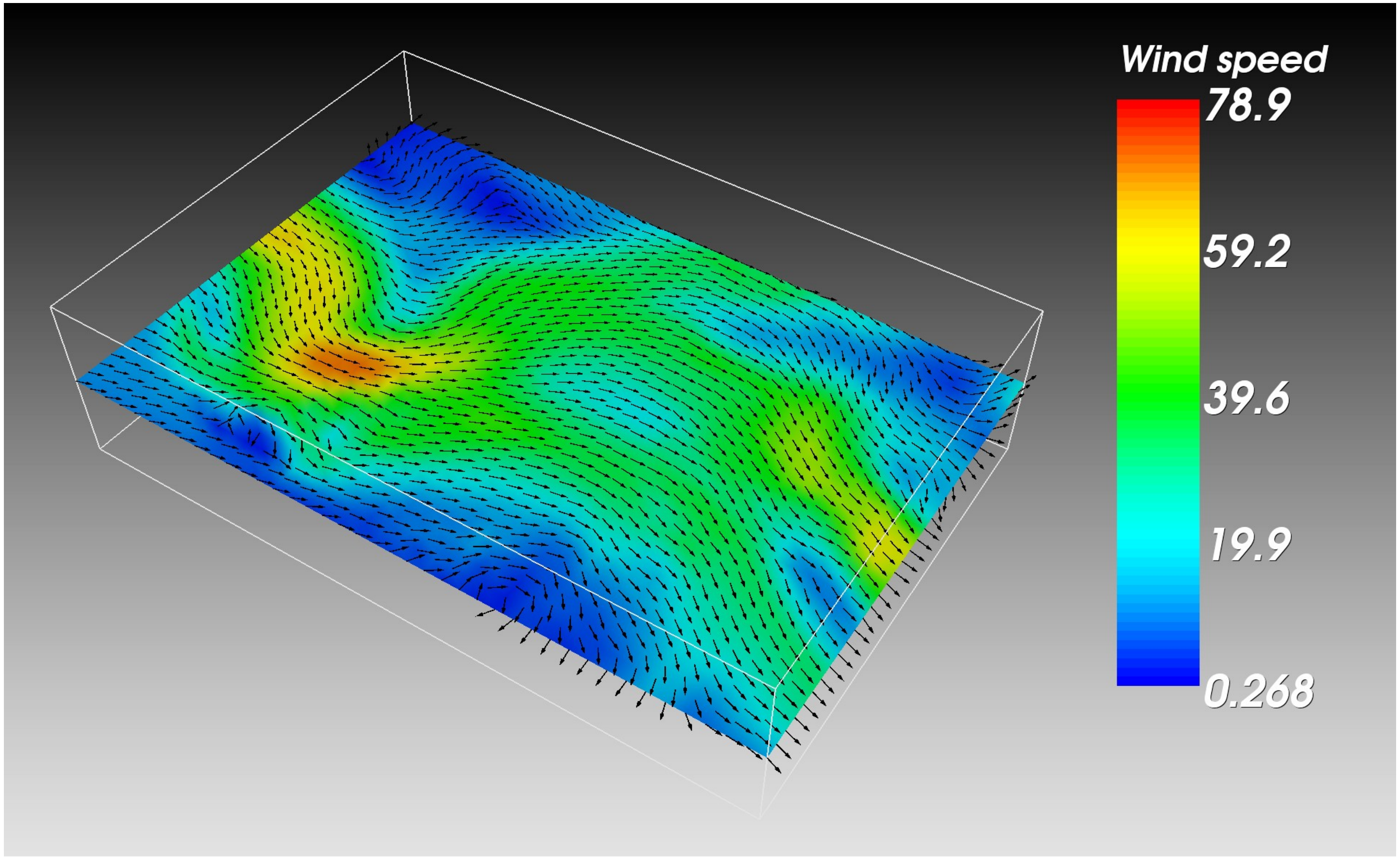
Cut planes



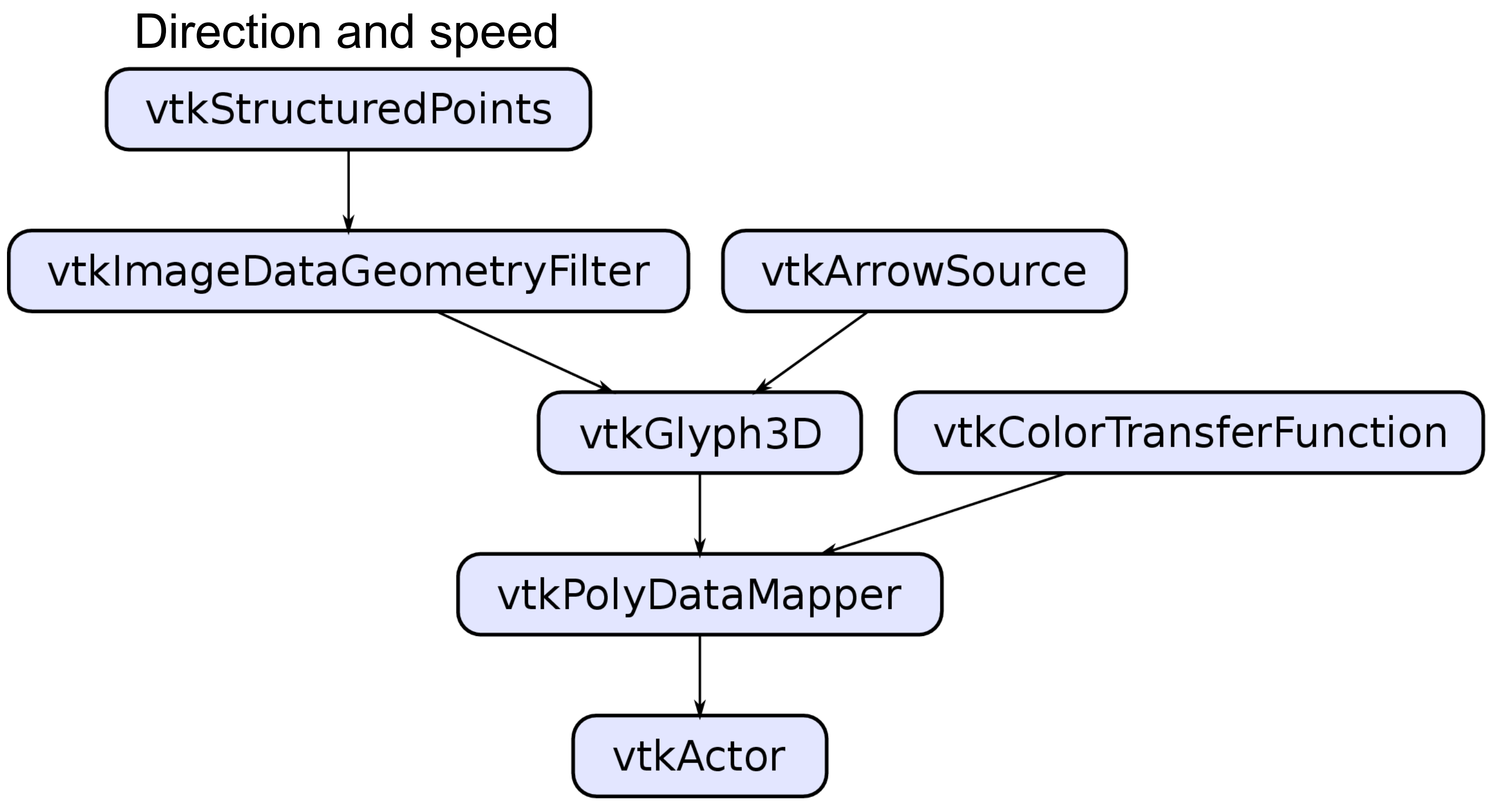
Cut planes


Direction and speed
vtkStructuredPoints
vtkImageDataGeometryFilter
vtkColorTransferFunction
vtkPolyDataMapper
vtkActor

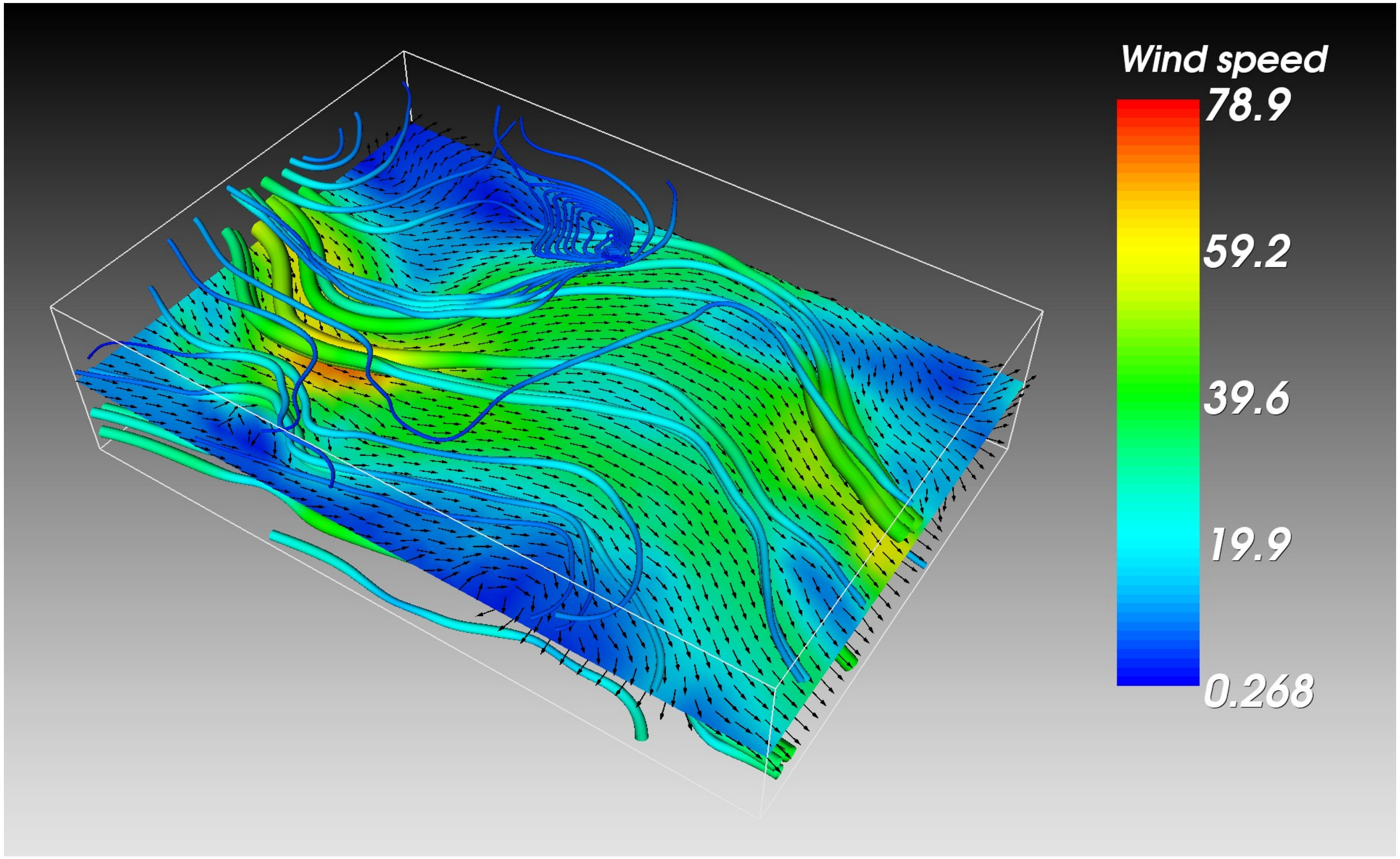
Arrow glyphs, second try



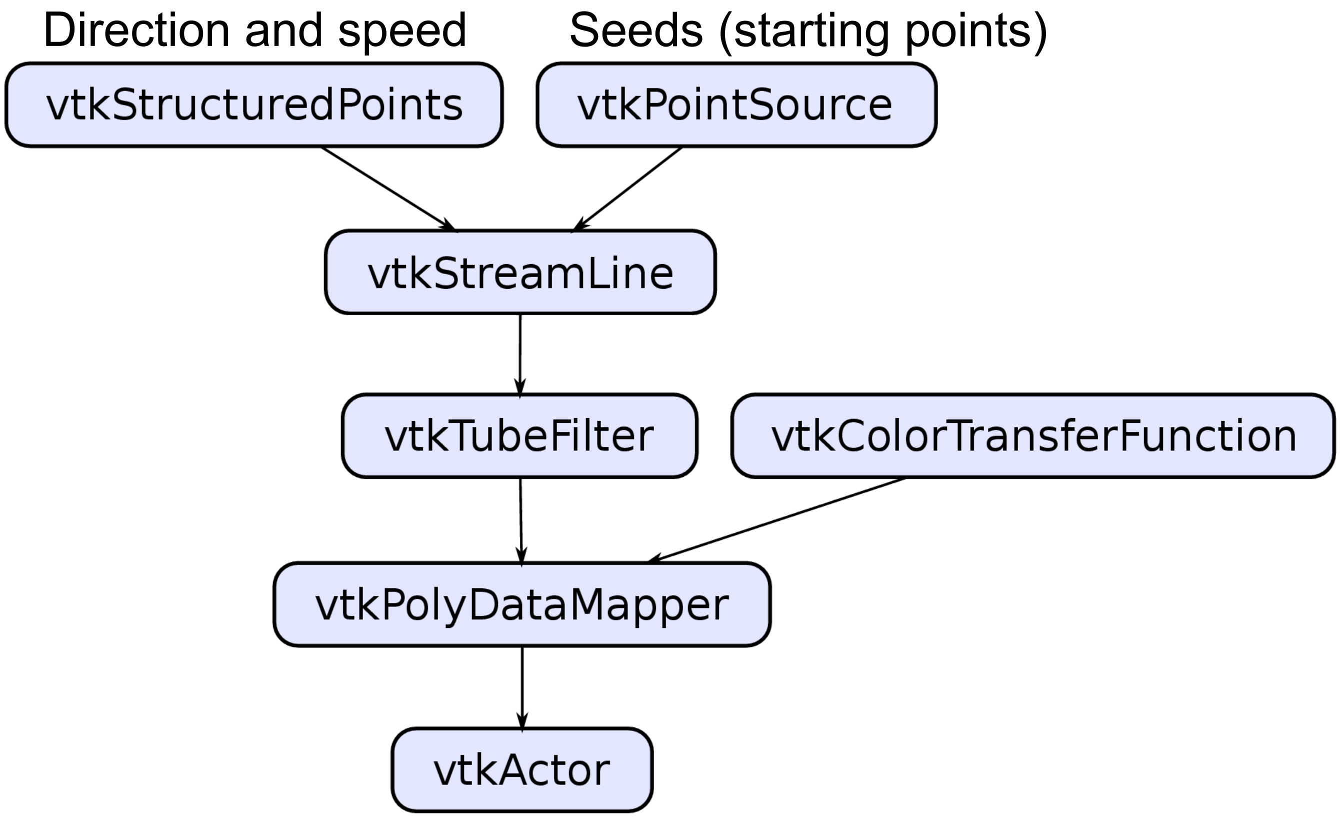
Arrow glyphs, second try



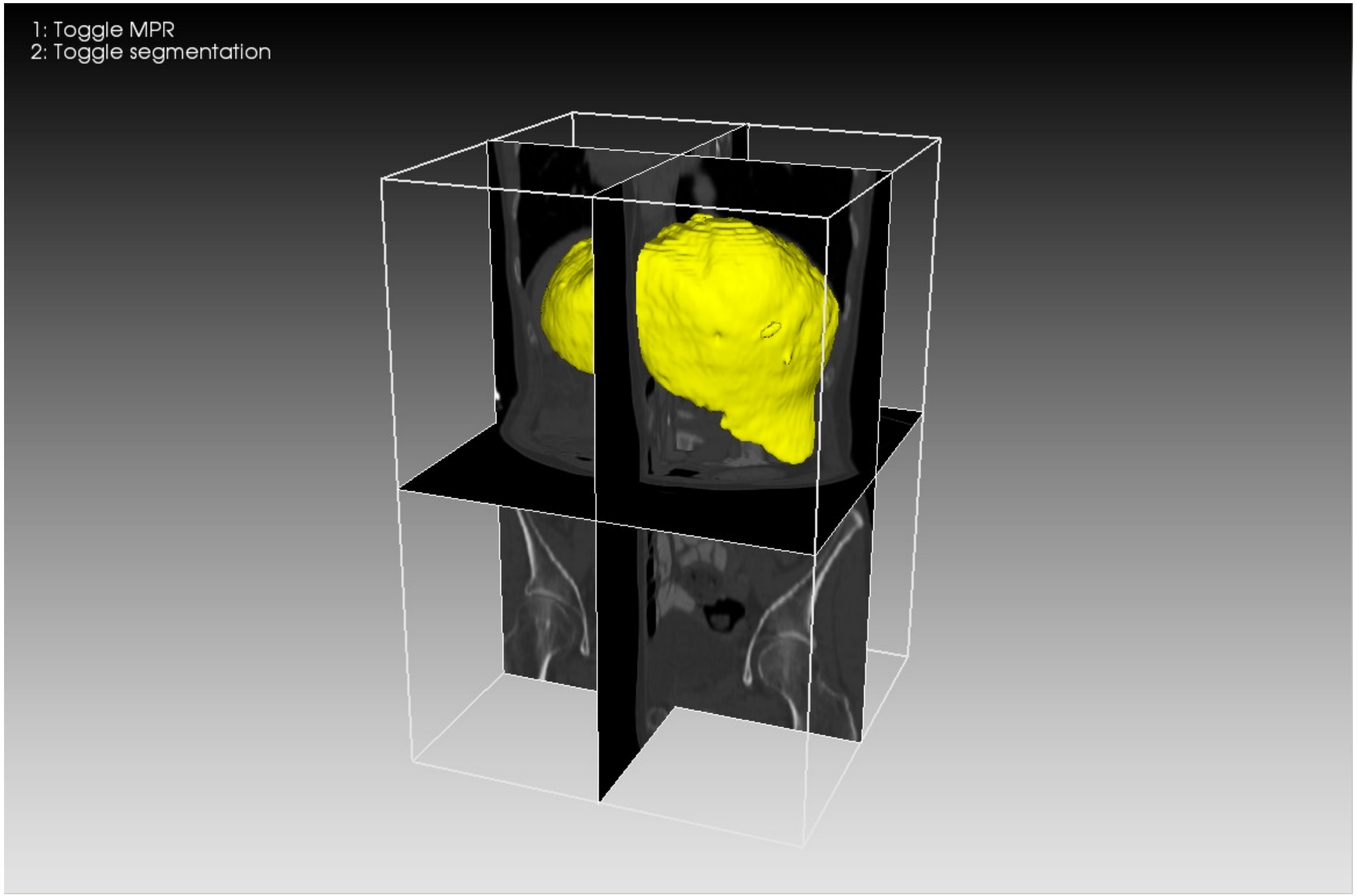
Streamtubes



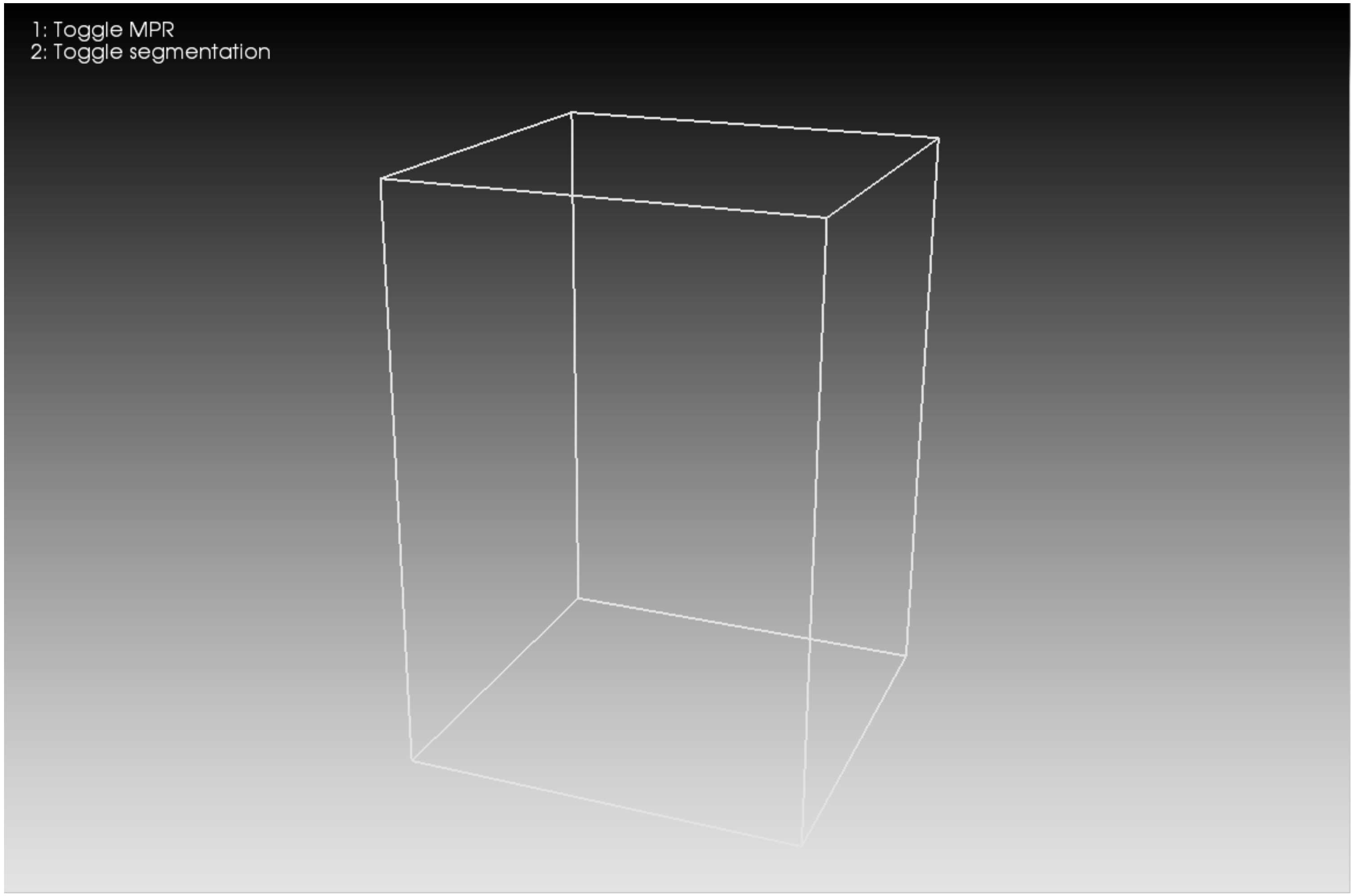
Streamtubes



Example 3: Medical 3D data

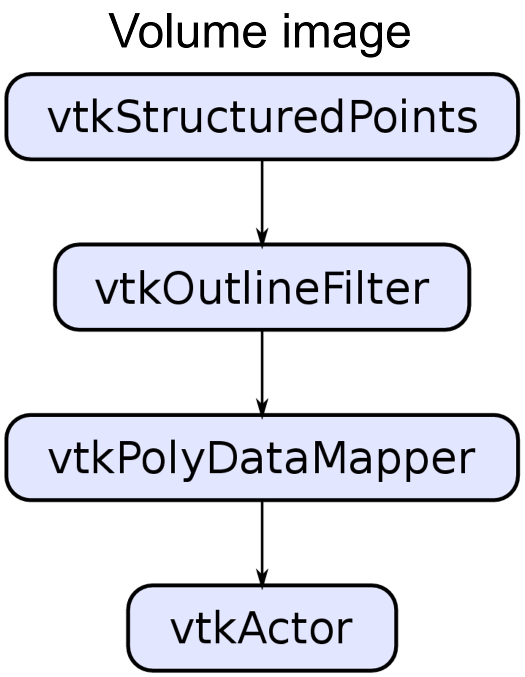


Outline

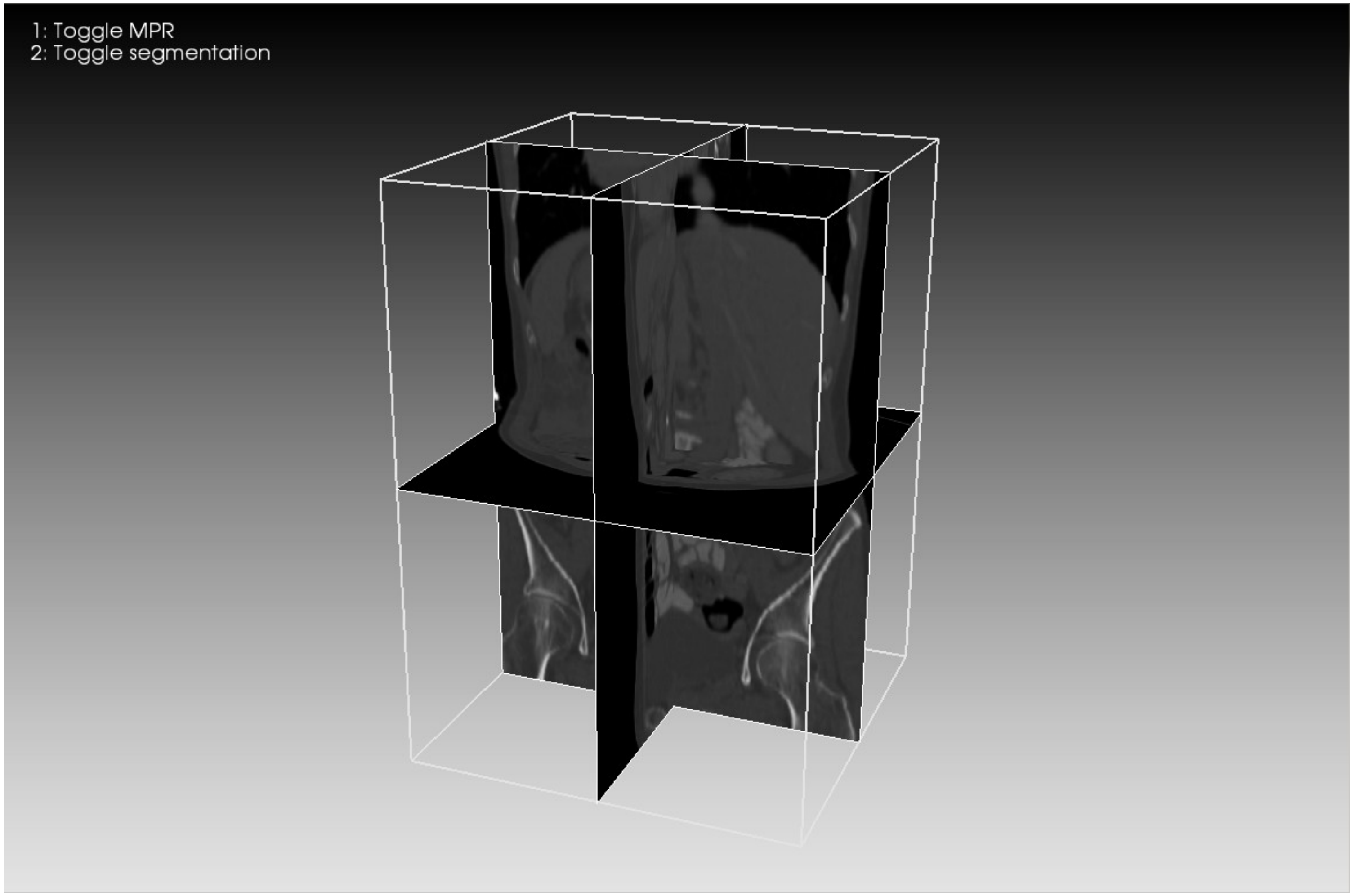


1: Toggle MPR
2: Toggle segmentation

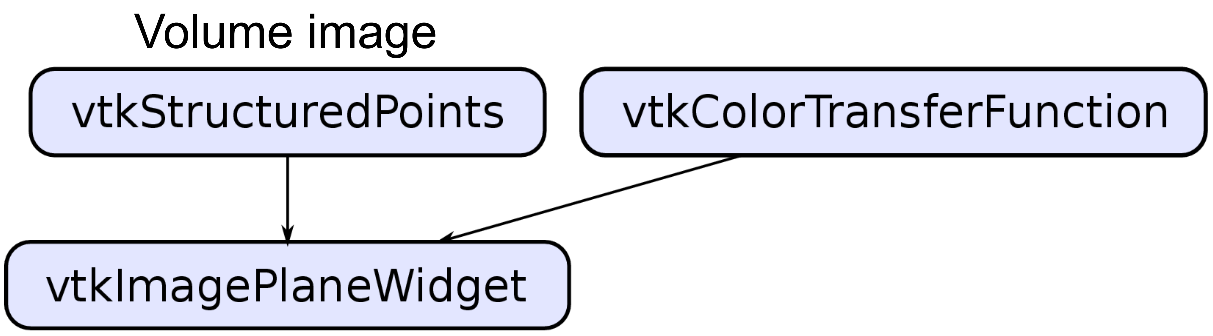
Outline


Volume image
vtkStructuredPoints
vtkOutlineFilter
vtkPolyDataMapper
vtkActor

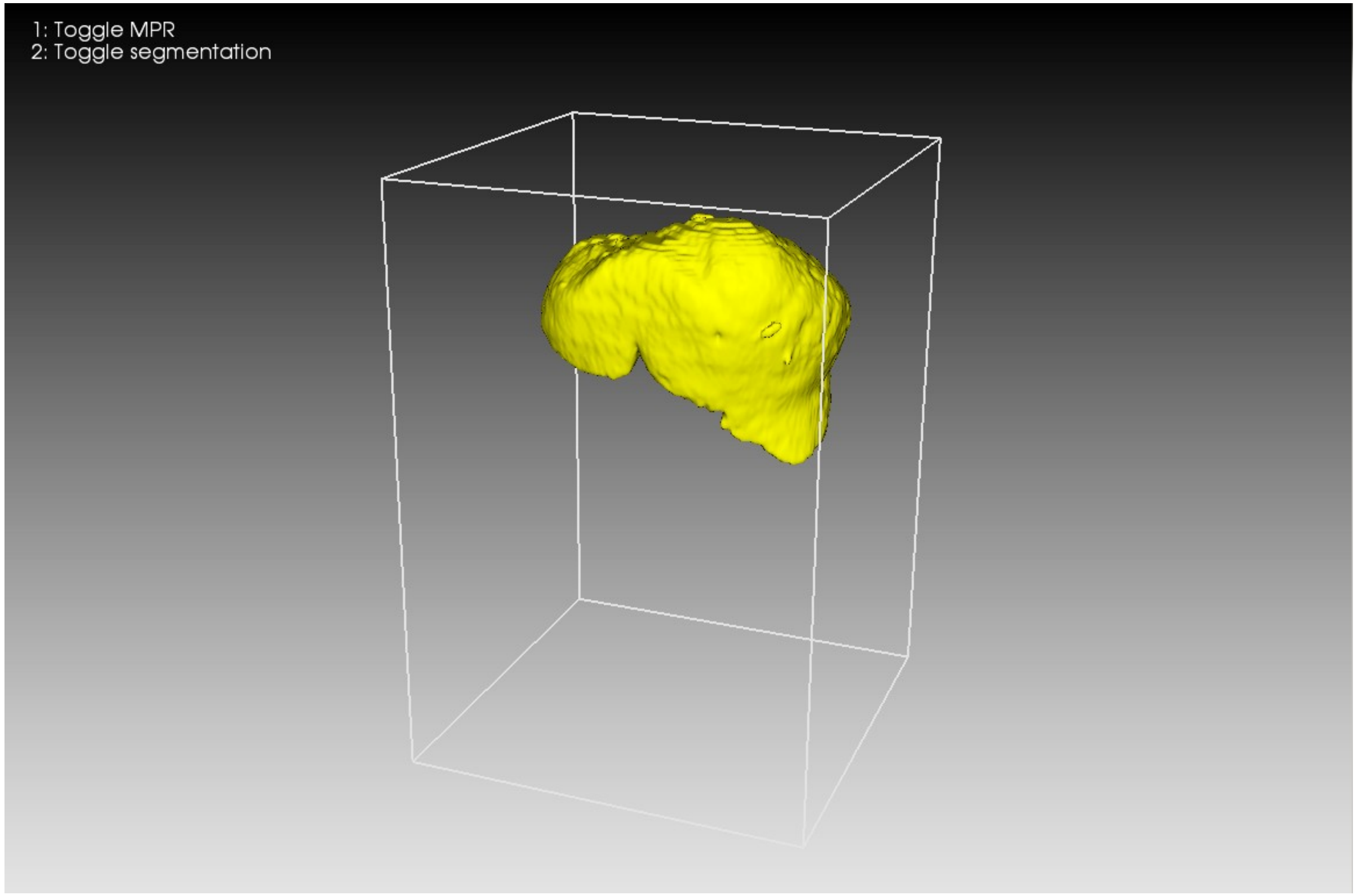
Multi-planar reformatting (MPR)



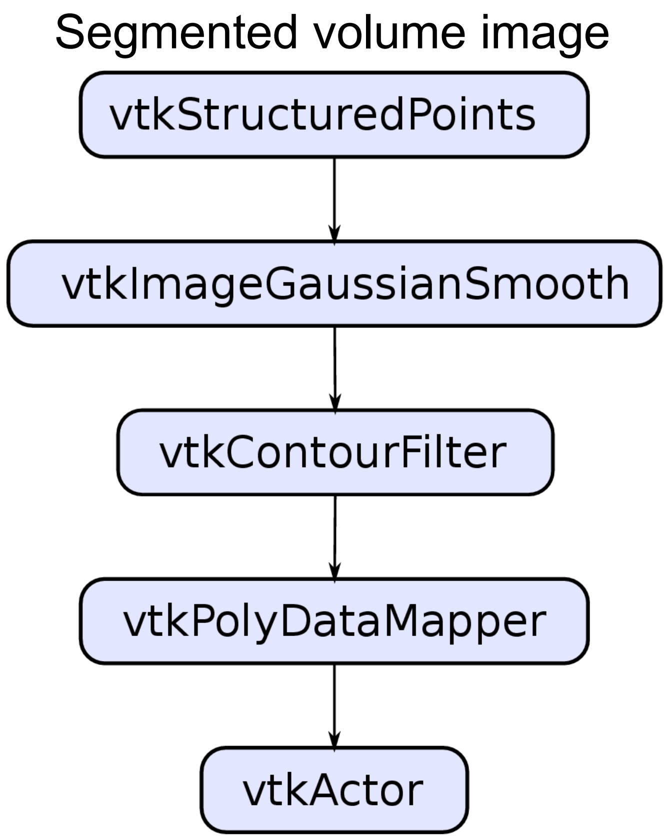
Multi-planar reformatting (MPR)



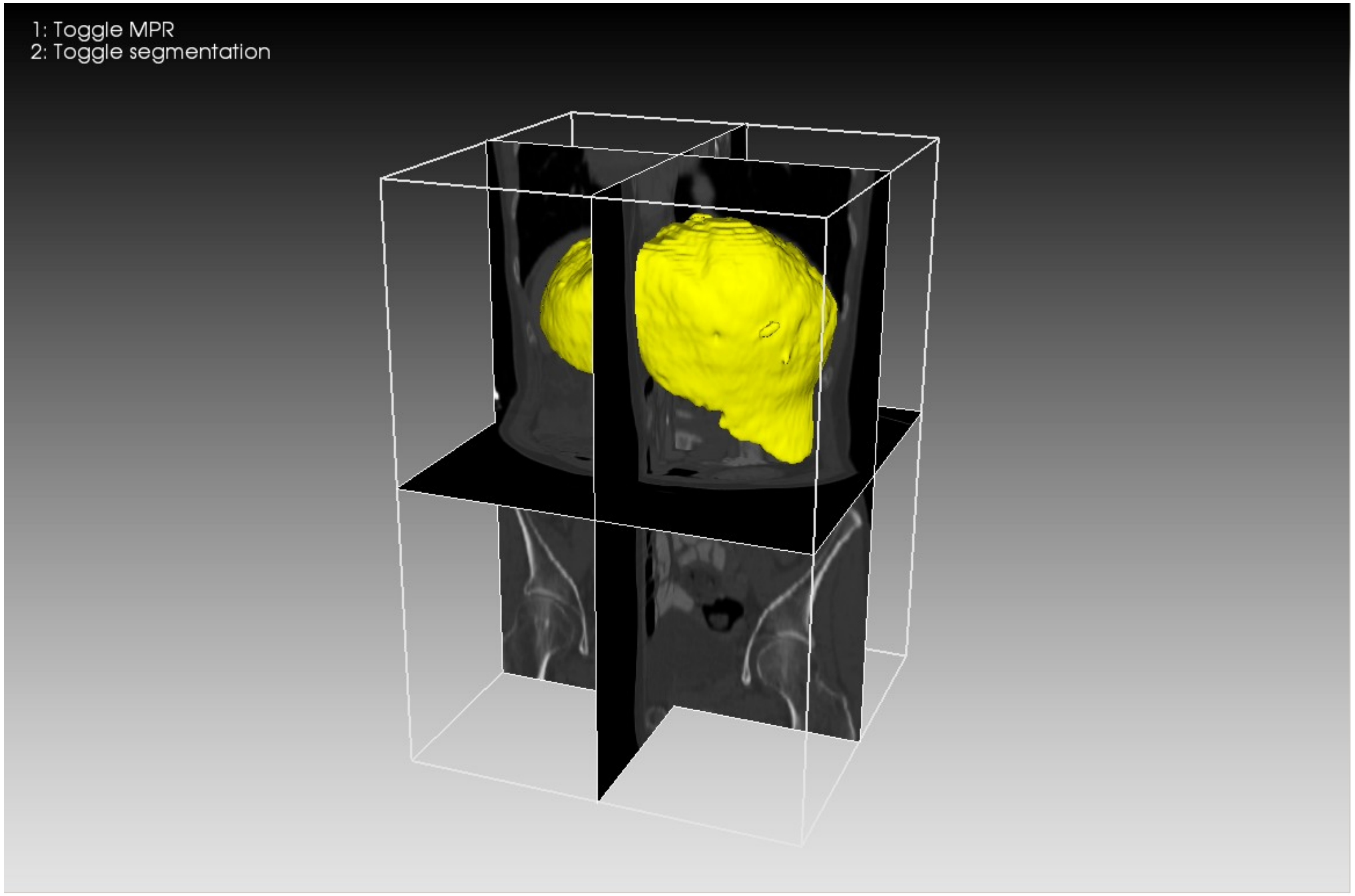
Surface rendering



Surface rendering



Combined visualization



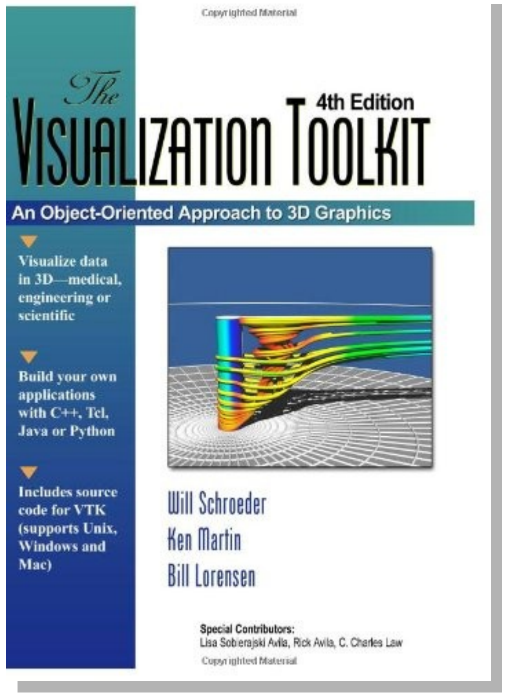
Summary

- VTK contains thousands of classes and might seem a bit intimidating at first...
  - however, one can create useful visualizations with just a few core classes
- The pipeline is typically

  source/reader → filter → mapper → actor → renderer → renderWindow → interactor
- Use VTK's example programs as templates when you write new programs!

Resources

- http://www.vtk.org/
- http://www.vtk.org/VTK/resources/software.html
- http://www.vtk.org/doc/release/5.10/html/
- http://www.vtk.org/Wiki/VTK/Examples



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The VISUALIZATION TOOLKIT 4th Edition

An Object-Oriented Approach to 3D Graphics

Visualize data in 3D—medical, engineering or scientific

Build your own applications with C++, Tcl, Java or Python

Includes source code for VTK (supports Unix, Windows and Mac)

Will Schroeder
Ken Martin
Bill Lorensen

Special Contributors:
Lisa Sobierajski Avila, Rick Avila, C. Charles Law

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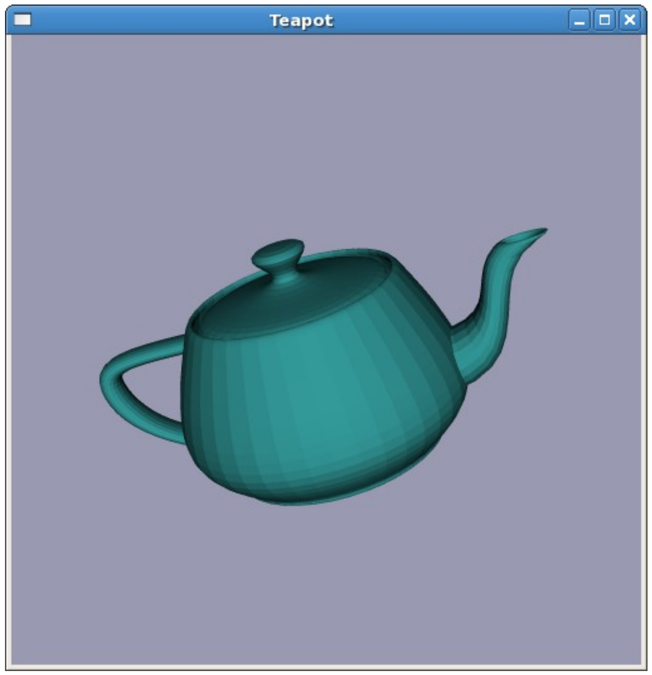
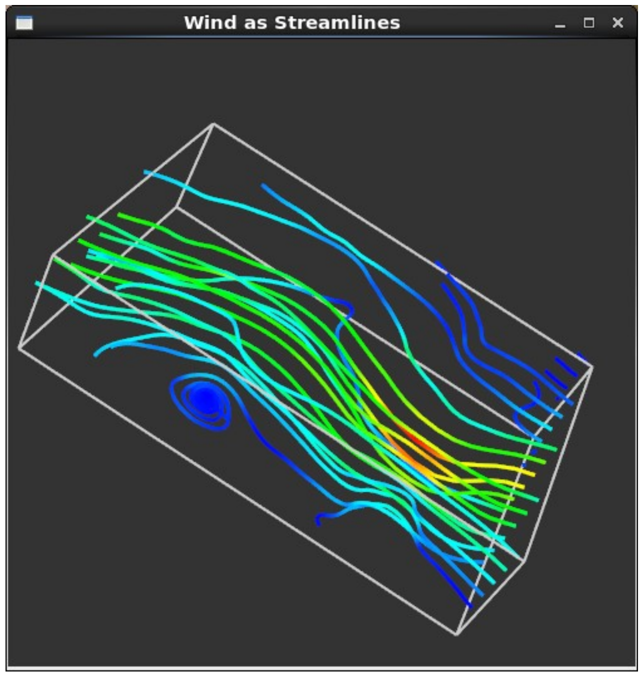
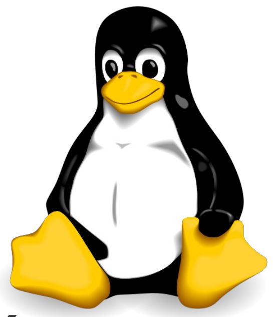
More resources

- Anders has created a tutorial demonstrating how to use VTK with Python
- Includes lots of examples
- You can access the tutorial here





Installing VTK on Linux



- Included in the package repository of most Linux distributions
- On Ubuntu 12.04 you can install VTK and the Python-wrapper with the command

```
sudo apt-get install libvtk5-dev python-vtk
```

- Also fairly easy to build VTK from source. You need GCC, CMake, + some extra dependencies
- Finally, you can install VTK via the Python distribution Anaconda (see next slide)

Installing VTK on Windows

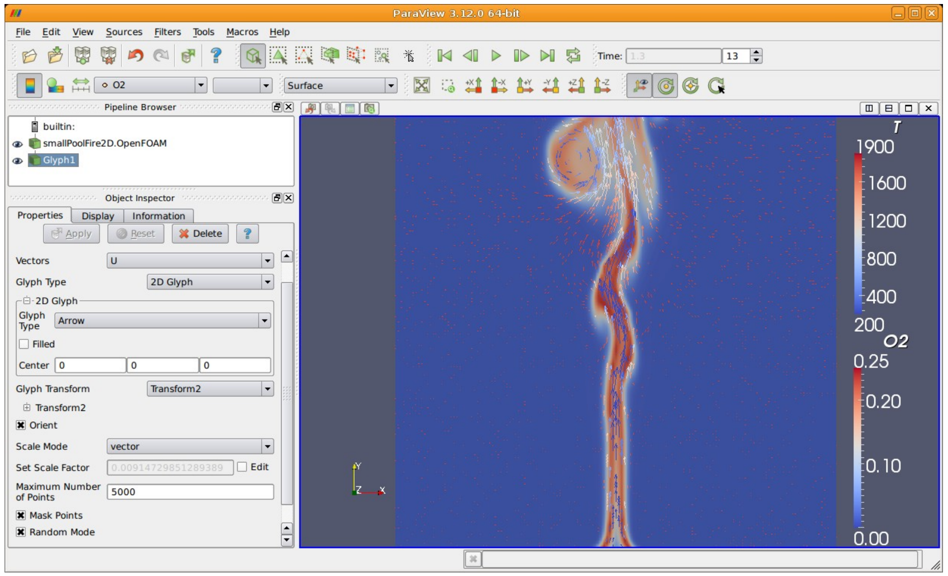
- Don't bother compiling it yourself (unless you have plenty of time to spare)
- Install it via one of the following Python distributions:
  - Anaconda (VTK is available in the package repository)
  - pythonxy (Warning! will override existing Python installations)
- More detailed installation instructions can be found on the course webpage

Installing VTK on Mac

- Install it via Anaconda (see previous slide)
- Expect to spend several hours in front of the compiler if you try to build it yourself...

Paraview and Mayavi

- Free data visualizers built on VTK
- You can use them to try out different visualization techniques (without writing a single line of code)
- Links:
  - http://www.paraview.org/
  - http://docs.enthought.com/mayavi/mayavi/index.html



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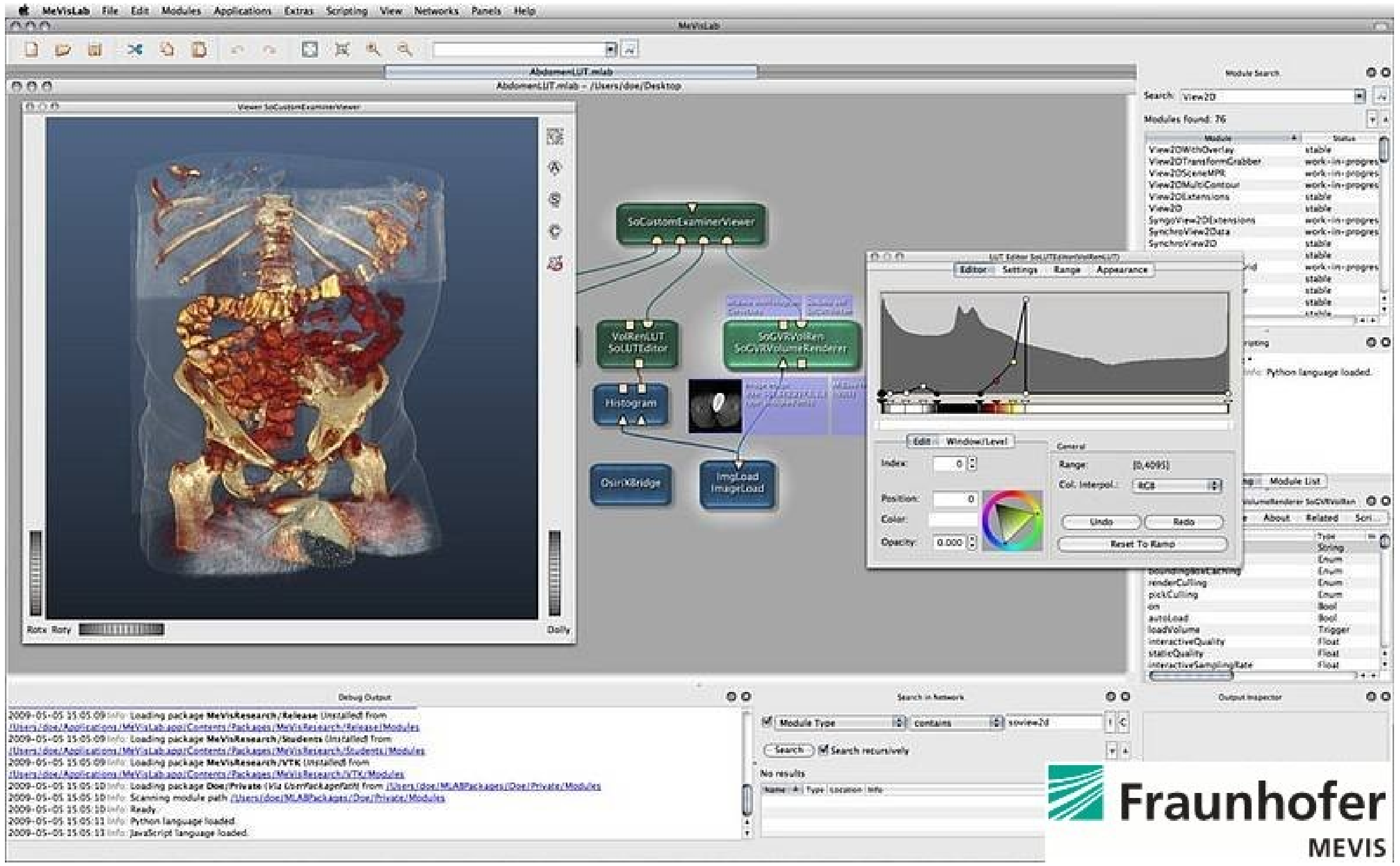
Glyph Type: 2D Glyph
2D Glyph
Glyph Type: Arrow
[ ] Filled
Center: 0 0 0
Glyph Transform: Transform2
Transform2
[x] Orient
Scale Mode: vector
Set Scale Factor: 0.00914729851289389 [ ] Edit
Maximum Number of Points: 5000
[x] Mask Points
[x] Random Mode

MeVisLab

- Graphical programming environment for medical image processing and visualization
- Uses VTK for visualization and ITK for image processing



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2009-05-05 15:05:09 Info: Loading package MeVisResearch/Students (installed) from
/Users/doe/Applications/MeVisLab.app/Contents/Packages/MeVisResearch/Students/Modules
2009-05-05 15:05:09 Info: Loading package MeVisResearch/VTK (installed) from
/Users/doe/Applications/MeVisLab.app/Contents/Packages/MeVisResearch/VTK/Modules
2009-05-05 15:05:10 Info: Loading package Doe/Private (via UserPackagePath) from /Users/doe/MLABPackages/Doe/Private/Modules
2009-05-05 15:05:10 Info: Scanning module path /Users/doe/MLABPackages/Doe/Private/Modules
2009-05-05 15:05:10 Info: Ready
2009-05-05 15:05:11 Info: Python language loaded.
2009-05-05 15:05:13 Info: JavaScript language loaded.
```

See you on the lab!