Welcome to UPPMAX Workshop on *Scientific Visualization with*

vtk

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UPPMAX

- Uppsala Multidisciplinary Center for Advanced Computational Science
- http://www.uppmax.uu.se/
- *”UPPMAX provides resources and a common environment for an extensive community of researchers in a wide range of high performance computing (HPC) research fields.”*

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- Application experts:
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  - Algorithm & Code Development: *Jarmo Rantakokko*
  - Scientific Visualization: *Ingela Nyström*
  - Molecular Dynamics: *Daniel Spångberg*
  - Bioinformatics: *Ann-Charlotte Sonnhammer*
- System experts

UPPMAX

- Interdisciplinary resource for projects in
  - Astronomy
  - Bioscience
  - Chemistry
  - Geoscience
  - Mathematics
  - Physics
  - Computer Science
  - and others

Dictionary

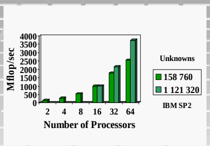
- **vi·su·al·ize**
  - To form a mental image of; envisage: *tried to visualize the scene as it was described*
  - To make visible

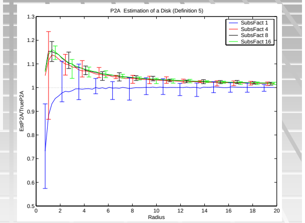
”Visualization offers a way to see the unseen”

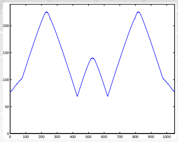
Interpreting data in visual terms

- When data is complex: Collected/Computed
- When numerous data
- Visualization is not a substitute to, but *in addition to*, statistical analysis and other quantitative methods
- Visualization takes advantage of human sensory abilities
  - Pattern recognition, Trend discovery, etc.

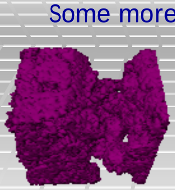
Graphs are one type of visualization





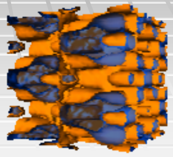


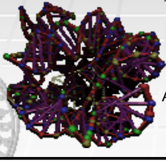
Some more sophisticated examples



Nuclear, Quantum, and Molecular Modeling

Structures, Fluids and Fields

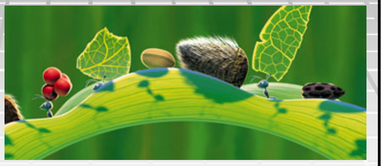




Advanced Imaging and Data Management

Computer Graphics

- Creating images with a computer – 3D



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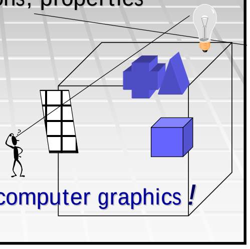
Computer Graphics

- Components
  - Model: geometry, surface properties, …
  - Lighting: number, positions, properties
  - Viewpoint
  - Projection



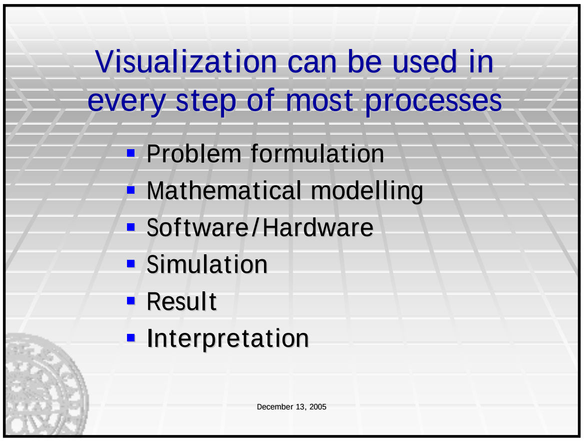
Visualization is more than computer graphics!

Scientific Visualization

- Scientific visualization is the process of exploring, transforming, and viewing data as images
- The dimensionality of the data is generally larger than or equal to 3
- Visualization is often **interactive**
- We are not trying to create realistic images, but to visualize the data in an informative way
- Dependent on the task given

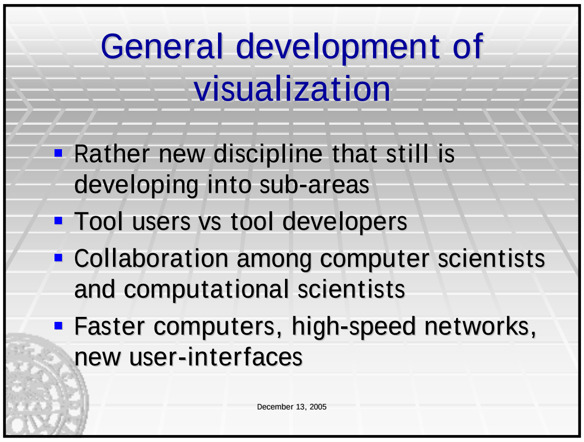
Visualization serves many purposes

- ”Pretty pictures”
- For further analysis
- Debugging
- …



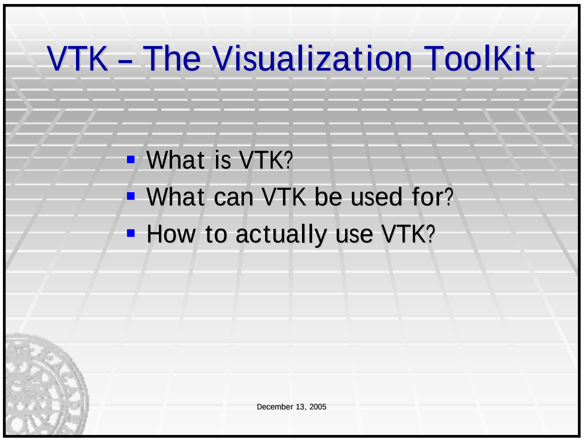
Visualization can be used in every step of most processes

- Problem formulation
- Mathematical modelling
- Software/Hardware
- Simulation
- Result
- Interpretation



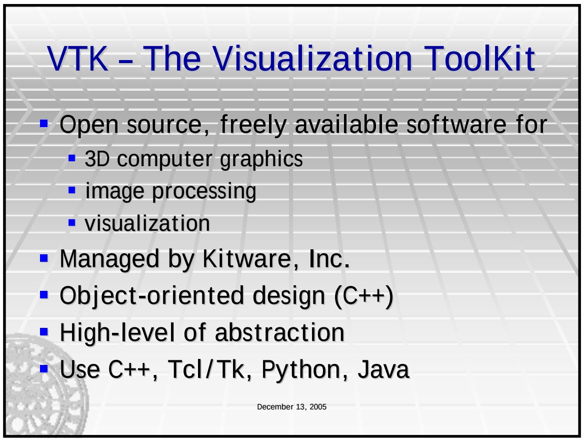
General development of visualization

- Rather new discipline that still is developing into sub-areas
- Tool users vs tool developers
- Collaboration among computer scientists and computational scientists
- Faster computers, high-speed networks, new user-interfaces



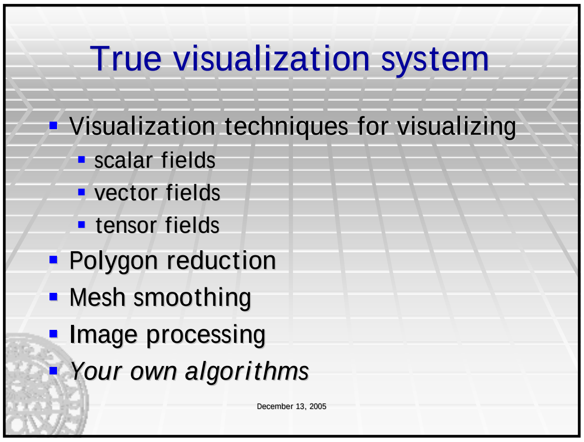
VTK – The Visualization ToolKit

- What is VTK?
- What can VTK be used for?
- How to actually use VTK?



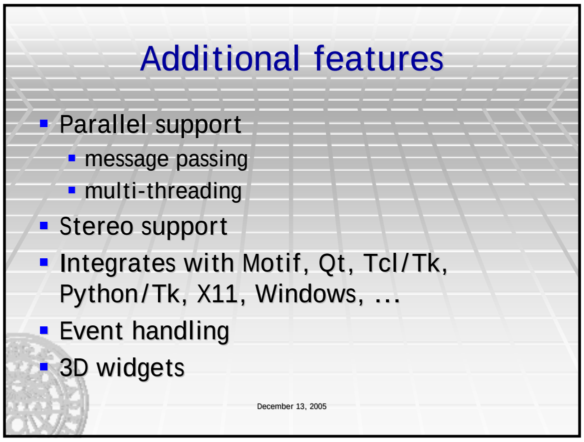
VTK – The Visualization ToolKit

- Open source, freely available software for
  - 3D computer graphics
  - image processing
  - visualization
- Managed by Kitware, Inc.
- Object-oriented design (C++)
- High-level of abstraction
- Use C++, Tcl/Tk, Python, Java



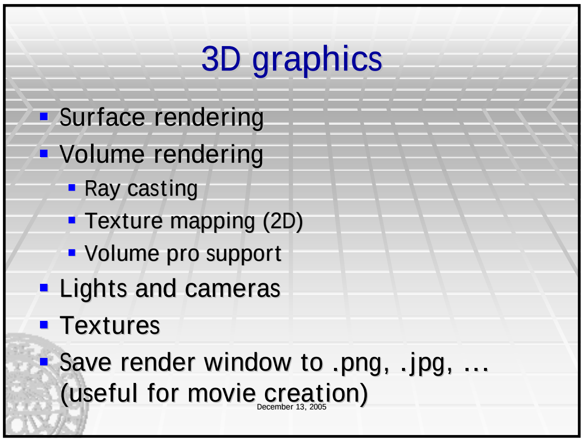
True visualization system

- Visualization techniques for visualizing
  - scalar fields
  - vector fields
  - tensor fields
- Polygon reduction
- Mesh smoothing
- Image processing
- *Your own algorithms*



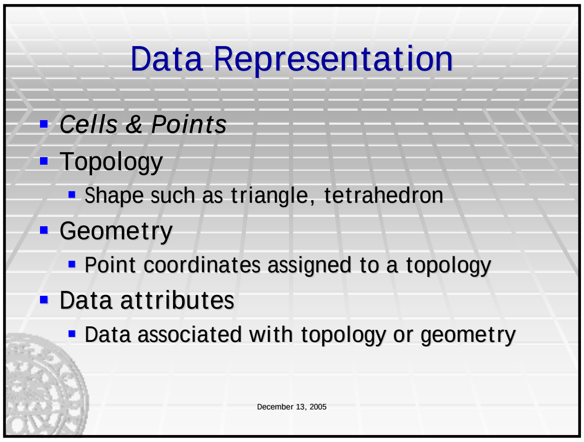
Additional features

- Parallel support
  - message passing
  - multi-threading
- Stereo support
- Integrates with Motif, Qt, Tcl/Tk, Python/Tk, X11, Windows, …
- Event handling
- 3D widgets



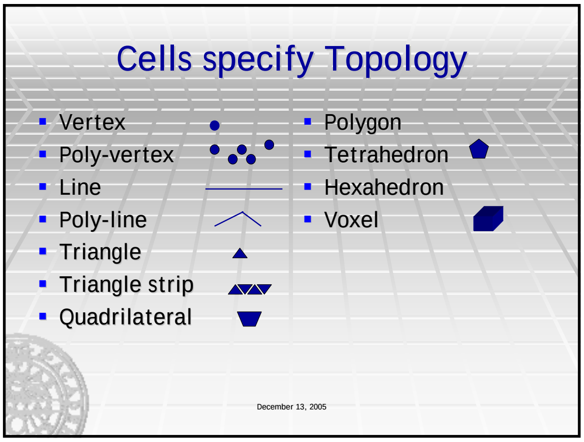
3D graphics

- Surface rendering
- Volume rendering
  - Ray casting
  - Texture mapping (2D)
  - Volume pro support
- Lights and cameras
- Textures
- Save render window to .png, .jpg, … (useful for movie creation)



Data Representation

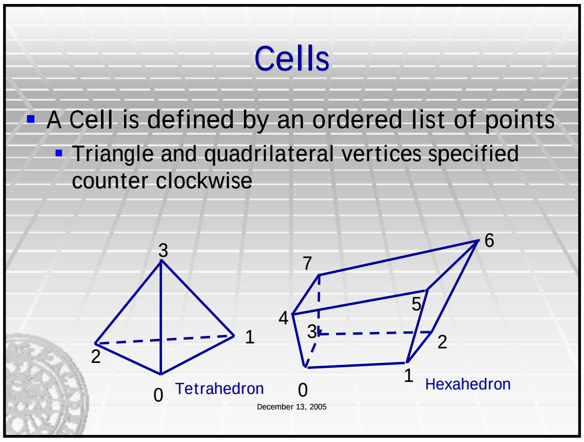
- *Cells & Points*
- Topology
  - Shape such as triangle, tetrahedron
- Geometry
  - Point coordinates assigned to a topology
- Data attributes
  - Data associated with topology or geometry



Cells specify Topology

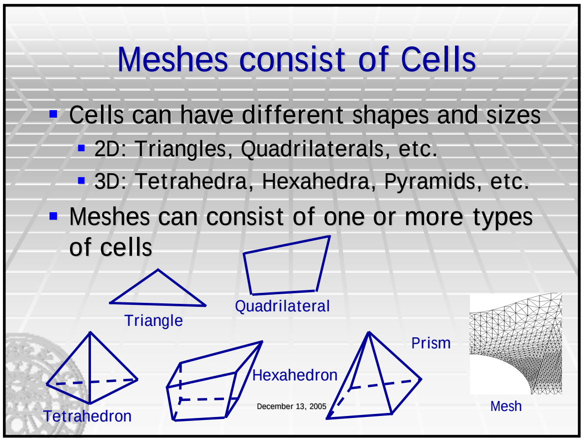
- Vertex
- Poly-vertex
- Line
- Poly-line
- Triangle
- Triangle strip
- Quadrilateral

- Polygon
- Tetrahedron
- Hexahedron
- Voxel



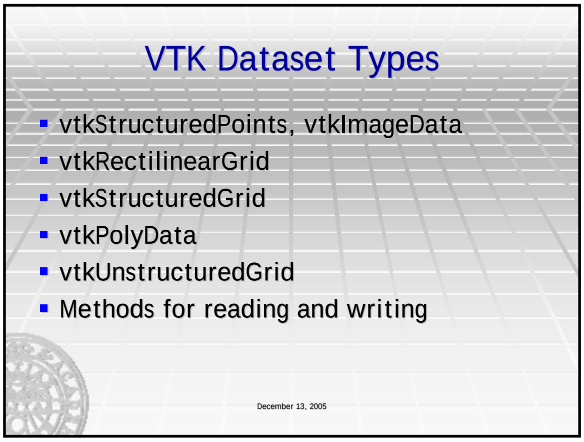
Cells

- A Cell is defined by an ordered list of points
  - Triangle and quadrilateral vertices specified counter clockwise



Meshes consist of Cells

- Cells can have different shapes and sizes
  - 2D: Triangles, Quadrilaterals, etc.
  - 3D: Tetrahedra, Hexahedra, Pyramids, etc.
- Meshes can consist of one or more types of cells

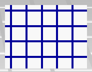


VTK Dataset Types

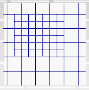
- vtkStructuredPoints, vtkImageData
- vtkRectilinearGrid
- vtkStructuredGrid
- vtkPolyData
- vtkUnstructuredGrid
- Methods for reading and writing

Datasets

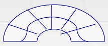
- Organizing structure plus attributes
  - Structured Points



  - Rectilinear Grid

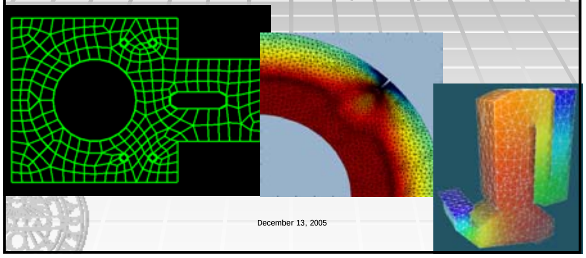


  - Structured Grid



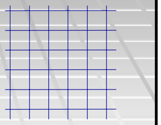
Unstructured Grid

A collection of vertices, edges, faces, and cells whose connectivity information must be explicitly stored



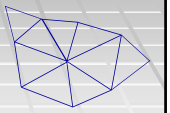
How are unstructured meshes different than regular grids?

- **Regular Grids**
  - mesh info accessed implicitly using grid point indices
  - efficient in both computation and storage
  - typically use finite difference (FD) discretization
  - Cartesian grids or logically rectangular grids



How are unstructured meshes different than regular grids?

- **Unstructured Meshes**
  - mesh connectivity information must be stored
  - handles complex geometries and grid adaptivity
  - typically use finite volume or finite element (FE) discretization
  - mesh quality becomes a concern

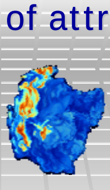


Data attributes assigned to points or cells

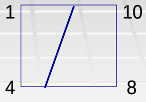
- Scalar
- Vector
  - magnitude and direction
- Normal
  - a vector of magnitude 1
  - used for lighting
- Texture coordinate
  - mapping data points into a texture space
- Tensor

Visualization of attributes

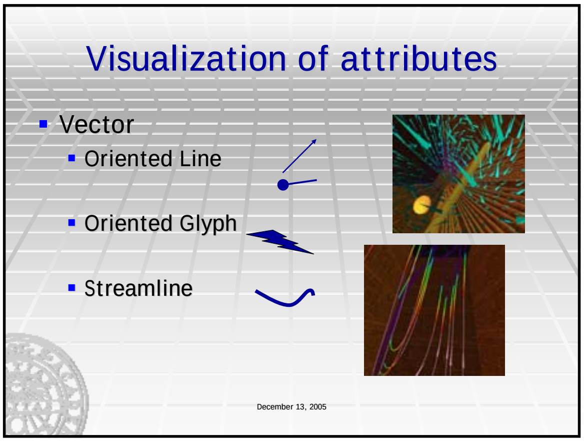
- Scalar
  - Color Mapping



  - Contouring
    - 3D isosurface

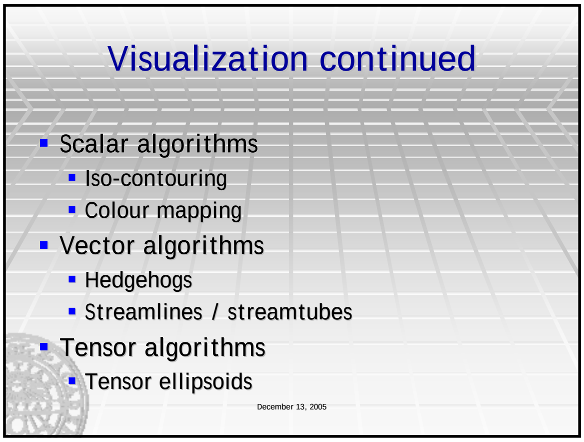


Contour value of 5



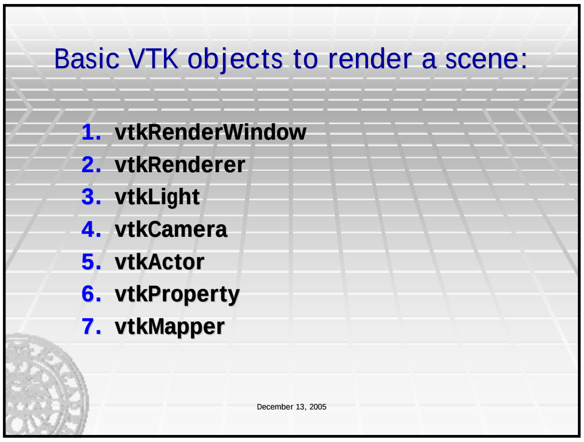
Visualization of attributes

- Vector
  - Oriented Line
  - Oriented Glyph
  - Streamline



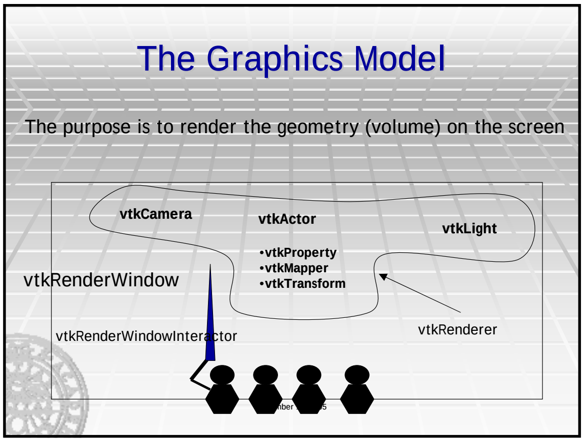
Visualization continued

- Scalar algorithms
  - Iso-contouring
  - Colour mapping
- Vector algorithms
  - Hedgehogs
  - Streamlines / streamtubes
- Tensor algorithms
  - Tensor ellipsoids



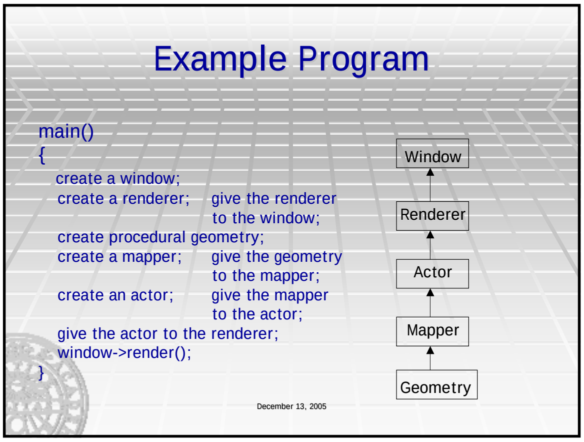
Basic VTK objects to render a scene:

1. **vtkRenderWindow**
2. **vtkRenderer**
3. **vtkLight**
4. **vtkCamera**
5. **vtkActor**
6. **vtkProperty**
7. **vtkMapper**



The Graphics Model

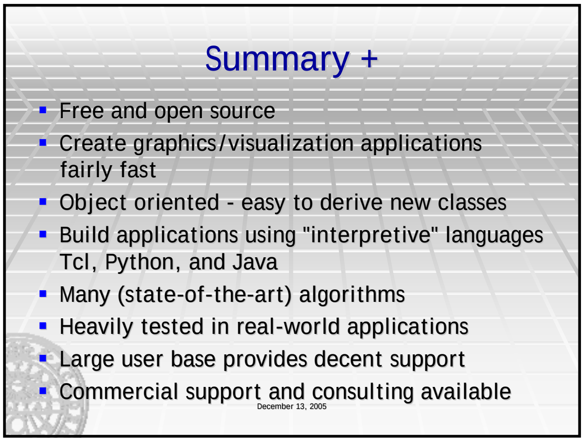
The purpose is to render the geometry (volume) on the screen



Example Program

```
main()
{
   create a window;
   create a renderer;     give the renderer
                          to the window;
   create procedural geometry;
   create a mapper;       give the geometry
                          to the mapper;
   create an actor;       give the mapper
                          to the actor;
   give the actor to the renderer;
   window->render();
}
```

Window
Renderer
Actor
Mapper
Geometry



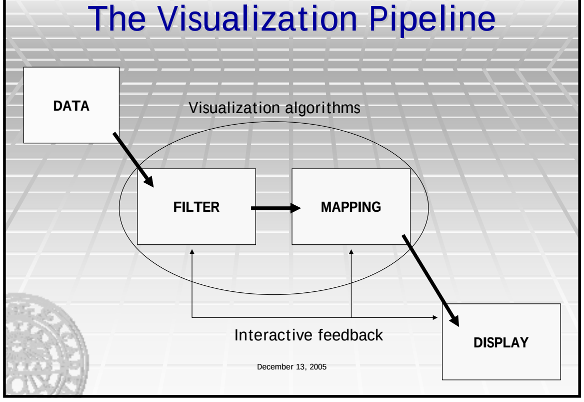
Summary +

- Free and open source
- Create graphics/visualization applications fairly fast
- Object oriented - easy to derive new classes
- Build applications using "interpretive" languages Tcl, Python, and Java
- Many (state-of-the-art) algorithms
- Heavily tested in real-world applications
- Large user base provides decent support
- Commercial support and consulting available

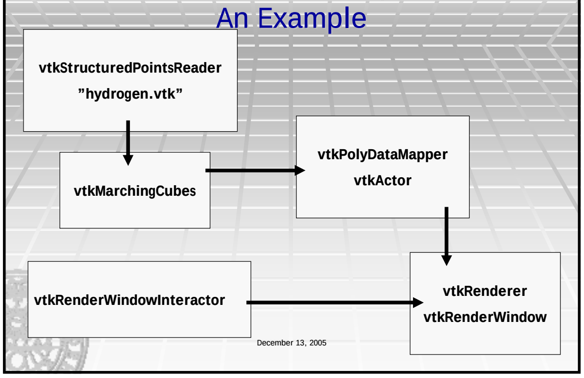
Summary -

- Not a super-fast graphics engine
  due to portability and C++ dynamic binding –
  you need a decent workstation
- Very large class hierarchy ➔
  learning threshold might be steep

The Visualization Pipeline



The Visualization Pipeline – An Example



Objects

- Data objects
  - vtkPolyData
  - vtkImageData
- Process objects
  - Source objects (vtkReader, vtkSphereSource)
  - Filter objects (vtkContourFilter)
  - Mapper objects (vtkPolyDataMapper)

The Hydrogen example - Python

call update to read

pipeline connections

```
# File: isosurface.py
import vtk

# image reader
reader = vtk.vtkStructuredPointsReader()
reader.SetFileName("hydrogen.vtk")
reader.Update()

# bounding box
outline = vtk.vtkOutlineFilter()
outline.SetInput( reader.GetOutput() )
outlineMapper = vtk.vtkPolyDataMapper()
outlineMapper.SetInput( outline.GetOutput() )
outlineActor = vtk.vtkActor()
outlineActor.SetMapper( outlineMapper )
outlineActor.GetProperty().SetColor(0.0,0.0,1.0)
```

Example continued

vtkContourFilter chooses appropriate method for the dataset

```
# iso surface
isosurface = vtk.vtkContourFilter()
isosurface.SetInput( reader.GetOutput() )
isosurface.SetValue( 0, .2 )
isosurfaceMapper = vtk.vtkPolyDataMapper()
isosurfaceMapper.SetInput( isosurface.GetOutput() )
isosurfaceMapper.SetColorModeToMapScalars()
isosurfaceActor = vtk.vtkActor()
isosurfaceActor.SetMapper( isosurfaceMapper )

# slice plane
plane = vtk.vtkImageDataGeometryFilter()
plane.SetInput( reader.GetOutput() )
planeMapper = vtk.vtkPolyDataMapper()
planeMapper.SetInput( plane.GetOutput() )
planeActor = vtk.vtkActor()
planeActor.SetMapper( planeMapper )
```

Example continued

create a legend
from the data and
a lookup table

```
# a colorbar
scalarBar = vtk.vtkScalarBarActor()
scalarBar.SetTitle("Iso value")

# renderer and render window
ren = vtk.vtkRenderer()
ren.SetBackground(.8, .8, .8)
renWin = vtk.vtkRenderWindow()
renWin.SetSize( 400, 400 )
renWin.AddRenderer( ren )
```

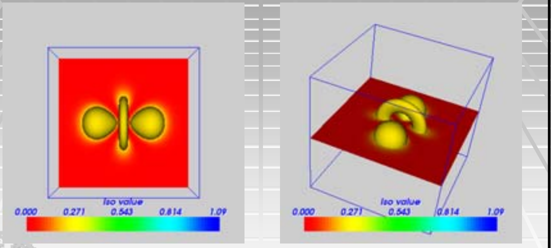
Example continued

vtkRenderWindowInteractor
contains functions
for mouse/keyboard
interaction

```
# render window interactor
iren = vtk.vtkRenderWindowInteractor()
iren.SetRenderWindow( renWin )

# add the actors
ren.AddActor( outlineActor )
ren.AddActor( isosurfaceActor )
ren.AddActor( planeActor )
ren.AddActor( scalarBar )

# this causes the pipeline to ”execute”
renWin.Render()

# initialize and start the interactor
iren.Initialize()
iren.Start()
```

renWin.Render()
calls Update() on the renderer,
which calls Update()
for all its actors,
which calls…

Renditions



Would you like an icecream?

User interaction

- vtkRenderWindowInteractor
  - allows the user to interact with the objects
- Try the following key presses

w wireframe mode s surface mode

j joystick mode t trackball mode

button1 rotate button2 translate

button3 scale r reset camera view

e, q exit

The VTK file format

a converter
from raw data
to vtk file format
is available on
Erik’s web-page

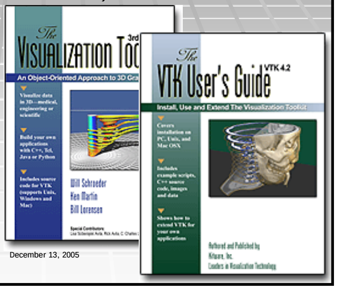
```
# vtk DataFile Version 2.0
Hydrogen orbital
ASCII
DATASET STRUCTURED_POINTS
DIMENSIONS 64 64 64
ORIGIN 32.5 32.5 32.5
SPACING 1.0 1.0 1.0
POINT_DATA 262144

SCALARS probability float
LOOKUP_TABLE default
0.0 0.0 0.01 0.01 …..
```

VTK and C++

- Build with CMake and your favorite compiler
- CMake generates makefiles or project files for your environment
- Use the resulting file(s) to build your executable
- With C++ you have full control and can derive own classes, but you need to write many lines of code…

VTK resources

- www.vtk.org
  - Download (source and binaries)
  - Documentation
  - Mailing lists
  - Links
  - FAQ, Search
- www.kitware.com
  - VTK Textbook
  - VTK User's guide
  - Mastering CMake


The Visualization Toolkit 3rd
An Object-Oriented Approach to 3D Graphics
Will Schroeder
Ken Martin
Bill Lorensen
The VTK User's Guide VTK 4.2
Install, Use and Extend The Visualization Toolkit
Authored and Published by Kitware, Inc.

Questions?

Let's try VTK