Scientific Visualization

Spring 2009

Reference

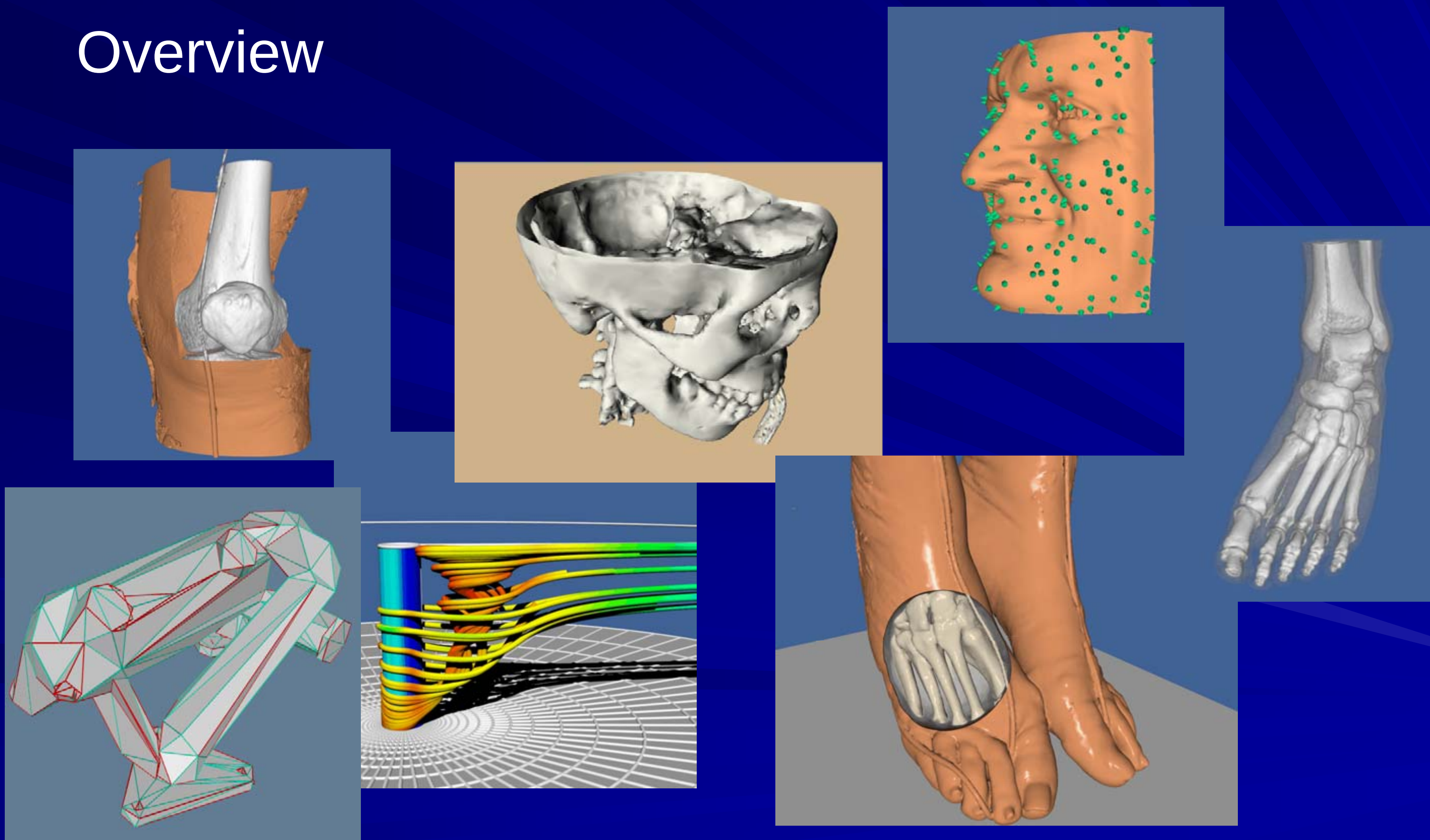
- The Visualization Toolkit : An Overview by William J. Schroeder, Kitware, Inc.

Agenda

- VTK Technology
  - Background
  - The Graphics Model
  - The Visualization Model

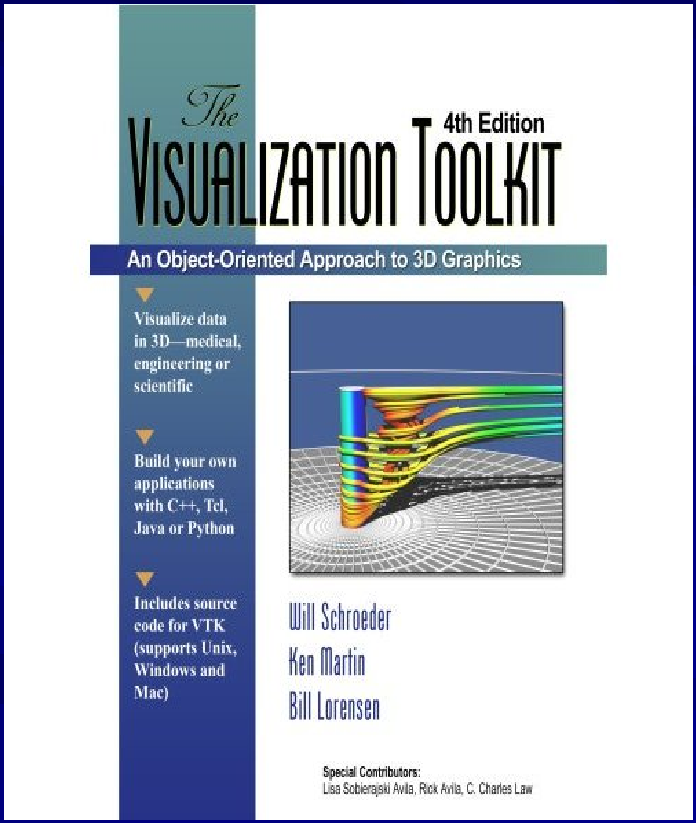
The Visualization Toolkit (VTK)

Overview



Textbook

Now in Fourth Edition



The Visualization Toolkit
An Object-Oriented Approach To 3D Graphics
Will Schroeder, Ken Martin, Bill Lorensen
ISBN 0-13-954694-4
Prentice Hall

Work on first edition began in 1994

What Is VTK?

A visualization toolkit

- Designed and implemented using object-oriented principles
- C++ class library (250,000 LOC, <100,000 executable lines)
- Automated Java, TCL, Python bindings
- Portable across Unix, Windows
- Supports 3D/2D graphics, visualization, image processing, volume rendering

VTK Is Not a System

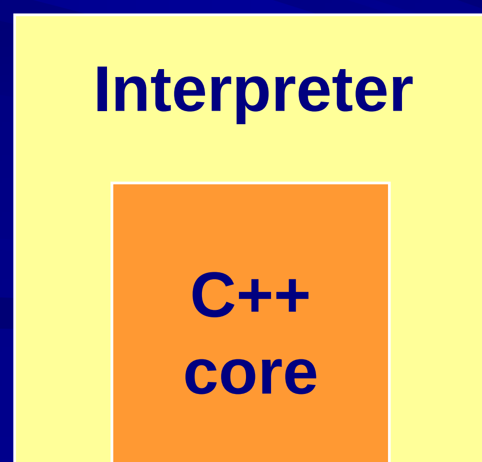
- Embeddable
  – Plays with other software
- Separable
  – Can pull out “pieces”
- Adaptable
  – Not dependent on GUI
  – Not dependent on rendering library

VTK Architecture

Hybrid approach

- compiled C++ (faster algorithms)
- interpreted applications (rapid development) (Java, Tcl, Python)
- A *toolkit*

Interpreted layer generated automatically



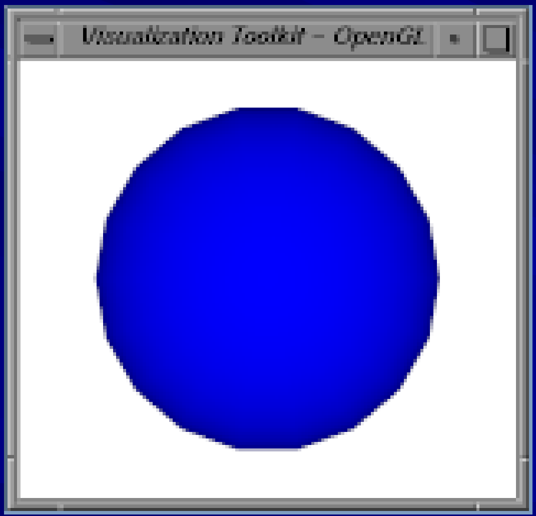
Interpreters

- Tcl
- Java
- Python

Interpreters provide faster turn-around; suffer from slower execution

Example Code

- http://www.vtk.org/example-code.php
- Create a sphere



C++ Code

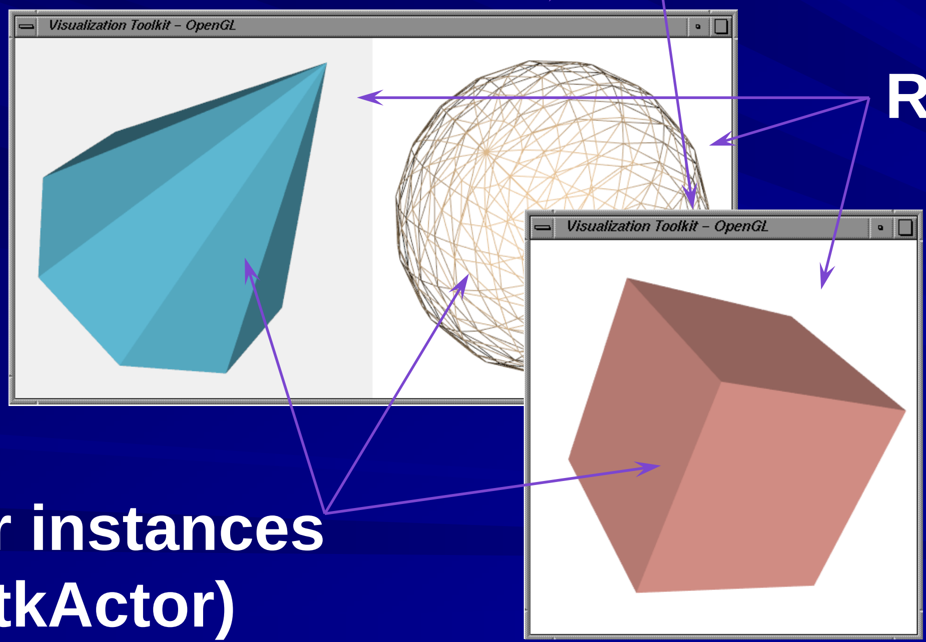
```
#include "vtkSphereSource.h"
#include "vtkPolyDataMapper.h"
#include "vtkActor.h"
#include "vtkRenderWindow.h"
#include "vtkRenderer.h"
#include "vtkRenderWindowInteractor.h"

void main ()
{

  // create sphere geometry
  vtkSphereSource *sphere = vtkSphereSource::New();
  sphere->SetRadius(1.0);
  sphere->SetThetaResolution(18);
  sphere->SetPhiResolution(18);

  // map to graphics library
  vtkPolyDataMapper *map = vtkPolyDataMapper::New();
  map->SetInput(sphere->GetOutput());

  // actor coordinates geometry, properties, transformation
  vtkActor *aSphere = vtkActor::New();
  aSphere->SetMapper(map);
  aSphere->GetProperty()->SetColor(0,0,1); // sphere color blue
```

C++ Code

```
// a renderer and render window
 vtkRenderer *ren1 = vtkRenderer::New();
 vtkRenderWindow *renWin = vtkRenderWindow::New();
 renWin->AddRenderer(ren1);

 // an interactor
 vtkRenderWindowInteractor *iren = vtkRenderWindowInteractor::New();
 iren->SetRenderWindow(renWin);

 // add the actor to the scene
 ren1->AddActor(aSphere);
 ren1->SetBackground(1,1,1); // Background color white

 // render an image (lights and cameras are created automatically)
 renWin->Render();

 // begin mouse interaction
 iren->Start();
}
```

Graphics Model

Instances of render window (vtkRenderWindow)



Renderer instances (vtkRenderer)

Actor instances (vtkActor)

Graphics Model

- RenderWindow - contains final image
- Renderer - *draws into render window*
- Actor - *combines properties / geometry*
- Lights - illuminate actors
- Camera - renders scene
- Mappers - represent geometry
- Transformations - position actors

TCL Code

```
package require vtk
package require vtkinteraction

# create sphere geometry
vtkSphereSource sphere
sphere SetRadius 1.0
sphere SetThetaResolution 18
sphere SetPhiResolution 18

# map to graphics library
vtkPolyDataMapper map;
map SetInput [sphere GetOutput]

# actor coordinates geometry, properties, transformation
vtkActor aSphere
aSphere SetMapper map
[aSphere GetProperty] SetColor 0 0 1; # blue
```

TCL Code

- # create a window to render into
- vtkRenderWindow renWin
- vtkRenderer ren1
- renWin AddRenderer ren1

- # create an interactor
- vtkRenderWindowInteractor iren
- iren SetRenderWindow renWin

- # add the sphere
- ren1 AddActor aSphere
- ren1 SetBackground 1 1 1;# Background color white

- # Render an image; since no lights/cameras specified, created automatically
- renWin Render

- # prevent the tk window from showing up then start the event loop
- wm withdraw .

Comparison

```cpp
// create sphere geometry
vtkSphereSource *sphere = vtkSphereSource::New();
sphere->SetRadius(1.0);
sphere->SetThetaResolution(18);
sphere->SetPhiResolution(18);

// map to graphics library
vtkPolyDataMapper *map = vtkPolyDataMapper::New();
map->SetInput(sphere->GetOutput());

// actor coordinates geometry, properties, transformation
vtkActor *aSphere = vtkActor::New();
aSphere->SetMapper(map);
aSphere->GetProperty()->SetColor(0,0,1); //blue
```

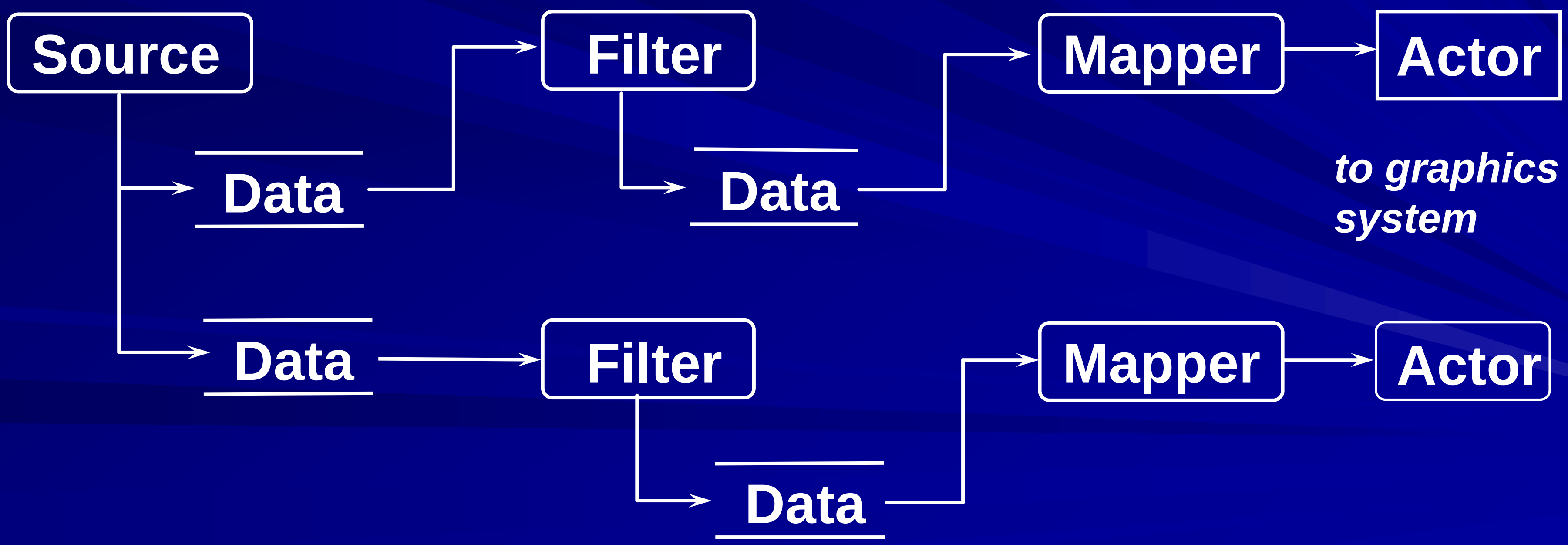
```tcl
# create sphere geometry
vtkSphereSource sphere
sphere SetRadius 1.0
sphere SetThetaResolution 18
sphere SetPhiResolution 18

# map to graphics library
vtkPolyDataMapper map;
map SetInput [sphere GetOutput]

# actor coordinates geometry, properties…
vtkActor aSphere
aSphere SetMapper map
[aSphere GetProperty] SetColor 0 0 1; # blue
```

Agenda

- VTK Technology
  - Background
  - The Graphics Model
  - The Visualization Model

What Is The Visualization Pipeline?

A sequence of *process objects* that operate on *data objects* to generate geometry that can be rendered by the graphics engine



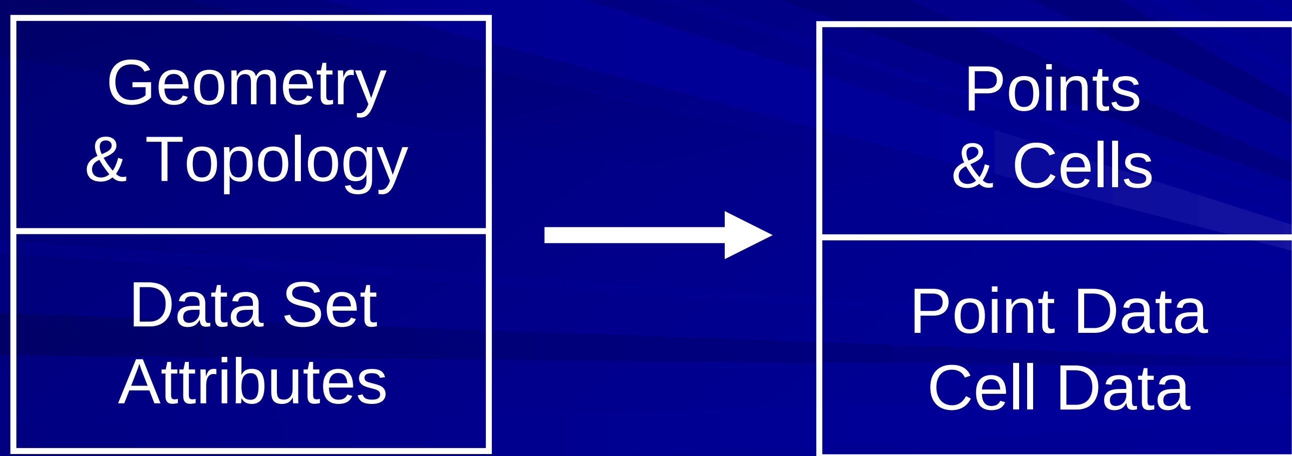
Visualization Model

- Data Objects
  - represent data
  - provide access to data
  - compute information particular to data (e.g., bounding box, derivatives)

- Process Objects
  - Ingest, transform, and output data objects
  - represent visualization algorithms

Data Objects / Data Sets

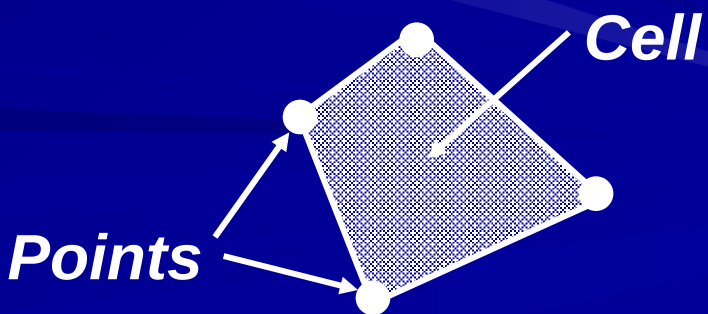
- vtkDataObject is a “blob” of data
  - Contains an instance of vtkFieldData
- vtkDataSet is data with geometric & topological structure; and with <u>attribute</u> data



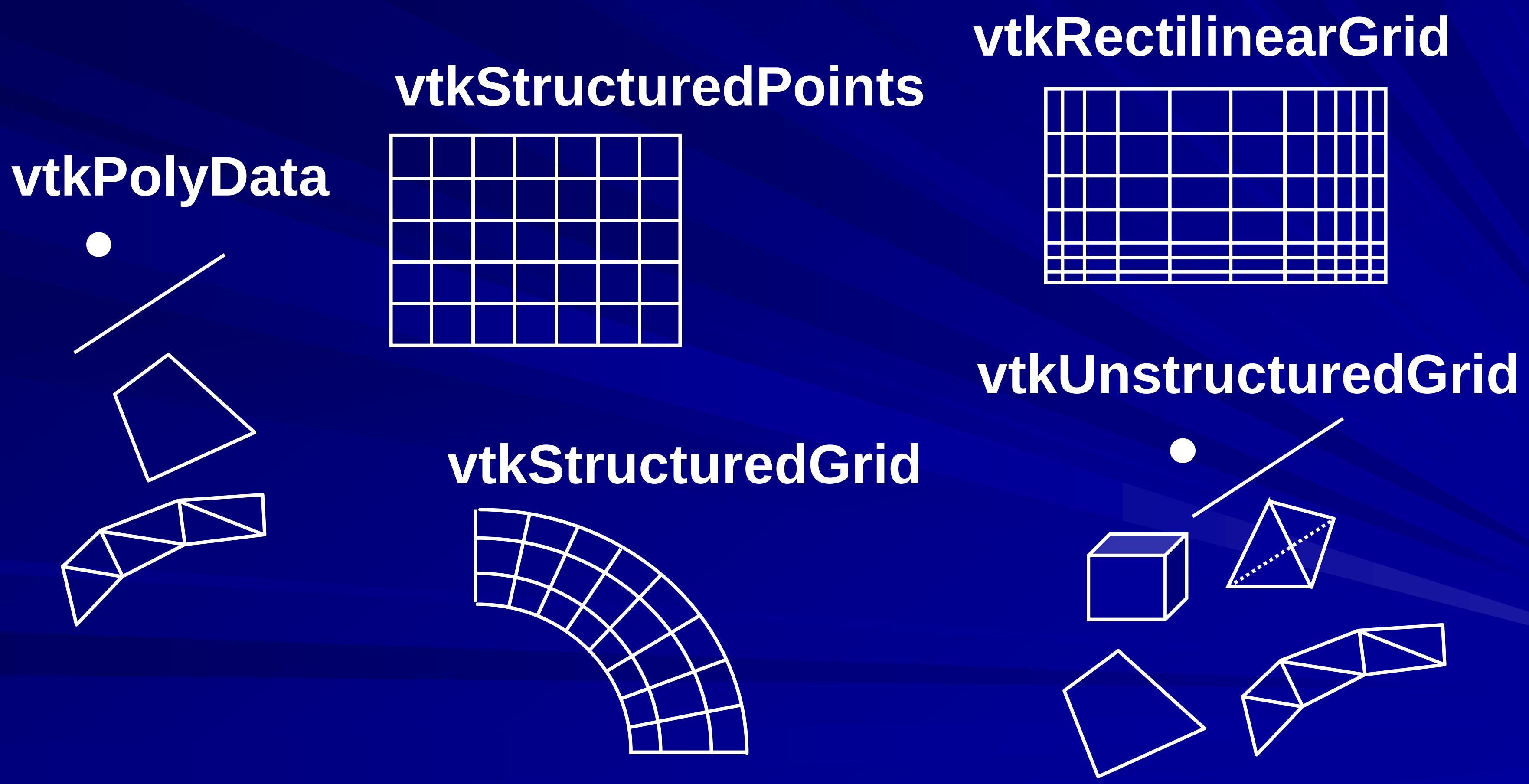
Dataset Model

- A dataset is a data object with structure

- Structure consists of
  - cells (e.g., polygons, lines, voxels)
  - points (x-y-z coordinates)
  - cells defined by connectivity list referring to points
  - implicit representations
  - explicit representations



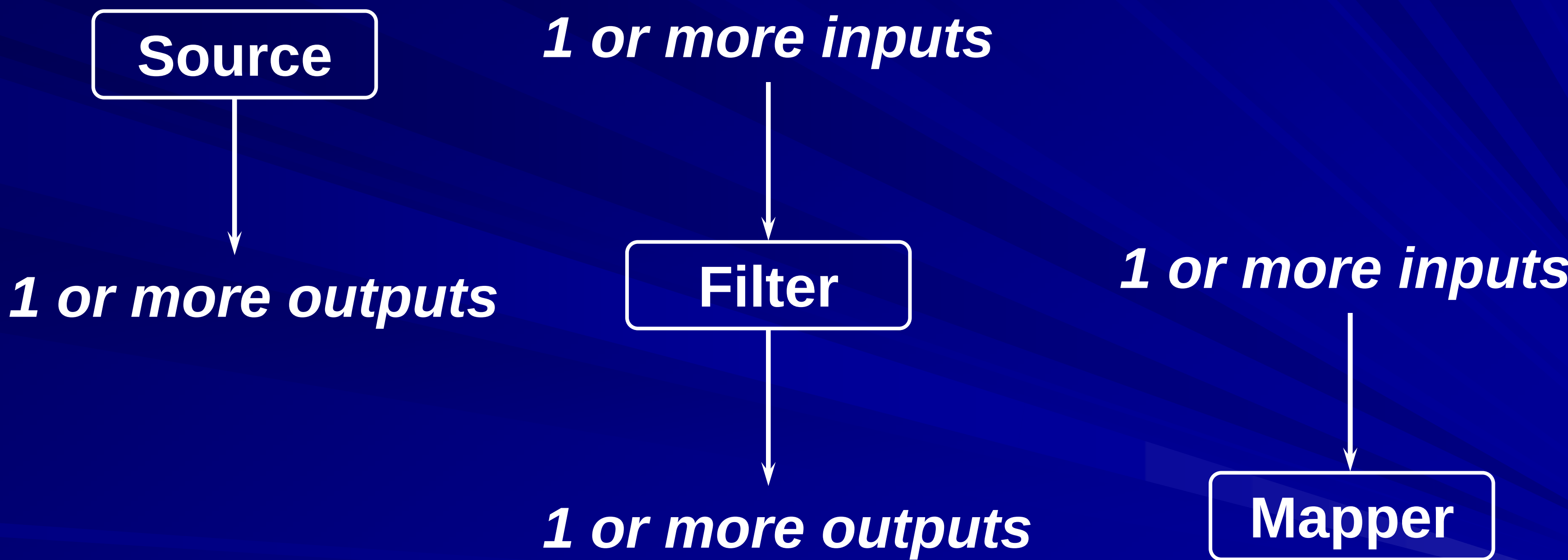
Dataset Types



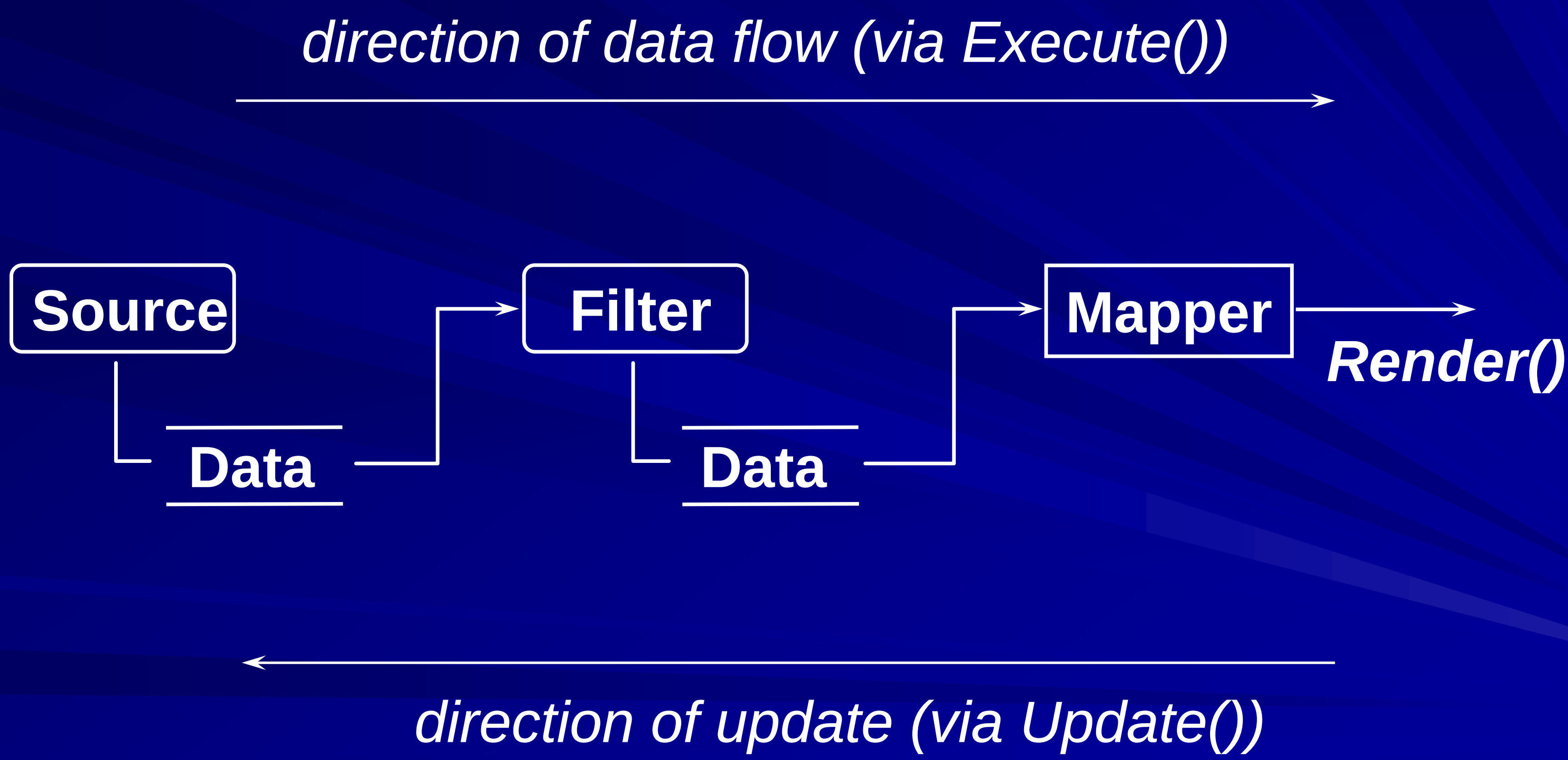
Data Set Attributes

- **Scalars** - 1-4 values (*vtkScalars*)
  - – single value ranging to RGBA color
- **Vectors** - 3-vector (*vtkVectors*)
- **Tensors** - 3x3 symmetric matrix (*vtkTensors*)
- **Normals** - unit vector (*vtkNormals*)
- **Texture Coordinates** 1-3D (*vtkTCoords*)
- **Field Data** (an array of arrays) (*vtkFieldData*)

Process Objects



Pipeline Execution Model



Creating Pipeline Topology

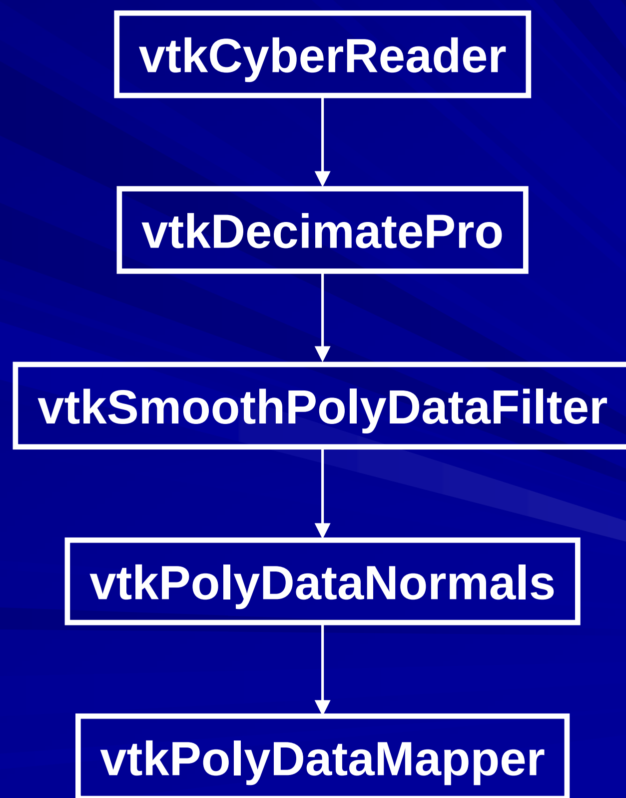
- aFilter->SetInput(bFilter->GetOutput());

- The Role of Type-Checking
  - SetInput() accepts dataset type or subclass
  - C++ compile-time checking
  - Interpreter run-time checking

Example Pipeline

- Decimation, smoothing, normals
- Implemented in C++

Note: data objects are not shown -> they are implied from the output type of the filter



Create Reader & Decimator

```
vtkCyberReader *cyber = vtkCyberReader::New();
   cyber->SetFileName("../../vtkdata/fran_cut");

vtkDecimatePro *deci = vtkDecimatePro::New();
   deci->SetInput( cyber->GetOutput() );
   deci->SetTargetReduction( 0.9 );
   deci->PreserveTopologyOn();
   deci->SetMaximumError( 0.0002 );
```

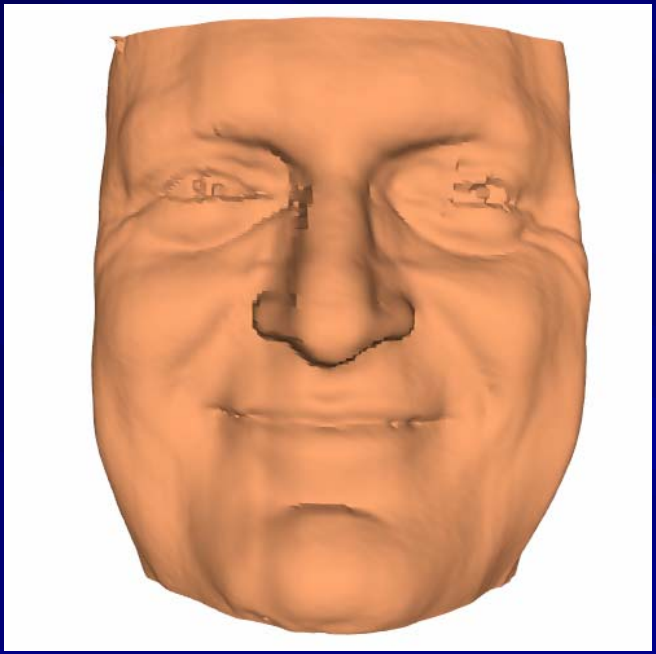
Smoother & Graphics Objects

```
vtkSmoothPolyDataFilter *smooth = vtkSmoothPolyDataFilter::New();
  smooth->SetInput(deci->GetOutput());
  smooth->SetNumberOfIterations( 20 );
  smooth->SetRelaxationFactor( 0.05 );

vtkPolyDataNormals *normals = vtkPolyDataNormals::New();
  normals->SetInput( smooth->GetOutput() );

vtkPolyDataMapper *cyberMapper = vtkPolyDataMapper::New();
  cyberMapper->SetInput( normals->GetOutput() );

vtkActor *cyberActor = vtkActor::New();
  cyberActor->SetMapper (cyberMapper);
  cyberActor->GetProperty()->SetColor ( 1.0, 0.49, 0.25 );
  cyberActor->GetProperty()->SetRepresentationToWireframe();
```

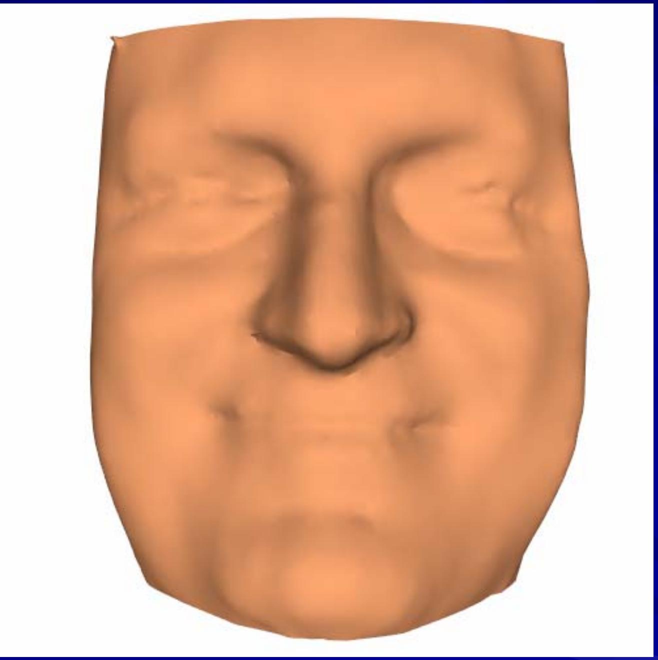
More Graphics Objects

```
vtkRenderer *ren1 = vtkRenderer::New();

vtkRenderWindow *renWin = vtkRenderWindow::New();
   renWin->AddRenderer( ren1 );

vtkRenderWindowInteractor *iren =
            vtkRenderWindowInteractor ::New();
   iren->SetRenderWindow( renWin );

ren1->AddActor( cyberActor );
ren1->SetBackground( 1, 1, 1 );
renWin->SetSize( 500, 500 );

iren->Start();
```

Results



Before
(52,260 triangles)



After Decimation
and Smoothing
(7,477 triangles)

Filter Overview: Sources

<u>Readers</u>

- vtkOBJReader
- vtkBYUReader
- vtkCyberReader
- vtkDataSetReader
- vtkMCubesReader
- vtkPLOT3DReader
- vtkPolyDataReader
- vtkRectilinearGridReader

- vtkSLCReader
- vtkSTLReader
- vtkStructuredGridReader
- vtkStructuredPointsReader
- vtkUnstructuredGridReader
- vtkVolume16Reader
- vtkFieldDataReader
- vtkBMPReader
- vtkPNMReader
- vtkTIFFReader

Sources

Procedural Sources

- vtkEarthSource
- vtkConeSource
- vtkCylinderSource
- vtkDiskSource
- vtkLineSource
- vtkOutlineSource
- vtkPlaneSource
- vtkPointSource
- vtkTextSource
- vtkVectorText

- vtkSphereSource
- vtkTexturedSphereSource
- vtkAxes
- vtkCursor3D
- vtkProgrammableSource
- vtkPointLoad

Filters

- vtkAppendFilter
- vtkAppendPolyData
- vtkBooleanTexture
- vtkBrownianPoints
- vtkCastToConcrete
- vtkCellCenters
- vtkCellDataToPointData
- vtkCullVisiblePoints
- vtkCleanPolyData
- vtkClipPolyData

- vtkClipVolume
- vtkConnectivityFilter
- vtkContourFilter
- vtkCutter
- vtkDashedStreamLine
- vtkDecimate
- vtkDecimatePro
- vtkDelaunay2D
- vtkDelaunay3D
- vtkDicers

Filters (2)

- vtkEdgePoints
- vtkElevationFilter
- vtkExtractEdges
- vtkExtractGeometry
- vtkExtractGrid
- vtkExtractTensorComponents
- vtkExtractUnstructuredGrid
- vtkExtractVOI
- vtkExtractVectorComponents
- vtkFeatureEdges

- vtkGaussianSplatter
- vtkGeometryFilter
- vtkGlyph3D
- vtkHedgeHog
- vtkHyperStreamline
- vtkIdFilter
- vtkLinearExtrusionFilter
- vtkMaskPolyData
- vtkOutlineFilter
- vtkPointDataToCellData

Filters (3)

- vtkProgrammableFilter
- vtkProjectedTexture
- vtkRecursiveDividingCubes
- vtkReverseSense
- vtkRibbonFilter
- vtkRotationalExtrusionFilter
- vtkShepardMethod
- vtkShrinkFilter
- vtkShrinkPolyData
- vtkSmoothPolyDataFilter

- vtkMaskPoints
- vtkMaskPolyData
- vtkMergeFilter
- vtkMergePoints
- vtkPolyDataNormals
- vtkProbeFilter
- vtkProgrammableAttributeDataFilter
- vtkSelectVisiblePoints
- vtkSpatialRepresentationFilter
- vtkStreamLine

Filters (4)

- vtkStreamPoints
- vtkStripper
- vtkStructuredGridGeometryFilter
- vtkStructuredGridOutlineFilter
- vtkStructuredPointsGeometryFilter
- vtkTensorGlyph
- vtkTextureMapToBox
- vtkTextureMapToCylinder
- vtkTextureMapToPlane
- vtkTextureMapToSphere

- vtkTexturedSphereSource
- vtkThreshold
- vtkThresholdPoints
- vtkThresholdTextureCoords
- vtkTransformFilter
- vtkTransformPolyDataFilter
- vtkTransformTextureCoords
- vtkTriangleFilter
- vtkTriangularTCoords
- vtkTriangularTexture

Filters (5)

- vtkTubeFilter
- vtkVectorDot
- vtkVectorNorm
- vtkVectorTopology
- vtkVoxelModeller
- vtkWarpScalar
- vtkWarpTo
- vtkWarpVector

Mappers

Writers

- vtkIVWriter
- vtkBYUWriter
- vtkSTLWriter
- vtkMCubesWriter
- vtkPolyDataWriter
- vtkRectilinearGridWriter
- vtkStructuredGridWriter
- vtkStructuredPointsWriter
- vtkUnstructuredGridWriter
- vtkFieldDataWriter
- vtkBMPWriter
- vtkPNMWriter
- vtkTIFFWriter

Graphics Mappers

- vtkPolyDataMapper
- vtkDataSetMapper
- (volume mappers - later)
- (image mappers - later)