Chapter 2
VTK – The Visualization Toolkit

An introduction based on

- *Visualizing with VTK: A Tutorial*, Schroeder, Avila and Hoffman, IEEE Computer Graphics and Applications, Vol. 20, No. 5, pp. 20-27.

- *The Design and Implementation of an Object-Oriented Toolkit for 3D Graphics and Visualization*, Schroeder, Martin and Lorensen, Proceedings of IEEE Visualization '96, pp. 93-100.

Overview

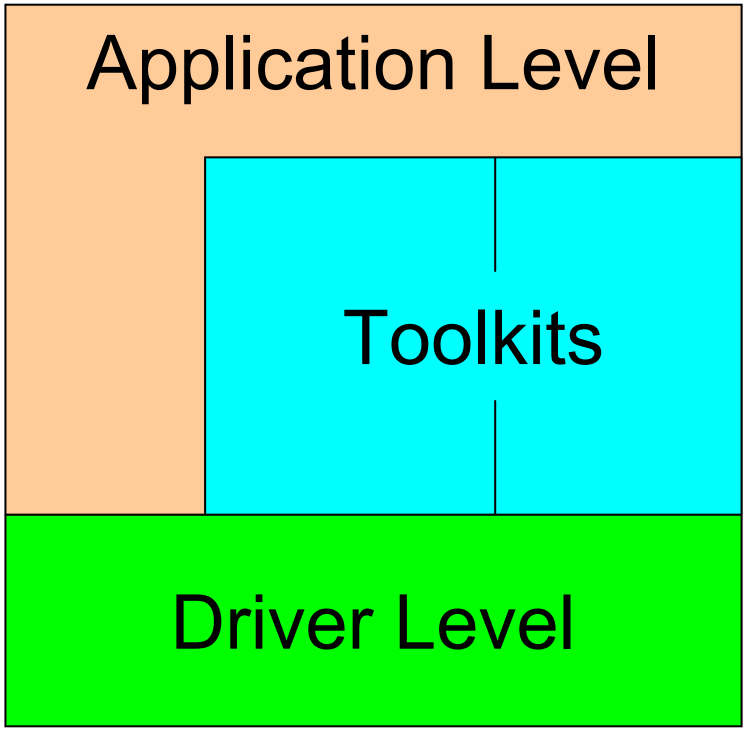
2.1 Design Goals
2.2 Object Models
2.3 Implementation Issues
2.4 Example

2.1 Design Goals

- Toolkit Philosophy
- Interpreted Language Interface
- Standards Based
- Portable
- Freely Available
- Simple

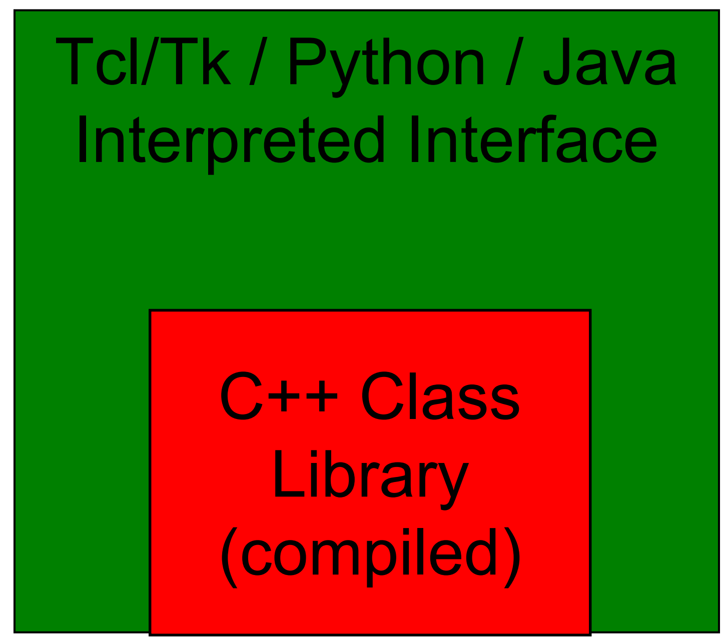
Toolkit Philosophy

- Sharply focused object library
- Easily embedded in applications
- Enables the building of complex systems
  - Pieces well defined
  - Simple interfaces



Interpreted Language Interface

- Compiled languages
  - Faster
  - Low level manipulations
- Interpreted
  - Simpler more compact code
  - Faster application development
  - Higher level
  - Easier to debug



Standards Based

- Use standard components and languages
- Encourages use of the toolkit
- Eases support and maintenance

Portable

- Authors skeptical that any graphics library will ever become a “standard.”
  - Toolkit uses high-level abstraction for 3D graphics
  - System can be easily ported as new standards become available
- Toolkit independent of system
  - Operating system
  - Windowing system

Freely Available

- For software to succeed it must be
  - Widely used (cheap/useful)
  - Well supported (expandable/source code available)
- Benefits
  - Better dissemination of algorithms
  - Collaboration with other researchers
  - Credibility in the Visualization field
  - Used for education and research

Simple

"Everything should be as simple as possible, but no simpler" – Albert Einstein

- Benefits
  - Encourages wider use of 3D graphics and visualization
  - Easier to maintain
  - Easier to interface
  - Easier to extend?
- Avoid cool but complex toolkit features
  - Interesting to programmers … but overwhelming to users

2.2 Object Models

- Graphics Model
  - Abstract model of 3-D graphics
- Visualization Model
  - Data flow model of the visualization process

Graphics Model

- Render Window – manages window
- Renderer – coordinates rendering
- Light – illuminates the scene
- Camera – view of scene
- Actor – object in scene
- Property – appearance of actor
- Mapper – geometry of actor
- Transform – position and orientation of actor, camera, lights

Device Dependent Subclasses

- Portability of the design achieved by using device objects, which extend the functionality of graphics classes in a device dependent way.
  - The VTK toolkit returns a subclass specific to the system
- Example:

```
vtkRenderMaster rm;
renderWindow = rm.MakeRenderWindow();
aRen = renderWindow->MakeRenderer();
```

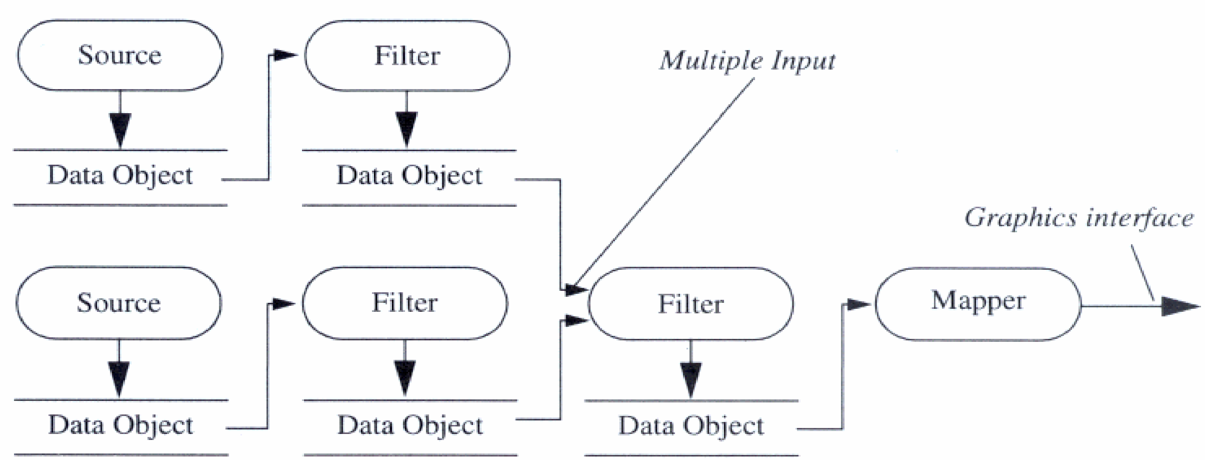
Application running on Sun UNIX creates an X-Windows window and a SUN XGL renderer whereas on a PC it creates a Windows rendering window and an OpenGL renderer.

Visualization Model

- Data flow paradigm
  - Modules connected to form a network.
  - Data flows through network, modules perform operations on the data.
  - Execution demand driven (pulls data from source) or event driven (responds to user input).
- Visualization model consists of
  - Process objects – visualization algorithms
  - Data objects – datasets to be visualized

Process Objects

- Sources
  - Generate output datasets
- Filters
  - Transform datasets into new datasets
- Mappers
  - Map datasets into Actors (graphics objects)



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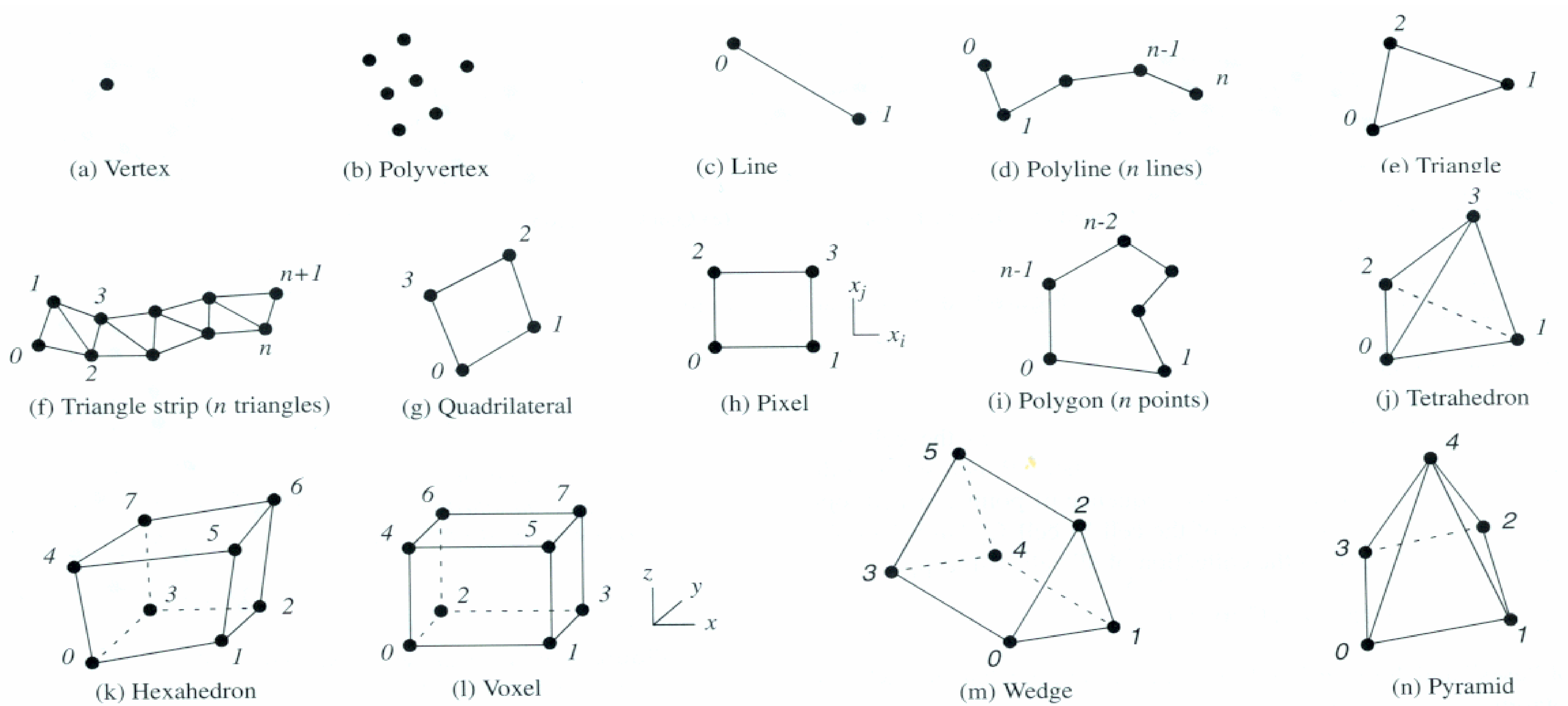
Dataset Objects

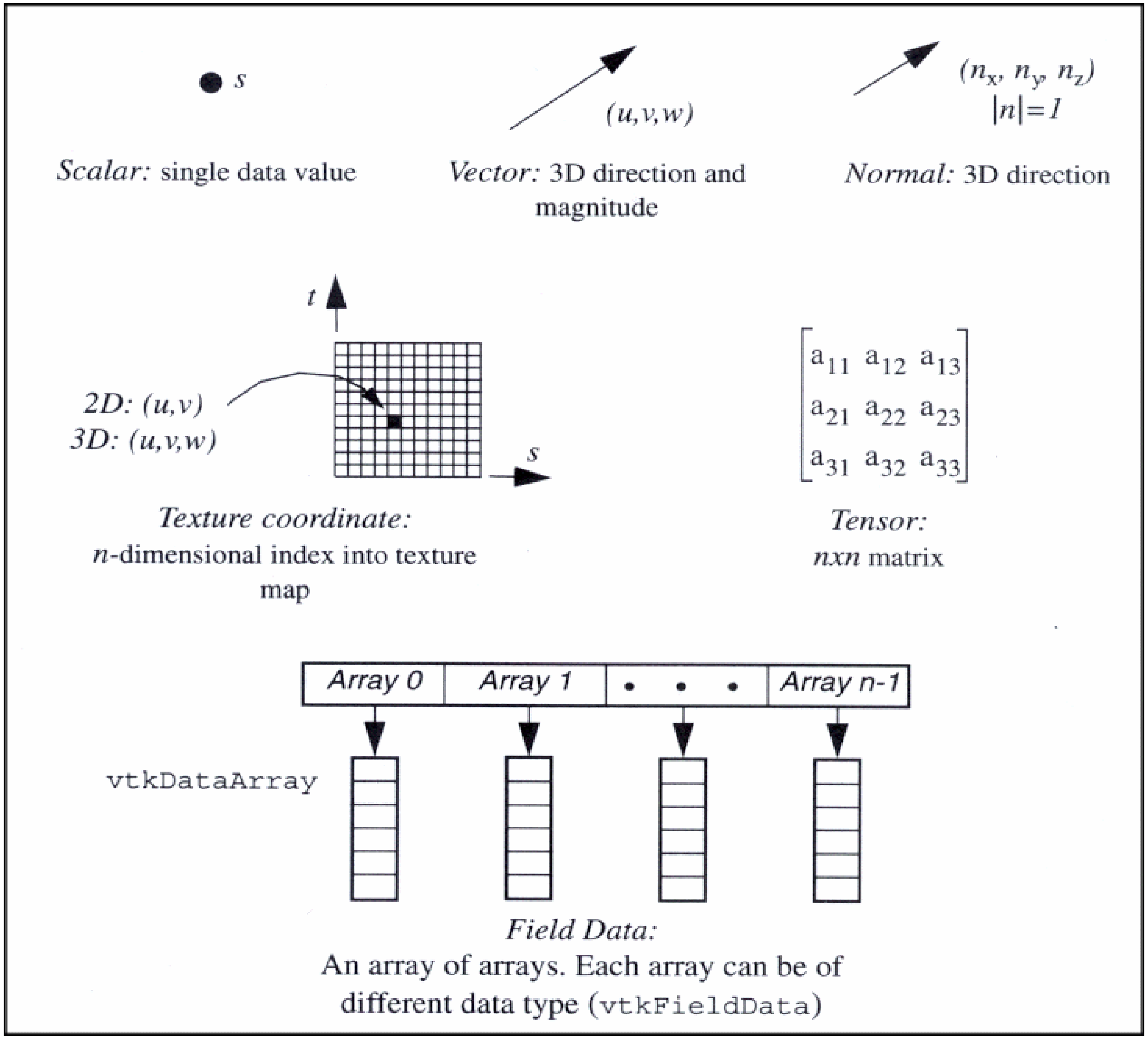
Data objects have a …

- Structure consisting of
  - Points: specify geometry (position in space)
  - Cells: specify topology (type of shape, allows interpolation between points)
- Associated Data Attributes
  - information associated with topology and/or geometry, e.g. scalars, vectors, normals, tensors, texture coordinates.

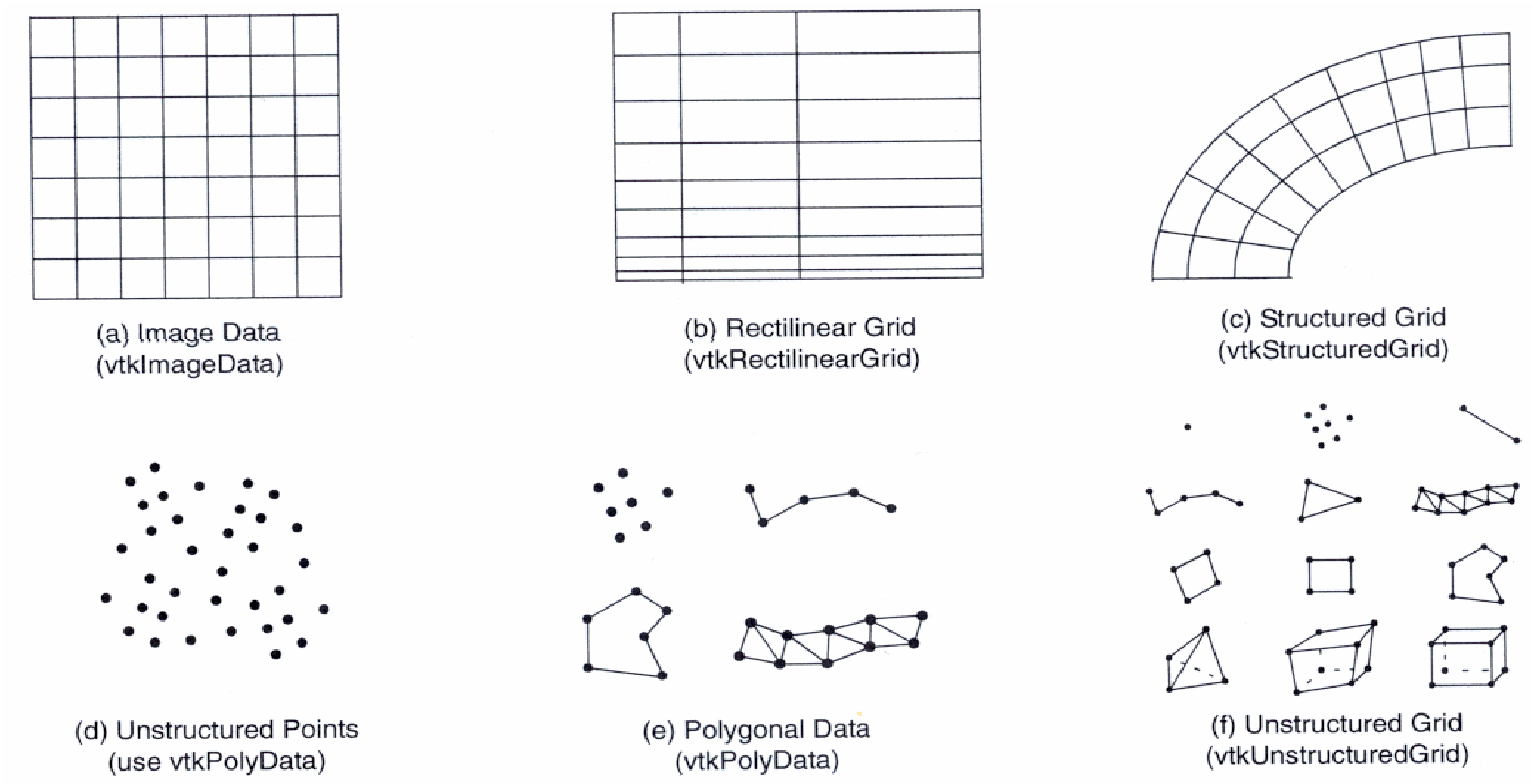
Cell Types


(a) Vertex
(b) Polyvertex
(c) Line
(d) Polyline (n lines)
(e) Triangle
(f) Triangle strip (n triangles)
(g) Quadrilateral
(h) Pixel
(i) Polygon (n points)
(j) Tetrahedron
(k) Hexahedron
(l) Voxel
(m) Wedge
(n) Pyramid

Attribute Data



Types of Data



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Types of Data (cont'd)

- Image Data (`vtkImageData`)
  - Topology and geometry completely regular.
  - Represented implicitly by data dimension (n_x, n_y, n_z), origin, spacing.
- Rectilinear Grid (`vtkRectilinearGrid`)
  - Collection of points and cells on a regular lattice.
- Structured Grid (`vtkStructuredGrid`)
  - Regular topology and irregular geometry.
  - Geometry represented by array of point coordinates.
- Unstructured Grid (`vtkUnstructuredGrid`)
  - The most general form of a dataset.
  - Topology and geometry completely unstructured.
- Polygonal data (`vtkPolyData`)
  - Bridge between data, algorithms and high-speed computer graphics.

Object Oriented Design

- Generic Filter
  - Operates on any type of data (e.g. contour filter)
- Specific Filter
  - Operates only on one particular type of data (e.g. the decimation filter has been specifically constructed for polygonal data)
- Allows the implementer to trade of generality with efficiency

2.3 Implementation Issues

- Why C++?
  - Efficient *and* object-oriented
  - Strongly typed
- Get/Set macros
  - Uniform access to all object variables
  - Debugging, auditing (tracks modifications)
  - Enforce uniform object behaviour (e.g. maintain internal modification time → network execution)

Memory Management

- Garbage Collection
  - Datasets often shared by multiple processes
  - Dataset objects maintain reference counters
  - When reference count is zero, object commits suicide (deletes itself).
- Resource Management
  - Memory scarce – delete result after use
  - CPU scarce – save result after use

Making OO Fast

- Avoid creating/destroying large numbers of objects
  - Datasets are large but contained in single object
- Minimize data copying
  - Datasets encapsulated in objects
  - Dataset objects passed by reference
- Reduce object function overhead
  - Use inline functions when possible

2.4 Example

```
// Create a cone represented by polygons
vtkConeSource *cone = vtkConeSource::New();
cone->SetHeight( 3.0 );
cone->SetRadius( 1.0 );
cone->SetResolution( 10 );

// map the polygonal data into graphics primitives.
// Connect the output of the cone source to the
// input of this mapper.
vtkPolyDataMapper *coneMapper = vtkPolyDataMapper::New();
coneMapper->SetInput( cone->GetOutput() );
```

Example (cont'd)

```
// Create an actor to represent the cone. The actor
// orchestrates rendering of the mapper's graphics
// primitives using given properties and an
// internal transformation matrix.
vtkActor *coneActor = vtkActor::New();
coneActor->SetMapper( coneMapper );

// Create the Renderer and assign actors to it.
vtkRenderer *ren1= vtkRenderer::New();
ren1->AddActor( coneActor );
ren1->SetBackground( 0.1, 0.2, 0.4 );
```

Example (cont'd)

```
// Create the render window put renderer into it
vtkRenderWindow *renWin = vtkRenderWindow::New();
renWin->AddRenderer( ren1 );
renWin->SetSize( 300, 300 );

// Loop over 360 degrees and
// render the cone each time.
int i;
for (i = 0; i < 360; ++i){
   renWin->Render();
   ren1->GetActiveCamera()->Azimuth( 1 );
}
```