12th Summer School on SCIENTIFIC VISUALIZATION

Introduction to Visualization ToolKit

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CINECA

SCS SuperComputingSolutions a cineca company

Index

- General Introduction
- Data Structures
- Filtering
- Rendering
- Strategies and optimizations

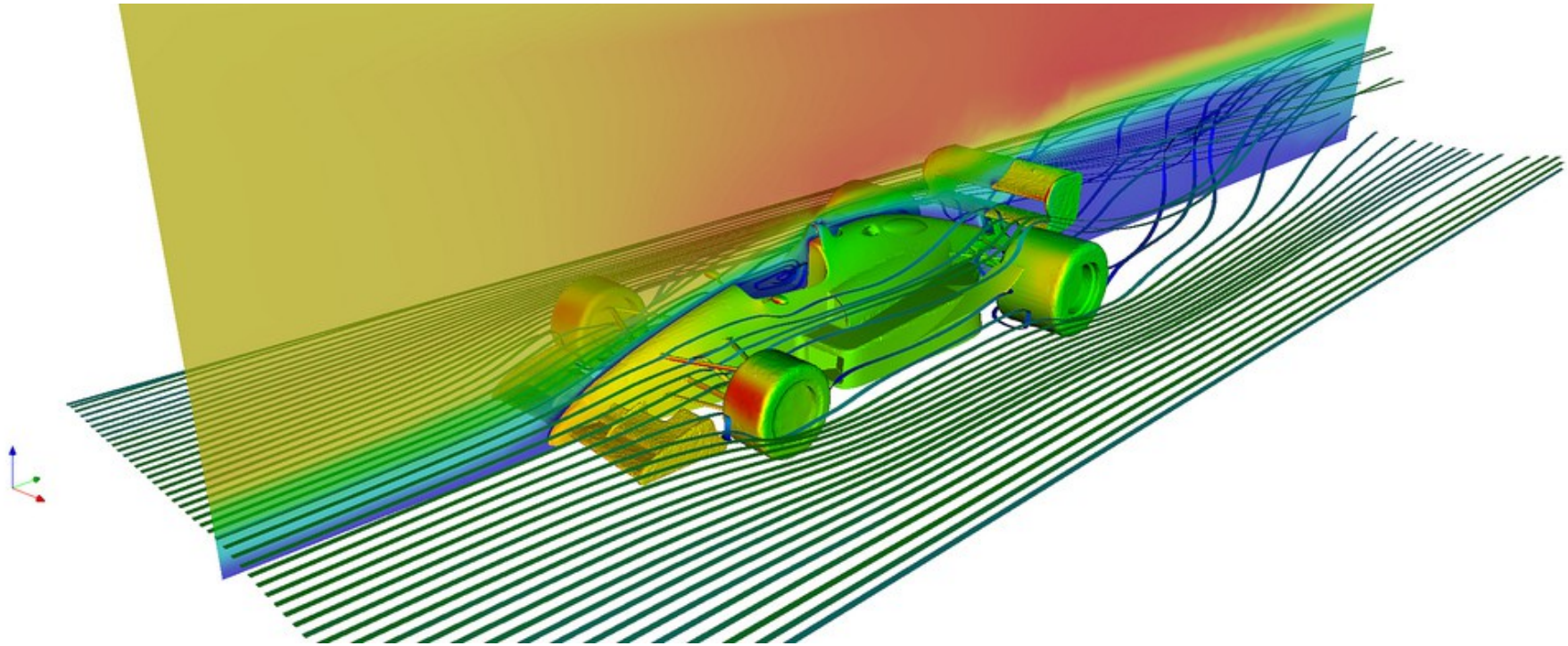
What is VTK

- History - born in 1993 as example code from the visualization textbook. Ever since then it has grown via open source services funded model
- Kitware hosts the project and are primary developers
- VTK is a library - something that applications use

What can VTK do for me?

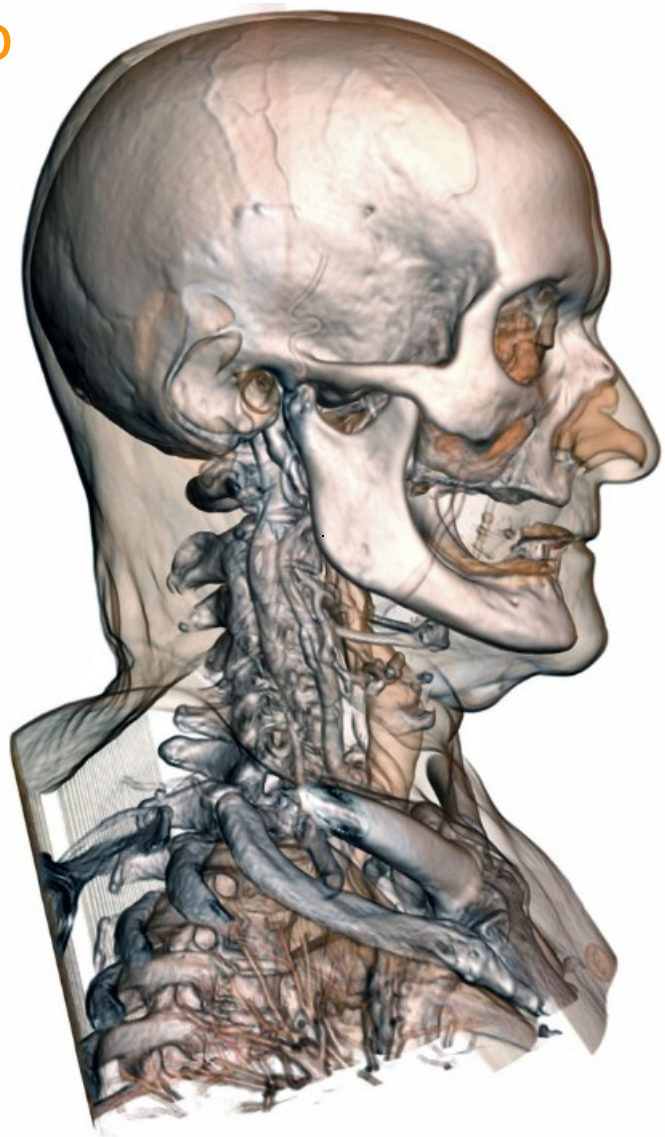
- SCI VIS — 2 to 4D data processing and (volume) rendering
- image processing
- text analysis and information visualization
- charting/plotting
- application support GUI support, Widgets)

What VTK can do for me



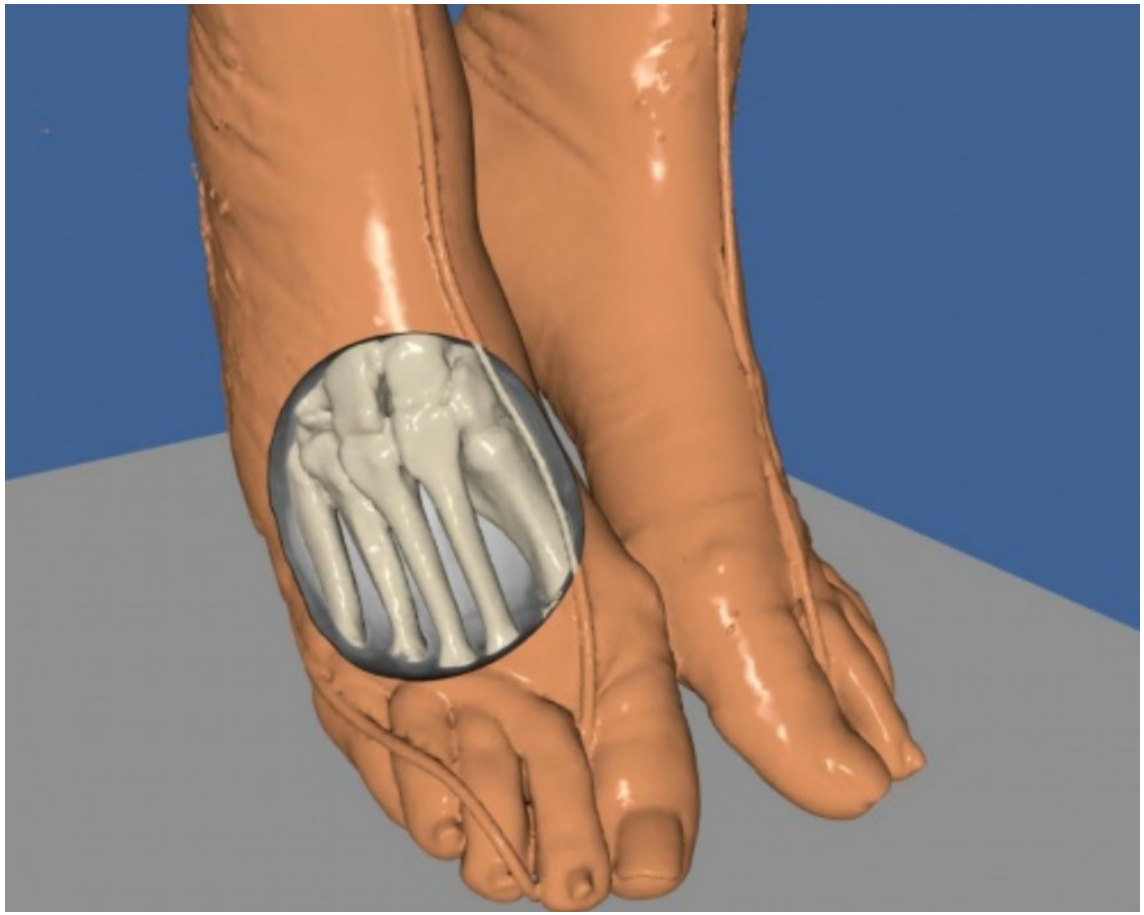
Flow Around Car

What VTK can do for me



Volume rendering

What VTK can do for me

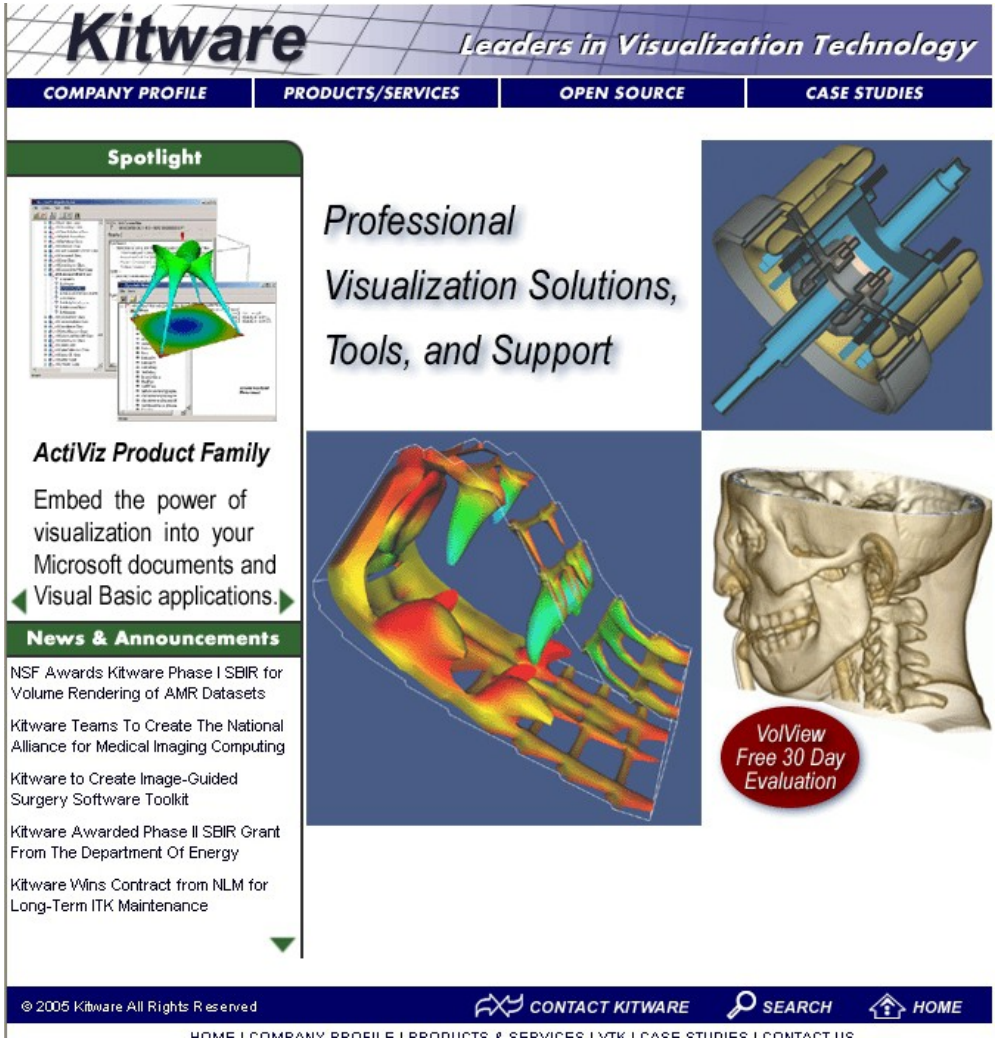


CT scan from the visible woman dataset. An isosurface of the skin is clipped with a sphere to reveal the underlying bone structure.
Author: Bill Lorensen.

Kitware

- Site
- Cmake
- ITK
- Paraview
- VolView

www.kitware.com



Characteristics

VKT is a C++ library

- FREE
- Open Source
- Cross Platform
- Extensible
- More then 600 classes
- Documented
- Dashboards

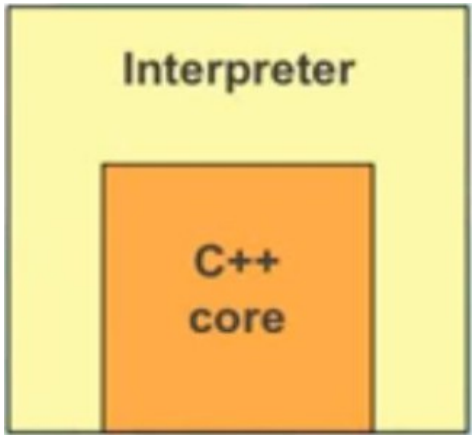
Characteristics (2)

- Structure :

  object oriented c++ core

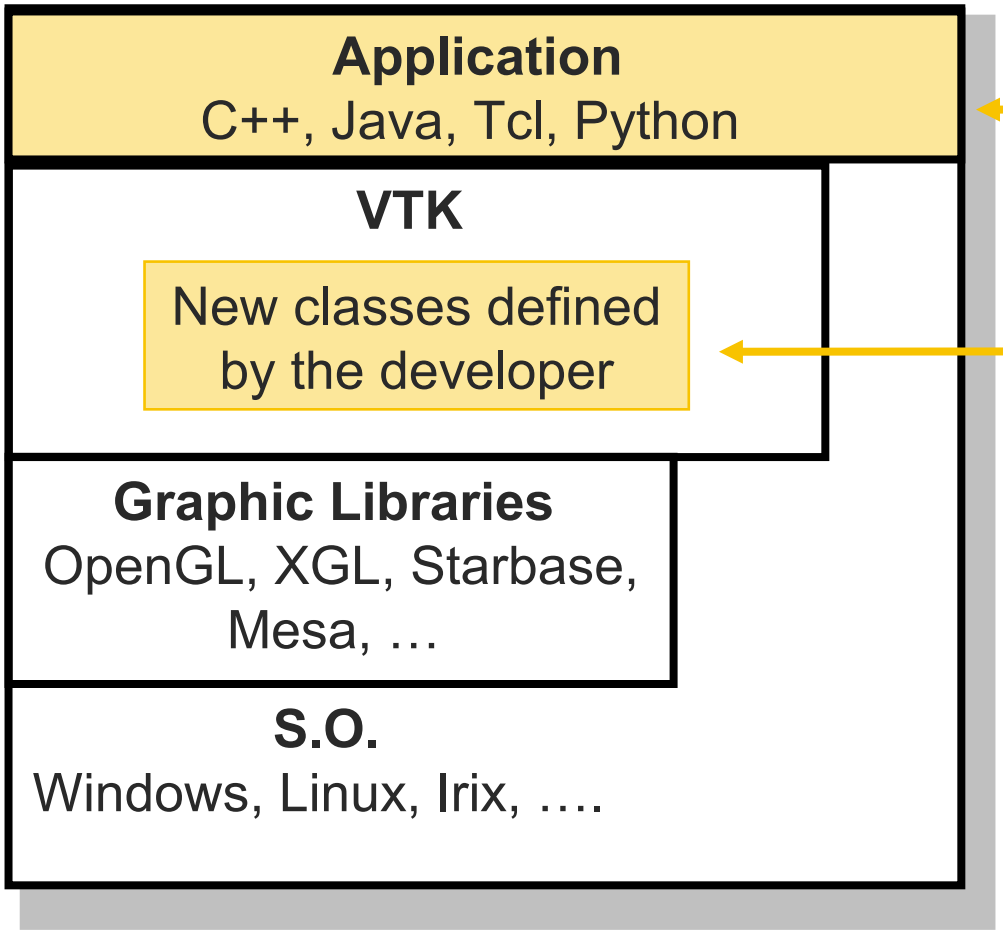
  interpreted wrappings

- Interpreted layer generated automatically by VTK wrapping process



Interpreted layer generated automatically by VTK wrapping process

Characteristics of VTK



High level programming
Creation of applications

Low level programming
Extending the library

Data

Information
One or more values that vary in a certain domain

Discretization or sampling

Domain partitioning in cells and measure values corresponding to the vertices. (and/or cells)

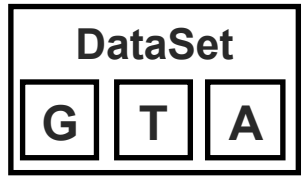
Data
Discrete representation of the information

Structure

Attributes
Whole measures

Geometry
vertices property

Topology
cells property

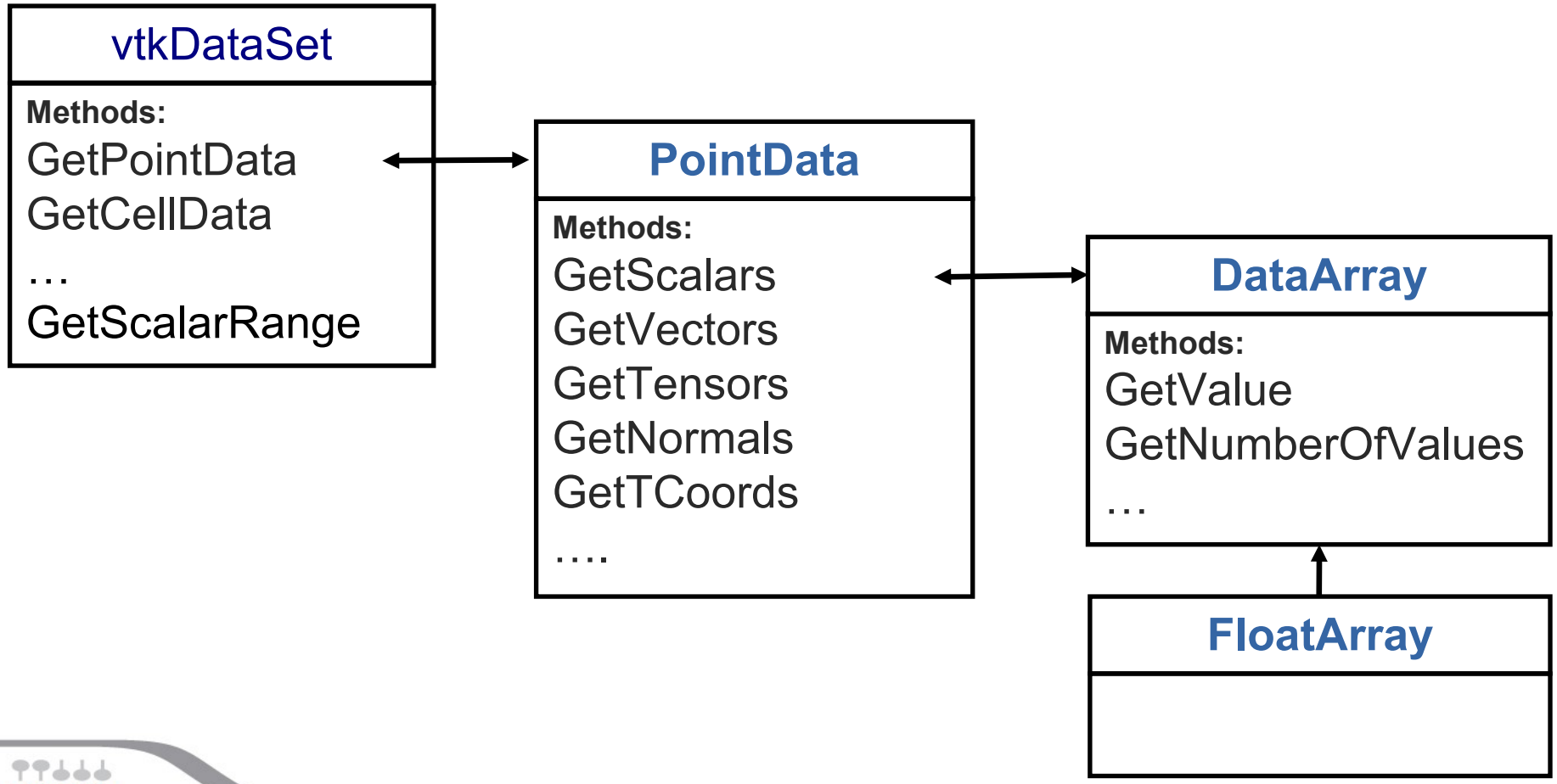


Attributes

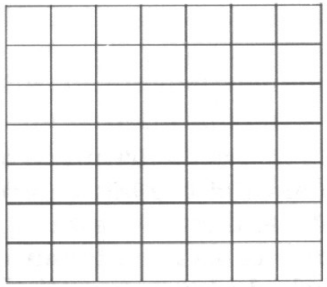
- Association
  - Points attributes
  - Cells attributes
- Type
  - Scalars (max 4 components)
  - Vectors (3 components)
  - Tensors rank 3 (9 components)
  - Normal (3 components)
  - Texture Coordinates (max 3 components)
  - Fields (n*m components)
- Representation
  - char …. double

Attributes

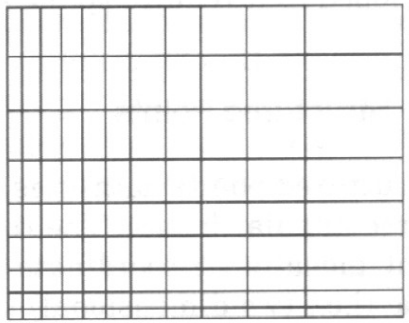
```
Dato->GetPointData()->GetScalars()->GetValue(1);
```



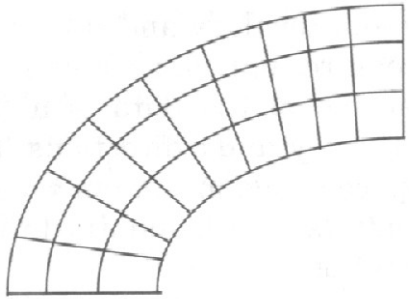
Data types



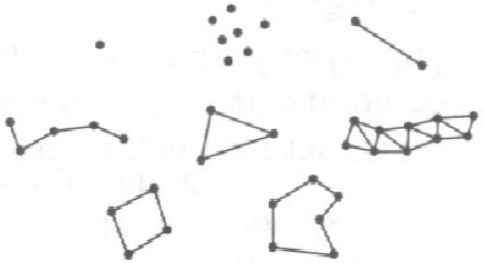
vtkStructuredPoints
(vtkImageData)



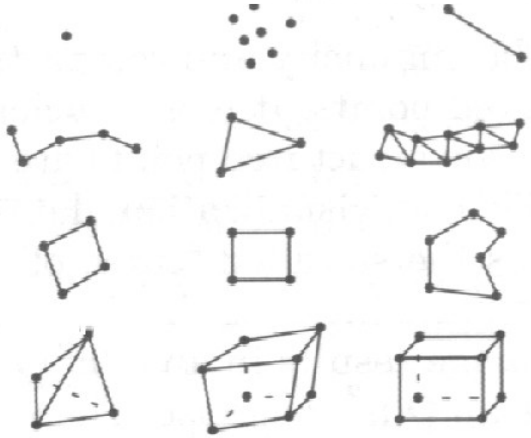
vtkRectilinearGrid



vtkStructuredGrid



vtkPolyData

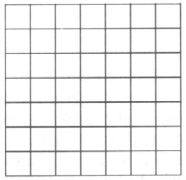


vtkUnstructuredGrid

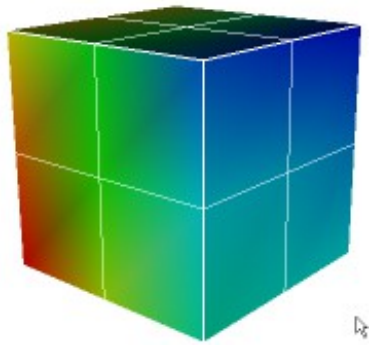
vtkStructuredPoints

Geometry and Topology (voxel) are both implicit
and are determined using Origin, Dimensions, and Spacing.

Sample C++ code that creates a StructuredPoints


(a) Structured Points

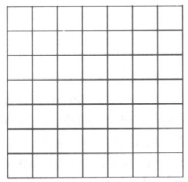
```
vtkStructuredPoints *sp = vtkStructuredPoints::New();
sp->SetOrigin     (0,0,0);
sp->SetDimensions(3,3,3);
sp->SetSpacing    (1,1,1);

vtkFloatArray *fa = vtkFloatArray::New();
for(i=0; i<27; i++)
   fa->InsertValue( i, i );
SP->GetPointData()->SetScalars( fa );
```



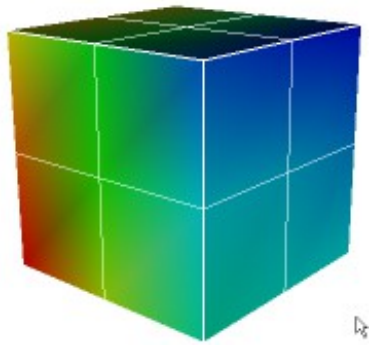
vtkStructuredPoints

Sample Python code that creates a StructuredPoints

```
sp = vtk.vtkStructuredPoints()
sp.SetOrigin     (0,0,0)
sp.SetDimensions(3,3,3)
sp.SetSpacing    (1,1,1)

fa = vtk.vtkFloatArray()
for i in range(0,26):
   fa.InsertValue( i, i )

sp.GetPointData().SetScalars( fa );
```

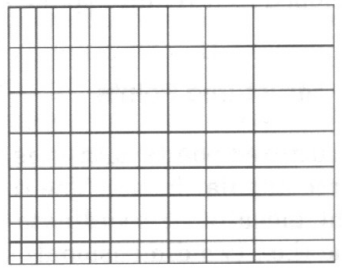


(a) Structured Points



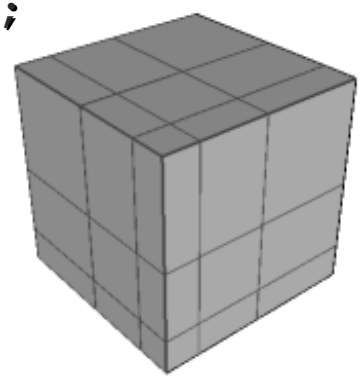
vtkRectilinearGrid

- Implicit Topology (hexahedron)
- Geometry obtained combining values of X,Y,Z coordinates specified using three arrays.



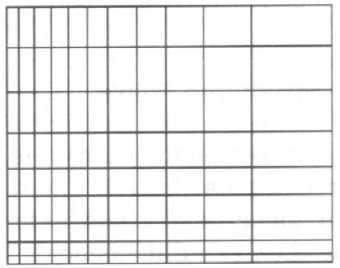
(b) Rectilinear Grid

```
vtkFloatArray *FA = vtkFloatArray::New();
FA->InsertValue( 0, 0 );
FA->InsertValue( 1, 1 );
FA->InsertValue( 2, 3 );
FA->InsertValue( 3, 6 );

vtkRectilinearGrid *RG = vtkRectilinearGrid::New();
RG->SetDimensions (4,4,4);
RG->SetXCoordinates(FA);
RG->SetYCoordinates(FA);
RG->SetZCoordinates(FA);
```



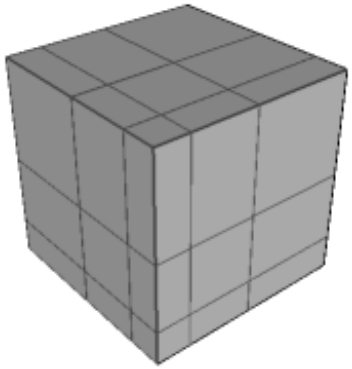
vtkRectilinearGrid

- Implicit Topology (hexahedron)
- Geometry obtained combining values of X,Y,Z coordinates specified using three arrays.



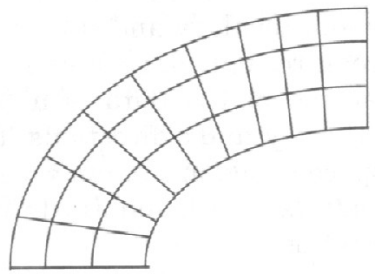
(b) Rectilinear Grid

```
fa = vtk.vtkFloatArray()
fa.InsertValue( 0, 0 )
fa.InsertValue( 1, 1 )
fa.InsertValue( 2, 3 )
fa.InsertValue( 3, 6 )

rg = vtk.vtkRectilinearGrid()
rg.SetDimensions(4,4,4)
rg.SetXCoordinates(fa)
rg.SetYCoordinates(fa)
rg.SetZCoordinates(fa)
```



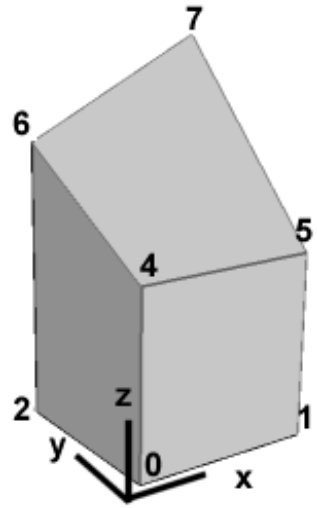
vtkStructuredGrid

- Implicit Topology – (hexahedron)
- Explicit Geometry



(c) Structured Grid

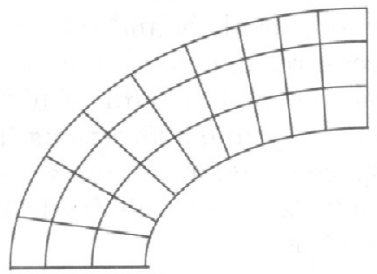
```
vtkPoints *p = vtkPoints::New();
p->InsertNextPoint( 0,0,0 );
p->InsertNextPoint( 1,0,0 );
p->InsertNextPoint( 0,1,0 );
p->InsertNextPoint( 1,1,0 );
p->InsertNextPoint( 0,0,1 );
p->InsertNextPoint( 1,0,1 );
p->InsertNextPoint( 0,1,1.5 );
p->InsertNextPoint( 1,1,2   );

vtkStructuredGrid *sg = vtkStructuredGrid::New();
sg->SetDimensions (2,2,2);
sg->SetPoints(p);
```



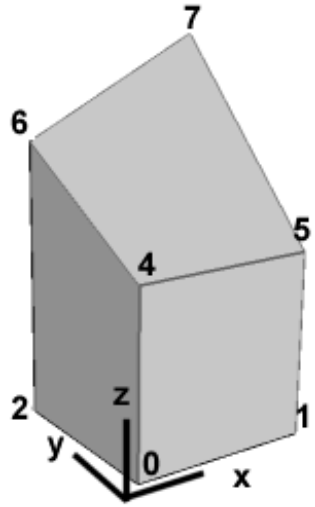
vtkStructuredGrid

- Implicit Topology – (hexahedron)
- Explicit Geometry

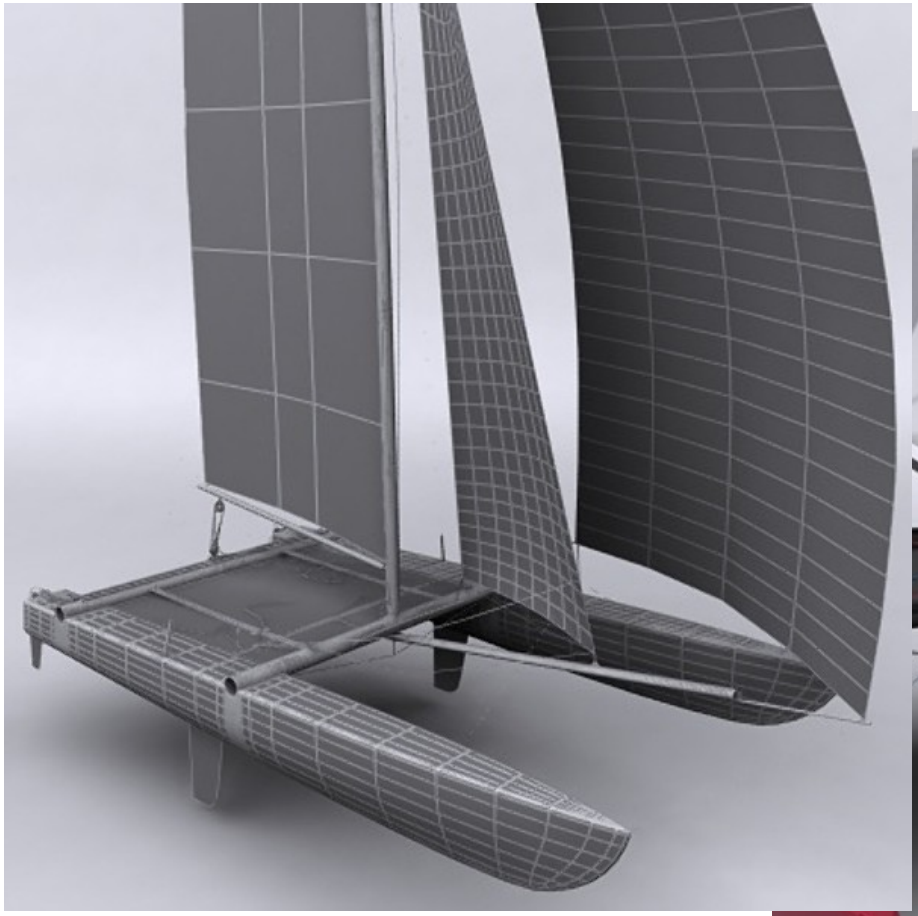
```
p = vtk.vtkPoints()
p.InsertNextPoint( 0,0,0 )
p.InsertNextPoint( 1,0,0 )
p.InsertNextPoint( 0,1,0 )
p.InsertNextPoint( 1,1,0 )
p.InsertNextPoint( 0,0,1 )
p.InsertNextPoint( 1,0,1 )
p.InsertNextPoint( 0,1,1.5 )
p.InsertNextPoint( 1,1,2   )

sg = vtk.vtkStructuredGrid()
sg.SetDimensions (2,2,2)
sg.SetPoints(p)
```

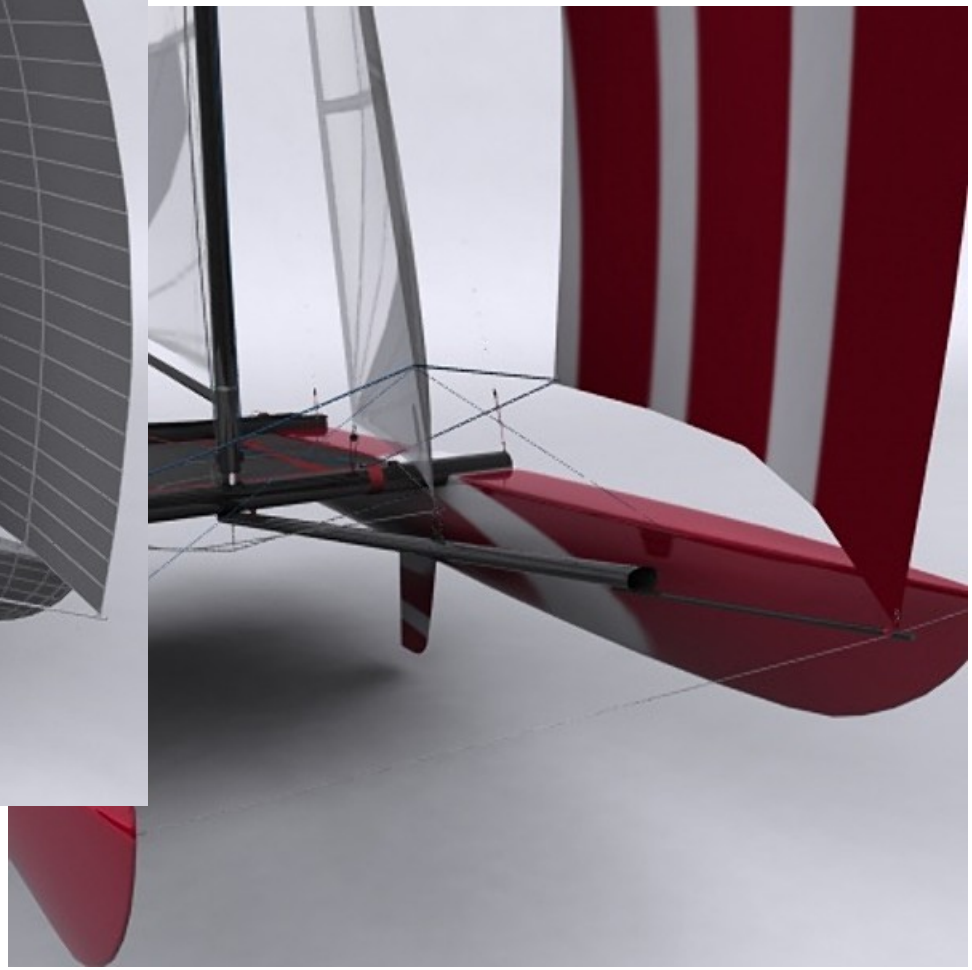


(c) Structured Grid



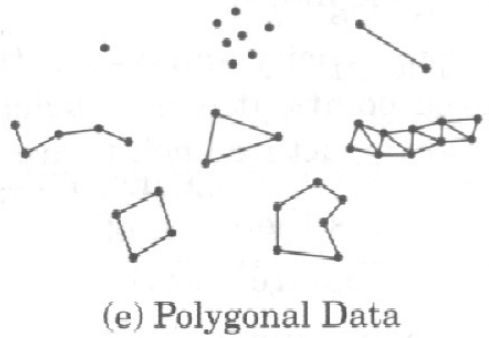
vtkPolyData



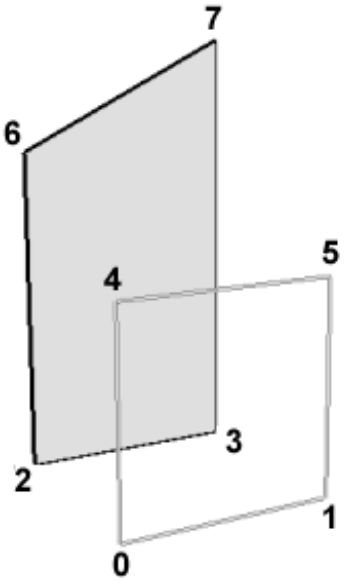


vtkPolyData

- Geometry and Topology both explicit
- Cells are subdivided in four classes: Verts, Lines, Polys, Strip

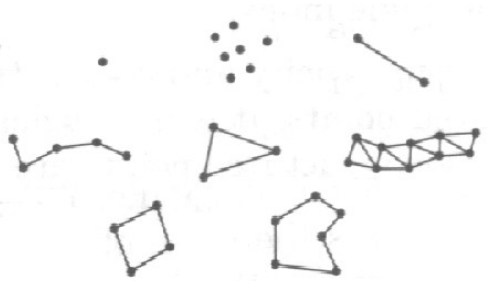

(e) Polygonal Data

```
vtkCellArray *quad = vtkCellArray::New();
quad->InsertNextCell( 4 );
quad->InsertCellPoint( 3 );
quad->InsertCellPoint( 2 );
quad->InsertCellPoint( 6 );
quad->InsertCellPoint( 7 );
// create polyline cell with indexes 0,1,5,4,0

vtkPolyData *pd = vtkPolyData::New();
pd->SetPoints( p  );
pd->SetPolys ( quad );
pd->SetLines ( polyline );
```

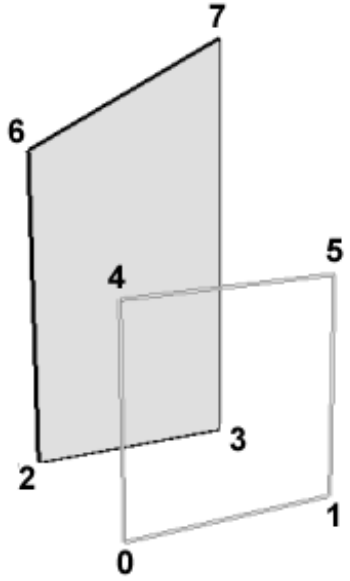


vtkPolyData

```
quad = vtk.vtkCellArray()
quad.InsertNextCell( 4 )
quad.InsertCellPoint( 3 )
quad.InsertCellPoint( 2 )
quad.InsertCellPoint( 6 )
quad.InsertCellPoint( 7 )

polyline = vtk.vtkCellArray()
polyline.InsertNextCell( 5 )
polyline.InsertCellPoint( 0 )
polyline.InsertCellPoint( 1 )
polyline.InsertCellPoint( 5 )
polyline.InsertCellPoint( 4 )
polyline.InsertCellPoint( 0 )
```

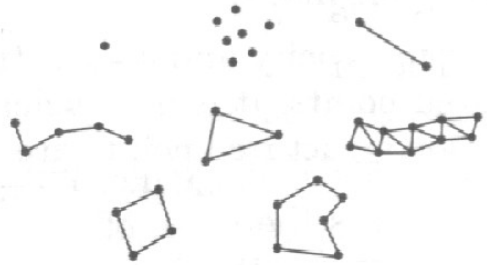


(e) Polygonal Data

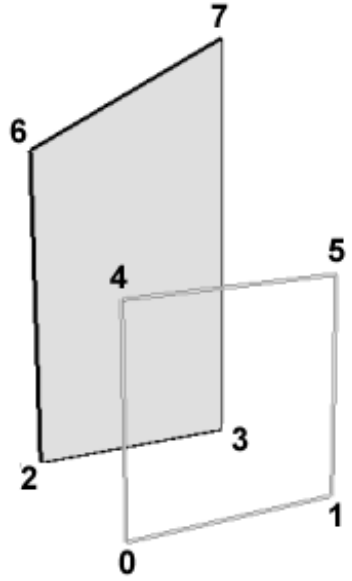


vtkPolyData

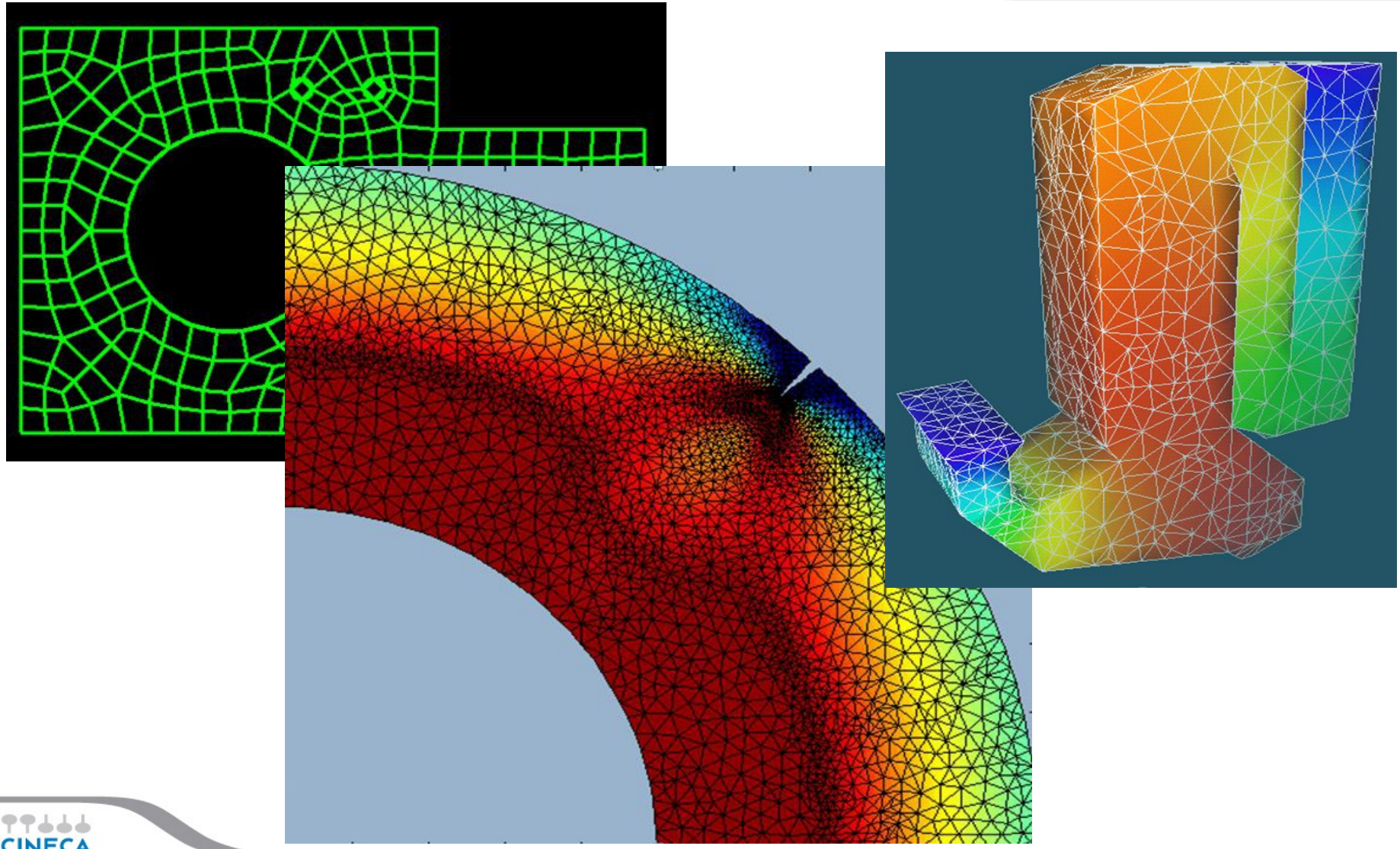
```
pd = vtk.vtkPolyData()
pd.SetPoints( p  )
pd.SetPolys ( quad )
pd.SetLines ( polyline )
```



(e) Polygonal Data

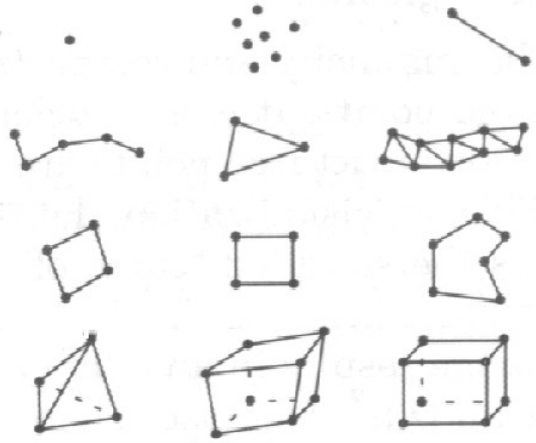


vtkUnstructuredGrid



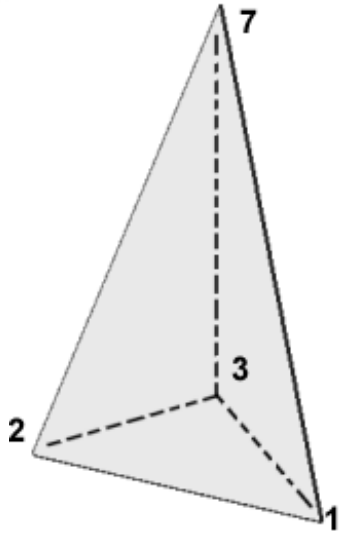
vtkUnstructuredGrid

- Geometry and Topology both explicit
- Celle can be 0,1,2 or 3D



(f) Unstructured Grid

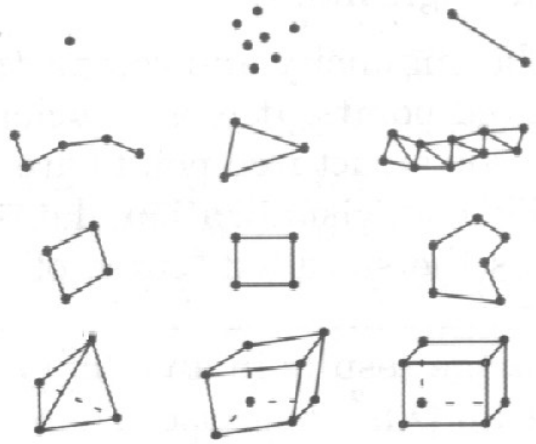
```
vtkIdList *il = vtkIdList::New();
il->InsertNextId( 1 );
il->InsertNextId( 2 );
il->InsertNextId( 3 );
il->InsertNextId( 7 );

vtkUnstructuredGrid *ug = vtkUnstructuredGrid::New()
ug->SetPoints( p );
ug->InsertNextCell( VTK_TETRA, il );
```



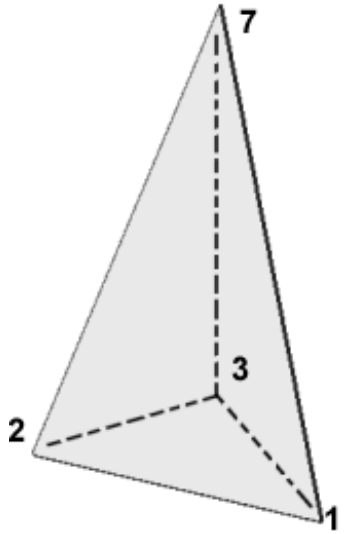
see vtkCellType.h

vtkUnstructuredGrid

- Geometry and Topology both explicit
- Celle can be 0,1,2 or 3D



(f) Unstructured Grid

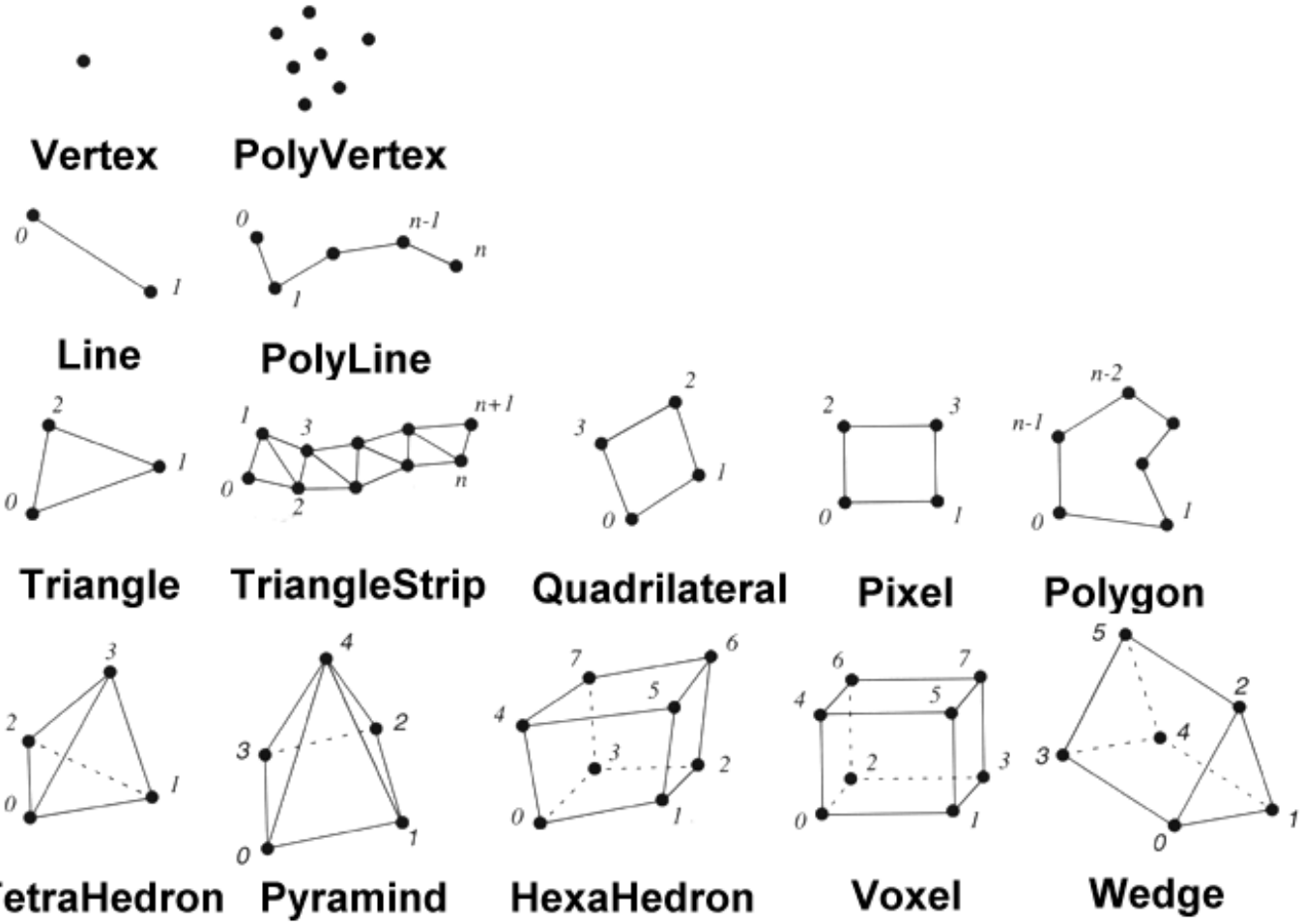



```
il = vtk.vtkIdList()
il.InsertNextId( 1 )
il.InsertNextId( 2 )
il.InsertNextId( 3 )
il.InsertNextId( 7 )

ug = vtk.vtkUnstructuredGrid()
ug.SetPoints( p )
ug.InsertNextCell( vtk.VTK_TETRA, il )
```

see vtkCellType.h

Cell types

- 0d
- 1d
- 2d
- 3d



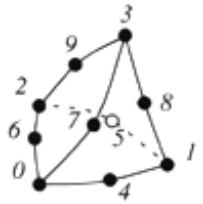
Cell types

- Non linear Cells

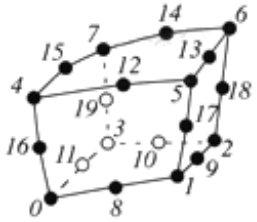
Quadratic Edge

Quadratic Triangle

Quadratic Quadrilateral



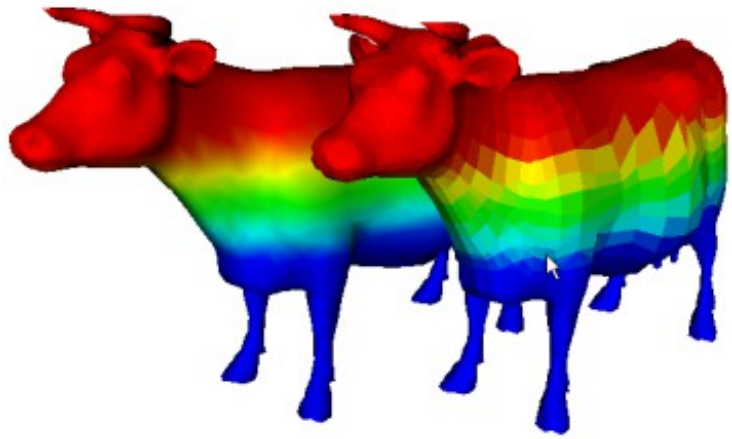
Quadratic Tetrahedron



Quadratic Hexahedron

Data querying

- Geometry
  - GetNumberOfPoints, GetPoint, FindPoint
  - GetCenter, GetBounds, GetLenght,
- Topology
  - GetNumberOfCells, GetCell, FindCell, IntersectWithLine
  - GetPointCells, GetCellPoints, GetCellNeighbors
- Attributes
  - GetScalarRange
  - GetScalar,GetVector ….
  - EvaluatePosition



Supported formats

- Reader/Writer – works only on one data
  - Native VTK format (ASCII, Binary, XML)
  - Images: BMP, JPEG, TIFF, PNG, PNM, RAW (also 3D), DEM, GESigna
  - Surfaces: STL, MCubes, PLY
  - Volumes: Plot3D, SLC, UGFacet
  - Other: Particles
- Importer/Exporter – works only on the scene
  - Import : 3DS, VRML
  - Export : IVO, OBJ, OOGLE, RIB, VRML

Data Import

Strategies:

- "ASCII ART"
  - The VTK ASCII format is really simple, in some cases you have only to add a header to the data and transform it in VTK.
- Create VTK data programmatically
  - If you are able to write a program that is able to read the data to be imported, can be created a VTK data type as seen in the previous slides (Programmable Source)
- Build a Reader
  - In case of frequent usage, building a reader is the best way to proceed, but also the more expensive. At the end it can be donated to the community.

Pipeline

data-flow paradigm

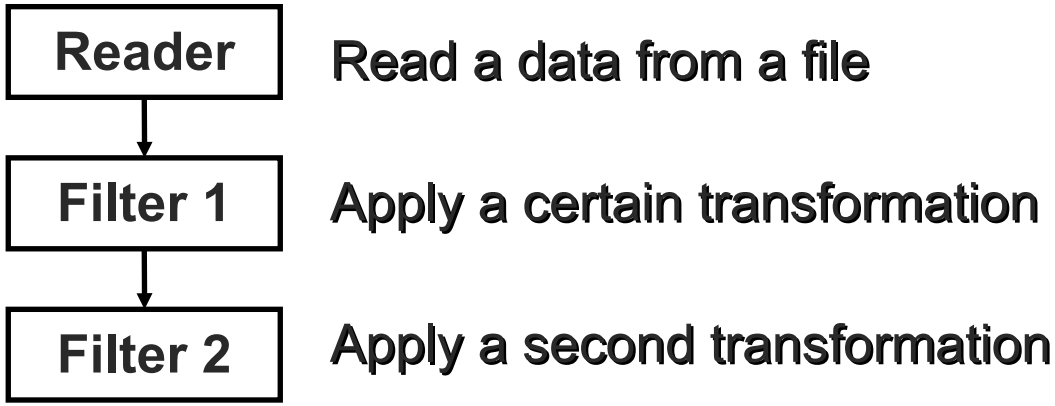
- Create a visualization using VTK means:
  - Find out in the VTK libraries the necessary filters
  - Link them together (this is called **pipeline**)
    In simple cases the pipeline will be a linear chain, while in more complex cases it can be a graph.

- The pipeline ends with a Window object
  Showing this window, we will see the first result of the elaboration; you can then pass to the interactive phase that allows you:
  - Change the object's properties or how they are linked
  - Evaluate the obtained result eventually go back to the previous value.

- No more code is strictly required.
  (execution demand driven)

Filters

- A **Filter** is an object that can elaborate a data, in particular receive a data from its **input**, elaborate it considering its **parameters**, gives the result using its **output**.
  In some cases, filters don't have inputs (Readers, Source) or don't have the output (Writer, Mapper)

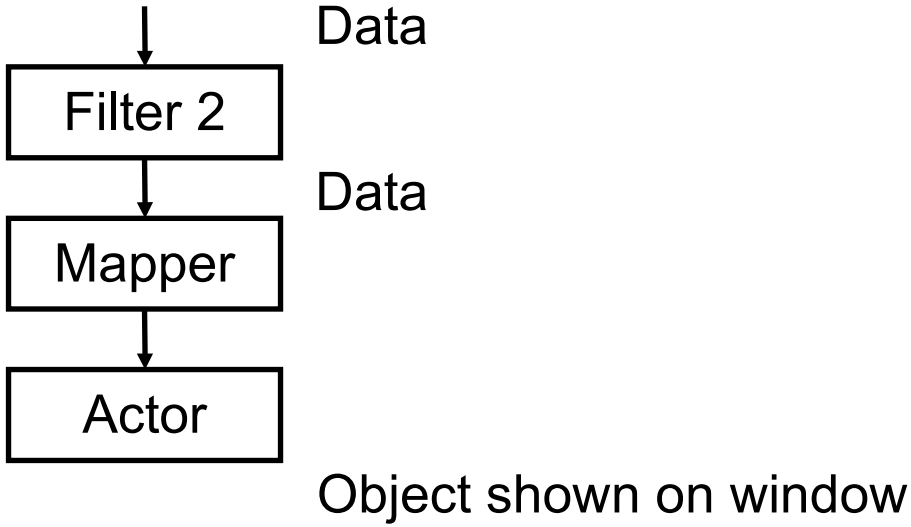


- Multiple Input / Output
- Multiple Fan-Out

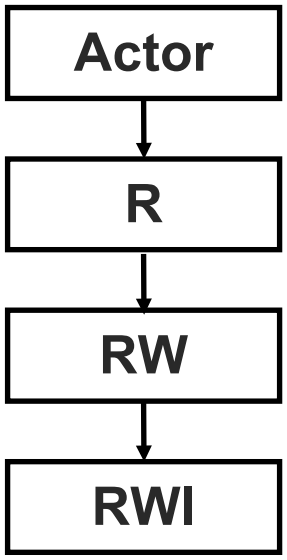
- Developer doesn't create data

Mapper and Actors

- In general a chain of filters end with two objects: the Mapper and the Actor.
- The Mapper specify interface between data and graphics primitives
- The Actor represents one of the objects shown into the window. The Actor is always linked to a Mapper.



R,RW,RWI



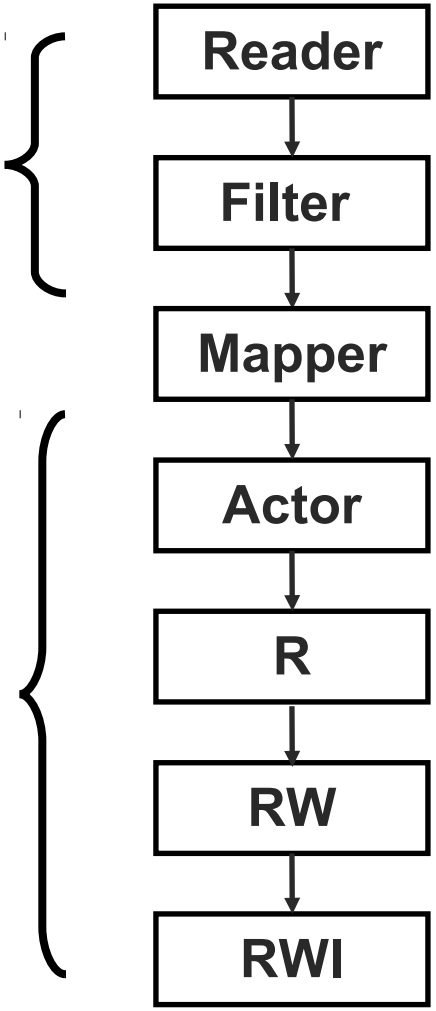
The pipeline visualization happen using the following objects:

- The **Renderer** receives one or more actors and represents "the visualized scene".
- The **RenderWindow** represents the window that you see on the screen and contains the scene.
- The **RenderWindowInteractor** add the interactivity, the possibility to manage the Mouse events. By default the interactor allows you to change the scene point of view.

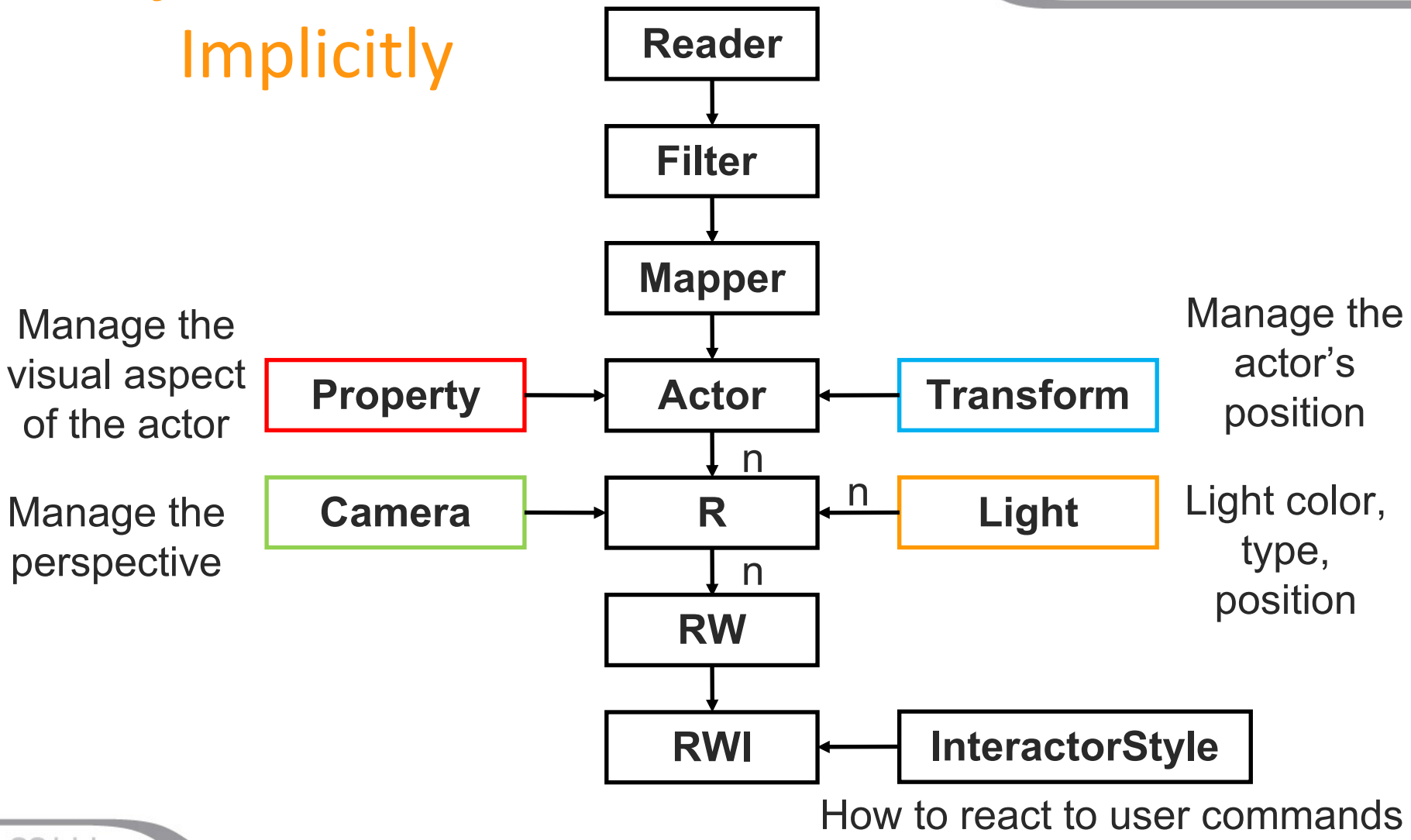
Complete Pipeline

Visualization Pipeline

Graphics Pipeline



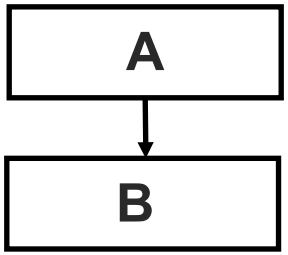
Objects Created Implicitly



Techniques and Optimization

- Filter's connection
- Reference Counting
- Pipeline execution
- Data sharing
- Caching
- Streaming
- Multithreading

Filters connection



Let's see what there's behind this diagram

STEP 1:

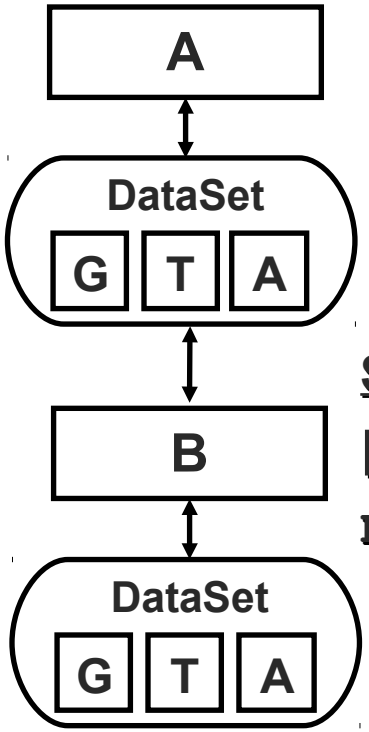
create A,

A create its own Output

STEP 2:

create B,

B create its own Output



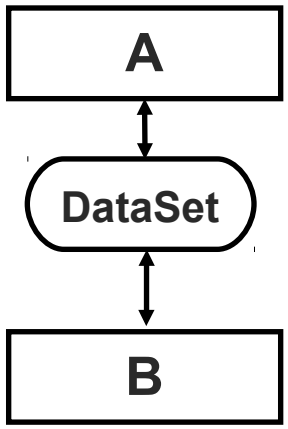
STEP 3:

Link B with A,

```
B->SetInputConnection(
   A->GetOutputPort())
```

Reference Count

What happen if A is deleted ?



- Each VTK object has internally a counter called “Reference Count” (RC), that keep trace of how many other objects have a pointer to it.
- This counter can be changed using two methods Register and Unregister.
- Normally these methods are invoked as side-effect of New, Delete and SetXYZMethod.

New and Delete

- **New** and **Delete** are invoked by an entity external to the object. Its implicit that if this entity create the object, than want to use it, so objects are created with RC=1.

```
vtkFilter::New()
{Register, …}
```

- When how created the object don't want to use it anymore, will call the **Delete** method of the object:

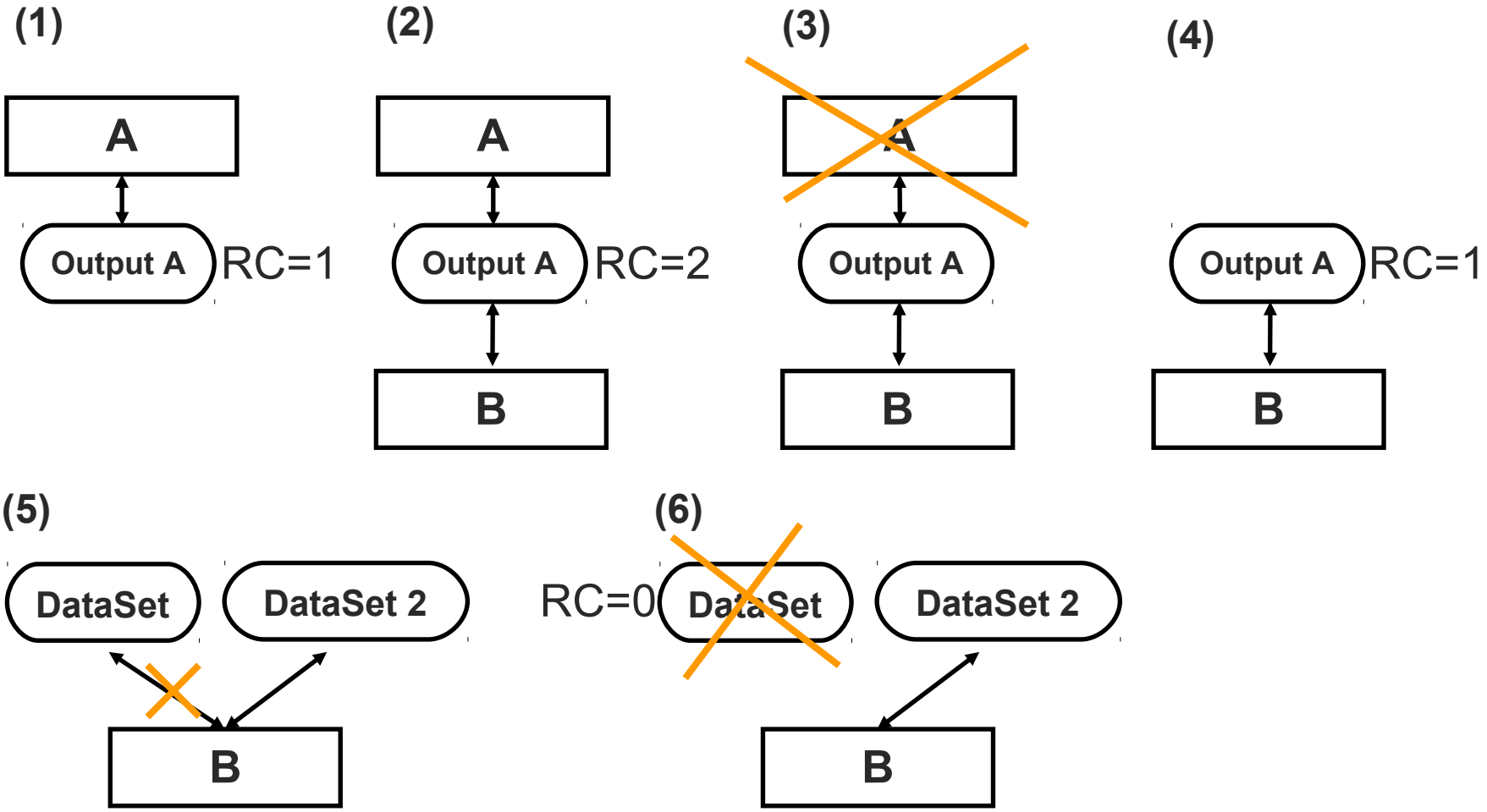
```
vtkFilter::Delete()
{
  Unregister,
if( RC == 0 ) delete this
}
```

SetInputConnection

- All methods that links together objects (like SetInputConnection) have a prefix “Set” and are created starting from macros.

```
vtkFilterXYZ::SetInputConnection(vtkAlgorithmOutput *Input)
{
   …
   I->Register(NULL);
   …
   this->Modified();
}
```

Scenario

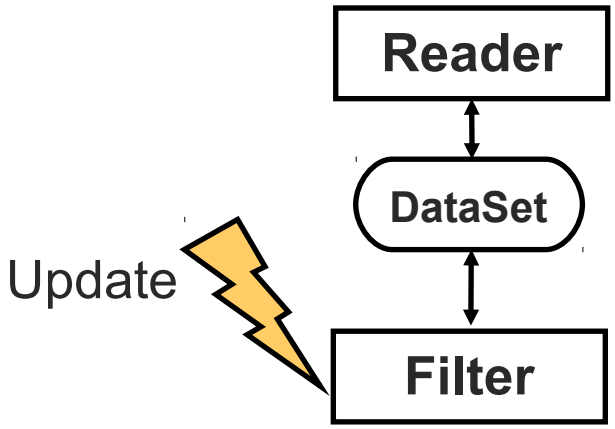

(1)
A
Output A
RC=1
(2)
A
Output A
RC=2
B
(3)
A
Output A
B
(4)
Output A
RC=1
B
(5)
DataSet
DataSet 2
B
(6)
RC=0
DataSet
DataSet 2
B

Pipeline execution

Pipeline execution is

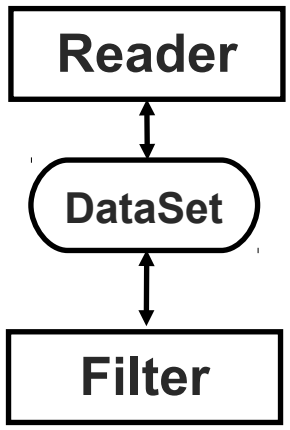
"On Demand" and is triggered

By an "Update" request



- Modified Time (MT)
- Executed Time (ET)
- Update
- Execute

Pipeline execution



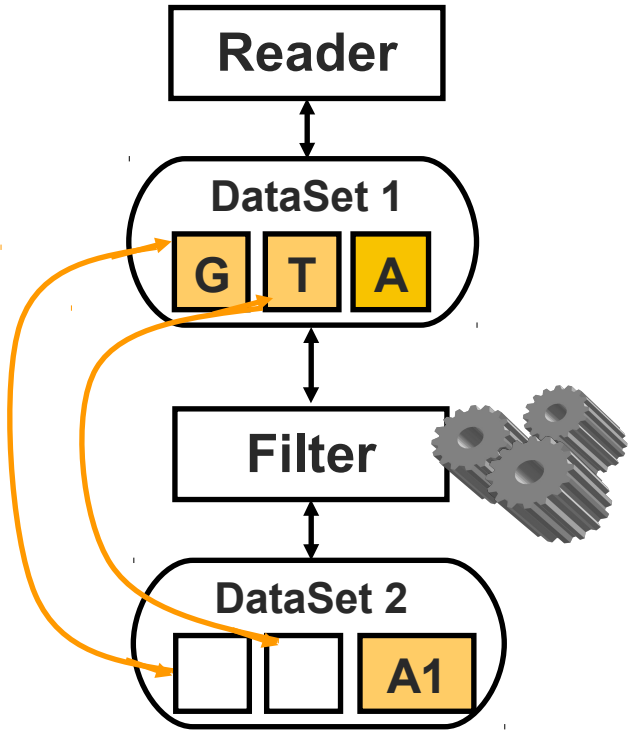
3 `Reader::Update()` 4
`{ if( MT > ET ) Execute(); }`

2 `DataSet::Update()`
`{ if( Source) Source->Update(); }`

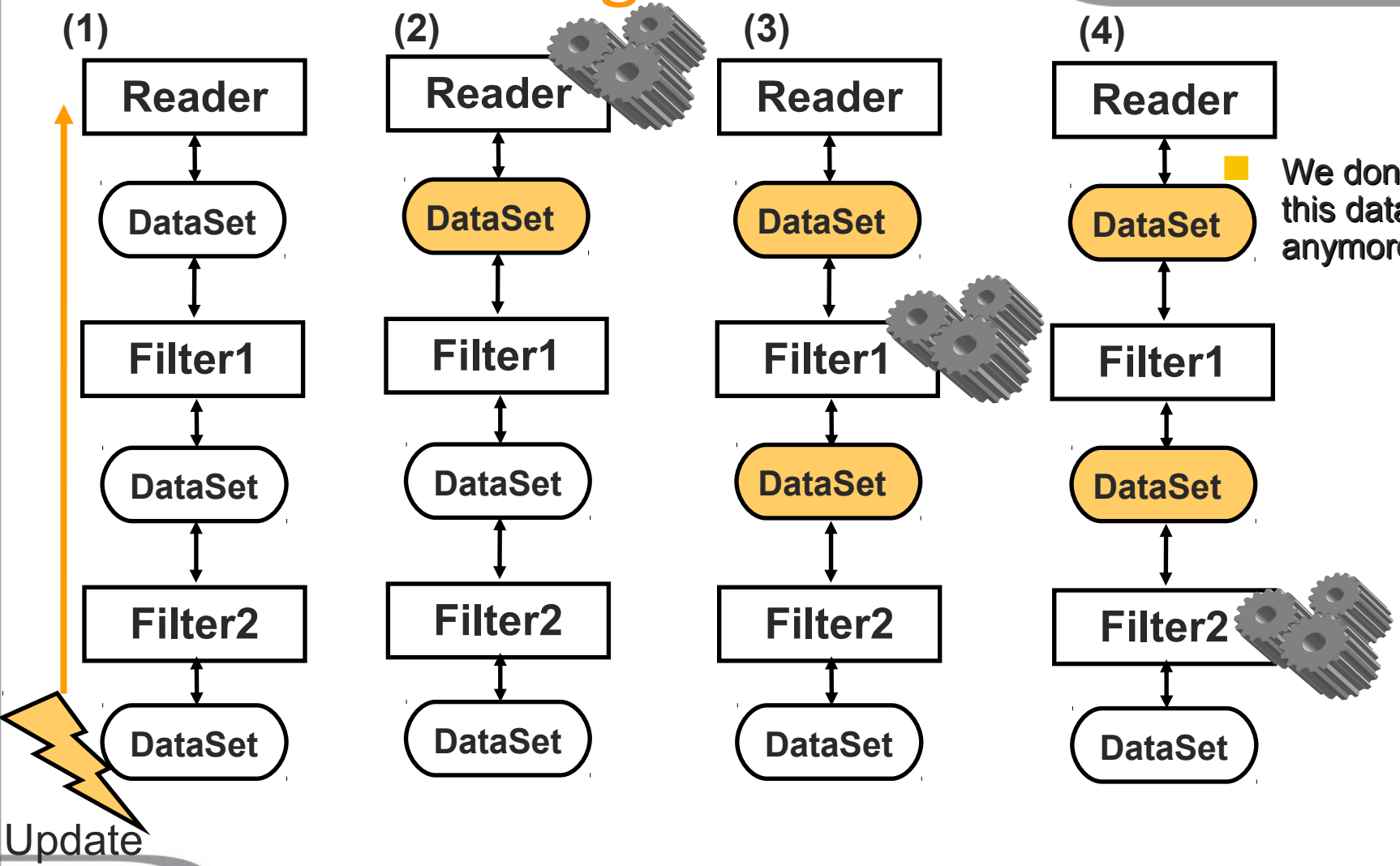
1 `Filter::Update()`
```
{
   Input->Update();
   if( Input->ET > ET || MT > ET )
         Execute(); 5
}
```

Data sharing

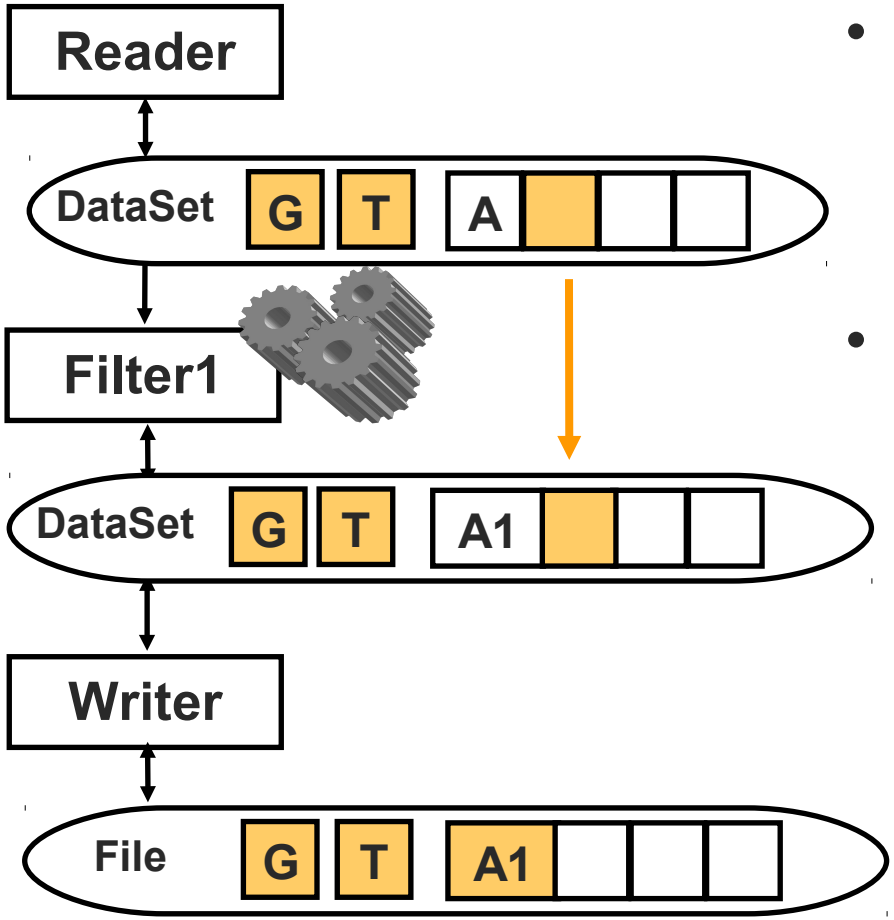
- The Reader terminated its execution and has “filled” G,T,A of its Output
- Now the filter can Execute. For example the Filter create new attributes.
- Geometry and Topology are then the same on the dataset1, so are good also for the dataset2, we don’t need to copy. In dataset2 will be only the pointers to G and T.
- G and T are portions of shared data, the RefCounting take care of their time life.



Caching

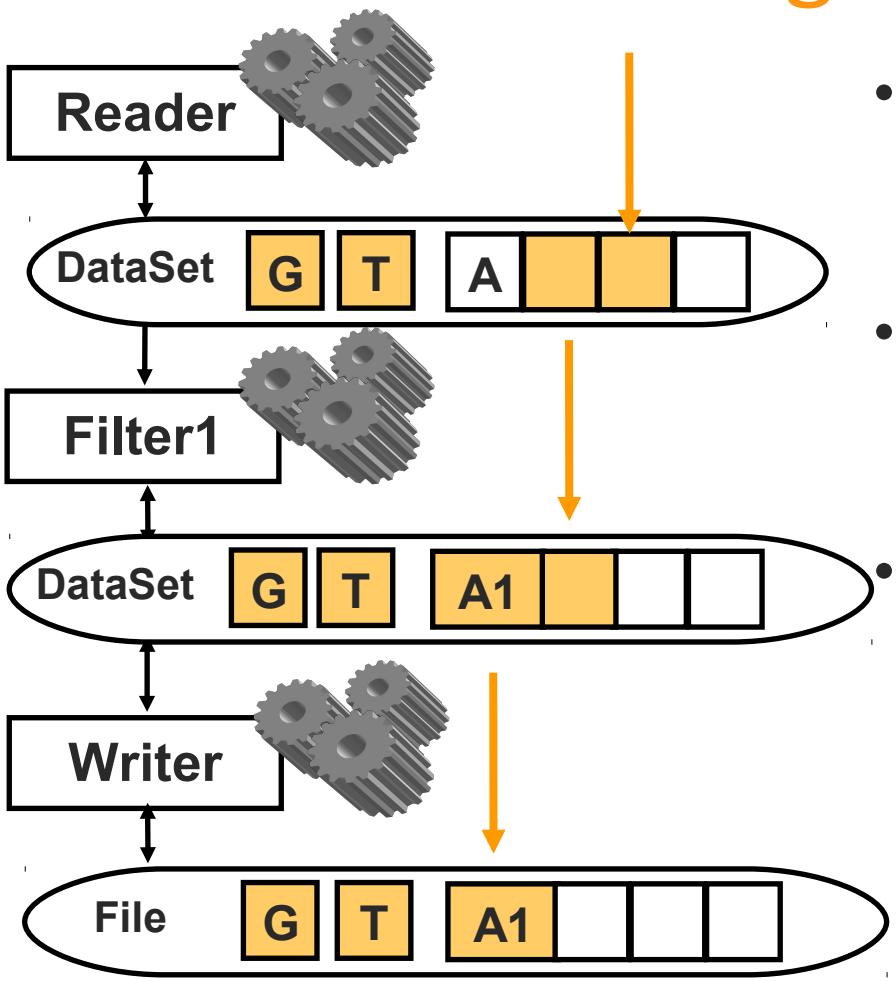

(1)
Reader
DataSet
Filter1
DataSet
Filter2
DataSet
Update
(2)
Reader
DataSet
Filter1
DataSet
Filter2
DataSet
(3)
Reader
DataSet
Filter1
DataSet
Filter2
DataSet
(4)
Reader
DataSet
Filter1
DataSet
Filter2
DataSet
We don't need this data anymore

Streaming



- There are algorithms that can execute on a single portion of the entire data
- In this case the Pipeline execution happen in more than one phase, each time a different portion of the data is produced.

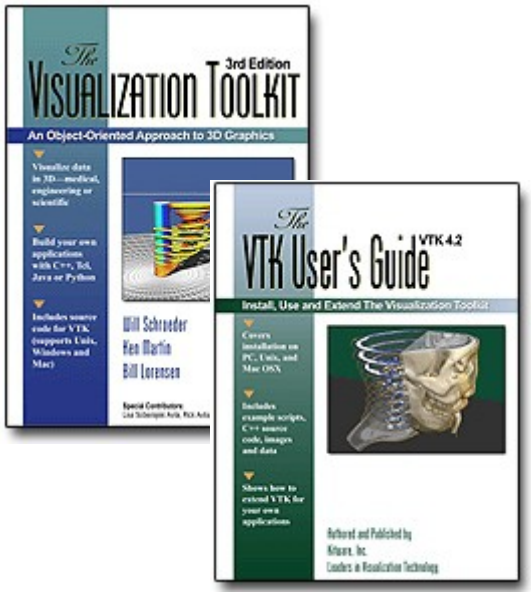
Multi-threading



- VTK supports two types of multi-threading
- A) Parallelism of filters.
  The Exec is multi-threaded.
- B) Parallelism between Filters.
  In case of elaborations using streaming, filters works on different portions of the same data

Tools

- User Guide
- Examples (http://www.vtk.org/Wiki/VTK/Examples)
- Help
- Sources
- Wiki
- Mailing List
- Git / DashBoard / BugList



Thank you ☺

Credits ☺

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