The Visualization Pipeline

CS9223 Data Visualization
NYU-Poly

Outline

- Procedural vs. Dataflow Programming
- Dataflow for Visualization Pipeline
- VTK Pipeline
- Quick guide on CMake/VTK and VisTrails

Programming Paradigms

- Imperative/Structured
  - Procedural
  - Object-oriented
- Declarative
  - Dataflow
  - Functional
- ... many many more (check out Wikipedia)

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Explicitly describe every step of execution, focus on the computation.

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  - Functional
- ... many many more (check out Wikipedia)

Focus on how computations are connected, graphical specification of procedures.

Example

Given a program implementation:

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int A() {...}
int B() {...}
int C(int,int) {...}
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The order of execution: A→B→C

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Example

Given a program implementation:

```
int A() {...}
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```

Procedural programming:

```
outB = B();
outA = A();
outC = C(outA,outB);
```

The order of execution: B→A→C

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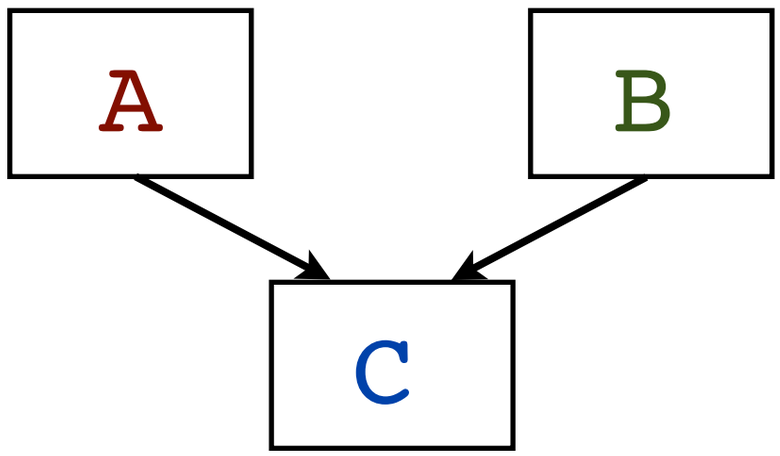
Example

Given a program implementation:

```
int A() {...}
int B() {...}
int C(int,int) {...}
```

Dataflow Programming:



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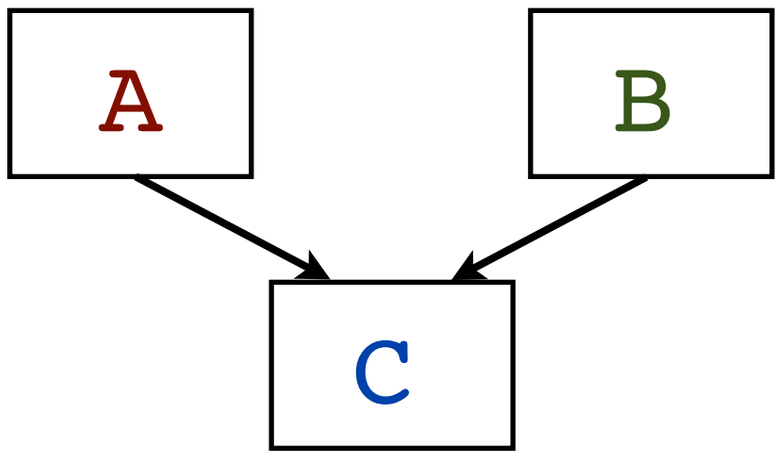


The order of execution: (A∪B)→C

Procedural vs. Dataflow Programming

- Procedural Programming:
  - The control flow has to be dictated
  - Sequential execution
  - Difficult to manage in large execution networks
- Dataflow:
  - The control flow is specified through data dependency
  - Freedom in execution order → concurrency
  - More flexible and easier for use

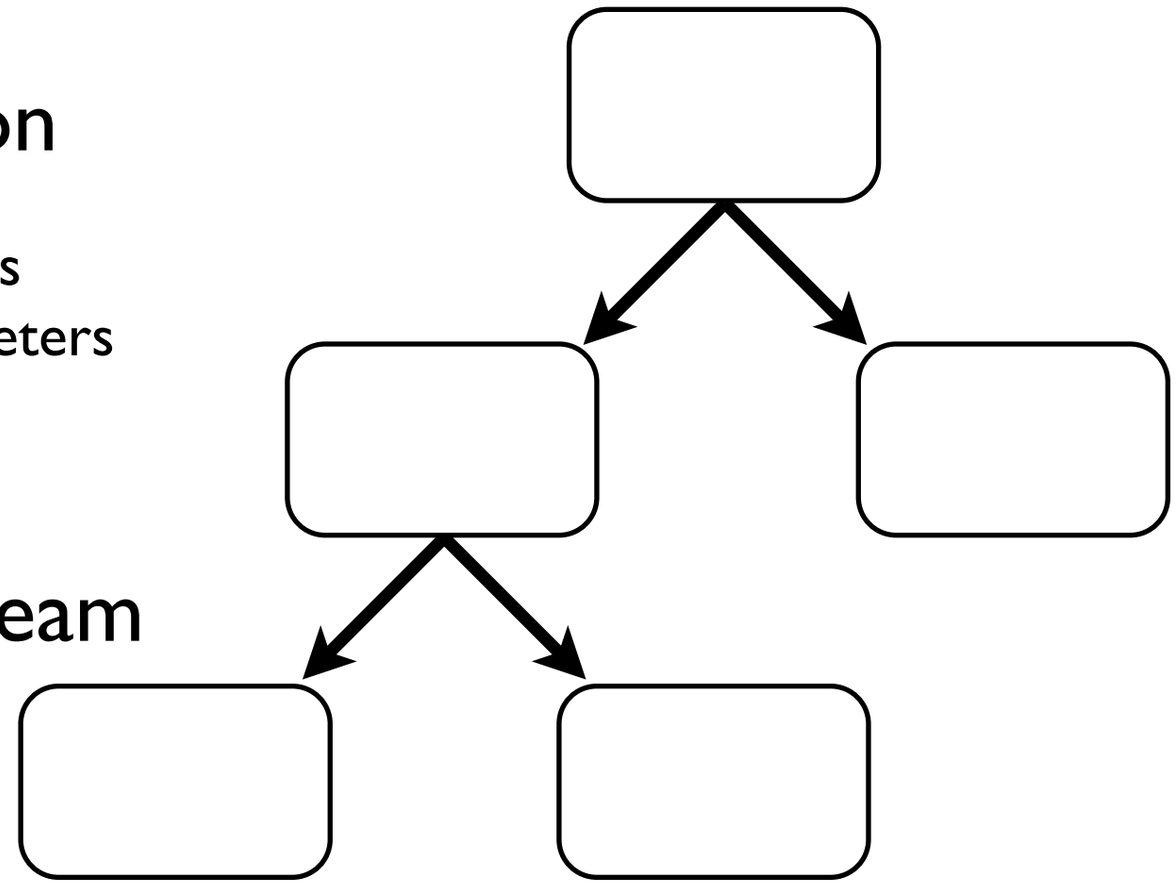
Dataflow Construction

- A directed graph
  - node (module) = computation

knows how to compute outputs
given a set of inputs and parameters

- edge (connection) = data stream

maintains data states and specifications



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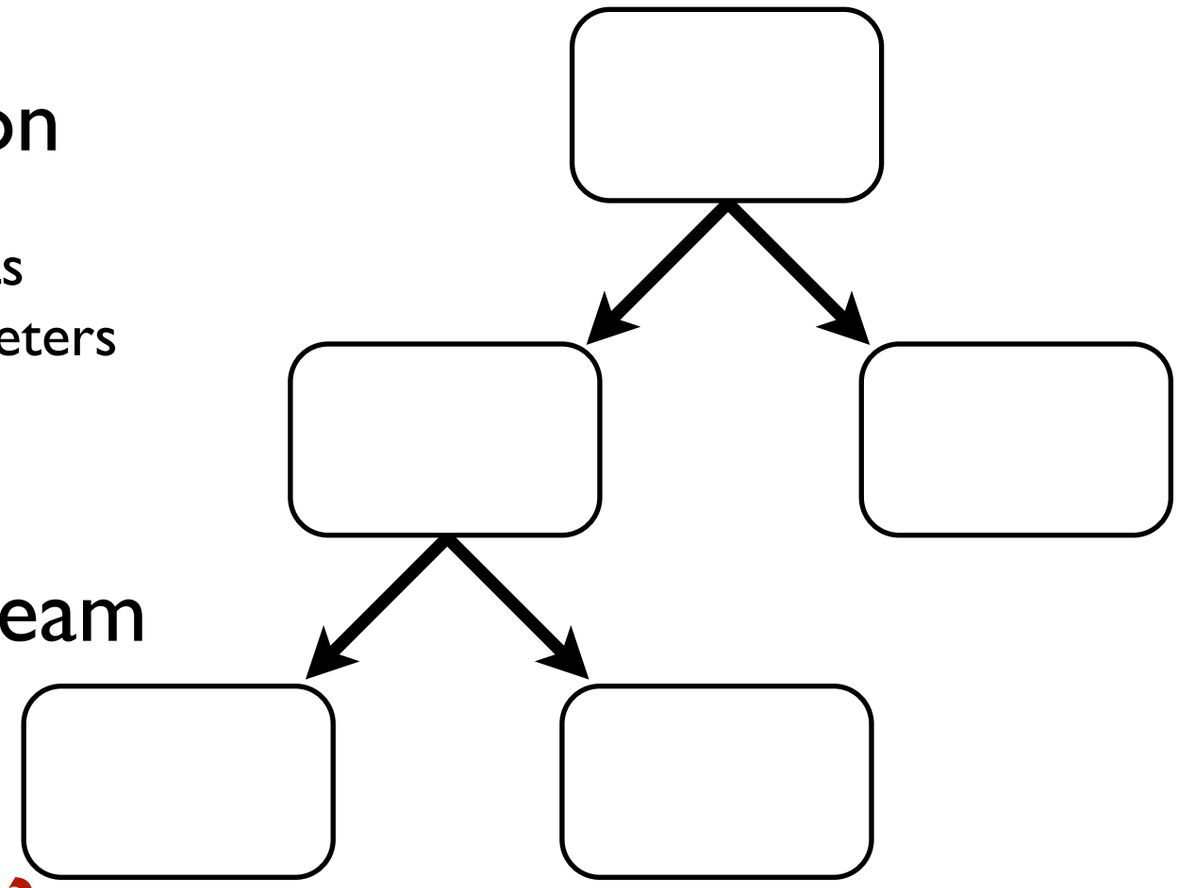

  - edge (connection) = data stream

maintains data states and specifications

What controls the execution?

Dataflow Construction

- A directed graph
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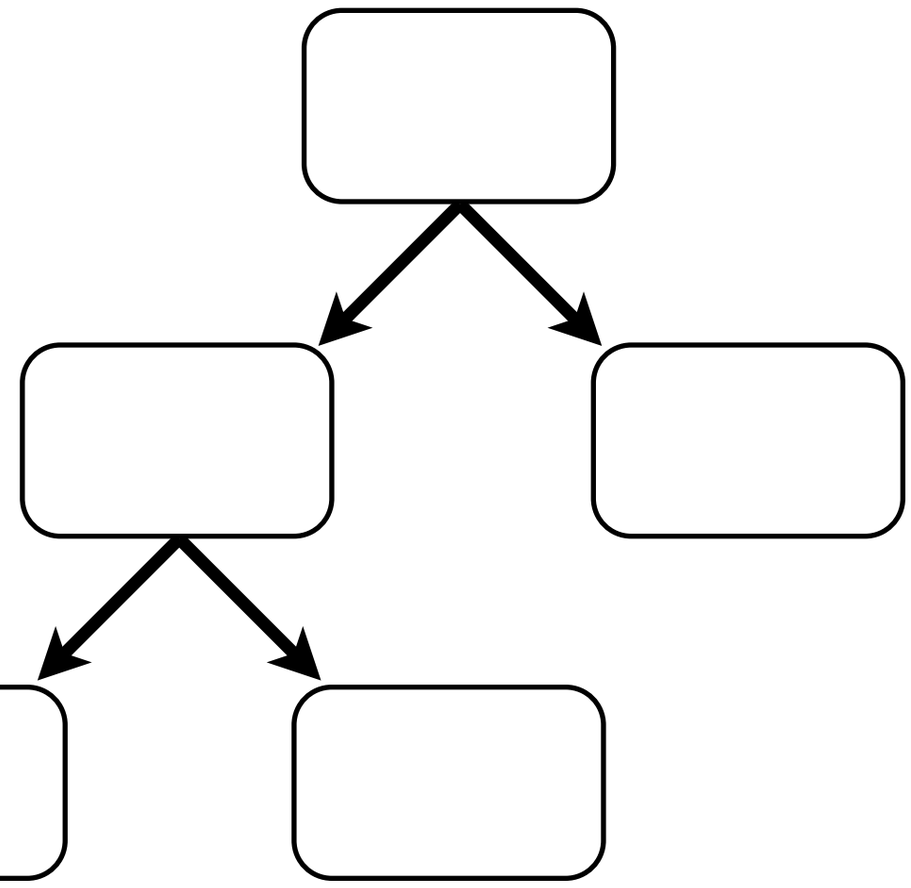
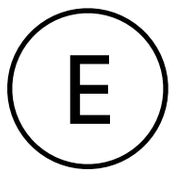


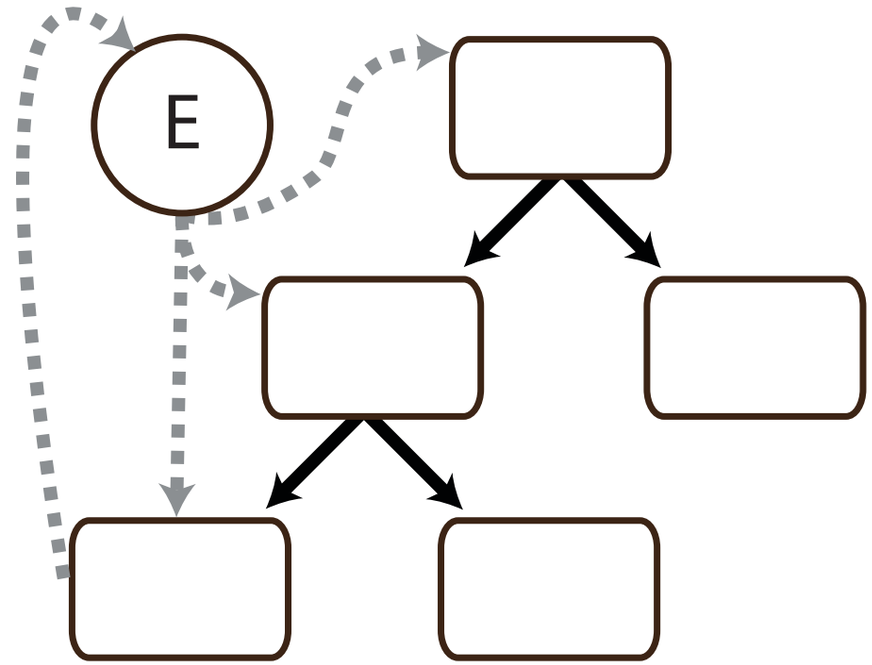
- edge (connection) = data stream

maintains data states and specifications

- executive = coordinate module execution

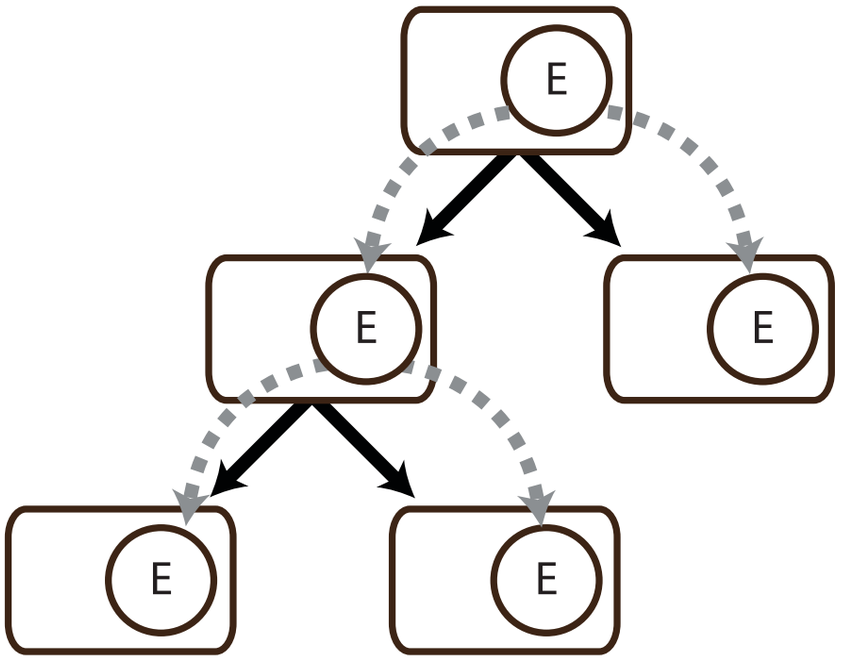


Executive Scope



Centralized

flexible scheduling



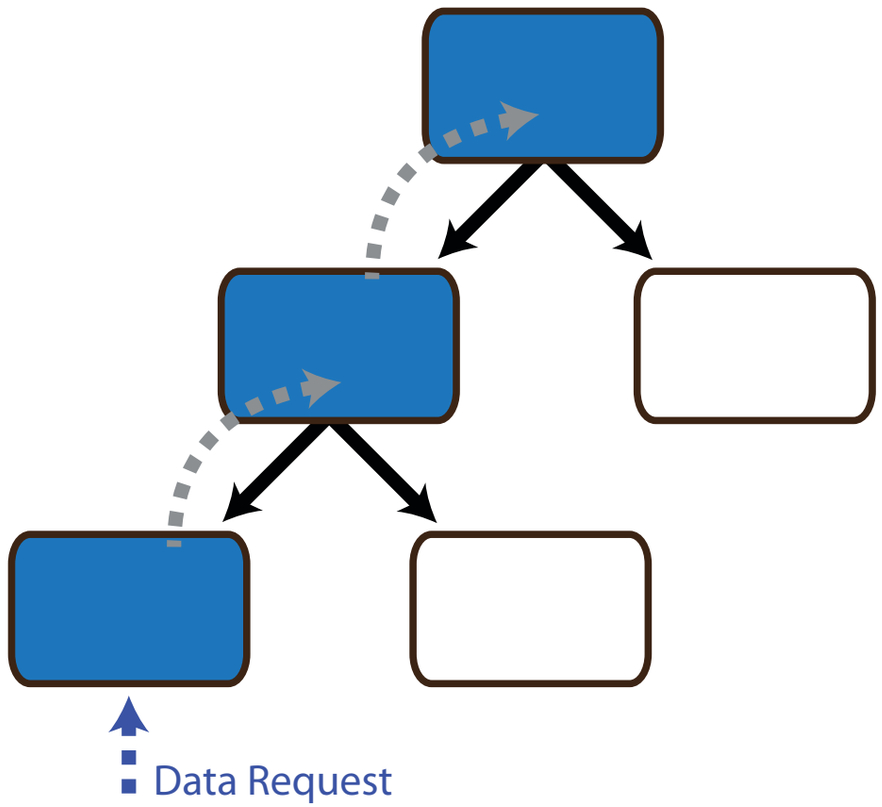
Distributed

good for scalability

Execution Policy

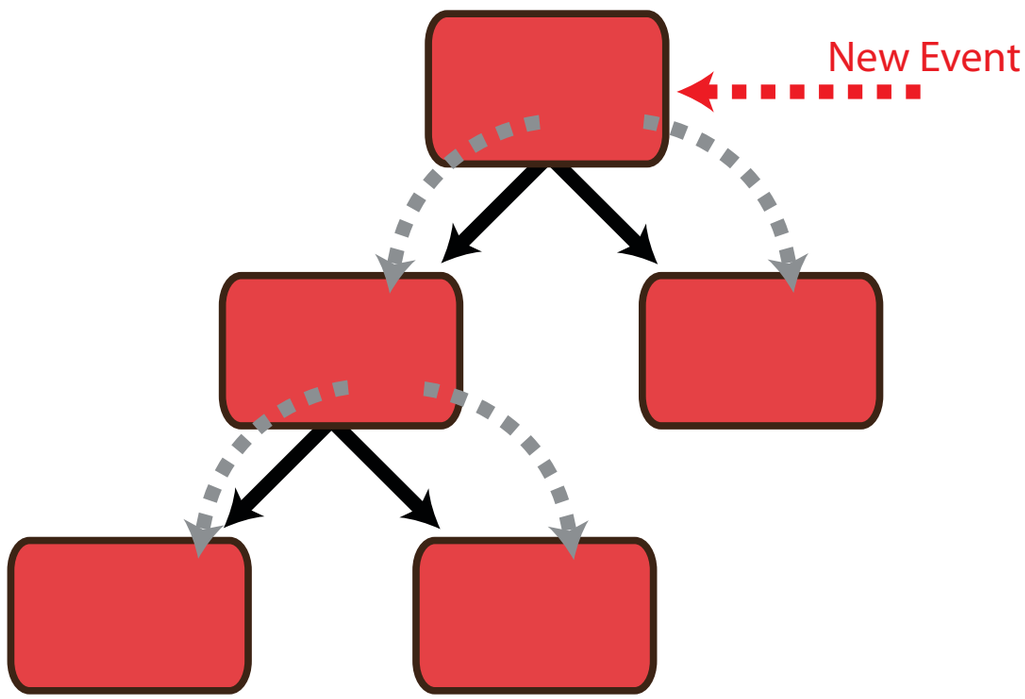
- Policy for communicating between modules

Pull (demand-driven)



minimize computation

Push (event-driven)



minimize coordination

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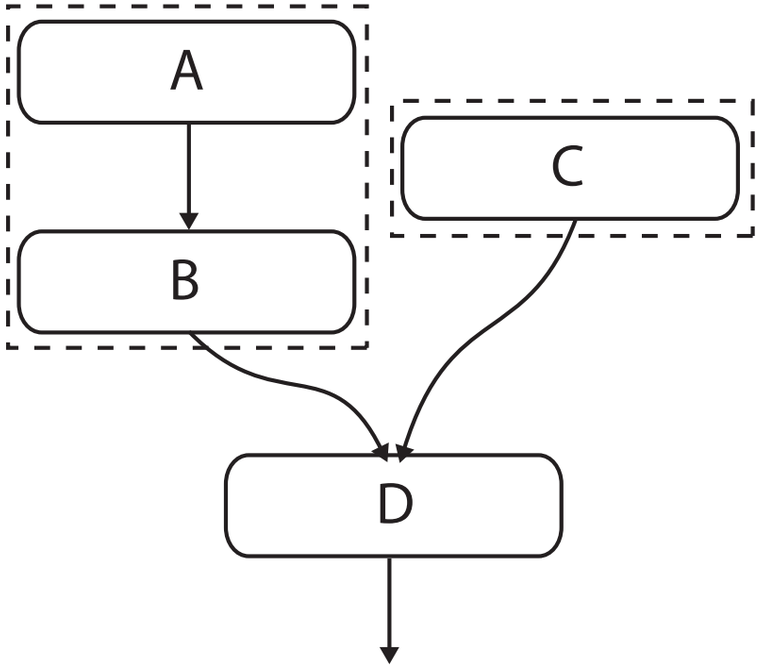
Types of Parallelism

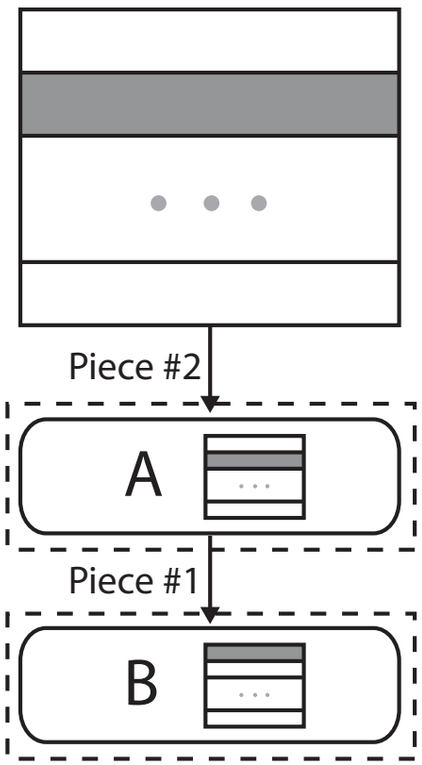
Task

Streamable/Separable Data Structure

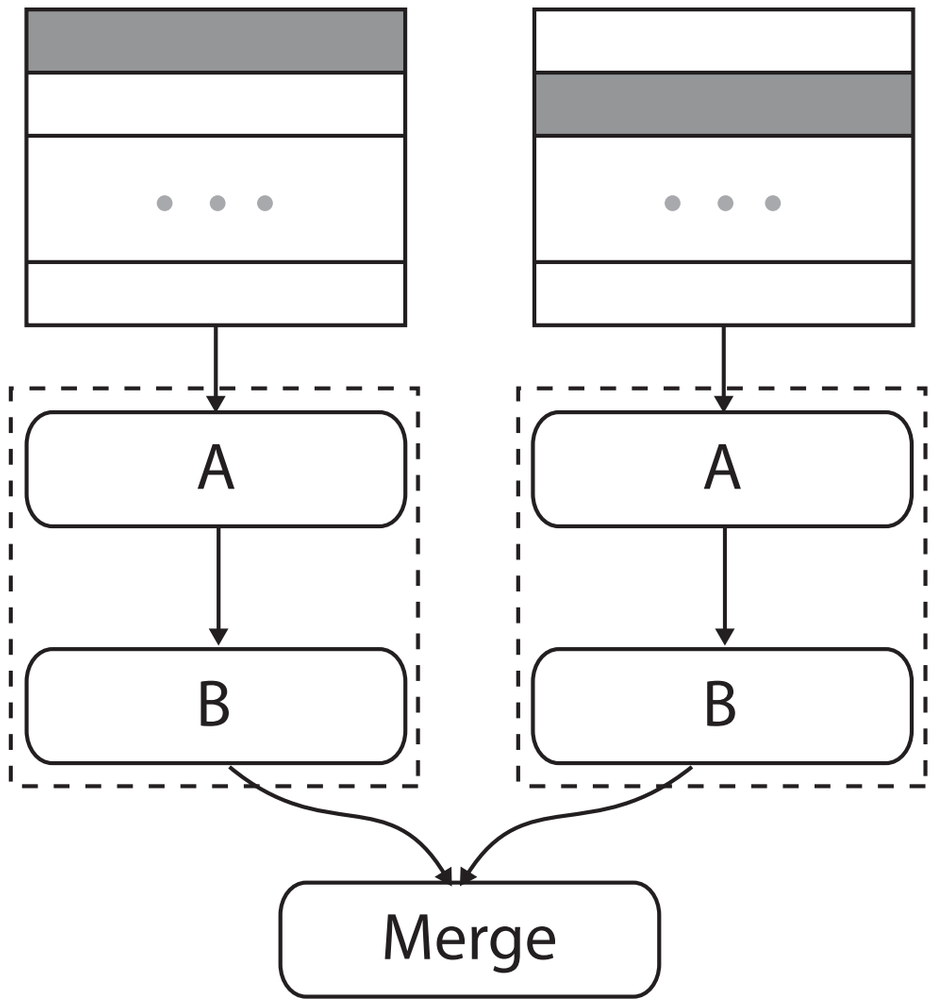
Concurrency Execution



Pipeline



Data



Dataflow Visualization Systems

System	Parallelism	Policy	Scope
VTK		Pull	Dist.
ParaView	Data	Pull	Dist.
Visit	Data + Task	Pull	Dist.
DeVIDE		Pull/Push	Cent.
SCIRun	Task	Push	Cent.
VisTrails		Pull	Cent.

AVS

SCIRun

VTK

VisIt

ParaView
Parallel Visualization Application

DeVIDE

VisTrails

voreen
volume rendering engine

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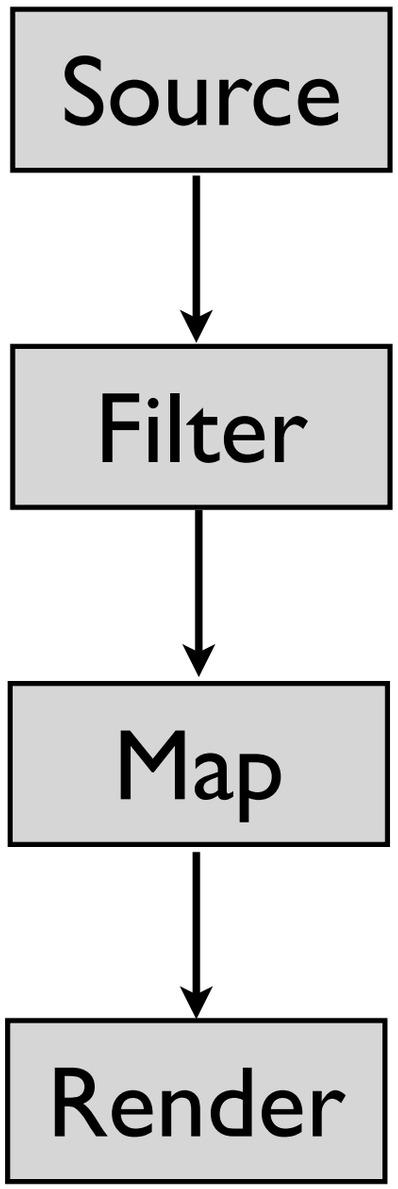
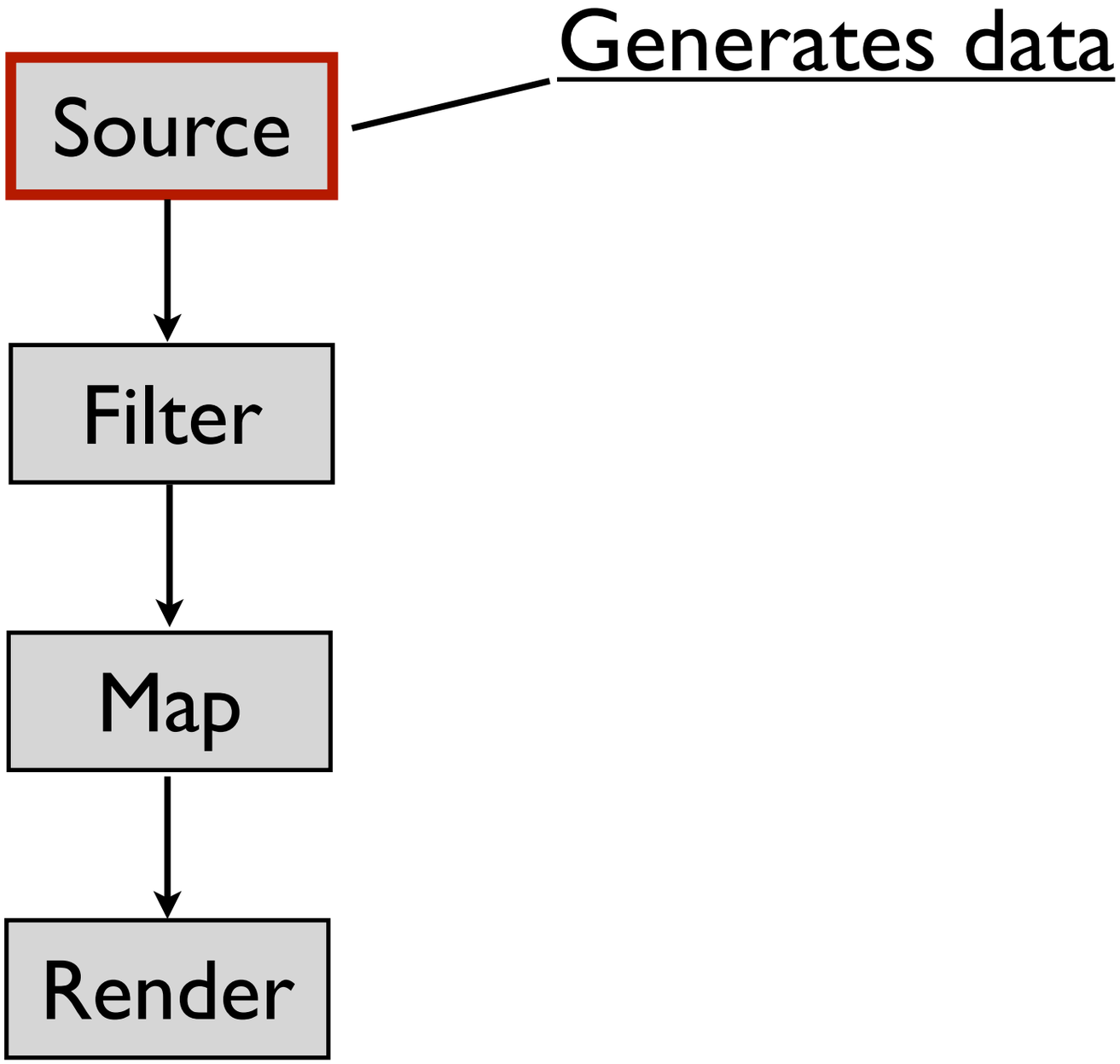
The Visualization Pipeline



The Visualization Pipeline



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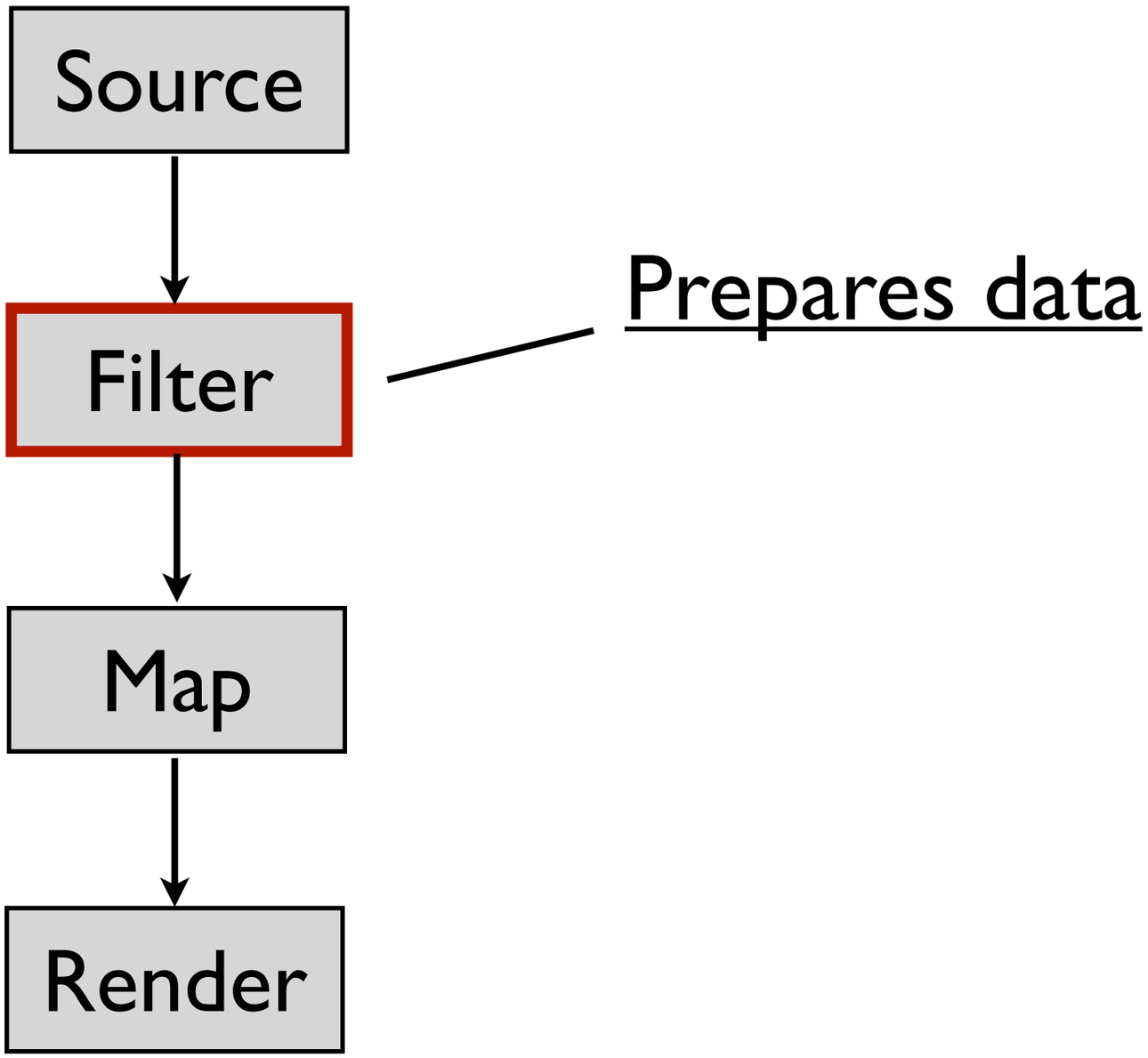

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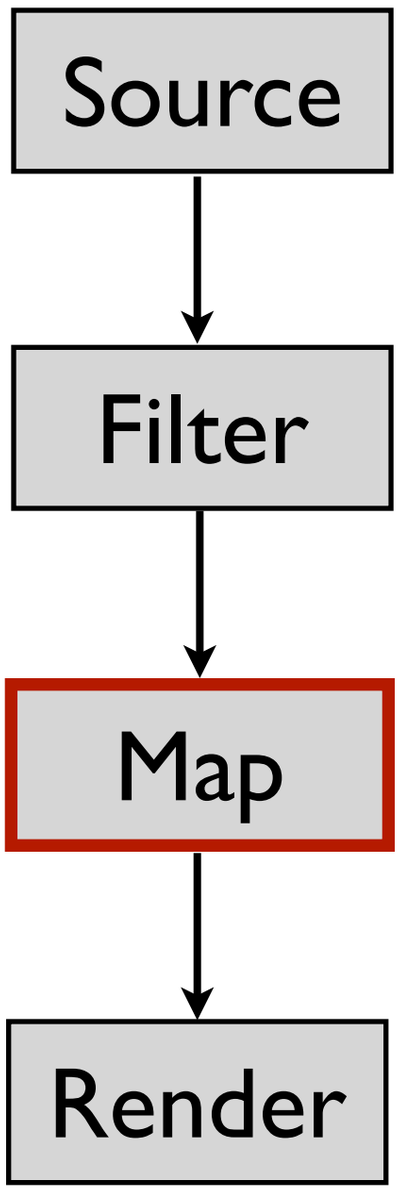
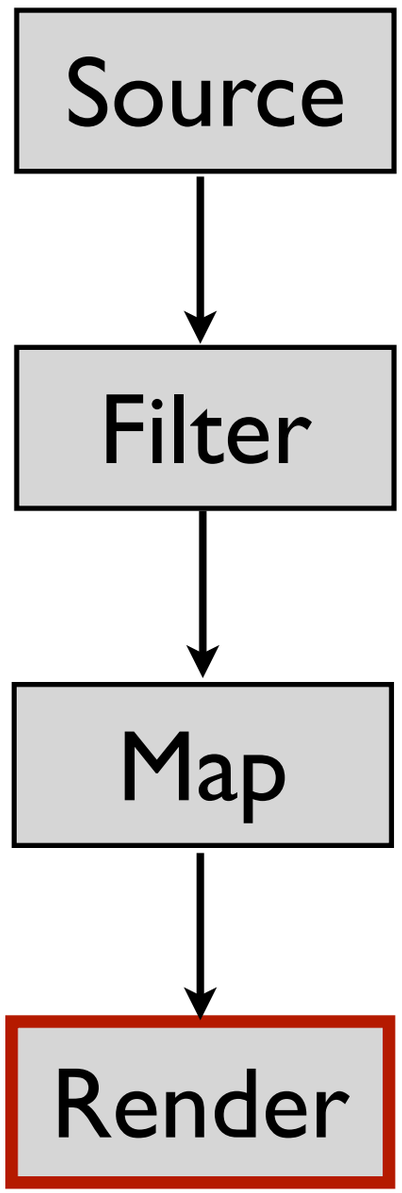


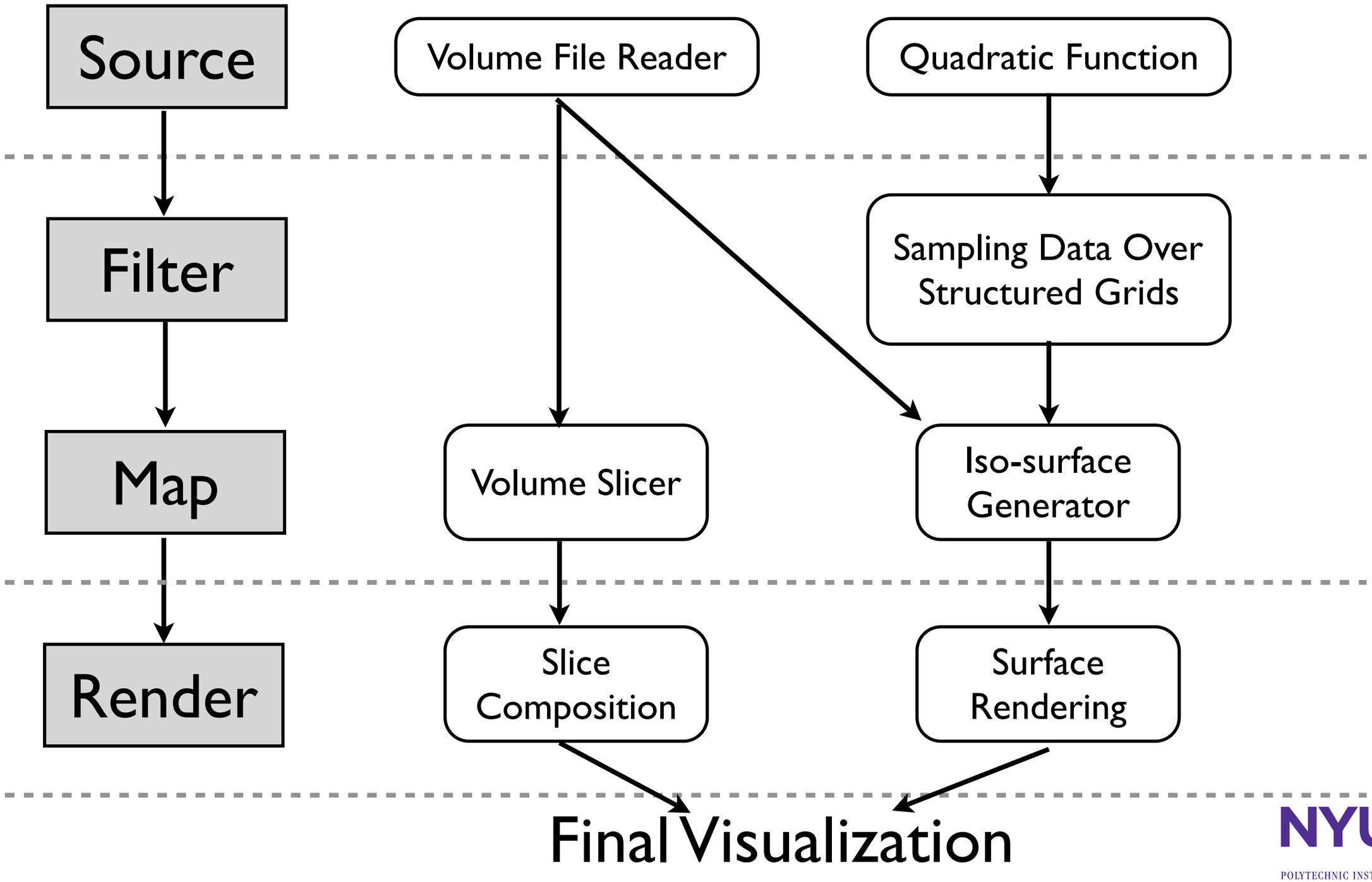
Construct graphics primitives

The Visualization Pipeline



Create actual images

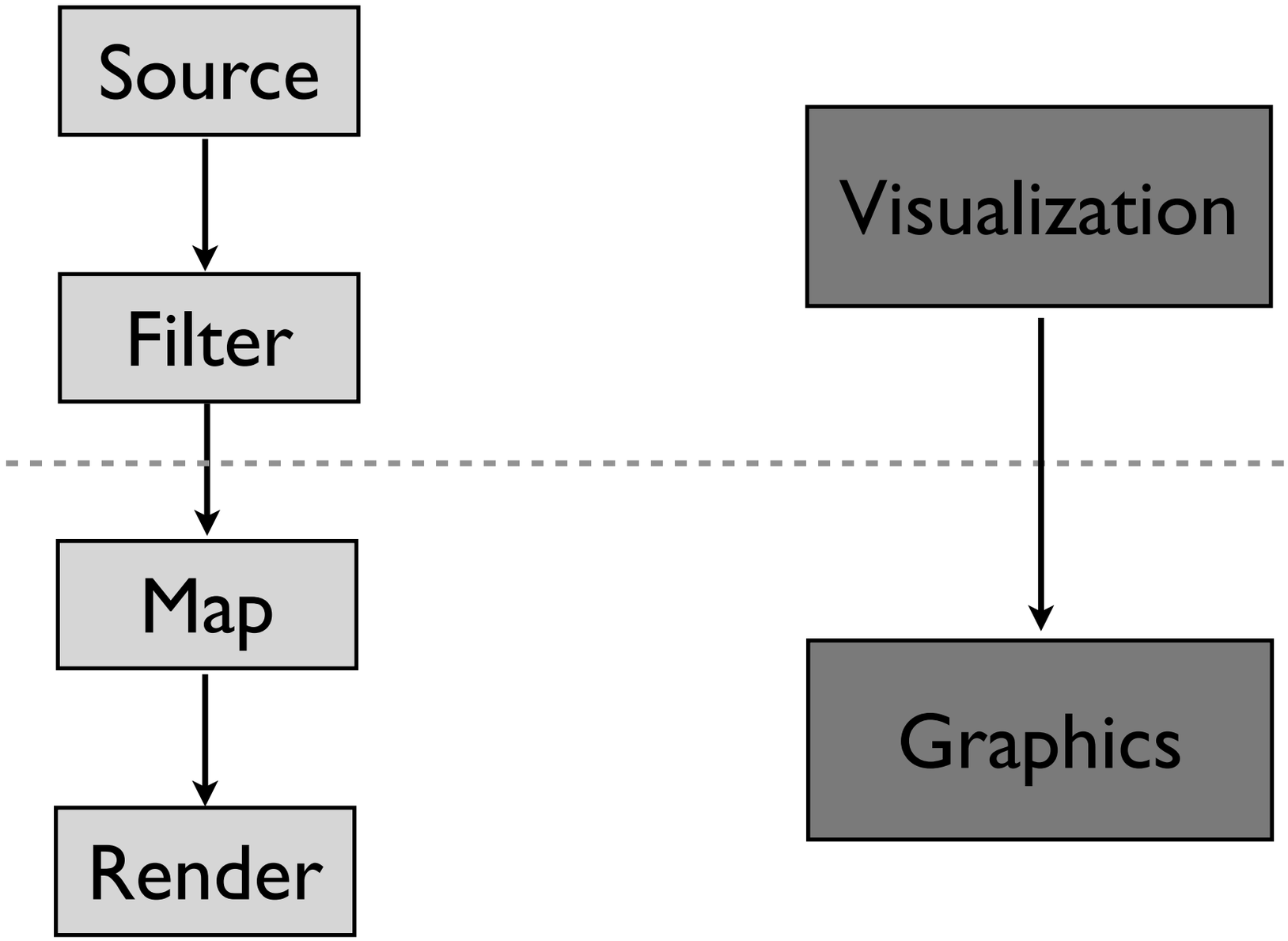
The Visualization Pipeline



The Visualization Toolkit (VTK)

- One of the most popular visualization packages
- Provide pieces to build complex applications
- Open-source, considerably cross-platform
- Written in C++ but has Python/Java/Tcl wrappings
- Advanced visualization applications based on VTK: ParaView, VisIt, 3DSlicer, MayaVi, DeVIDE

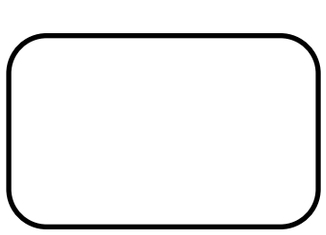
VTK Pipeline



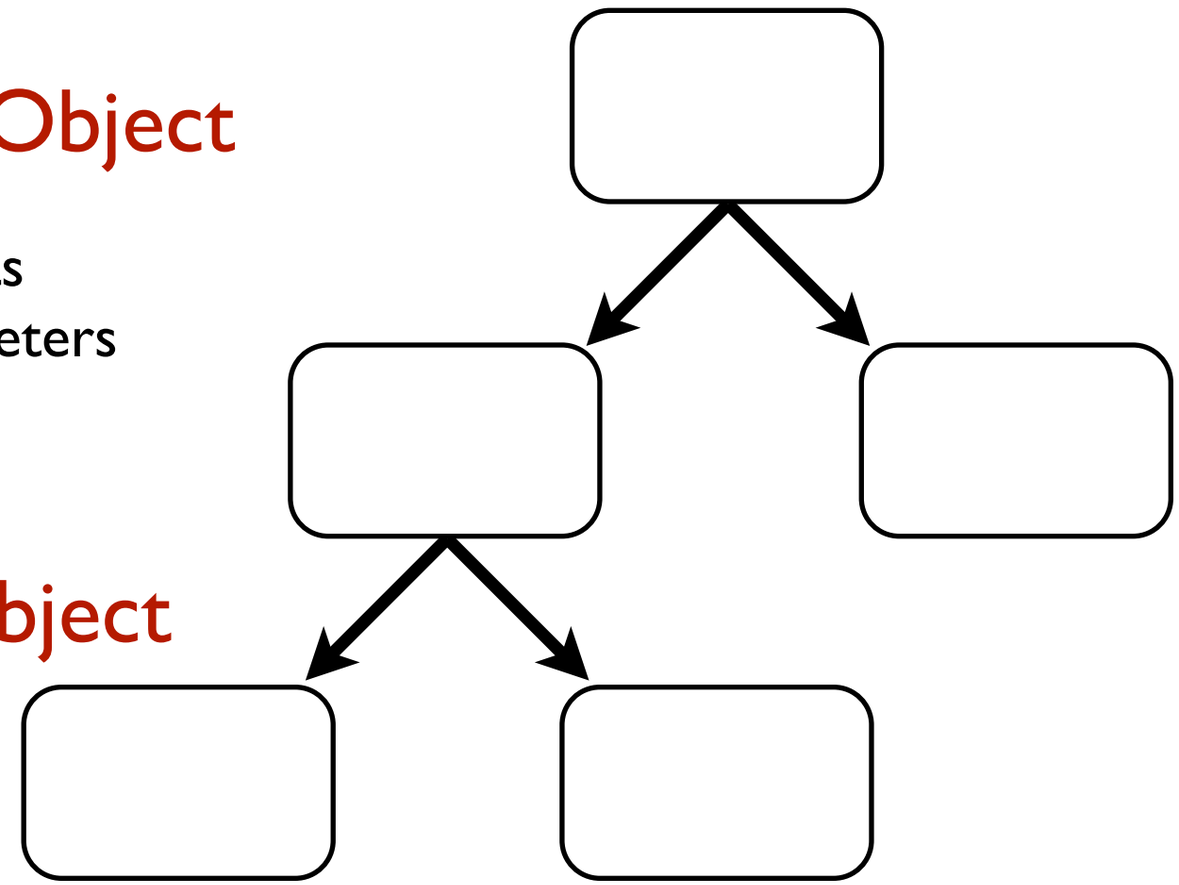
actual
dataflow
network

VTK Visualization Pipeline

- A directed graph
  - node (module) = Algorithm Object



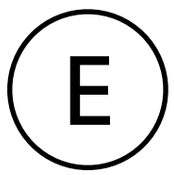
knows how to compute outputs
given a set of inputs and parameters



  - edge (connection) = Data Object

maintains data states and specifications

  - executive = Executive Object



VTK Algorithm Object
`vtkAlgorithm`

- Operates on data objects to produce new data objects
- Base classes for all sources, filters and some intermediate mappers
- Maintain module specifications, e.g. the number of input and output ports
  - Could be zero (for readers and writers)

VTK Data Object
`vtkDataObject`

- General representation of visualization data
  - Holding metadata to support multi-pass execution
- Base classes for all data types

VTK Executive Object
`vtkExecutive`

- Distributed executive
  - Each executive controls exactly one algorithm
- Holding metadata to support demand-driven execution, e.g. update timestamp
- Only knows immediate executives that it connects to

Using `vtkAlgorithm` vs. `vtkExecutive`

- Can be used interchangeably through the API since they have one-to-one mapping
  - Underneath VTK directs the correct calls to either vtkAlgorithm or vtkExecutive
- Chain SetInputConnection() and GetOutputPort() calls to construct VTK dataflow networks

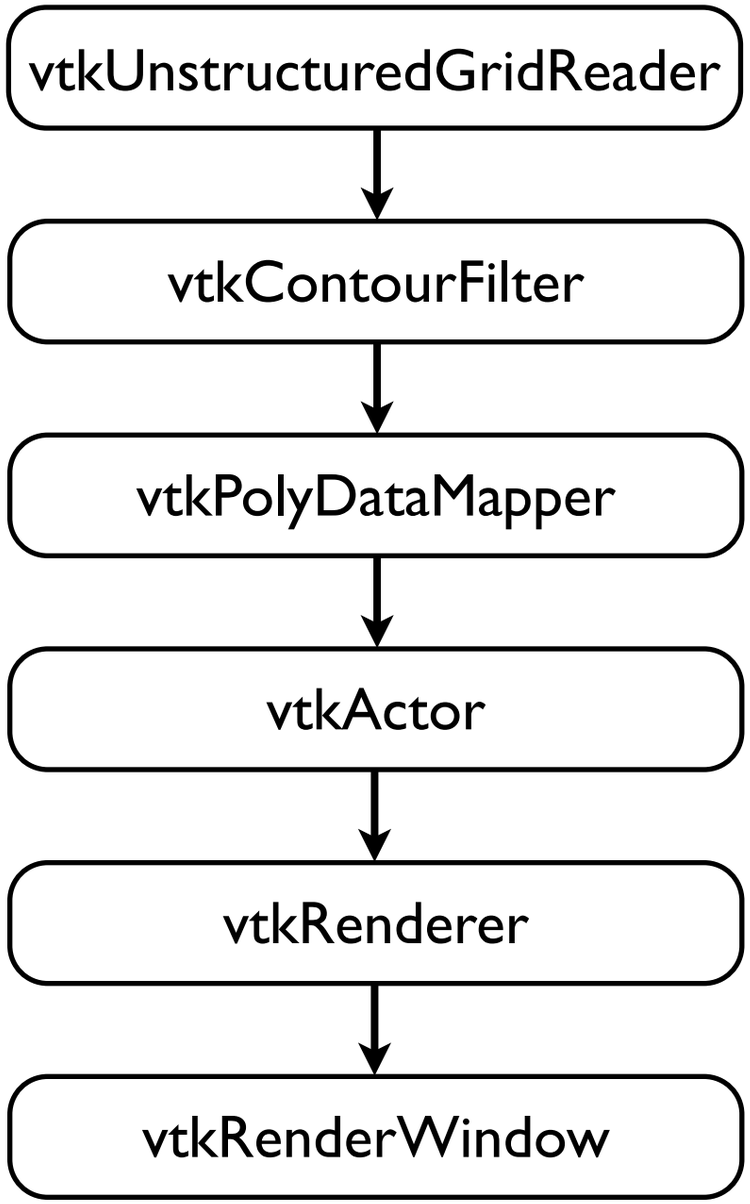
VTK Graphics Pipeline

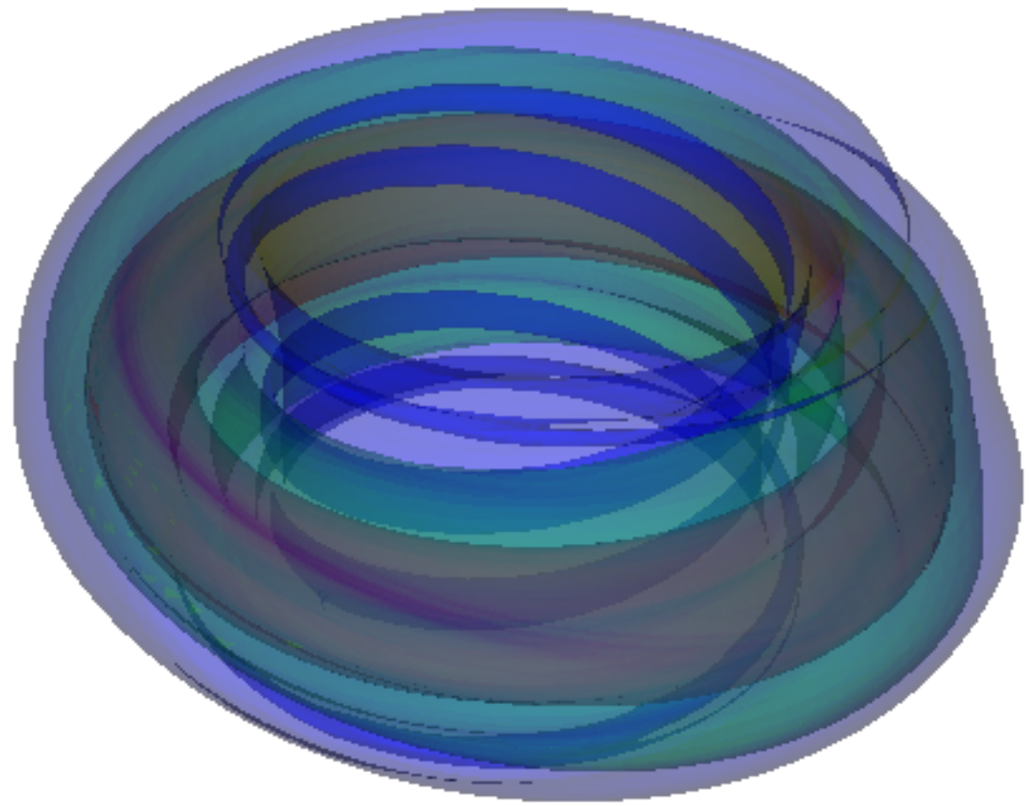
- Mapper: produce geometries, interfacing between the visualization and graphics phase of VTK
- Properties: rendering properties, e.g. color, material, etc.
- Actor: scene objects (geometry+properties)
- Renderer: specify the rendering logic with lights, camera, etc.
- Render Window and Interactor: manages windows and user interactions

VTK Pipeline Execution

- Pull/Demand-Driven
- Triggered by
  - mappers from the graphics phase requested geometry from the visualization dataflow
  - explicitly called to Update()
- Each update will propagate up to sources
- Not thread-safe

Example


vtkUnstructuredGridReader
vtkContourFilter
vtkPolyDataMapper
vtkActor
vtkRenderer
vtkRenderWindow

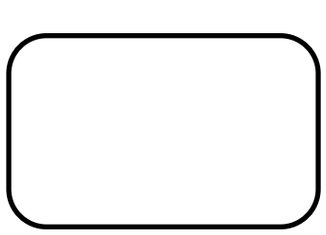


VisTrails

- Visual programming interface
  - Simplify the pipeline creation process
- Capture detailed provenance
- Provide comparative visualization through the spreadsheet
- Python-based
  - Seamlessly integrate with many libraries

VisTrails Visualization Pipeline

- A directed graph
  - node (module) = Computation Object



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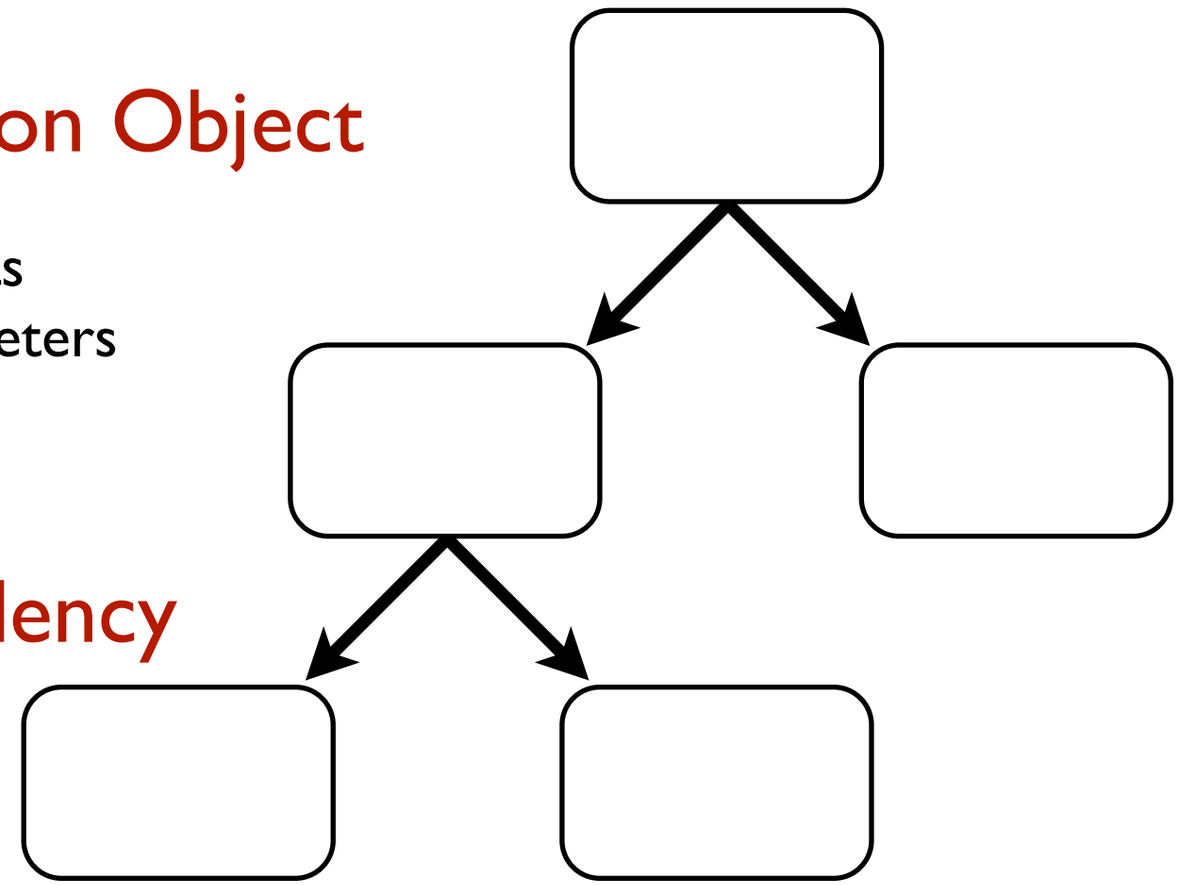
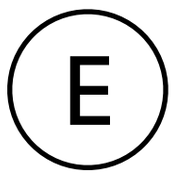


  - edge (connection) = Dependency

maintains data states and specifications

  - executive = Interpreter



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VisTrails Computation Object

- A python class with a compute() method
  - VTK is wrapped by calling Update() method inside compute()
- Data stays at the source module (the module that generates it)
- Maintain metadata such as the number of input/ output ports and annotations

VisTrails Connection Object

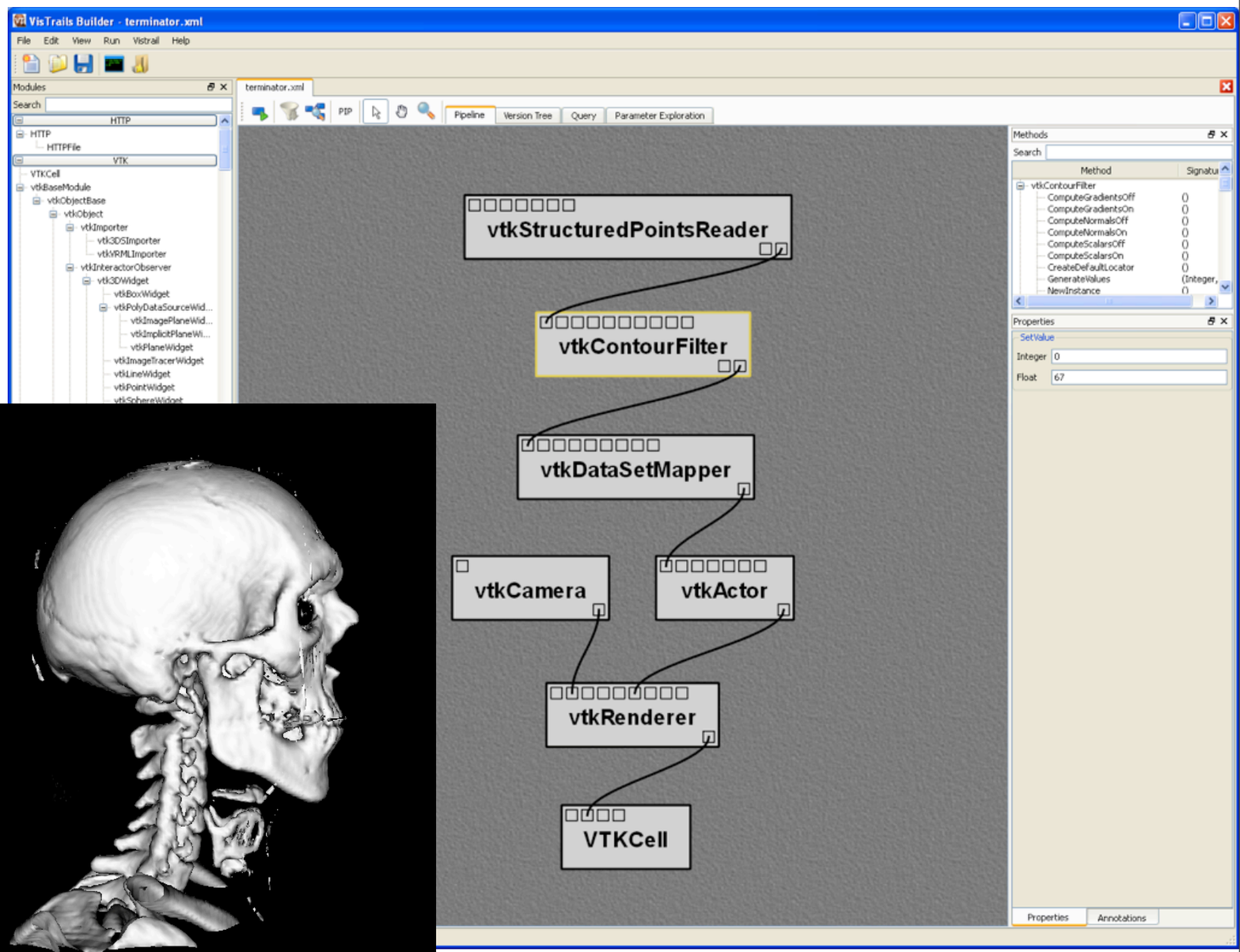
- Does not hold actual data
- Only keeps the information on the two ports that it connects to ensure correct execution order

VisTrails Interpreter

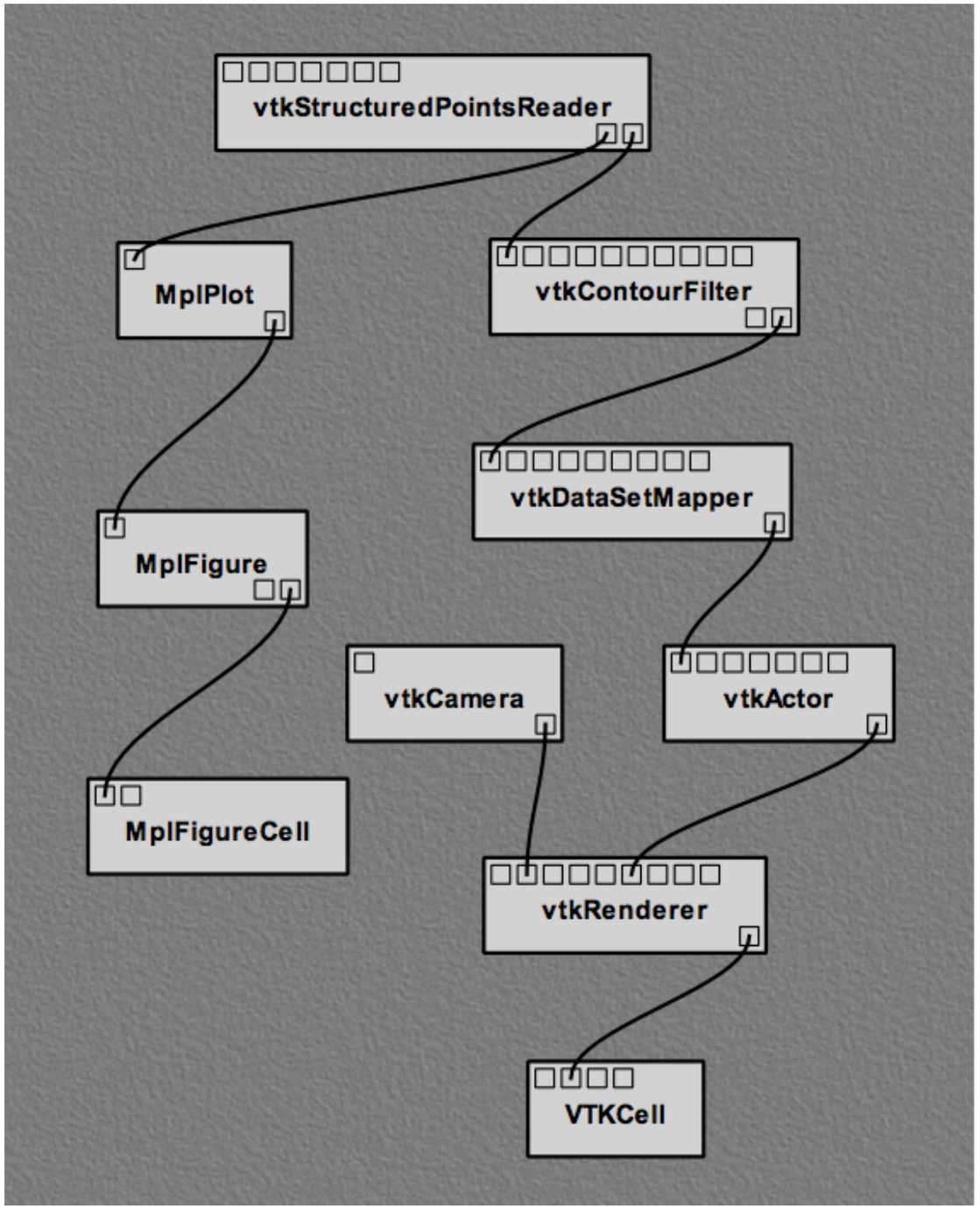
- Centralized executive
- Ensure the whole pipeline execution from sinks to sources (a BFS from sinks)
- Maintain output caches to speed up computation

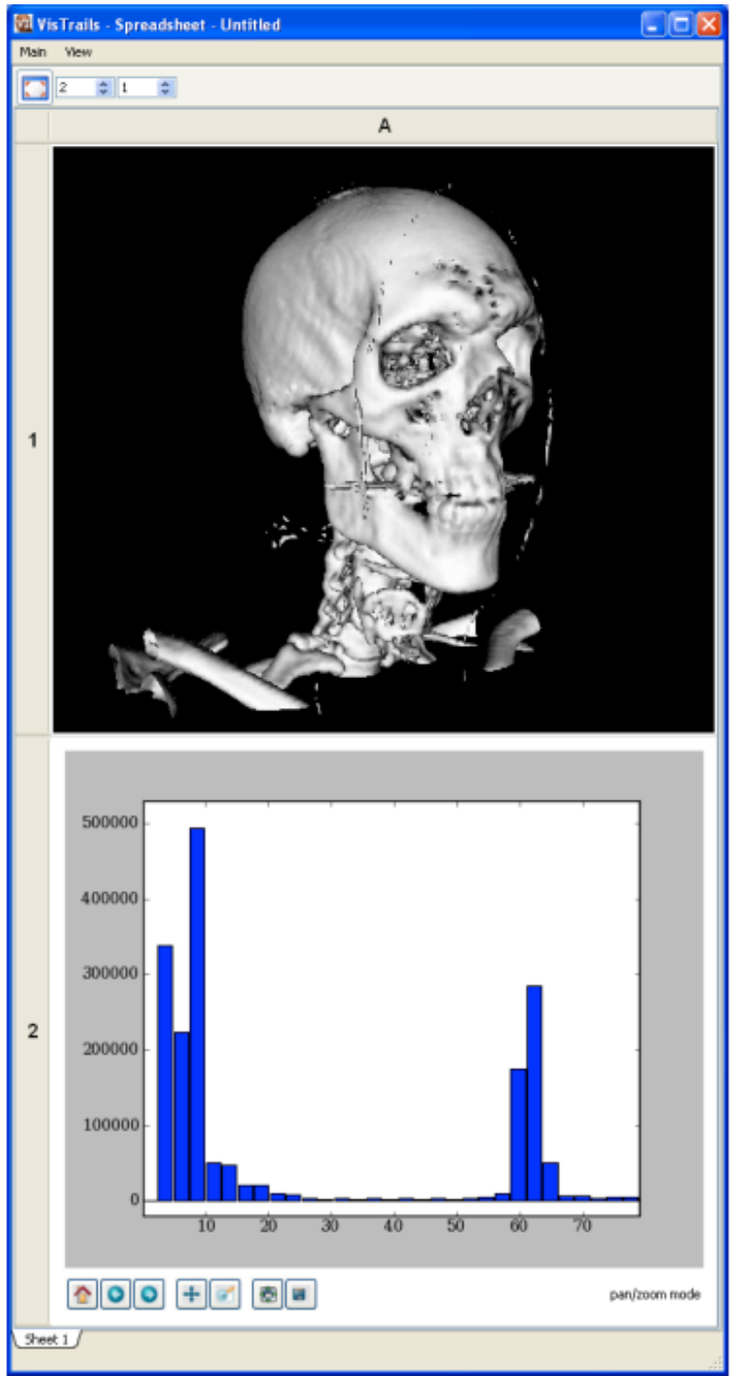
Example

```
import vtk
data = vtk.vtkStructuredPointsReader()
data.SetFileName("..examples/data/head.120.vtk")

contour = vtk.vtkContourFilter()
contour.SetInput(0,data.GetOutput())
contour.SetValue(0, 67)

mapper = vtk.vtkPolyDataMapper()
mapper.SetInput(contour.GetOutput())
mapper.ScalarVisibilityOff()

actor = vtk.vtkActor()
actor.SetMapper(mapper)

ren = vtk.vtkRenderer()
ren.AddActor(actor)
renwin = vtk.vtkRenderWindow()
renwin.AddRenderer(ren)

style = vtk.vtkInteractorStyleTrackballCamera()
iren = vtk.vtkRenderWindowInteractor()
iren.SetRenderWindow(renwin)
iren.SetInteractorStyle(style)
iren.Initialize()
iren.Start()
```

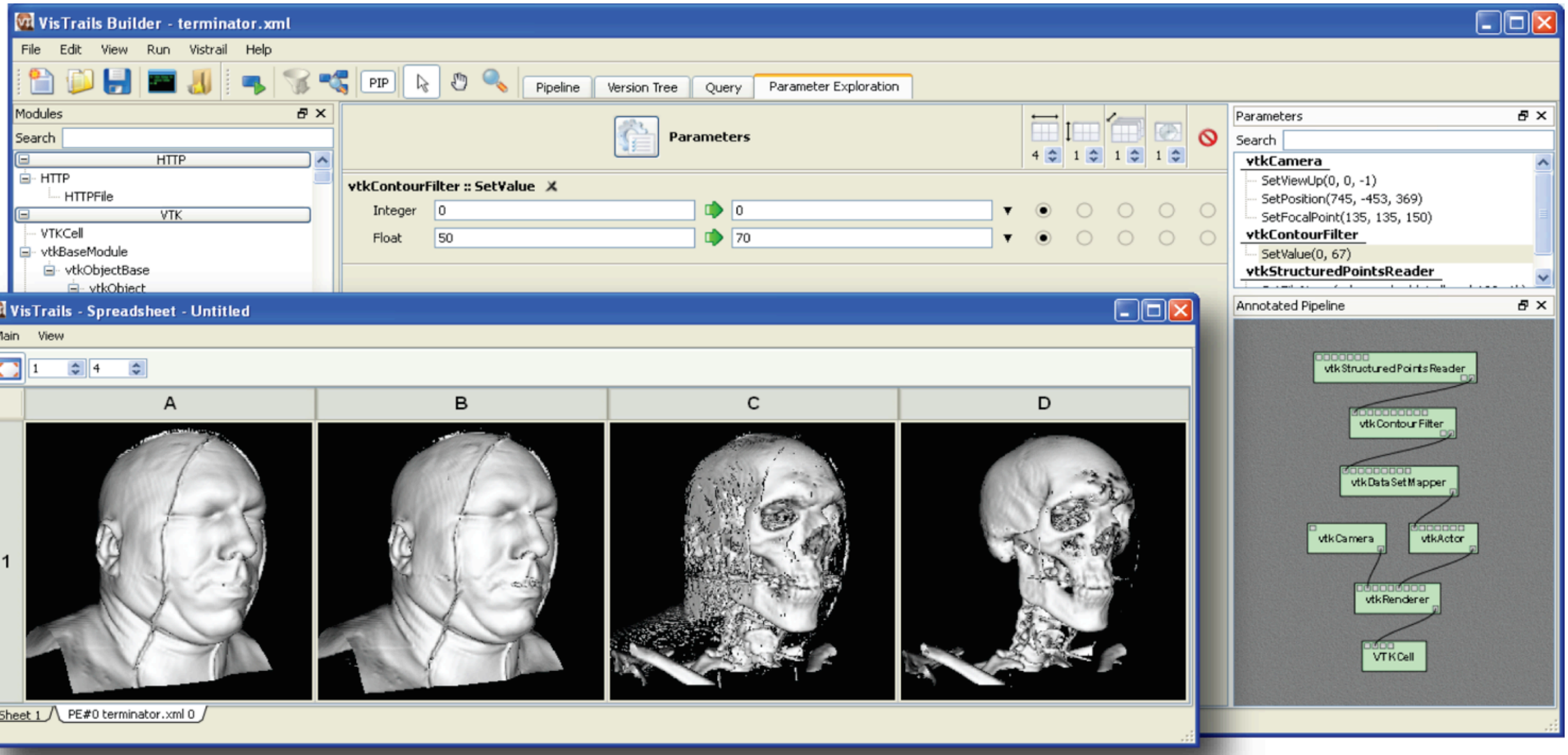


Example


vtkStructuredPointsReader
MplPlot
vtkContourFilter
vtkDataSetMapper
MplFigure
vtkCamera
vtkActor
MplFigureCell
vtkRenderer
VTKCell


VisTrails - Spreadsheet - Untitled
Main
View
A
1
2
500000
400000
300000
200000
100000
0
10
20
30
40
50
60
70
pan/zoom mode
Sheet 1

Example



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Quick Guide on Visualization Tools

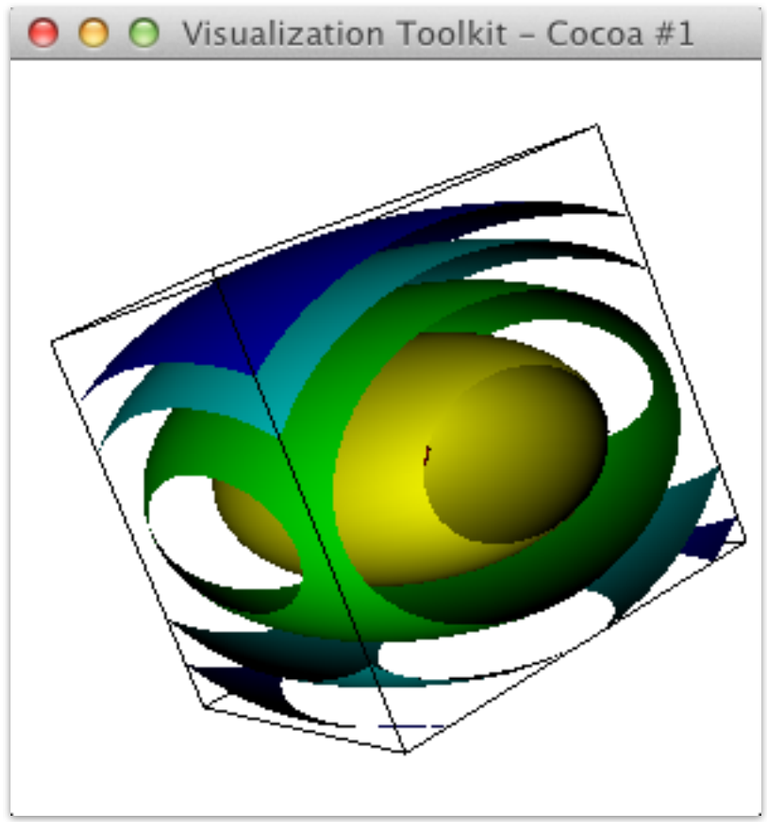
- VTK with C++ and CMake
- Python VTK, scripting programming
- VisTrails, visual programming

Build VTK from Source

- Required for Python/Java wrapping and for Linux/Mac distribution
- Recommended the trunk for development
- Cross-platform compilation using CMake

Exercise 1

- Compile VTK with Python support
- Testing: run Examples/VisualizationAlgorithms/Python/VisQuad.py



CMake

- Open-source, cross-platform Make
  - Out-of-source build
- Natively support linking with VTK, i.e. find_package(VTK)
- Tutorial available at www.cmake.org

Exercise 2

- Build the same program in Exercise 1 but using C++ and CMake

VisTrails

- Binaries and user guides are available at www.vistrails.org

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Exercise 3

- Build the same pipeline in VisTrails
- Perform parameter exploration

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