Lecture 19
ITK’s Path Framework

(Bio)Medical Image Analysis - Spring 2025
16-725 (CMU RI) : BioE 2630 (Pitt)
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Preface

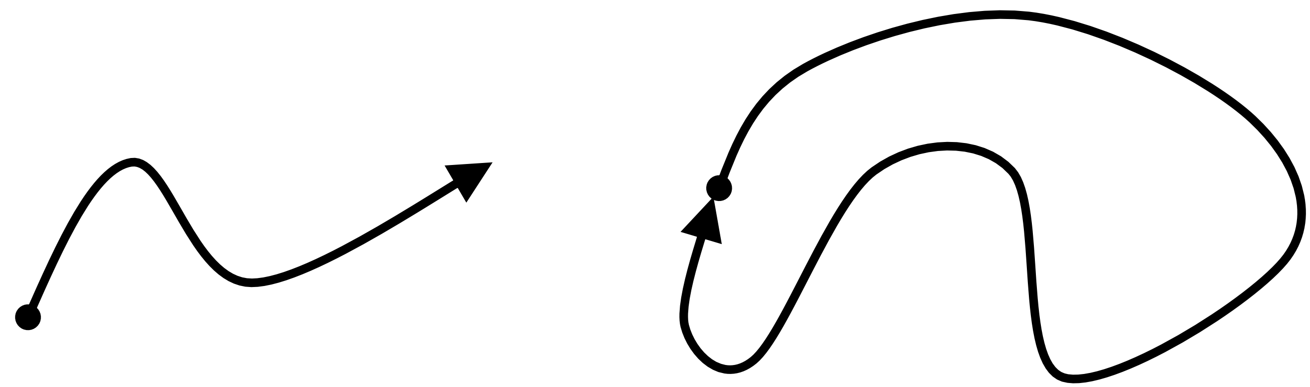
- This is based on the slides I presented at MICCAI 05's ITK workshop.
- They discuss the motivation and usage for the unified path framework I added to ITK.
- You can see the related Insight Journal article at http://hdl.handle.net/1926/40
  - (Note: It used to be one of the top-rated journal articles until I.J. was redone, and all the old reviews were scrapped.)

Introduction

- The need for paths in ITK
- Basic concepts and path types
- Implementation details
- Example usage

The Need for Paths in ITK

- A path is a curve that maps a scalar value to a point in n-dimensional space



The Need for Paths in ITK

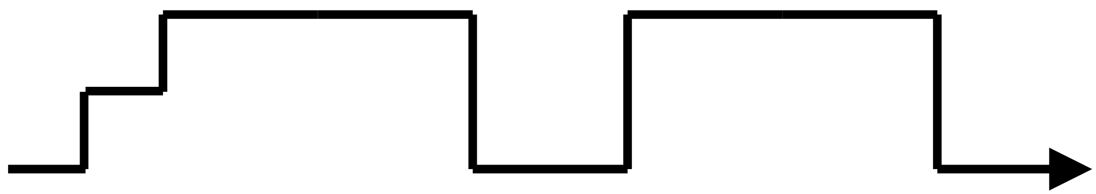
- Paths are useful for:
  - Segmentation algorithms
    - Active contours, snakes, LiveWire
  - Ridge tracking
  - Path planning
  - User interaction
- Implementation of the above in ITK can be simplified by having a common, existing path framework.

The Need for Paths in ITK

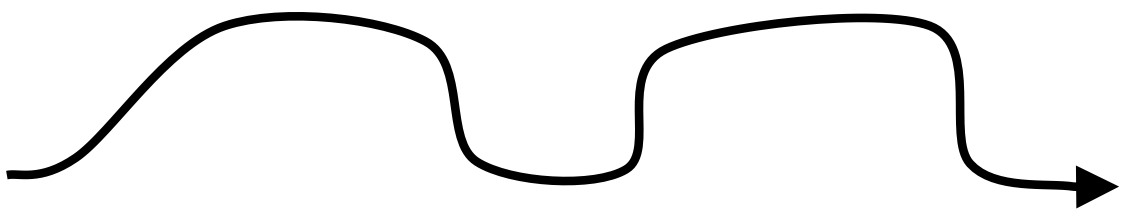
- Unfortunately, the ITK pipeline was originally designed to operate on image and mesh data types
  - Neither images nor meshes are well suited for path representation

Basic Concepts and Path Types

- Two common types of paths:
- Chain codes are a type of discrete curve

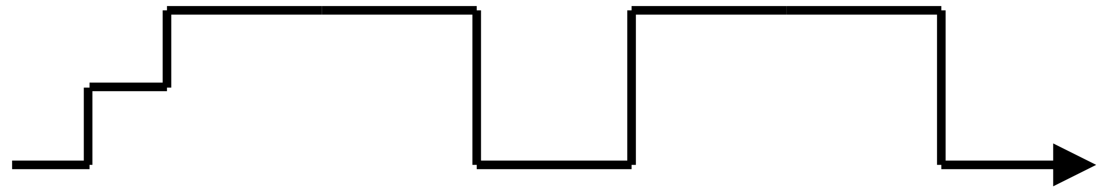


- Parametric curves are continuous



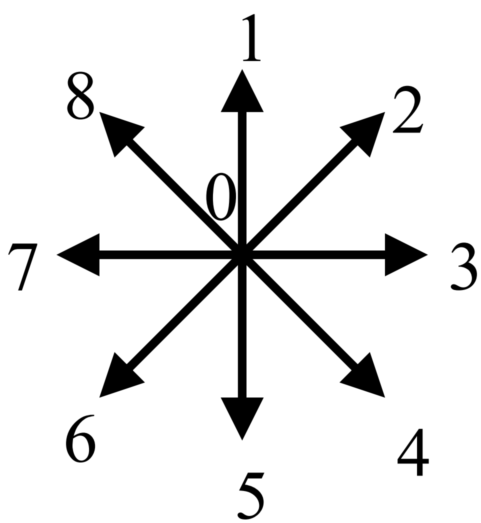
- Other types of paths are also possible

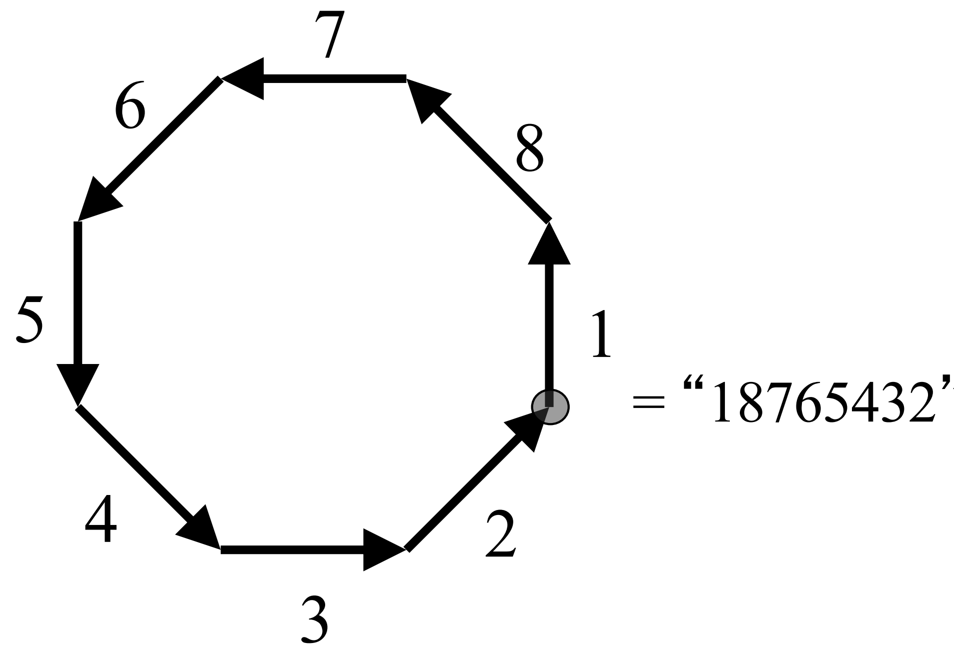
Chain Codes



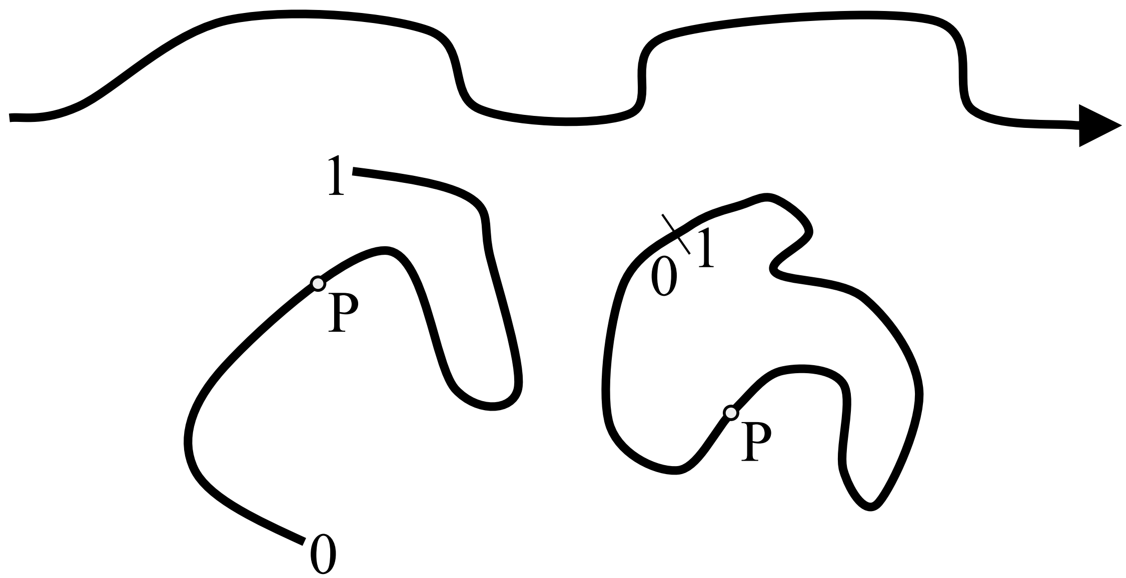
- Represent a path as as sequence of offsets between adjoining voxels
- Provide efficient incremental access and comparatively poor random index access

2D Chain Code Example: Freeman Code





Parametric Curves



- Represent a path as an algebraically defined curve parameterized over a scalar input
- Provide efficient random access and comparatively poor incremental index access
  - Difficult to know how much to increment the parameterized input to reach the next voxel

Implementation Details

- Necessary Functionality
- Path class hierarchy
- Path iterators
- Path filter hierarchy

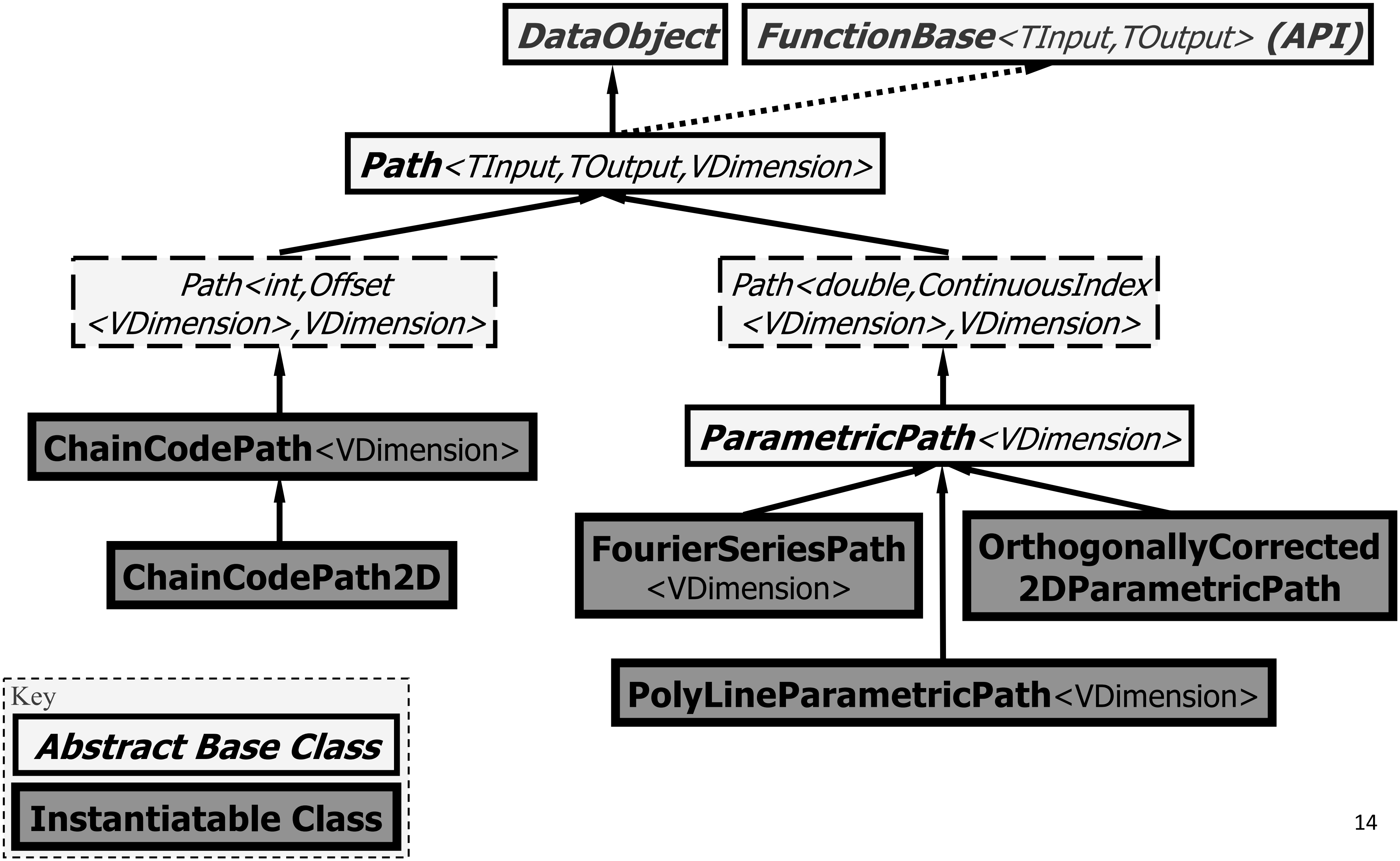
Necessary Functionality

- Efficiency
- Handle open, closed, & self-crossing paths
- Iterate along a path through an image
- Examine image data in an arbitrarily defined neighborhood surrounding any given point along a path

Necessary Functionality

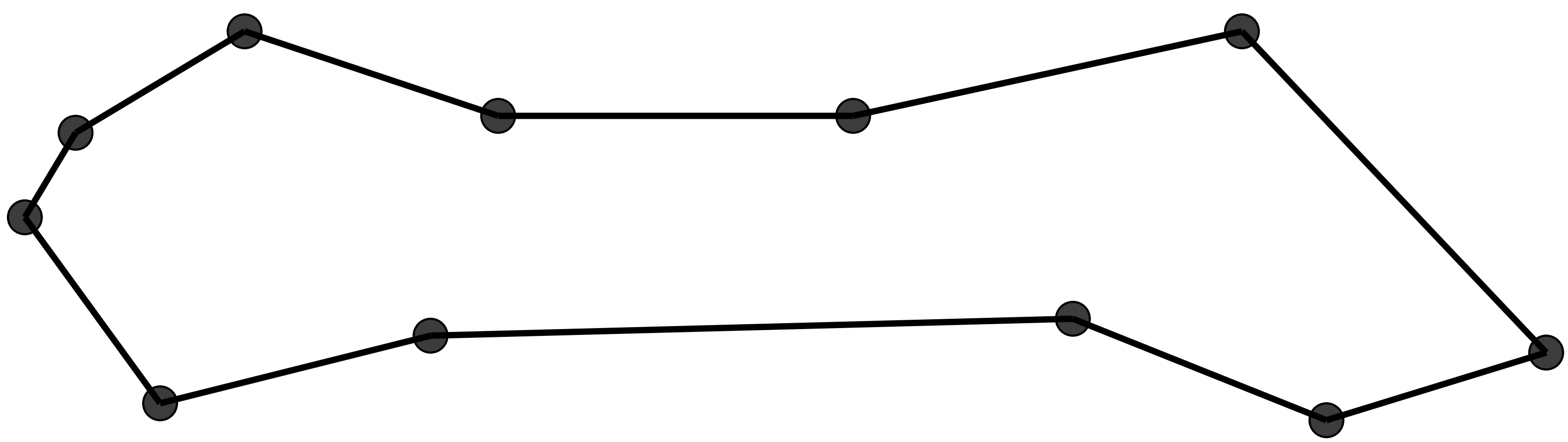
- Create and modify arbitrary chain codes
- Smooth paths in continuous index space
- Find exact normals to smooth paths
- Distort paths by orthogonal offsets at regular spacing
- Support user interaction

Path Class Hierarchy



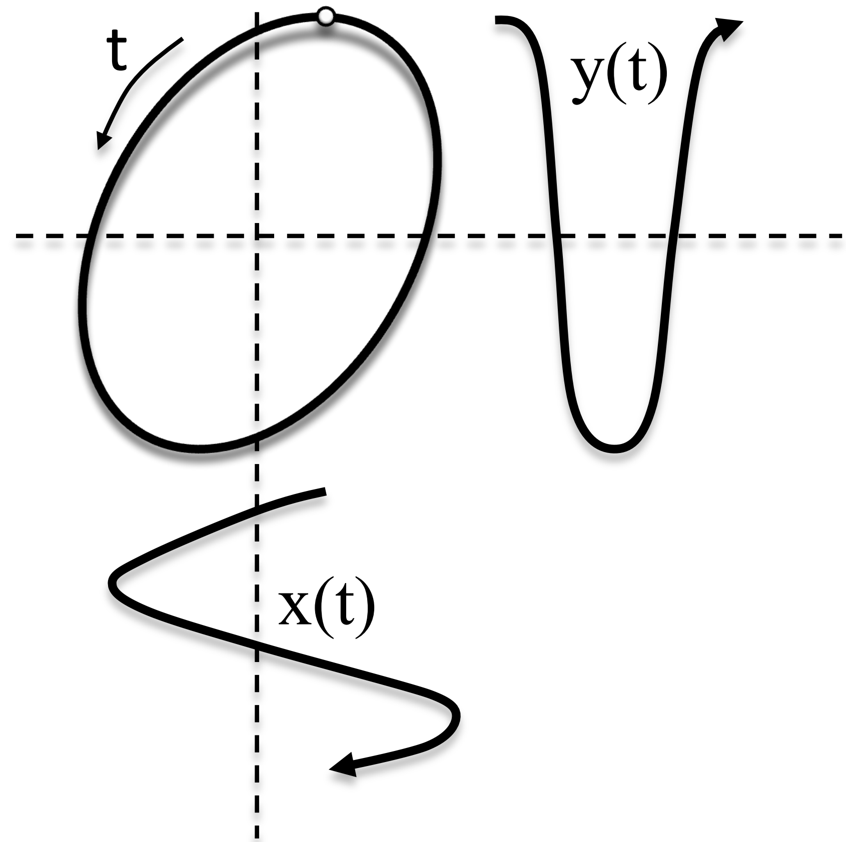
PolyLineParametricPath

- Represents a path as a series of vertices connected by line segments
- Provides a simple means of creating a path that can then be converted to other path types

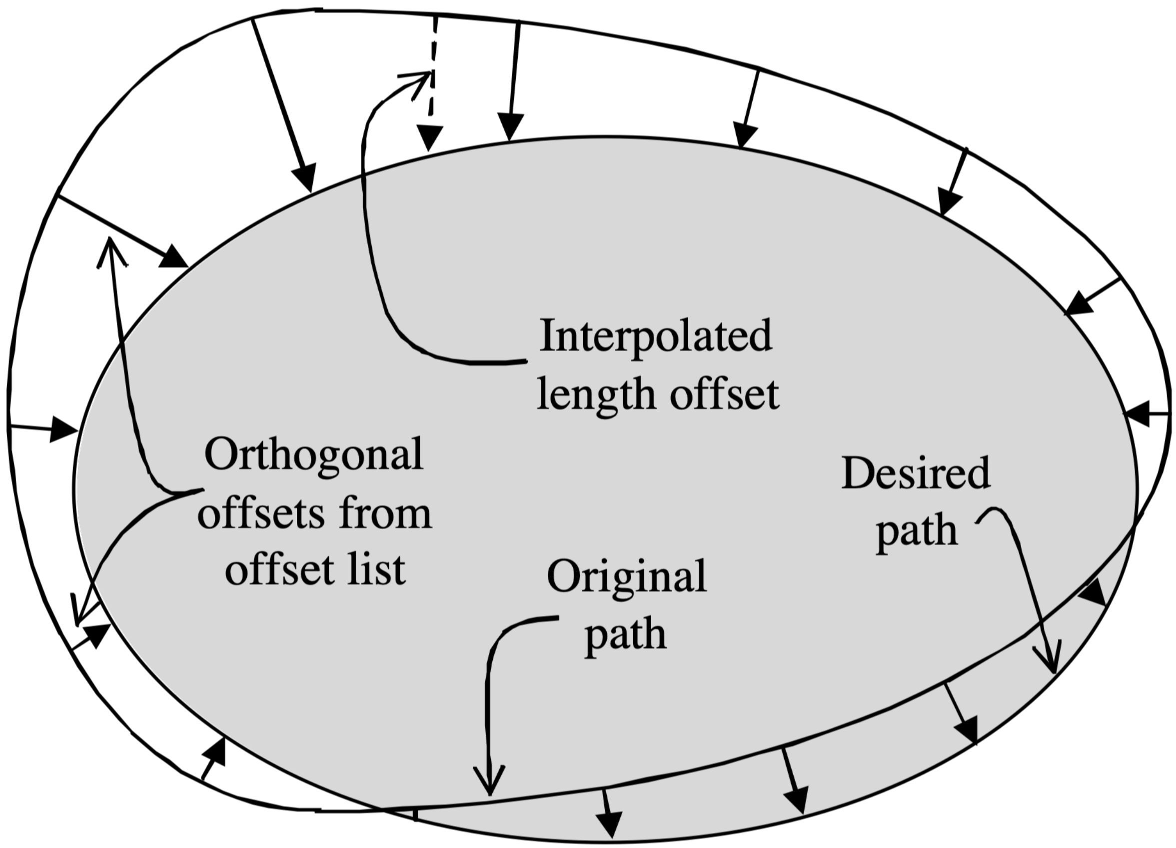


FourierSeriesPath

- Represents a closed path by its Fourier coefficients in each dimension
- Has continuous well-defined derivatives with respect to its input
  - At all points along the curve, the normal direction is well-defined and easy to compute.

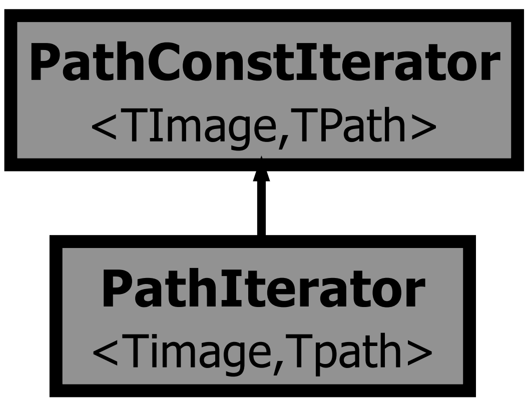


Orthogonally Corrected Path



Path Iterators

- Iterators traverse paths through images
  - Allows const paths
  - Necessary for path inputs in pipeline
- Implemented a universal path iterator



Path Iterators: Implementation

- Iterators traverse paths through images
  - Paths do not store a current position; iterators do
  - Allows const paths with many concurrent positions
  - The path iterator is able to traverse any type of path
- Path iterators are supported by the **`Path::IncrementInput(InputType & Input)`** function
  - All paths must know how much to increment a given path input to advance the path output to the next neighboring voxel along the path
  - For efficiency, **`IncrementInput()`** returns the offset resulting from its modification of Input

Current Base Class API

- **Path<TInput,TOutput,VDimension>**
  - **virtual InputType StartOfInput() const**
  - **virtual InputType EndOfInput() const**
  - **virtual OutputType Evaluate(InputType) const =0**
  - **virtual IndexType EvaluateToIndex(InputType) const =0**
  - **virtual OffsetType IncrementInput(InputType) const =0**

- **PathConstIterator<TImage,TPath>**
  - **GoToBegin()**
  - **bool IsAtEnd()**
  - **operator++()**
  - **IndexType GetIndex()**
  - **PathInputType GetPathPosition()**

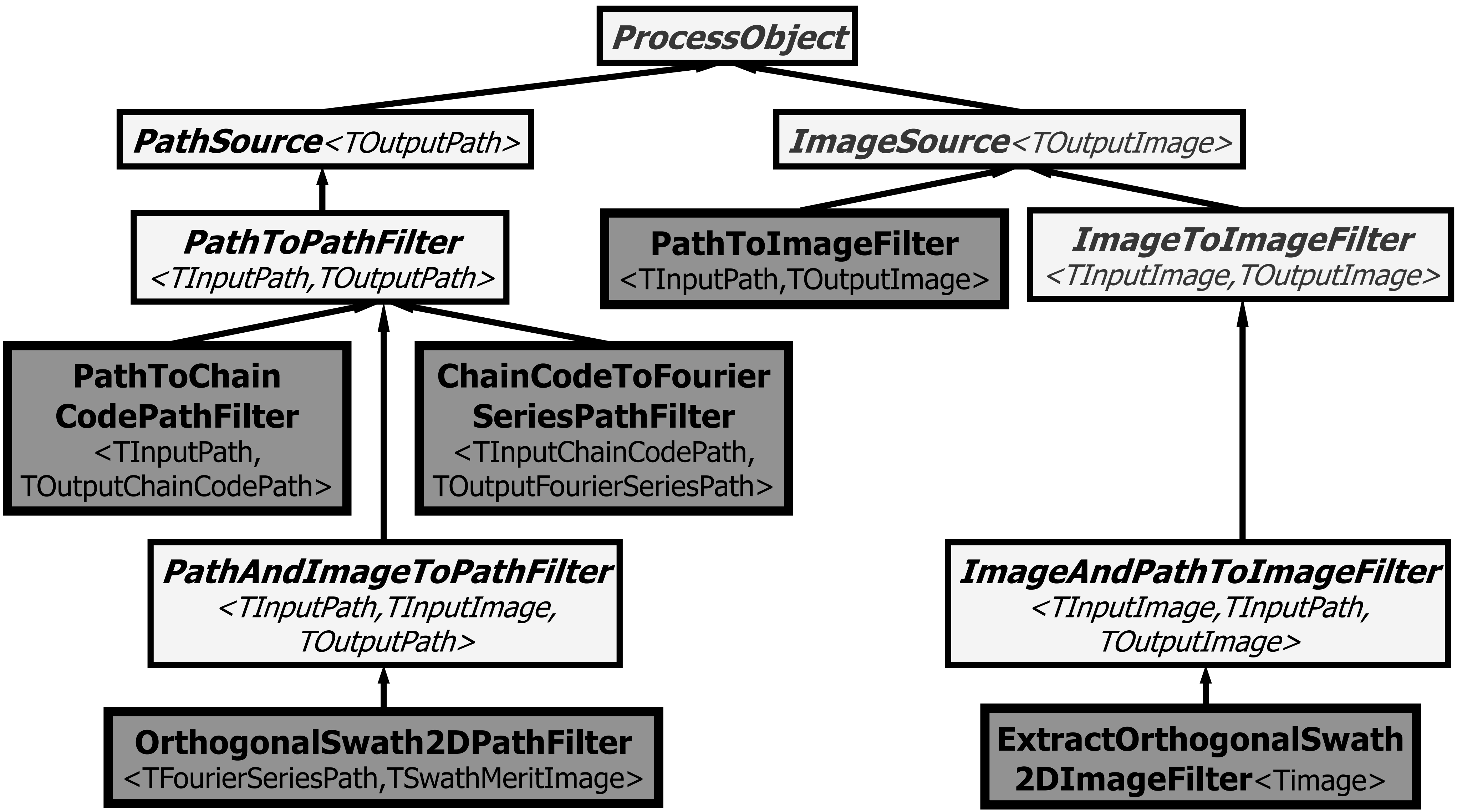
Subclass API Extensions

- `ChainCodePath<VDimension>`
  - `SetStart(IndexType)`
  - `IndexType GetStart()      const`
  - `unsigned  NumberOfSteps() const`
  - `InsertStep(InputType position, OffsetType step)`
  - `ChangeStep(InputType position, OffsetType step)`
  - `Clear()`

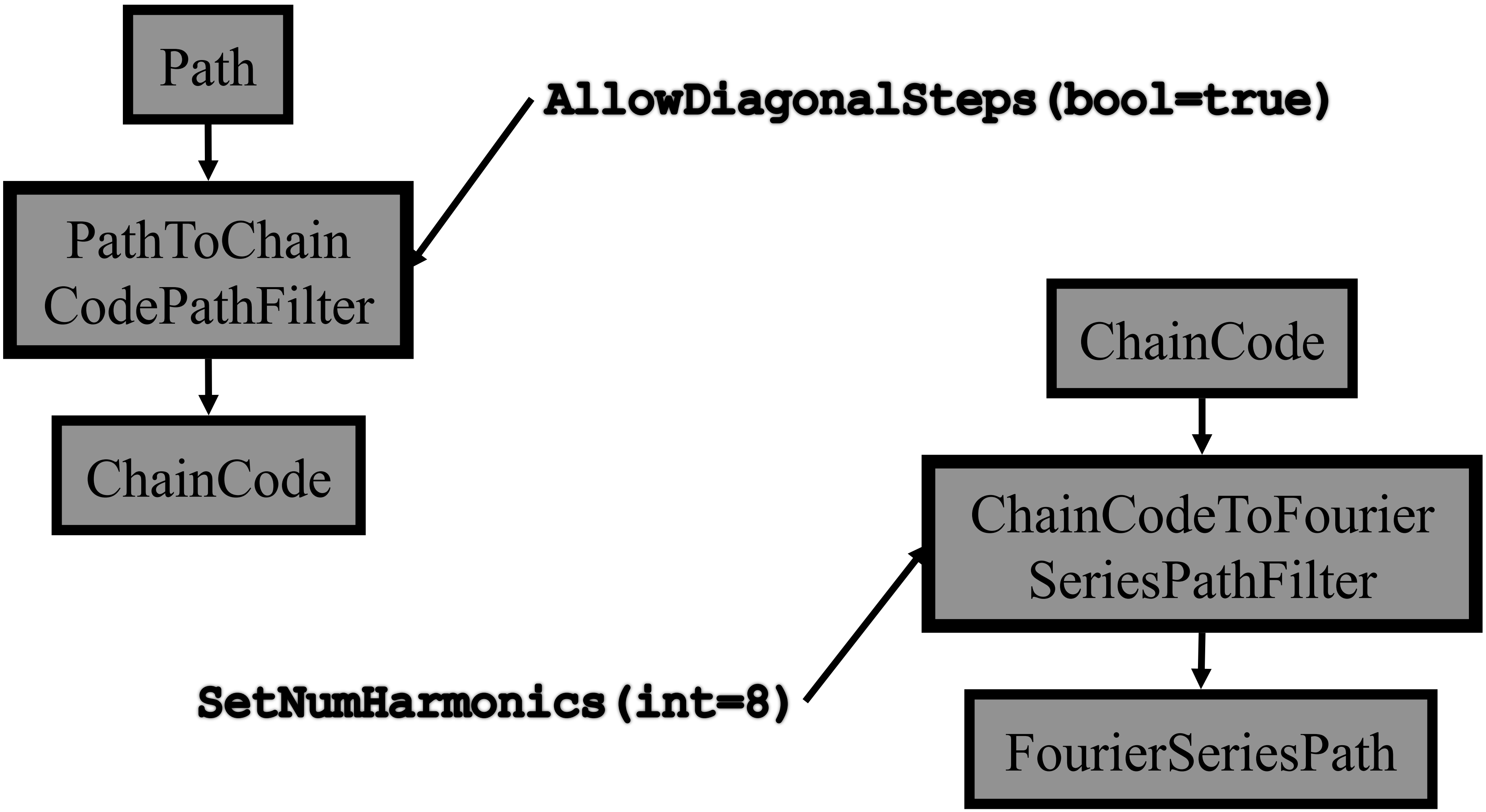
- `ParametricPath<VDimension>`
  - `VectorType EvaluateDerivative(InputType) const`

- `FourierSeriesPath<VDimension>`
  - `AddHarmonic(VectorType CosCoef, VectorType SinCoef)`
  - `Clear()`

Path Filter Hierarchy



Conversion Filters



Philosophical Comparison with Spatial Objects

- Spatial Objects represent geometric shapes (and therefore their associated boundaries)
  - A Spatial Object's interior is well defined
- Paths represent sequences of connected indices
  - A path may not be closed (no interior defined)
  - A closed path's interior is difficult to compute

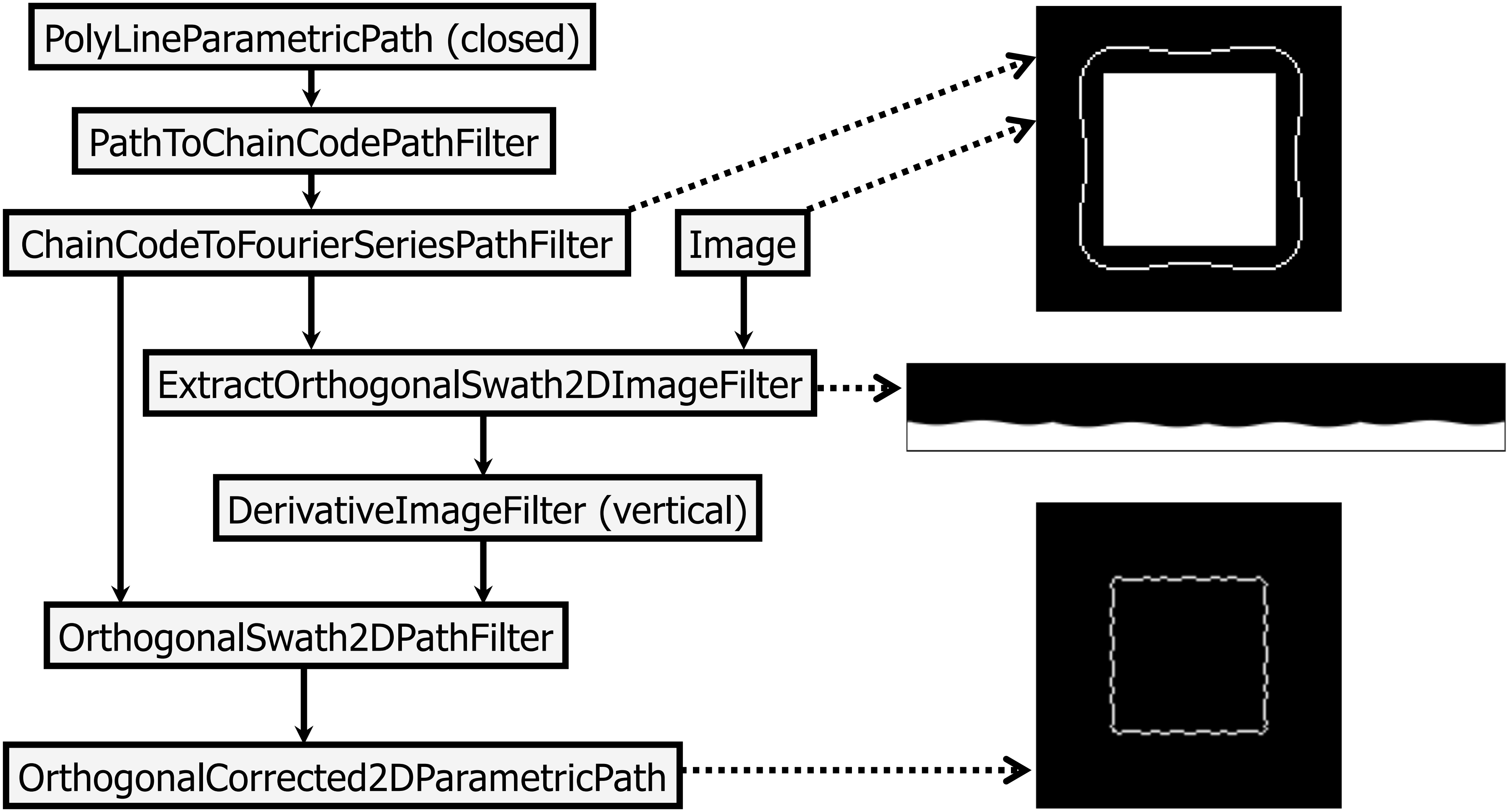
Empirical Comparison with Spatial Objects

- Spatial Objects are well suited to rendering, analysis, and data interchange
- Paths are well suited to computation, optimization, and iterator direction control
- ITK could be extended to enable simple conversion by:
  - Making a Spatial Object that uses one or more paths as an internal representation
  - Making a Path that uses one or more intersecting spatial objects as an internal representation

Example Usage

- Implementation of a published 2D active contour algorithm
  - Finds optimal orthogonal offsets at evenly spaced points along an initial path
  - Requires that neighboring offsets differ in value by at most one
- Added to ITK, including demonstration test code
  - **`Modules/Filtering/Path/test/itkOrthogonalSwath2DPathFilterTest.cxx`**

OrthogonalSwath2DPathFilter



Conclusion

- Added user-extensible path support to ITK
  - Data type hierarchy
  - Iterators
  - Filter hierarchy
  - Example implementation in test code
- New core data types *can* be added to ITK!