

SimpleITK Tutorial

Image processing for mere mortals

Insight Software Consortium

Sept 23, 2011

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What this Tutorial is about

- Provide working knowledge of the SimpleITK platform

Program

- Virtual Machines Preparation (10min)
- Introduction (15min)
- Basic Tutorials I (45min)
- Short Break (10min)
- Basic Tutorials II (45min)
- Coffee Break (30min)
- Intermediate Tutorials (45min)
- Short Break (10min)
- Advanced Topics (40min)
- Wrap-up (10min)

Virtual Machine Preparation

Virtual Machines Preparation

- Get DVD / USB Memory Stick
- Install VirtualBox from it
- Import the VirtualMachine file
- Boot the Virtual Machine
- Get familiar

- VirtualBoxInstallers

- VirtualBox-4.0.8-71778-OSX.dmg (Mac)
- VirtualBox-4.0.8-71778-Win.exe (Windows)
- (Ubuntu Linux)
 - virtualbox-4.0_4.0.8-71778 Ubuntu lucid_amd64.deb
 - virtualbox-4.0_4.0.8-71778 Ubuntu lucid_i386.deb
 - virtualbox-4.0_4.0.8-71778 Ubuntu maverick_amd64.deb
 - virtualbox-4.0_4.0.8-71778 Ubuntu maverick_i386.deb
 - virtualbox-4.0_4.0.8-71778 Ubuntu natty_amd64.deb
 - virtualbox-4.0_4.0.8-71778 Ubuntu natty_i386.deb
 - ...

- VirtualMachine

- SimpleITK.ova

Install VirtualBox

- Select the installer for your platform
- Run it

- You can also install VirtualBox by doing:
- `sudo apt-get install virtualbox-ose-qt`

Importing the Virtual Machine

- Run VirtualBox
- In File Menu select Import Appliance
- Provide the filename in the DVD / USB stick
`VirtualMachine/SimpleITK.ova`
- A progress bar will appear, and when it finishes you should see...

Now, on to the
tutorial...

Introductions

- Daniel Blezek, Ph.D., Mayo Clinic
- Luis Ibáñez, Ph.D., Kitware
- Hans Johnson, Ph.D., University of Iowa
- Bradley Lowekamp, Lockheed Martin (National Library of Medicine)

Tutorial Goals

- Gentle introduction to ITK
- Introduce SimpleITK
- Provide hands-on experience
- Problem solving, not direction following
- ...but please follow directions!

How many are familiar with ITK?

Ever seen code like this?

```
1  // Setup image types.
2  typedef      float InputPixelType;
3  typedef      float OutputPixelType;
4  typedef itk::Image<InputPixelType, 2> InputImageType;
5  typedef itk::Image<OutputPixelType,2> OutputImageType;
6  // Filter type
7  typedef itk::DiscreteGaussianImageFilter<
8      InputImageType, OutputImageType >
9      FilterType;
10 // Create a filter
11 FilterType::Pointer filter = FilterType::New();
12 // Create the pipeline
13 filter->SetInput( reader->GetOutput() );
14 filter->SetVariance( 1.0 );
15 filter->SetMaximumKernelWidth( 5 );
16 filter->Update();
17 OutputImageType::Pointer blurred = filter->GetOutput();
```

What if you could write this?

```
1 import SimpleITK
2 input = SimpleITK.ReadImage ( filename )
3 output = SimpleITK.DiscreteGaussianFilter( input, 1.0, 5 )
```


What if you could write this?

```
1 import SimpleITK
2 input = SimpleITK.ReadImage ( filename )
3 output = SimpleITK.DiscreteGaussianFilter( input, 1.0, 5 )
```

We are here to tell you that you can...

Goals of SimpleITK

- Be an “on-ramp” for ITK
- Simplify the use of ITK by
 - Providing a templateless, typeless layer for ITK in C++
 - Providing wrappings in scripting languages
 - Providing access to most ITK algorithms

SimpleITK Architectural Overview

- Conceptually, SimpleITK is an application library built on ITK
- All functionality provided by ITK
- Components:
 - Template expansion system
 - C++ library
 - Small SWIG definition (more details later)
 - “Glue” code for several scripting languages
 - Some language utilities
- Open Source, Apache licensed project
(<http://www.opensource.org/licenses/apache2.0.php>)
- Hosted by GitHub (<https://github.com/SimpleITK/SimpleITK>)

Templates in ITK

```
1 typedef unsigned char PixelType;
2 enum {ImageDimension = 2};
3 typedef itk::Image<PixelType,ImageDimension> ImageType;
4 typedef itk::Vector<float,ImageDimension> VectorType;
5 typedef itk::Image<VectorType,ImageDimension> FieldType;
6 typedef itk::Image<VectorType::ValueType,ImageDimension> FloatImageType;
7 typedef ImageType::IndexType IndexType;
8 typedef ImageType::SizeType SizeType;
9 typedef ImageType::RegionType RegionType;
10 typedef itk::MultiResolutionPDEDeformableRegistration
11 <ImageType, ImageType, FieldType> RegistrationType;
```

Template Freedom

```
1 using itk::simple;
2 // Read the image file
3 ImageFileReader reader;
4 reader.SetFileName ( "/my/fancy/file.nrrd" );
5 Image image = reader.Execute();
6
7 // This filters perform a gaussian blurring with sigma in
8 // physical space. The output image will be of real type.
9 SmoothingRecursiveGaussianImageFilter gaussian;
10 gaussian.SetSigma ( 2.0 );
11 Image blurredImage = gaussian.Execute ( image );
```

Programming Models

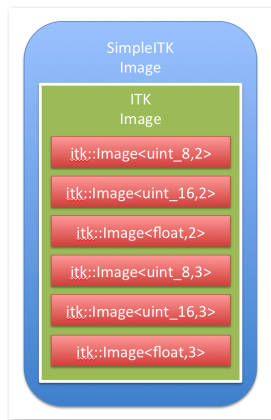
- Object oriented
- Function oriented

More about this later

Transformed by SWIG

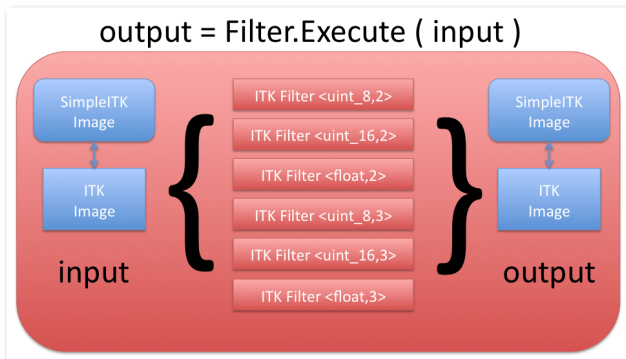
- Parses header and “interface” files
- Automatically creates scripting “glue”
- Wrappings available for:
 - Python
 - Java
 - C#
 - Tcl, Lua, Ruby
 - Others as requested...

Image Anatomy



- SimpleITK images contain `itk::Image`
- Hides the templates
- Adds useful “utility” functions

Filter Anatomy



- SimpleITK filters contain `itk::ImageToImageFilter`
- Hides the templates
- Adds useful “utility” functions
- (Mainly) `output = Filter.Execute (input)`

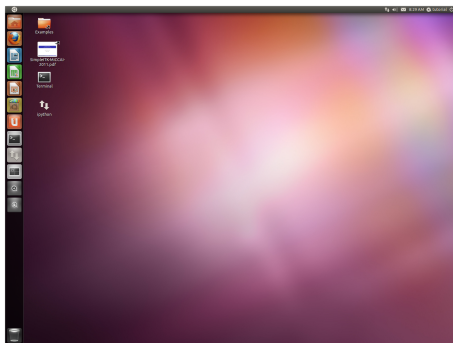
Basic Tutorial

Virtual Machine Check

How are we doing with the Virtual Box images?

Ubuntu Introduction

- User experience oriented version of Linux
- Familiar desktop paradigm



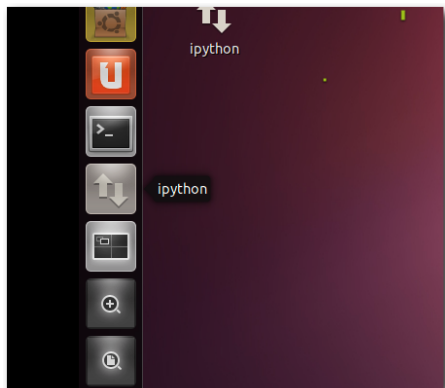
Ubuntu - Hands On



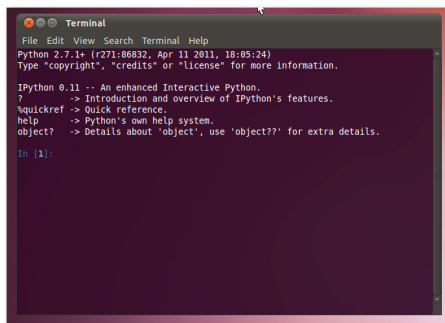
- Quick overview of relevant icons

Just Enough Python to be Dangerous

- Start a terminal
- Run iPython



Just Enough Python to be Dangerous



```
File Edit View Search Terminal Help
Python 2.7.1+ (r271:86832, Apr 11 2011, 18:05:24)
Type "copyright", "credits" or "license" for more information.

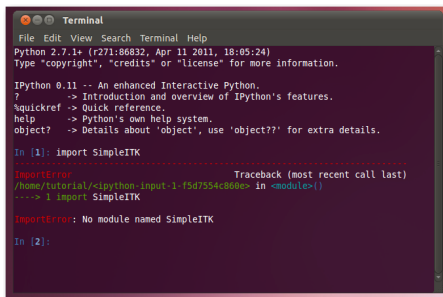
IPython 0.11 -- An enhanced Interactive Python.
?          -> Introduction and overview of IPython's features.
%quickref  -> Quick reference.
help       -> Python's own help system.
object?    -> Details about 'object', use 'object??' for extra details.

In [1]:
```

- iPython is a Python intrep
- Also functions as a shell (cd, ls, etc. . .)

Just Enough Python to be Dangerous

Import the SimpleITK package



```
Terminal
File Edit View Search Terminal Help
Python 2.7.1+ (r271:86832, Apr 11 2011, 18:05:24)
Type "copyright", "credits" or "license" for more information.

IPython 0.11 -- An enhanced Interactive Python.
?                -> Introduction and overview of IPython's features.
%quickref        -> Quick reference.
help             -> Python's own help system.
object?         -> Details about 'object', use 'object??' for extra details.

In [1]: import SimpleITK
-----
ImportError                               Traceback (most recent call last)
/home/tutorial/cipython-input-1-f5d7554c800e in <module>()
----> 1 import SimpleITK

ImportError: No module named SimpleITK

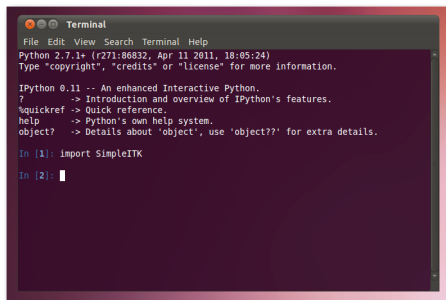
In [2]:
```

What just happened?

Just Enough Python to be Dangerous

Need to tell iPython where to find SimpleITK

See `/home/tutorial/.ipython/ipy_user_conf.py`

A screenshot of a terminal window titled "Terminal". The window has a menu bar with "File", "Edit", "View", "Search", "Terminal", and "Help". The terminal output shows the Python version (2.7.1+), the IPython version (0.11), and a list of shortcuts: "?" for introduction, "%quickref" for quick reference, "help" for Python's help system, and "object?" for details about objects. The user has entered two commands: "In [1]: import SimpleITK" and "In [2]:", with the cursor at the end of the second line.

```
Python 2.7.1+ (r271:86832, Apr 11 2011, 18:05:24)
Type "copyright", "credits" or "license" for more information.

IPython 0.11 -- An enhanced Interactive Python.
?      -> Introduction and overview of IPython's features.
%quickref -> Quick reference.
help    -> Python's own help system.
object? -> Details about 'object', use 'object??' for extra details.

In [1]: import SimpleITK

In [2]:
```

Note on the Tutorial

- Most examples will be Python
- Obvious translation to other languages
- C++ usage (generally) obvious

- Creation
- Number of dimensions, size, origin, spacing
- Pixel access

Back to iPython ([Examples/BasicTutorial1/Image.py](#))

What just happened?

```
1 import SimpleITK as sitk
2 # Create an image
3 image = sitk.Image ( 256, 256, 256, sitk.sitkInt16 );
4 # How about 2d?
5 twoD = sitk.Image ( 64, 64, sitk.sitkFloat32 )
```

- sitk is the module
- Image is the constructor for the Image class
- Height, width, depth (omit depth for 2D images)
- Datatype (more on this later)

Back to iPython ([Examples/BasicTutorial1/Image.py](#))

What just happened?

```
1 # Addressing pixels
2 image.GetPixel ( 0, 0, 0 )
3 image.SetPixel ( 0, 0, 0, 1 )
4 image.GetPixel ( 0, 0, 0 )
```

- Get the voxel value at [0,0,0]?
- Hmm, I don't like it, so set to 1
- What is the value at [0,0,0] now?

Back to iPython (Examples/BasicTutorial1/Image.py)

What just happened?

```
1 # Addressing pixels
2 image[0,0,0]
3 image[0,0,0] = 10
4 image[0,0,0]
```

Without warning, we sprinkled syntactic sugar on you!

- `image[0,0,0]` is shorthand for `Image.GetPixel(0,0,0)`
- `image[0,0,0] = 10` is shorthand for `Image.SetPixel(0,0,0,10)`

Summary

- Images are created using `SimpleITK.Image (w, h, d, Type)`
- Images can be 2- or 3-dimensional
- Images can describe themselves
- Images have simple pixel accessors

Questions before we move on?

Memory Management

Images...

- usually allocated on the stack
- are copy-on-write
- use internal smart-pointers

Back to `iPython (Examples/BasicTutorial1/MemoryManagement.py)`

Image Memory Management

```
1 image = SimpleITK.Image ( 32, 32, 32, SimpleITK.sitkInt16 )
2 print image
3 ...
4 Image (0x94f2d98)
5   Reference Count: 1
6 ...
7 # Clone image
8 b = SimpleITK.Image ( image )
9 print image
10 ...
11 Image (0x94f2d98)
12   Reference Count: 2
13 ...
14 print b
15 ...
16 Image (0x94f2d98)
```

Image Memory Management

```
1 print b
2 ...
3 Image (0x94f2d98)
4 ...
5 b[0,0,0] = 1
6 print b
7 ...
8 Image (0x94f4cb0)
9   Reference Count: 1
10 ...
11 print image
12 ...
13 Image (0x94f2d98)
14   Reference Count: 1
15 ...
```

Filters...

- usually allocated on the stack
- tend to clean up after themselves
- do not hold on to images
- no access to the ITK pipeline

...more on this later...

Memory Management Strategies

C++...

- No need for explicit management
- Let images clean up after themselves
- Let filters clean up after themselves

Wrapped...

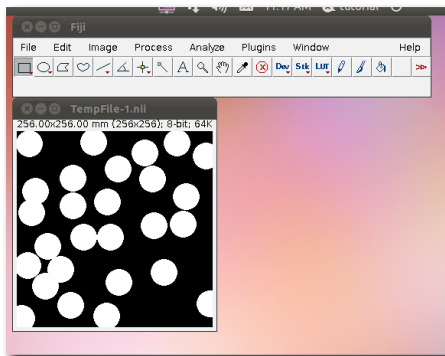
- Utilize language-specific memory management
- Automatic in Python, Java, Ruby, C#, Lua
- More manual in Tcl

Input/Output

Read/Write/Display Images

Back to iPython ([Examples/BasicTutorial1/InputOutput.py](#))

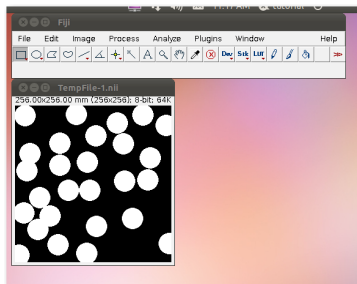
Display



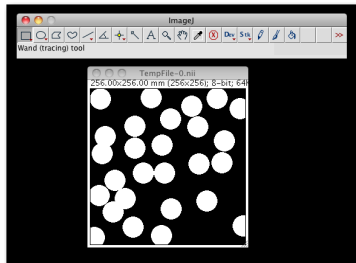
What just happened?

```
1 # What's the image look like?  
2 sitk.Show ( image )
```


Display



Ubuntu



Mac

- ImageJ/Fiji used for display
- SimpleITK looks in most likely location for ImageJ
- Image written in Nifti format
- Need to install Nifti plugin for ImageJ
- <http://rsbweb.nih.gov/ij/plugins/nifti.html>

Questions/Break

Basic Tutorial 2

Hands On

`Examples/BasicTutorial2/Filters.py`

What just happened?

```
1 # Simple smoothing
2 smooth = sitk.SmoothingRecursiveGaussian ( image, 2.0 )
3 sitk.Show ( sitk.Subtract ( image, smooth ) )
4 ...
5 RuntimeError: Exception thrown in SimpleITK Subtract: ...
6 sitk::ERROR: Both images for SubtractImageFilter don't match type or dimension!
7 ...
```

- The output of SmoothingRecursiveGaussian is of type float
- The input image is signed short
- Most SimpleITK filters with 2 inputs require the same type
- Let's fix the problem

Introducing Cast

```
1 # Much better
2 print "Before: ", smooth.GetPixelIDTypeAsString()
3 smooth = sitk.Cast ( smooth, image.GetPixelIDValue() )
4 print "After: ", smooth.GetPixelIDTypeAsString()
5 sitk.Show ( sitk.Subtract ( image, smooth ), "DiffWithGaussian" )
```

Back to iPython ([Examples/BasicTutorial2/Filters.py](#))

Sizes and Indices

```
1 # Extract
2 size = [64, 64, 1]
3 start = [64, 0, 0]
4 sitk.Show ( sitk.Extract ( image, size, start ), "Extracted" )
```

in C++ / ITK code this would use

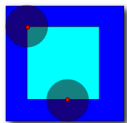
```
1 typedef unsigned char PixelType;
2 enum {ImageDimension = 2};
3 typedef itk::Image<PixelType, ImageDimension> ImageType;
4
5 typedef ImageType::IndexType IndexType;
6 typedef ImageType::SizeType SizeType;
7 typedef ImageType::RegionType RegionType;
```

- SimpleITK uses STL vectors
- Wrapping converts to language-specific constructs (tuples/arrays)

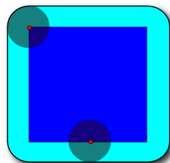
Morphology

`Examples/BasicTutorial2/Morphology.py`

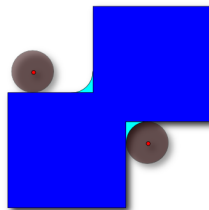
Operators



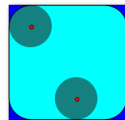
Erosion



Dilation



Closing



Opening

Images from

http://en.wikipedia.org/wiki/Mathematical_morphology

Back to iPython (`Examples/BasicTutorial2/Morphology.py`)

Pixel-wise Operators

```
1 # Use pixel-wise operators
2 sitk.Show ( 127 * image + 127 * sitk.BinaryErode ( image ), "ThinErosion" )
```

Table: SimpleITK Pixel-wise Operators

Operator	Equivalent	Usage [†]
+	Add, AddConstantTo	$A + B, s + A, s + B$
-	Subtract, SubtractConstantFrom	$A - B, s - A, s - B$
*	Multiply, MultiplyByConstant	$A * B, s * A, s * B$
/	Divide, DivideByConstant	$A/B, s/A, B/s$
&	And “and”	$A \& B$
	Or “or”	$A B$
~	Not “not”	A
** ^{††}	Pow, PowToConstant	$A ** B, A ** s$

[†] A and B are images (2D or 3D), s is a scalar

^{††} python only

Operator Example

```
1 sitk.Hash ( image + 2 )  
2 sitk.Hash ( sitk.AddConstantTo ( image, 2 ) )  
3  
4 sitk.Hash ( image * 2 )  
5 sitk.Hash ( sitk.MultiplyByConstant ( image, 2 ) )
```

- Hash calculates the MD5 or SHA1 hash of the *image* data
- Used to tell if two images are exactly identical

[Back to iPython \(Examples/BasicTutorial2/Morphology.py\)](#)

Let's take a break

Interactive Sessions

Data To Interact With

```
1 # Read image, using ipython's tab auto-complete
2 image = sitk.ReadImage( '~/SimpleITK-MICCAI-2011-Tutorial/iasem-cells.nrrd' )
3
4 # Get familiar with the image
5 print image
6 ...
7 sitk.Show( image )
```

- “Dual-Beam” or Ion-Abrasion Scanning Electron Microscopy
- Heavily pre-processed
- X-Z cross-section of a 3D volume

Image Masks or Binary Images

Image masks are just SimpleITK Images

- Follow some conventions
- Pixel type of `uint8_t`
- 0-value is background, 1-value is the foreground
- Masks are used for output of thresholding, binary morphology, etc. . .
- The 1-value was chosen to ease of computation with operators
- If a mask needs to be directly shown, multiply by 255

Threshold-based Segmentation

- **Threshold**

$$Output(x_i) = \begin{cases} Input(x_i) & \text{if } Lower \leq x_i \leq Upper; \\ OutsideValue & \text{otherwise.} \end{cases}$$

- **BinaryThreshold**

$$Output(x_i) = \begin{cases} InsideValue & \text{if } LowerThreshold \leq x_i \leq UpperThreshold; \\ OutsideValue & \text{otherwise.} \end{cases}$$

- **OtsuThreshold** - Automatic Threshold values based on minimizing intra-class variance.
- **DoubleThreshold** - A morphology based filters. Uses two sets of thresholds.

```
1 # quick visualizations of masked image
2 sitk.Show( image * mask )
3 sitk.Show( .5*image*~mask+image*mask )
```

- **BinaryOpeningByReconstruction** - Removes binary elements which are smaller than the structuring element.
- **BinaryClosingByReconstruction** - Fills binary holes which are smaller than the structuring element.
- **BinaryFillHole** - Fills all holes in image.
- **BinaryGrindPeak** - Removes all binary elements not connected to boarder.

Change Border Problem

Problem:

- Registration leaves a border in the image
- Border value is average intensity
- Change to 0

Change Border Solution

To iPython

(`Examples/InteractiveTutorial/05-01-BorderChange.py`)

SimpleITK with Numpy

Numpy is:

- Python's universal numerics foundation
- Provides high performance basic linear algebra

numpy interface functions:

```
1 def GetArrayFromImage(image):  
2     """Get a numpy array from a SimpleITK Image."""  
3  
4 def GetImageFromArray(arr):  
5     """Get a SimpleITK Image from a numpy array."""
```

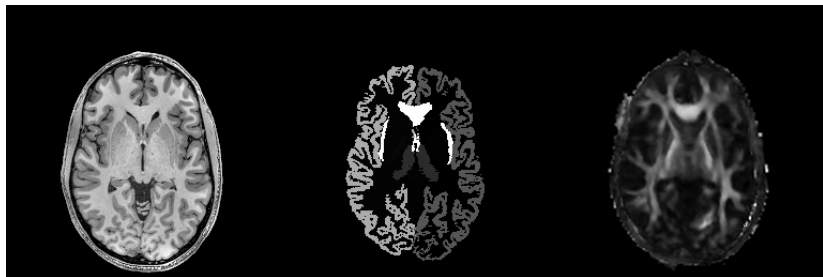
- Both of these methods do a deep copy of the image
- Ensures safety, bypassing error-prone memory issues

Python Example

To iPython (`Examples/InteractiveTutorial/05-02-Numpy.py`)

Image Measurements

The Scenerio



- You collected 1000 Diffusion Weighted Imaging scan sessions
- Now, compute the fractional anisotropy measures for a set of anatomical regions

Python Example

To iPython (`Examples/InteractiveTutorial/MeasureRegions.py`)

Feature Detection

More Data To Interact With

```
1 # Read image, using ipython's tab auto-complete
2 image = sitk.ReadImage( '~/SimpleITK-MICCAI-2011-Tutorial/iasem-mito.nrrd' )
3
4 # Get familiar with the image
5 print image
6 ...
7 sitk.Show( image )
```

• CannyEdgeDetection

```
1 Image CannyEdgeDetection ( const Image& ,  
2     double inLowerThreshold = 0.0 ,  
3     double inUpperThreshold = 0.0 ,  
4     std::vector<double> inVariance = std::vector<double>(3, 0.0) ,  
5     std::vector<double> inMaximumError = std::vector<double>(3, 0.01) );
```

• SobelEdgeDetection

```
1 Image SobelEdgeDetection ( const Image& );
```

• ZeroCrossingBasedEdge

```
1 Image ZeroCrossingBasedEdgeDetection ( const Image& ,  
2     double inVariance = 1 ,  
3     uint8_t inForegroundValue = 1u ,  
4     uint8_t inBackgroundValue = 0u ,  
5     double inMaximumError = 0.1 );
```

• GradientMagnitudeRecursiveGaussian

```
1 Image GradientMagnitudeRecursiveGaussian ( const Image& ,  
2     double inSigma = 1.0 ,  
3     bool inNormalizeAcrossScale = false );
```

• Derivative

```
1  Image Derivative ( const Image& ,  
2      unsigned int inDirection = 0u,  
3      unsigned int inOrder = 1u,  
4      bool inUseImageSpacing = true );
```

• RecursiveGaussian

```
1  Image RecursiveGaussian ( const Image& ,  
2      double inSigma = 1.0,  
3      bool inNormalizeAcrossScale = false ,  
4      itk::simple::RecursiveGaussianImageFilter::OrderEnumType inOrder = itk::simple::RecursiveGaussianImageFilter::ORDER_1,  
5      unsigned int inDirection = 0u );
```

• ZeroCrossing

```
1  Image ZeroCrossing ( const Image& ,  
2      uint8_t inForegroundValue = 1u,  
3      uint8_t inBackgroundValue = 0u );
```

Ridge and Valley Detection Problem

Where $g(x; t)$ is a Gaussian function:

$$g(x; t) = \frac{1}{\sqrt{2t\pi}} e^{\left(-\frac{x^2}{2t}\right)} \quad (1)$$

Let L denote a scale-space representation of an image I :

$$L(x, y; t) = g(x, y; t) * I(x, y) \quad (2)$$

And then L_x is the partial derivative of the scale-space representation of I with respect to x .

Ridge and Valley Detection Problem (continued)

Derivatives can also be taken in other, directions. If v is a direction parallel to image gradient, then the following defines a ridge:

$$L_{uv} = 0, L_{uu}^2 - L_{vv}^2 \geq 0 \quad (3)$$

Where these directional derivatives have the following properties:

$$L_v^2 L_{uu} = L_x^2 L_{yy} - 2L_x L_y L_{xy} + L_y^2 L_{xx}, \quad (4)$$

$$L_v^2 L_{uv} = L_x L_y (L_{xx} - L_{yy}) - (L_x^2 - L_y^2) L_{xy}, \quad (5)$$

$$L_v^2 L_{vv} = L_x^2 L_{xx} + 2L_x L_y L_{xy} + L_y^2 L_{yy} \quad (6)$$

This view of the Ridge Detection is taken from Tony Lindeberg's works.

Ridge Detection Example

To iPython

(`Examples/InteractiveTutorial/05-04-RidgeDetection.py`)

Advanced Topics

Building SimpleITK in 5 Easy Commands

```
git clone --recursive https://github.com/SimpleITK/SimpleITK
mkdir SimpleITK/SimpleITK-build
cd SimpleITK/SimpleITK-build
cmake ../SuperBuild
make -j 5
```

More complete version

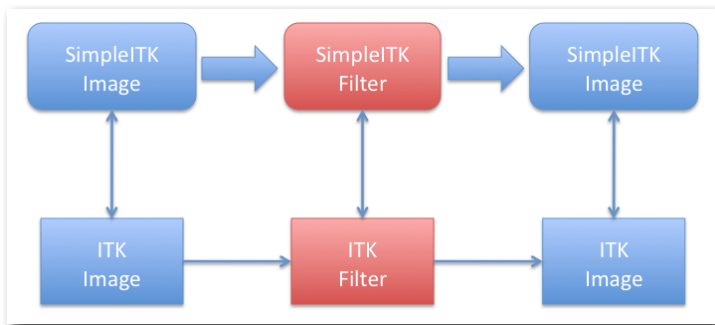
- Check out the code from GitHub
(<https://github.com/SimpleITK/SimpleITK>)
- Run CMake (<http://www.cmake.org/>) using SimpleITK/SuperBuild as the source directory
- Build using your favorite compiler

Supported Platforms

- Windows: Visual Studio 10
- Windows: Visual Studio 9 (Requires TR1 service pack)
- Mac OSX: gcc 4.x (Xcode 4.x)
- Linux: gcc 4.x

SimpleITK Architecture

Filter Anatomy

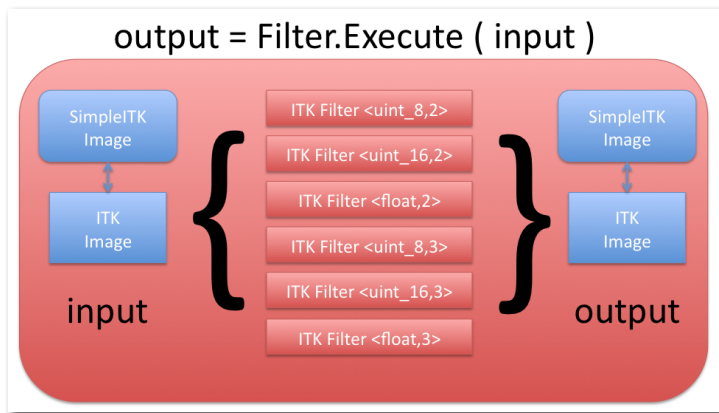


- SimpleITK filters create ITK filters
- Templated based on input type
- Output type is usually the same as input type
- Instantiated for many possible image types

Image and Filter Types

- Dimensions
 - 2 dimensional
 - 3 dimensional
- Scalar types
 - *int8_t*
 - *uint8_t*
 - *int16_t*
 - *uint16_t*
 - *int32_t*
 - *uint32_t*
 - *float*
 - *double*
 - *std :: complex < float >*
 - *std :: complex < double >*
- Vector Types
 - *int8_t*
 - *uint8_t*
 - *int16_t*
 - *uint16_t*
 - *int32_t*
 - *uint32_t*
 - *float*
 - *double*
- Label Types
 - *uint8_t*
 - *uint16_t*
 - *uint32_t*

Filter Anatomy



- Filter interrogates *input*
- Instantiates proper ITK filter
- Executes ITK filter
- Constructs *output* from ITK image

Using Filters

Object Paradigm (C++)

```
1 #include <SimpleITK.h>
2 namespace sitk = itk::simple;
3 ...
4 // Create a smoothing filter
5 sitk::SmoothingRecursiveGaussianImageFilter gaussian;
6
7 // Set a parameter
8 gaussian.SetSigma ( 2.0 );
9
10 // "Execute" the Filter
11 sitk::Image blurredImage = gaussian.Execute ( image );
```

Object Paradigm (C++)

Flexibility

```
1 #include <SimpleITK.h>
2 namespace sitk = itk::simple;
3 ...
4 // Create a smoothing filter
5 sitk::SmoothingRecursiveGaussianImageFilter gaussian;
6
7 // Set parameter(s), then execute
8 sitk::Image blurredImage = gaussian
9                               .SetSigma ( 2.0 )
10                               .Execute ( image );
```

Object Paradigm (C++)

```
1 #include <SimpleITK.h>
2 namespace sitk = itk::simple;
3 ...
4 blurredImage = sitk::SmoothingRecursiveGaussianImageFilter()
5                 .SetSigma ( 2.0 )
6                 .SetRadius ( 5 )
7                 .Execute ( image );
```

One line: create anonymous filter, set parameters, and execute

“Function” Paradigm (C++)

```
1 #include <SimpleITK.h>
2 namespace sitk = itk::simple;
3 ...
4 // Call the function version
5 // NB: Drop the "ImageFilter"!
6 // Signature:
7 /*
8     sitk::Image SmoothingRecursiveGaussian (
9         const Image&,
10         double inSigma = 1.0,
11         bool inNormalizeAcrossScale = false );
12 */
13 sitk::Image blurredImage = sitk::SmoothingRecursiveGaussian (
14     image,
15     2.0,
16     false );
```

Mix & Match (C++)

```
1 #include <SimpleITK.h>
2 namespace sitk = itk::simple;
3 ...
4 // Get our gaussian ready
5 sitk::SmoothingRecursiveGaussianImageFilter gaussian;
6 gaussian.SetSigma ( 2.0 );
7
8 // What is the effect on the image
9 sitk::Image difference = sitk::Subtract (
10     image,
11     gaussian.Execute ( image )
12 );
13 sitk::Image difference2 = sitk::Subtract (
14     image,
15     sitk::SmoothingRecursiveGaussian (
16         image, 2.0
17     )
18 );
```

Code Philosophy

Filter Class Overview (C++)

```
1 class SmoothingRecursiveGaussianImageFilter :
2     public ImageFilter {
3     typedef SmoothingRecursiveGaussianImageFilter Self;
4
5     /** Default Constructor that takes no arguments
6     and initializes default parameters */
7     SmoothingRecursiveGaussianImageFilter();
```

- In line 1, we declare a subclass of ImageFilter
- Line 3 creates a special typedef for use later
- The default constructor is line 7 (never any parameters)

Filter Class Overview (C++) Continued

```
1  /** Define the pixels types supported by this filter */  
2  typedef BasicPixelIDTypeList  PixelIDTypeList;
```

- Notice *PixelIDTypeList* in line 2
- Used to instantiate ITK filters
- Determines valid input image types
- *BasicPixelIDTypeList* expands to:
 - *int8_t, uint8_t*
 - *int16_t, uint16_t*
 - *int32_t, uint32_t*
 - *float, double*

Filter Class Overview (C++) Continued

```
1 Self& SetSigma ( double t ) { ... return *this; }
2 double GetSigma() { return this->m_Sigma; }
3
4 Self& SetNormalizeAcrossScale ( bool t ) { ... }
5 Self& NormalizeAcrossScaleOn() { ... }
6 Self& NormalizeAcrossScaleOff() { ... }
7
8 bool GetNormalizeAcrossScale() { ... }
```

- Get/Set parameters
- Set methods always return *Self&* (more later)
- Generally, a direct mapping to ITK
- Boolean parameters generate *On* and *Off* methods

Filter Class Overview (C++) Continued

```
1  /** Name of this class */  
2  std::string GetName() const { ... }  
3  
4  /** Print ourselves out */  
5  std::string ToString() const;
```

- Return the name and description of the filter

Filter Class Overview (C++) Continued

```
1  /** Execute the filter on the input image */
2  Image Execute ( const Image & );
3
4  /** Execute the filter with parameters */
5  Image Execute ( const Image &,
6      double inSigma,
7      bool inNormalizeAcrossScale );
8  }; /* End of class SmoothingRecursiveGaussian */
9
10 Image SmoothingRecursiveGaussian ( const Image& ,
11     double inSigma = 1.0,
12     bool inNormalizeAcrossScale = false );
```

- Run the filter on an image and return the result
- Notice extra function (line 10), adds flexibility
- Drop *ImageFilter* from class name to get function name

Questions?

Using ITK with SimpleITK

Problem: Use ITK from SimpleITK (or vice versa)

```
./ToITK input.nii output.nii
```

Steps:

- Load image using SimpleITK
- Filter using ITK
- Save using OpenCV

Starting code: ToITK/ToITK.cxx

Directory:

SimpleITK-MICCAI-2011-Tutorial/Examples/AdvancedTutorial

```
1 namespace sitk = itk::simple;
2 ...
3 // Load the image via SimpleITK
4 sitk::Image sitkImage = sitk::ReadImage ( inputFilename );
5
6 // Construct the ITK Pipeline
7 // Link pipeline to SimpleITK
8 // Update pipeline
9 // Create output SimpleITK image
10 // Save image via SimpleITK
11 sitk::WriteImage ( sOutput, outputFilename );
12 return EXIT_SUCCESS;
```


ToITK – Step 1: Construct the ITK Pipeline

```
1 // Construct the ITK Pipeline
2 typedef itk::Image<float,3> ImageType;
3 typedef itk::MirrorPadImageFilter<ImageType,ImageType> PadFilterType;
4 PadFilterType::SizeType upperBound, lowerBound;
5
6 PadFilterType::Pointer pad = PadFilterType::New();
7 for ( unsigned int i = 0; i < 3; i++ )
8 {
9     upperBound[i] = sitkImage.GetSize()[i];
10    lowerBound[i] = sitkImage.GetSize()[i];
11 }
12 pad->SetPadUpperBound ( upperBound );
13 pad->SetPadLowerBound ( lowerBound );
```

ToITK – Step 2: Link pipeline to SimpleITK

```
1 // Link pipeline to SimpleITK
2 ImageType::Pointer inputImage = (ImageType*) sitkImage.GetImageBase();
3 pad->SetInput ( inputImage );
```

ToITK – Step 3: Update ITK Pipeline

```
1 // Update pipeline  
2 pad->Update();
```

ToITK – Step 4: Create the SimpleITK output image

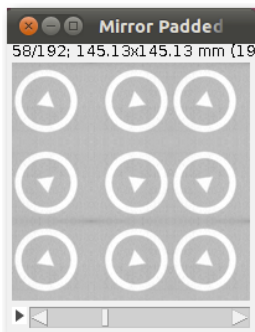
```
1 // Create output SimpleITK image
2 sitk::Image sOutput ( pad->GetOutput() );
```

ToITK – (Optional) Step 5: Show

```
1 // (Optional) Show the results
2 sitk::Show ( sOutput );
```

To ITK Solution

```
~/Source/AdvancedTutorial-build/ToITK/ToITKSolution \  
~/Source/SimpleITK/Testing/Data/Input/RA-Float.nrrd \  
/tmp/foo.nii
```



To OpenCV

Problem: Use SimpleITK from another image processing library (OpenCV)

`./ToOpenCV input.png output.png`

Steps:

- Load image using SimpleITK
- Convert to OpenCV
- Filter using OpenCV
- Save using OpenCV

Starting code: ToOpenCV/ToOpenCV.cxx

Directory:

SimpleITK-MICCAI-2011-Tutorial/Examples/AdvancedTutorial

```
1  #include <SimpleITK.h>
2  #include <opencv2/opencv.hpp>
3  namespace sitk = itk::simple;
4  ...
5      sitk::Image sitkImage = sitk::ReadImage ( inputFilename );
6
7      // Convert SimpleITK to OpenCV image
8      cv::Mat ocvImage;
9
10     // Filter and write using OpenCV
11     cv::Mat output;
12     cv::medianBlur ( ocvImage, output, 5 );
13
14     cv::imwrite ( outputFilename, output );
15     ...
```


Convert the SimpleITK image to a float

```
1  if ( sitkImage.GetPixelIDValue() != sitk::sitkFloat32 )
2  {
3      std::cout << "Input image is " << sitkImage.GetPixelIDTypeAsString()
4              << " converting to float" << std::endl;
5      sitkImage = sitk::Cast ( sitkImage, sitk::sitkFloat32 );
6  }
```

Get SimpleITK pixel data

```
1 // Convert SimpleITK to OpenCV image
2 cv::Mat ocvImage ( sitkImage.GetHeight(), sitkImage.GetWidth(), CV_32F,
3   (void*)sitkImage.GetBufferAsFloat() );
```

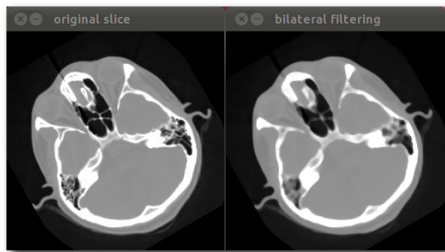
ToOpenCV – Step 3 (Optional)

Display the before and after

```
1 // NB: the imshow function requires 8-bit data, so convert
2 cv::Mat temp;
3 cvImage.convertTo ( temp, CV_8U );
4 cv::imshow ( "original slice", temp );
5 output.convertTo ( temp, CV_8U );
6 cv::imshow ( "bilateral filtering", temp );
7
8 std::cout << "Press any key to continue" << std::endl;
9 cv::waitKey();
```

To OpenCV Solution

```
~/Source/AdvancedTutorial-build/ToOpenCV/ToOpenCV \  
~/Source/SimpleITK/Testing/Data/Input/cthead1.png \  
/tmp/head.png
```



To OpenCV and Back

Problem: Use OpenCV to process a SimpleITK volume slice-by-slice
`./ToOpenCVAndBack input.nii output.nii`

Steps:

- Load image using SimpleITK
- Extract slice
- Convert to OpenCV
- Filter using OpenCV
- Past slice back to SimpleITK
- Save result

To OpenCV and Back

Starting code: ToOpenCVAndBack/ToOpenCVAndBack.cxx

Directory:

SimpleITK-MICCAI-2011-Tutorial/Examples/AdvancedTutorial

```
1  namespace sitk = itk::simple;
2  ...
3  sitk::Image sitkImage = sitk::ReadImage ( inputFilename );
4
5  for ( unsigned int s = 0; s < sitkImage.GetDepth(); s++ )
6  {
7      // Extract a slice
8      // Go through ITK to grab the data
9      // Convert ITK to OpenCV image
10     // Filter using OpenCV
11     // Convert back to SimpleITK
12     // Paste the image back into SimpleITK
13 }
14 sitk::WriteImage ( sOutput, outputFilename );
```

To OpenCV and Back - Step 1: Extract a slice

```
1 // Extract a slice
2 std::vector<unsigned int> size = sitkImage.GetSize();
3 size[2] = 1;
4 std::vector<int> index ( 3, 0 );
5 index[2] = s;
6 std::cout << "Extracting: " << s << std::endl;
7 sitk::Image slice = sitk::RegionOfInterest ( sitkImage, size, index );
8
9 if ( slice.GetPixelIDValue() != sitk::sitkFloat32 )
10 {
11     slice = sitk::Cast ( slice, sitk::sitkFloat32 );
12 }
```

To OpenCV and Back - Step 2: Convert to OpenCV

```
1 // Convert ITK to OpenCV image
2 cv::Mat ocvImage ( slice.GetHeight(), slice.GetWidth(),
3                   CV_32F, (void*)sitkImage.GetBufferAsFloat() );
```


To OpenCV and Back - Step 3: Filter using OpenCV

```
1 // Filter using OpenCV
2 cv::Mat output;
3 cv::Sobel ( ocvImage, output, -1, 1, 1 );
```

To OpenCV and Back - Step 4: Back to SimpleITK

```
1 // Convert back to SimpleITK
2 sitk::ImportImageFilter importer;
3 importer.SetSize ( size );
4 importer.SetSpacing ( sitkImage.GetSpacing() );
5 importer.SetOrigin ( sitkImage.GetOrigin() );
6 importer.SetBufferAsFloat ( output.ptr<float>() );
7
8 sitk::Image toSimpleITKImage = importer.Execute();
```

To OpenCV and Back - Step 5: Paste back into SimpleITK volume

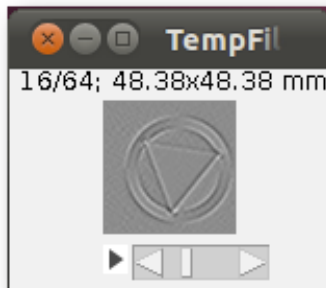
```
1 // Paste the image back into SimpleITK
2 // Paste ( Destination, Source, SourceSize, SourceIndex, DestIndex )
3 sOutput = sitk::Paste ( sOutput, toSimpleITKImage,
4                       toSimpleITKImage.GetSize(), std::vector<int> ( 3,0 ), index );
```

To OpenCV and Back – (Optional) Step 6: Show

```
1 // (Optional) Show the results
2 sitk::Show ( sOutput );
```

To OpenCV and Back Solution

```
~/Source/AdvancedTutorial-build/\  
ToOpenCVAndBack/ToOpenCVAndBack \\  
~/Source/SimpleITK/Testing/Data/Input/RA-Float.nrrd \  
/tmp/foo.nii
```



Using SimpleTK from Java/Groovy

`Examples/AdvancedTutorial/Java/Example.groovy`

- Language build on Java
- Superset of Java
- Can be used interactively

```
1 import org.itk.simple.*;
2
3 Image i;
4 i = new Image ( 64, 64, 64, PixelIDValueEnum.sitkInt16 );
5 SimpleITK.show ( i, "Blank" );
```

groovysh -classpath

./SimpleITK-Build/SimpleITK-Build/Wrapping/org.itk.simple.jar

Registration Framework Preview

Registration Framework Preview

Simple Gaussian in 8 languages

`AdvancedTutorial/SimpleGaussian/SimpleGaussian.*`

```

1 #include <SimpleITK.h>
2 namespace sitk = itk::simple;
3 int main ( int argc, char* argv[] ) {
4     // Read the image file
5     sitk::ImageFileReader reader;
6     reader.SetFileName ( std::string ( argv[1] ) );
7     sitk::Image image = reader.Execute();
8
9     // This filters perform a gaussian blurring with sigma in physical
10    // space. The output image will be of real type.
11    sitk::SmoothingRecursiveGaussianImageFilter gaussian;
12    gaussian.SetSigma ( atof ( argv[2] ) );
13    sitk::Image blurredImage = gaussian.Execute ( image );
14
15    // Convert the real output image back to the original pixel type, to
16    // make writing easier, as many file formats don't support real
17    // pixels.
18    sitk::CastImageFilter caster;
19    caster.SetOutputPixelType( image.GetPixelIDValue() );
20    sitk::Image outputImage = caster.Execute( blurredImage );
21
22    // write the image
23    sitk::ImageFileWriter writer;
24    writer.SetFileName ( std::string ( argv[3] ) );
25    writer.Execute ( outputImage );
26
27    return 0;
28 }

```

```
1 require 'simpleitk'
2
3 if ARGV.length != 3 then
4   puts "Usage: SimpleGaussian <input> <sigma> <output>";
5   exit( 1 )
6 end
7
8 reader = Simpleitk::ImageFileReader.new
9 reader.set_file_name( ARGV[0] )
10 image = reader.execute
11
12 inputPixelType = image.get_pixel_idvalue
13
14 gaussian = Simpleitk::SmoothingRecursiveGaussianImageFilter.new
15 gaussian.set_sigma ARGV[1].to_f
16 image = gaussian.execute image;
17
18 caster = Simpleitk::CastImageFilter.new
19 caster.set_output_pixel_type inputPixelType
20 image = caster.execute image
21
22 writer = Simpleitk::ImageFileWriter.new
23 writer.set_file_name ARGV[2]
24 writer.execute image
```

```

1 # Run with:
2 #
3 # Rscript --vanilla SimpleGaussian.R input sigma output
4 #
5
6 library(SimpleITK)
7
8 args <- commandArgs( TRUE )
9
10 myreader <- ImageFileReader()
11 myreader <- ImageFileReader_SetFileName( myreader, args[[1]] )
12 myimage <- ImageFileReader_Execute( myreader )
13
14 pixeltype <- Image_GetPixelIDValue( myimage )
15
16 myfilter <- SmoothingRecursiveGaussianImageFilter()
17 myfilter <- SmoothingRecursiveGaussianImageFilter_SetSigma( myfilter, as.real(args[2]) )
18 smoothedimage <- SmoothingRecursiveGaussianImageFilter_Execute( myfilter, myimage )
19
20 mycaster <- CastImageFilter()
21 mycaster <- CastImageFilter_SetOutputPixelType( mycaster, pixeltype )
22 castedimage <- CastImageFilter_Execute( mycaster, smoothedimage )
23
24 mywriter <- ImageFileWriter()
25 mywriter <- ImageFileWriter_SetFileName( mywriter, args[[3]] )
26 mywriter <- ImageFileWriter_Execute( mywriter, castedimage )

```

```

1  using System;
2  using itk.simple;
3
4  namespace itk.simple.examples {
5      class SimpleGaussian {
6          static void Main(string[] args) {
7              try {
8                  if (args.Length < 3) {
9                      Console.WriteLine("Usage: SimpleGaussian <input> <sigma> <output>");
10                     return;
11                 }
12                 // Read input image
13                 ImageFileReader reader = new ImageFileReader();
14                 reader.SetFileName(args[0]);
15                 Image image = reader.Execute();
16
17                 // Execute Gaussian smoothing filter
18                 SmoothingRecursiveGaussianImageFilter gaussian = new SmoothingRecursiveG
19                 gaussian.SetSigma(Double.Parse(args[1]));
20                 image = gaussian.Execute(image);
21
22                 // Write output image
23                 ImageFileWriter writer = new ImageFileWriter();
24                 writer.SetFileName(args[2]);
25                 writer.Execute(image);
26
27             } catch (Exception ex) {
28                 Console.WriteLine(ex);
29             }
30         }
31     }
32 }

```

```
1 import org.itk.simple.*;
2
3 class SimpleGaussian {
4
5     public static void main(String argv[]) {
6
7         if ( argv.length < 3 ) {
8             System.out.println("Usage: java SimpleGaussian <input> <sigma> <output>");
9             return;
10        }
11
12        org.itk.simple.ImageFileReader reader = new org.itk.simple.ImageFileReader();
13        reader.setFileName(argv[0]);
14        Image img = reader.execute();
15
16        SmoothingRecursiveGaussianImageFilter filter =
17            new SmoothingRecursiveGaussianImageFilter();
18        filter.setSigma( Double.valueOf( argv[1] ).doubleValue() );
19        Image blurredImg = filter.execute(img);
20
21        CastImageFilter caster = new CastImageFilter();
22        caster.setOutputPixelType( img.getPixelIDValue() );
23        Image castImg = caster.execute( blurredImg );
24
25        ImageFileWriter writer = new ImageFileWriter();
26        writer.setFileName(argv[2]);
27        writer.execute( castImg );
28    }
29 }
30
31 }
```



```

1
2
3 if #arg < 3 then
4   print ( "Usage: SimpleGaussian <input> <sigma> <output>" )
5   os.exit ( 1 )
6 end
7
8 reader = SimpleITK.ImageFileReader()
9 -- Remember that Lua arrays are 1-based,
10 -- and that arg does not contain the application name!
11 reader:SetFileName ( arg[1] )
12 image = reader:Execute();
13
14 inputPixelType = image:GetPixelIDValue()
15
16 gaussian = SimpleITK.SmoothingRecursiveGaussianImageFilter()
17 gaussian:SetSigma ( arg[2] )
18 image = gaussian:Execute ( image );
19
20 caster = SimpleITK.CastImageFilter();
21 caster:SetOutputPixelType( inputPixelType );
22 image = caster:Execute( image )
23
24 writer = SimpleITK.ImageFileWriter()
25 writer:SetFileName ( arg[3] )
26 writer:Execute ( image );

```

```
1
2 import SimpleITK as sitk
3 import sys
4
5 if len ( sys.argv ) < 4:
6     print "Usage: SimpleGaussian <input> <sigma> <output>";
7     sys.exit ( 1 )
8
9
10 reader = sitk.ImageFileReader()
11 reader.SetFileName ( sys.argv[1] )
12 image = reader.Execute()
13
14 pixelID = image.GetPixelIDValue()
15
16 gaussian = sitk.SmoothingRecursiveGaussianImageFilter()
17 gaussian.SetSigma ( float ( sys.argv[2] ) )
18 image = gaussian.Execute ( image )
19
20 caster = sitk.CastImageFilter()
21 caster.SetOutputPixelType( pixelID )
22 image = caster.Execute( image )
23
24 writer = sitk.ImageFileWriter()
25 writer.SetFileName ( sys.argv[3] )
26 writer.Execute ( image );
```

```
1
2 if { $argc < 3 } {
3     puts "Usage: SimpleGaussian <input> <sigma> <output>"
4     exit 1
5 }
6
7 ImageFileReader reader
8 reader SetFileName [ lindex $argv 0 ]
9 set image [ reader Execute ]
10
11 set pixelID [ $image GetPixelIDValue ]
12
13 SmoothingRecursiveGaussianImageFilter gaussian
14 gaussian SetSigma [ lindex $argv 1 ]
15 set image [ gaussian Execute $image ]
16
17 CastImageFilter caster
18 caster SetOutputPixelType $pixelID
19 set image [ caster Execute $image ]
20
21 ImageFileWriter writer
22 writer SetFileName [ lindex $argv 2]
23 writer Execute $image
24
25 # Tcl requires explicit cleanup Cleanup
26 reader -delete
27 gaussian -delete
28 caster -delete
29 $image -delete
30 writer -delete
```

Conclusion

- Gentle introduction to ITK
- Introduce SimpleITK
- Provide hands-on experience
- Problem solving, not direction following

Where to go next

Some resources for using and extending SimpleITK

- Home Page
 - <http://www.simpleitk.org>
- Documentation
 - <http://www.itk.org/SimpleITKDoxygen/html/>
- Conventions
 - <http://www.itk.org/SimpleITKDoxygen/html/Conventions.html>
- Contributions
 - <http://www.itk.org/SimpleITKDoxygen/html/Developer.html>

SimpleITK Tutorial

Image processing for mere mortals

Insight Software Consortium

Sept 23, 2011