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Open Source for Medical Imaging –

Segmentation, Registration, and Interactive Applications using ITK and MITK

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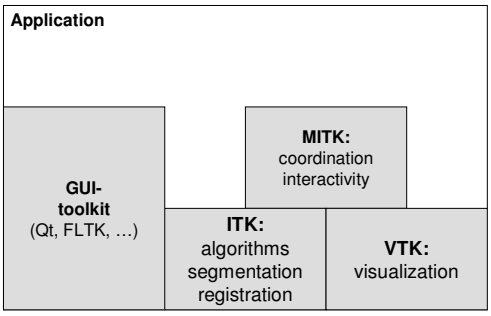
Overview



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Why Open-Source?
Why these Toolkits?

4

Papers allow others to reproduce the results

Really ??

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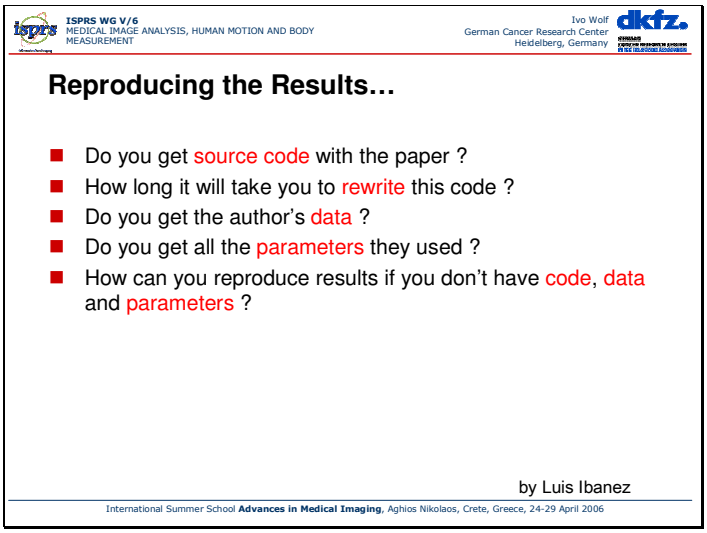
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dkfz.
Reproducing the Results…
Do you get source code with the paper ?
How long it will take you to rewrite this code ?
Do you get the author's data ?
Do you get all the parameters they used ?
How can you reproduce results if you don't have code, data and parameters ?
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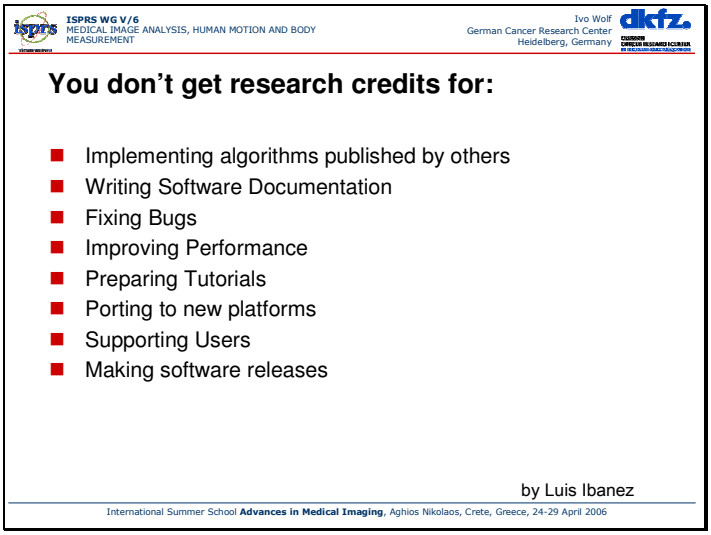
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You don't get research credits for:
Implementing algorithms published by others
Writing Software Documentation
Fixing Bugs
Improving Performance
Preparing Tutorials
Porting to new platforms
Supporting Users
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ITK: Sponsors
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The National Institute for Dental and Craniofacial Research
The National Science Foundation
NIMH
National Institute of Mental Health
The National Institute of Neurological Disorders and Stroke
National Eye Institute
TATRC
NATIONAL CANCER INSTITUTE
NIDCD
Grants: more than $ 10 Mio.
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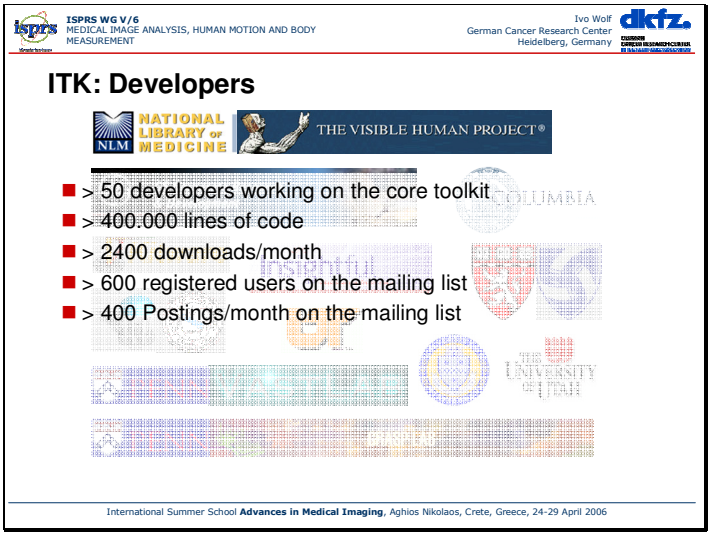
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ITK: Developers
NATIONAL LIBRARY OF MEDICINE
THE VISIBLE HUMAN PROJECT®
> 50 developers working on the core toolkit
> 400.000 lines of code
> 2400 downloads/month
> 600 registered users on the mailing list
> 400 Postings/month on the mailing list
COLUMBIA
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ITK: Mailing List

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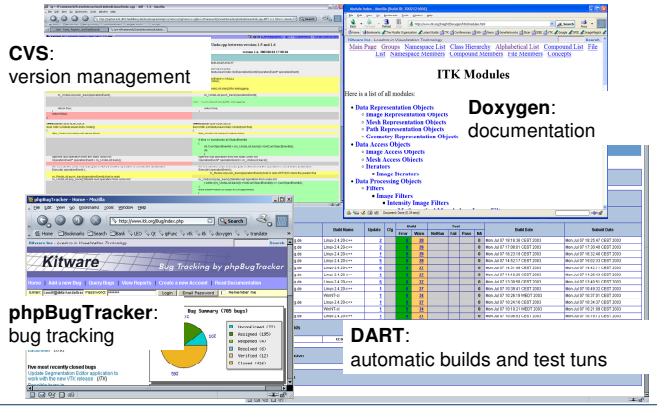
Software-process and documentation



CVS:
version management

Doxygen:
documentation

phpBugTracker:
bug tracking

DART:
automatic builds and test tuns

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Common features of ITK, VTK, MITK

- Toolkits
- Object-oriented class libraries
- C++
- Support of different compilers
- Platform independent
- GUI-toolkit independent
- Open source

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ITK: Intensive Use of Generic Programming

Example: STL Standard Template Library

Abstraction of Types and Behaviors

std::vector< T >

std::vector< int >
std::vector< double >
std::vector< char * >
std::vector< Point >
std::vector< Image >

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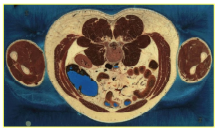
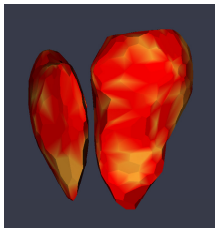
Data Classes

- itk::Image< PixelType, Dimension >



- itk::Mesh< PixelType, Dimension, MeshTraits >



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Basic Filtering

- Thresholding
- Edge Detection
- Casting and Intensity Mapping
- Gradient and Derivative Filters
- Neighborhood Filters
- Smoothing Filters
- Distance Maps
- Resampling Filters
- FFT
- Surface Extraction

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Pipeline Concept

- Example: Load image – Median filtering – save result

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The Code for the Example

```
typedef   itk::Image< unsigned char , 2 >   ImageType;
typedef   itk::ImageFileReader< ImageType >   ReaderType;
typedef   itk::MedianImageFilter<ImageType,ImageType>   FilterType;
typedef   itk::ImageFileWriter< ImageType >   WriterType;

ReaderType::Pointer  reader     = ReaderType::New();
FilterType::Pointer     filter     = FilterType::New();
WriterType::Pointer   writer     = WriterType::New();

reader->SetFileName("InputImage.png");
filter->SetInput(  reader->GetOutput()  );
writer->SetInput(  filter->GetOutput()  );
writer->SetFileName("OutputImage.png");

writer->Update();
```

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Segmentation with ITK

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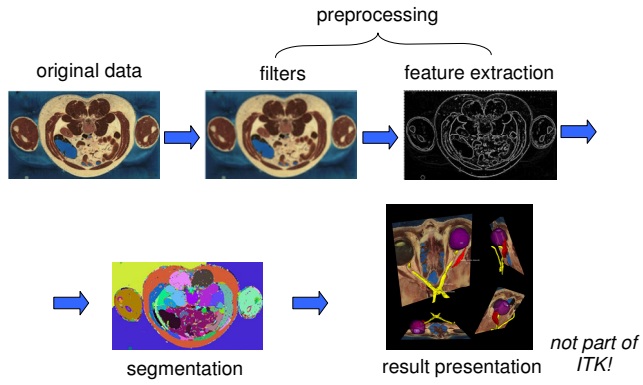
Typical Segmentation Pipeline



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Segmentation Filters

- Intensity-based filters
  - Otsu thresholding, pixel classification, watershed
- Region-based filters
  - region growing: Connected threshold, ~ neighborhood, confidence connected, isolated connected
  - fuzzy connectedness
  - Markov random fields
- Deformable models
  - level sets, simplex meshes
- Hybrid filters
  - Voronoi partitioning (e.g. together with fuzzy connectedness)
  - combinations (e.g. level sets on region-based segmentation)

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Connected Threshold from the Outside

```
typedef   itk::Image< unsigned char , 2 >   ImageType;
typedef   itk::ConnectedThresholdImageFilter<ImageType,ImageType>
                ConnectedFilterType;

ConnectedFilterType::Pointer connectedThresholdFilter  =
                                ConnectedFilterType ::New();
connectedThresholdFilter->SetInput( image );
connectedThresholdFilter->SetLower( lowerThreshold );
connectedThresholdFilter->SetUpper( upperThreshold );
connectedThresholdFilter->SetSeed( seedIndex );
…
writer->SetInput(connectedThresholdFilter->GetOutput()  );
writer->SetFileName("OutputImage.png");

writer->Update();
```

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Connected Threshold from the Inside

```
typedef BinaryThresholdImageFunction<InputImageType>
                        FunctionType;
FunctionType::Pointer function = FunctionType::New();
function->SetInputImage ( inputImage );
function->ThresholdBetween ( m_Lower, m_Upper );

typedef FloodFilledImageFunctionConditionalIterator<OutputImageType,
                        FunctionType> IteratorType;
IteratorType it ( outputImage, function, m_SeedList );
it.GoToBegin();
while( !it.IsAtEnd())
{
  it.Set(m_ReplaceValue);
  ++it;
}
```

"function" defines the rule for accepting a pixel to be part of the region.

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Neighborhood Connected from the Inside

```
typedef NeighborhoodBinaryThresholdImageFunction<InputImageType>
                        FunctionType;
FunctionType::Pointer function = FunctionType::New();
function->SetInputImage ( inputImage );
function->ThresholdBetween ( m_Lower, m_Upper );
function->SetRadius ( m_Radius );

typedef FloodFilledImageFunctionConditionalIterator<OutputImageType,
                        FunctionType> IteratorType;
IteratorType it ( outputImage, function, m_SeedList );
it.GoToBegin();
while( !it.IsAtEnd())
{
  it.Set(m_ReplaceValue);
  ++it;
}
```

Neighborhood Connected: accept a pixel if **all** its neighbors with a certain radius have intensities that fit in the interval.

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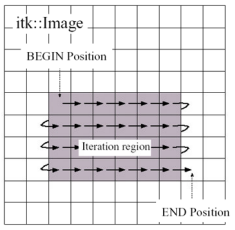
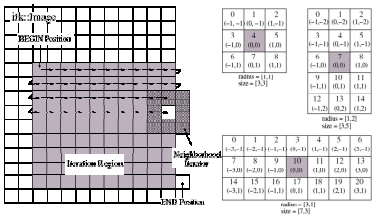
Image Iterators

- powerful concept to simplify common image processing tasks
- wide variety of access types



ImageRegionIterator



NeighborHoodIterator

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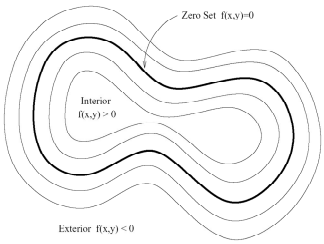
Level Set Segmentation

- Contour/surface evolution
- implicit description as zero level-set of function Ψ with dimension n+1
- evolved contour at time t by extracting the zero level-set $\Gamma((\mathbf{X}),\mathbf{t}) = \{\psi(\mathbf{X},\mathbf{t}) = \mathbf{0}\}$
- evolution according to partial differential equation. Generic level-set equation:



$$\frac{d}{dt}\psi = -\alpha\mathbf{A}(\mathbf{x})\cdot\nabla\psi - \beta P(\mathbf{x})\,|\,\nabla\psi\,| + \gamma Z(\mathbf{x})\kappa\,|\,\nabla\psi\,|$$

A advection term, *P* propagation term, *Z* spatial modifier for mean curvature κ

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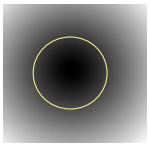
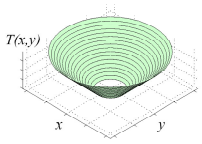
Fast Marching

- Applicable when level-set equation has a simple form:
- evolution by speed function F=|A| with F > 0, A perpendicular to Γ and depending on the position only
- result is time-of-arrival map T derived by solving
  $|\nabla T|F = 1, \quad T = 0 \text{ on } \Gamma$
- Special case: F=1 gives distance functions
  Example for a Γ=circle:





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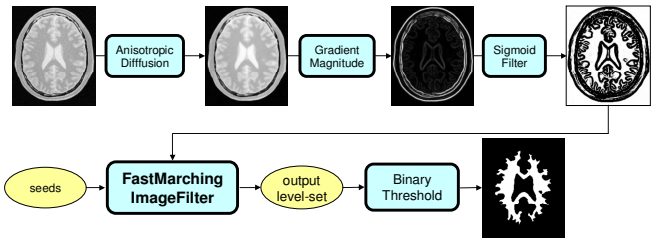
Fast Marching with ITK

- Define seeds as initial level-set and speed function
- Typical steps:



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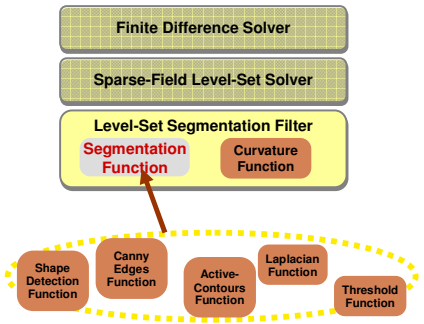
General Level-Set Segmentation Framework

- Solves generic equation $\frac{d}{dt}\psi = -\alpha \mathbf{A}(\mathbf{x}) \cdot \nabla\psi - \beta P(\mathbf{x}) \mid \nabla\psi \mid + \gamma Z(\mathbf{x})\kappa \mid \nabla\psi \mid$



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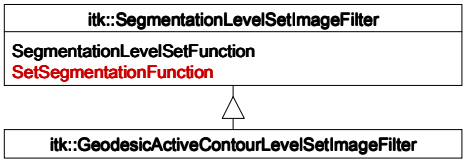
General Level-Set Segmentation Framework

- Example: Geodesic Active Contour Level-Set Filter



- Inside the filter not much more than:

```
typedef GeodesicActiveContourLevelSetFunction<OutputImageType,
        FeatureImageType> LevelSetFunctionType;
m_GeodesicActiveContourFunction = LevelSetFunctionType ::New();
this->SetSegmentationFunction( m_GeodesicActiveContourFunction );
```

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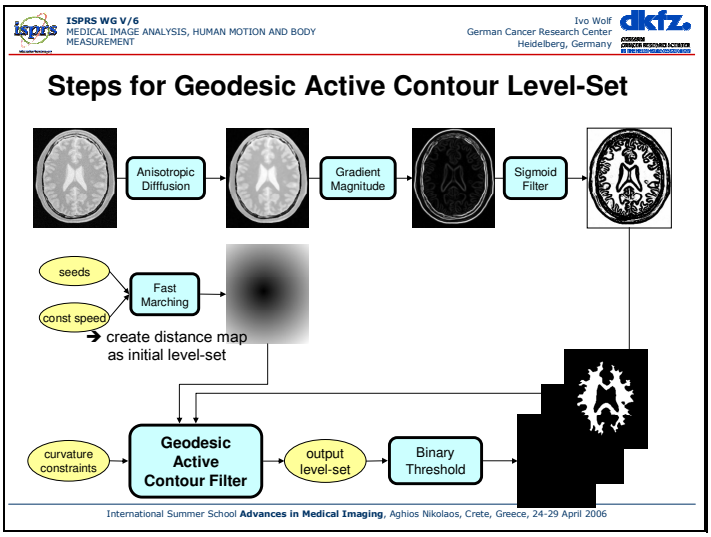
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Steps for Geodesic Active Contour Level-Set
Anisotropic Diffusion
Gradient Magnitude
Sigmoid Filter
seeds
const speed
Fast Marching
create distance map as initial level-set
curvature constraints
Geodesic Active Contour Filter
output level-set
Binary Threshold
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Image Registration with ITK
itk
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Introduction

- Image registration
  - Process of finding the spatial transform that maps all points from one image to their homologous points in another image
- Medical applications
  - Monitoring change in an individual
  - Compensate for differences in patient placement
  - Fuse information from multiple sources to aid clinical interpretation
  - Subtraction/overlay of registered images can be used for visualization and quantification
  - Compare one subject to another
  - Atlas-based segmentation: map image to a labeled atlas

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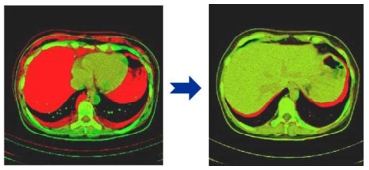
Example

CT liver, arterial phase

CT liver, venous phase



before registration

after registration

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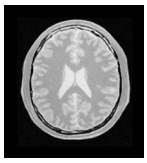
Measuring Overlap: Similarity Metric

image 1
(fixed image F)



$E(F, T_0(M)) = x$

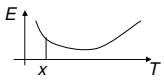
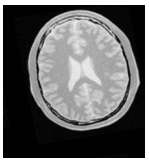


image 2
(moving image M)



not registered

E: Similarity Metric

T: Transformation

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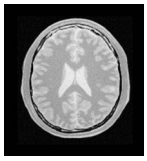
Measuring Overlap: Similarity Metric

image 1
(fixed image F)



$E(F, T_0(M)) = x$

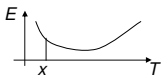
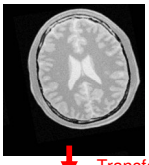
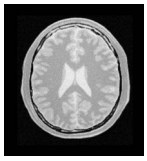


image 2
(moving image M)

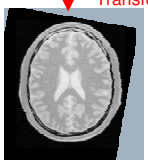


not registered

Transformation T_i



$E(F, T_i(M)) = \min$



registered

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Basic Components of Registration

- Similarity Metric
  - Quantitative measure of a "good match"
  - Focus on intensity based measures
- Transformation
  - Allowable mapping from one image to another
  - Rigid versus non-rigid
- Optimizer
  - Optimize transform parameters w.r.t. Similarity Metric
- Image interpolation method
  - Value of image at non-grid position

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ITK Registration Framework

- Generic framework for building intensity-based registration algorithms
- Basic components are inter-changeable
- Allows a combinatorial variety of registration methods
- Components are generic
  - ➔ Can be used outside the registration framework

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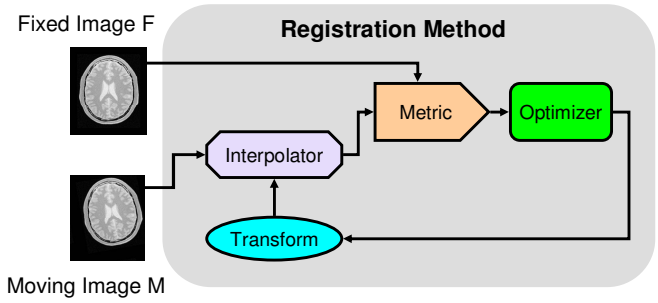
ITK Registration Framework



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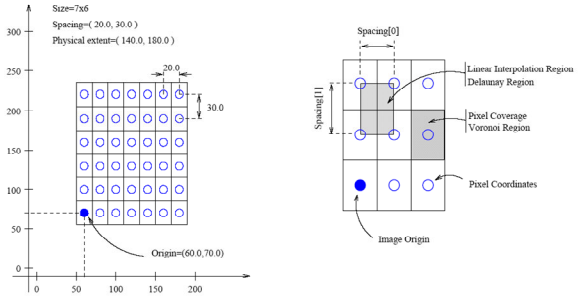
ITK Image Physical Coordinate System




```
image->SetSpacing(spacing)
image->SetOrigin(origin)
```

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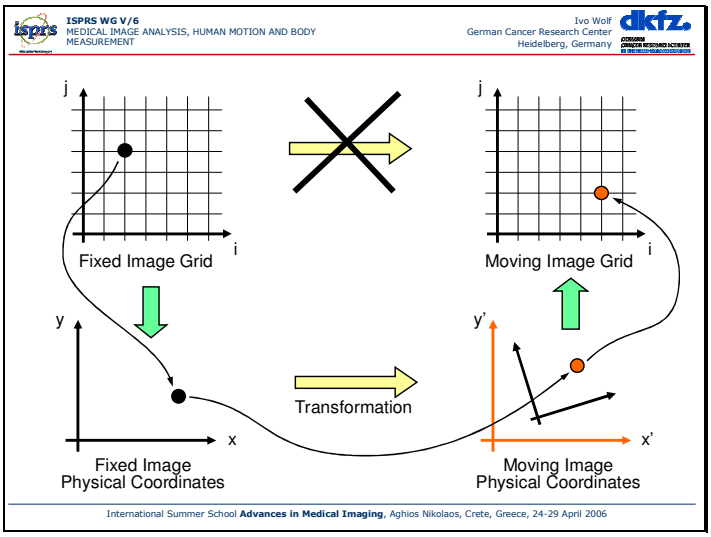
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j
i
Fixed Image Grid
Moving Image Grid
y
x
y'
x'
Transformation
Fixed Image
Physical Coordinates
Moving Image
Physical Coordinates
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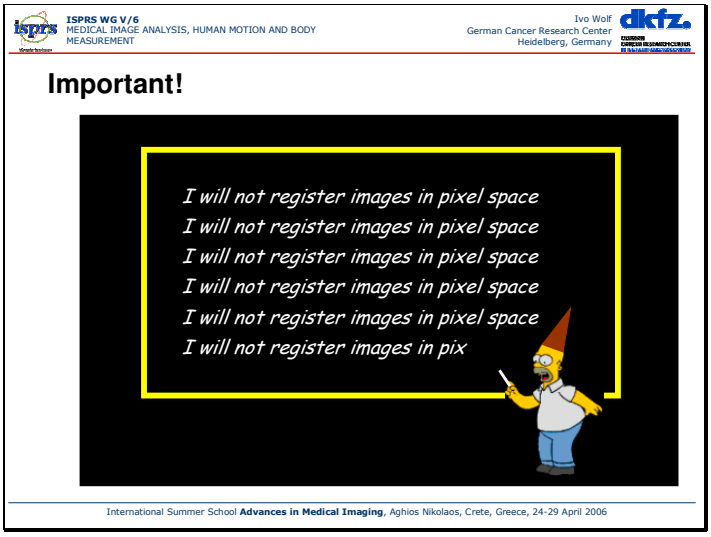
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Heidelberg, Germany
Important!
I will not register images in pixel space
I will not register images in pixel space
I will not register images in pixel space
I will not register images in pixel space
I will not register images in pixel space
I will not register images in pix
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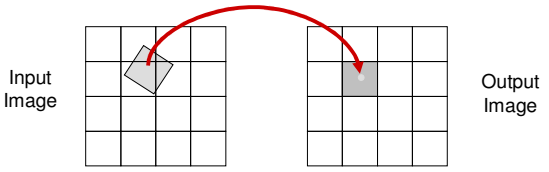
Inverse Mapping



- Output pixels are mapped back onto the input image
- Output pixel value must be interpolated from a neighborhood in the input image
- Scheme avoids any holes and overlaps in the output image because all pixels are scanned sequentially

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Registration and Inverse Mapping

- The registration framework uses **inverse** mapping
- The transform component maps points from the **fixed** image space to the **moving** image space

$$\mathbf{x}' = \mathbf{T}(\mathbf{x}|\mathbf{p})$$

Point in moving image space

Point in fixed image space

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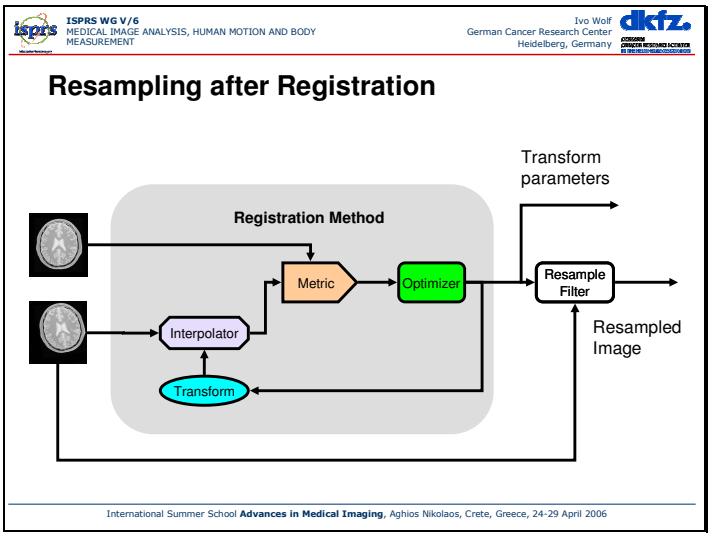
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German Cancer Research Center
Heidelberg, Germany
Resampling after Registration
Transform parameters
Registration Method
Metric
Optimizer
Resample Filter
Interpolator
Resampled Image
Transform
International Summer School Advances in Medical Imaging, Aghios Nikolaos, Crete, Greece, 24-29 April 2006

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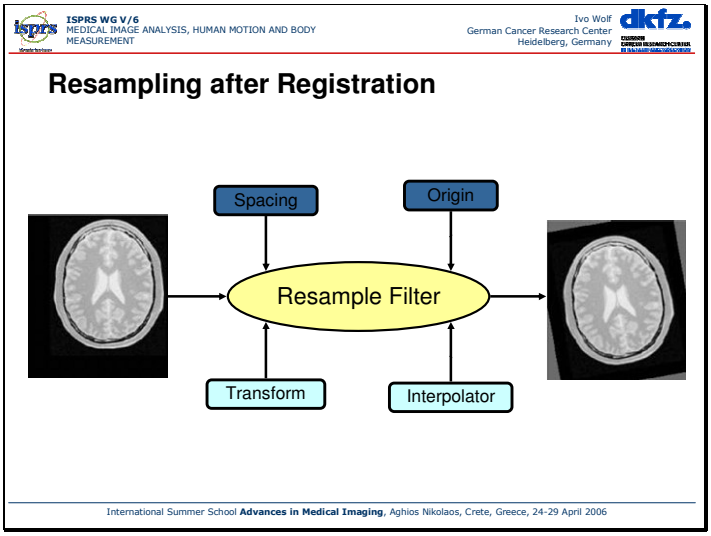
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Ivo Wolf
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Heidelberg, Germany
Resampling after Registration
Spacing
Origin
Resample Filter
Transform
Interpolator
International Summer School Advances in Medical Imaging, Aghios Nikolaos, Crete, Greece, 24-29 April 2006

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Available Components

- Similarity Metrics
  - Mean Squares, Correlation, Mutual Information (Parzen Windowing, Mattes, Viola and Wells), …
- Transformations
  - Translation, Scale, Rigid, Affine, B-Spline, ...
- Optimizer
  - Conjugate Gradient, Gradient Descent, One Plus One Evolutionary, Levenberg-Marquardt, …
- Image interpolation methods
  - Nearest Neighboor, Linear, B-Spline

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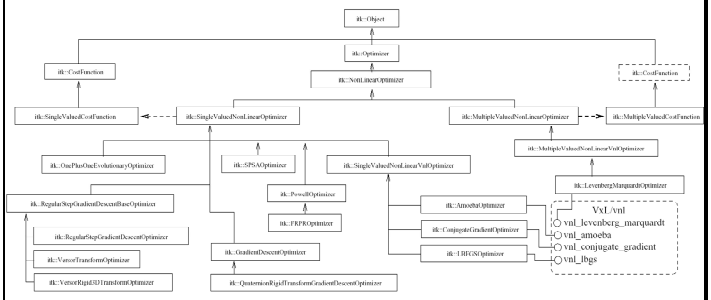
Optimizers



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Example Part I

```
// Type definitions

const unsigned int      Dimension = 2;
typedef float           PixelType;

typedef itk::Image< PixelType, Dimension >          FixedImageType;
typedef itk::Image< PixelType, Dimension >          MovingImageType;

typedef itk::TranslationTransform< double, Dimension >  TransformType;

typedef itk::RegularStepGradientDescentOptimizer    OptimizerType;

typedef itk::MeanSquaresImageToImageMetric<FixedImageType, MovingImageType>
                                                    MetricType;

typedef itk::LinearInterpolateImageFunction<MovingImageType,double >
                                                    InterpolatorType;

typedef itk::ImageRegistrationMethod<FixedImageType,MovingImageType >
                                                    RegistrationType;
```


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Example Part II

```
// Variable definitions and construction
MetricType::Pointer       metric       = MetricType::New();
TransformType::Pointer    transform    = TransformType::New();
OptimizerType::Pointer    optimizer    = OptimizerType::New();
InterpolatorType::Pointer interpolator = InterpolatorType::New();
RegistrationType::Pointer registration = RegistrationType::New();

// Initialization of registration filters
registration->SetMetric( metric );
registration->SetOptimizer( optimizer );
registration->SetTransform( transform );
registration->SetInterpolator( interpolator );
registration->SetFixedImage( fixedImageReader->GetOutput() );
registration->SetMovingImage( movingImageReader->GetOutput() );

// Initialization of transformation parameters
registration->SetInitialTransformParameters( initialParameters );

// Initialization of optimizer
optimizer->SetNumberOfIterations( 200 );
```

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Example Part III

```
// Start the registration
registration->StartRegistration();

// Read out the resulting transformation
ParametersType finalParameters = registration->GetLastTransformParameters();

TransformType::Pointer finalTransform = TransformType::New();
finalTransform->SetParameters( finalParameters );

// Read out the optimizer results
const unsigned int  numberOfIterations      = optimizer->GetCurrentIteration();
const double        bestValue               = optimizer->GetValue();
```


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Example Part IV

```
// Resampling

// create resampler and set input image and transform
typedef itk::ResampleImageFilter<MovingImageType,FixedImageType> ResampleFilterType;
ResampleFilterType::Pointer resample = ResampleFilterType::New();
resample->SetInput( movingImageReader->GetOutput() );
resample->SetTransform( finalTransform );

// set size and output origin from target (fixed) image
FixedImageType::Pointer fixedImage = fixedImageReader->GetOutput();
resample->SetSize( fixedImage->GetLargestPossibleRegion().GetSize() );
resample->SetOutputOrigin( fixedImage->GetOrigin() );
```

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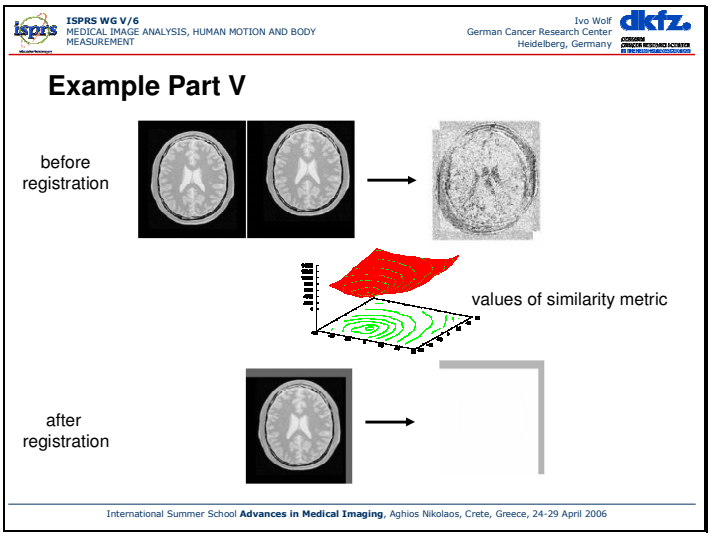
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Example Part V
before registration
values of similarity metric
after registration
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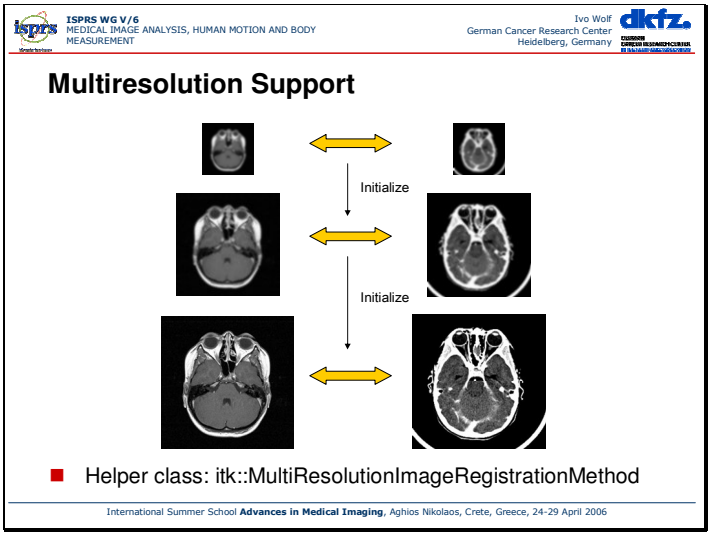
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Multiresolution Support
Initialize
Initialize
Helper class: itk::MultiResolutionImageRegistrationMethod
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Model-based Registration

- PointSetToImageMetric
  - MeanSquaresPointSetToImageMetric
  - NormalizedCorrelationPointSetToImageMetric
- PointSetToPointSetMetric
  - IterativeClosestPointMetric
- ImageToSpatialObjectMetric
  - Spatial Objects: Linien, Ellipsen, ...
  - ist selbst zu definieren

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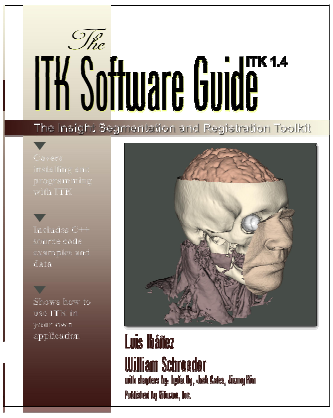
ITK Software Guide

- The ITK Software Guide is freely available as a PDF document at

  www.itk.org/
  ItkSoftwareGuide.pdf

  Its paper version can be ordered from Amazon.com and from Kitware's e-store.



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Interactive Applications with MITK

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Why yet another toolkit?

The goal of our group is …

- … to develop tools for direct **use in the clinic**

➔ not **one** algorithm that solves **one** problem,
➔ but solve a **clinical goal**, which normally **consists of a lot of problems**

- ➔ thus, solve **all** problems in **all circumstances**
- ➔ for **worst-case**: need of rather primitive, last-resort, **manual/interactive tools**

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Why yet another toolkit?

Something about history …

Heidelberg castle

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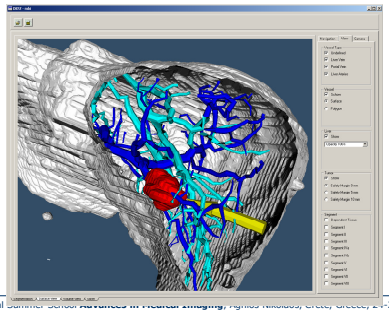
Why yet another toolkit?

Something about history …
~1999, we started to use VTK …
… and got nice visualizations



ARION – **A**ugmented **R**eality for **I**ntra-**O**perative **N**avigation

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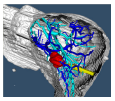
Why yet another toolkit?

Something about history …



… but we also needed segmentation tools

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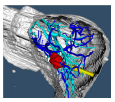
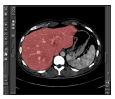
Why yet another toolkit?

Something about history …



The same was true for other projects …

➔ How to get that integrated?



➔ … without doing it for every project again and again?

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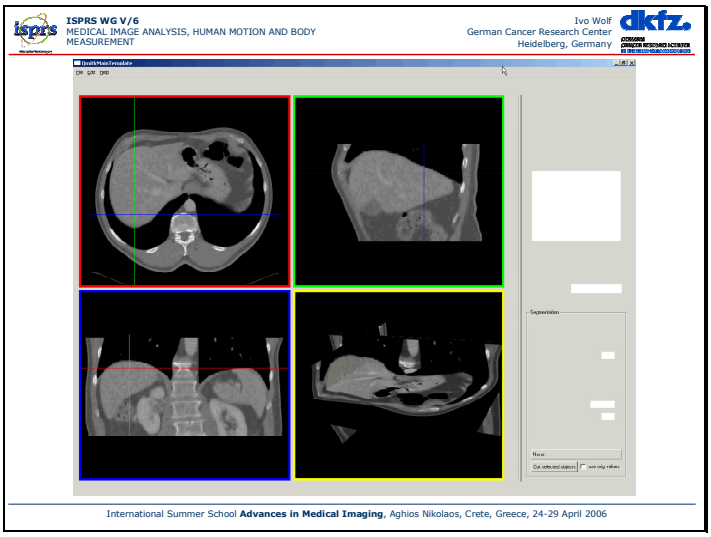
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dkfz.
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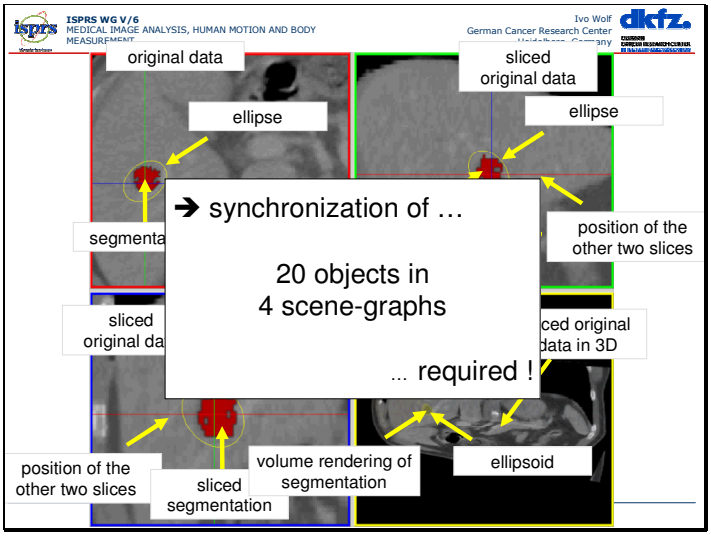
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dkfz.
original data
ellipse
sliced original data
ellipse
segmenta
position of the other two slices
➔ synchronization of …
20 objects in 4 scene-graphs
… required !
sliced original da
ced original data in 3D
position of the other two slices
sliced segmentation
volume rendering of segmentation
ellipsoid

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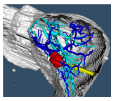
Why yet another toolkit?

Of course that could be done …

… but what when we want to see an additional surface:

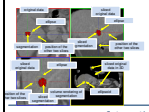


➔ For the liver boundary ➔ 4 more scene objects

➔ and the vessels ➔ again 4 more scene objects

… the segmentation could also be useful for our **heart** projects

… and we want to see segmentations of the **ventricels**, the **annulus** and the **coronaries** and … **and** … **and** …



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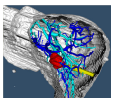
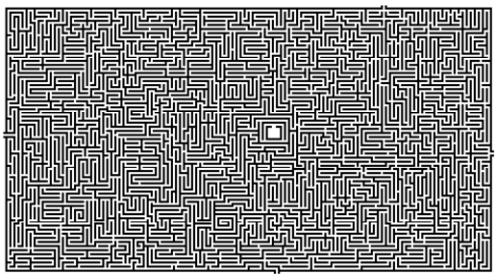
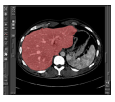
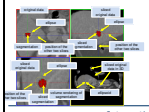
Why yet another toolkit?

➔ We would end up here …









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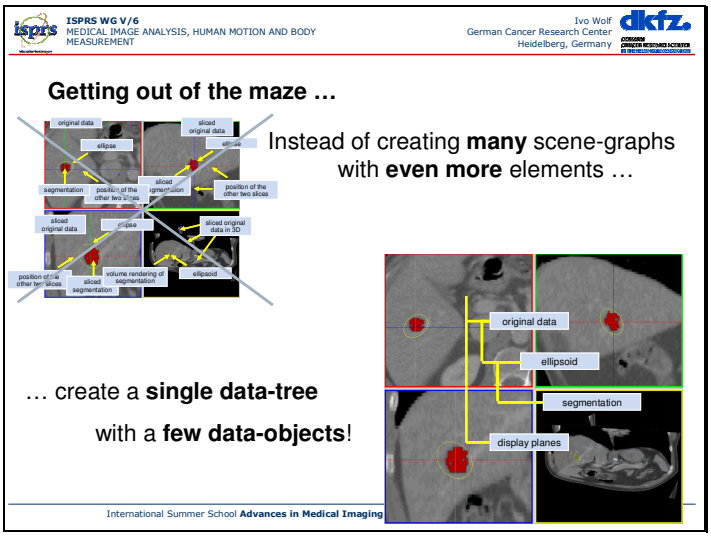
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Heidelberg, Germany
Getting out of the maze …
Instead of creating many scene-graphs with even more elements …
… create a single data-tree
with a few data-objects!
original data
ellipsoid
segmentation
display planes
International Summer School Advances in Medical Imaging

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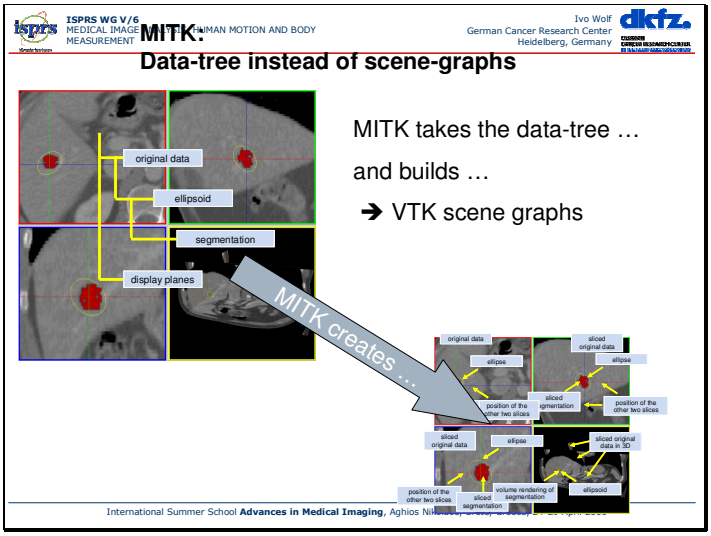
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MITK:
Data-tree instead of scene-graphs
original data
ellipsoid
segmentation
display planes
MITK takes the data-tree …
and builds …
➔ VTK scene graphs
MITK creates …
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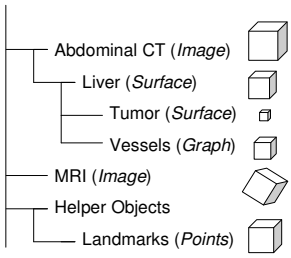
DataTree

- Hierarchical organization of data objects in a tree structure
- Any number of data objects
- Any kind of data objects
- Data objects with geometry frame (bounding-box, transform, etc.)



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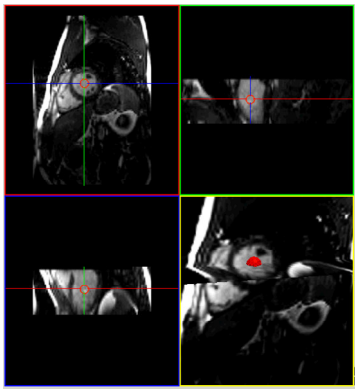
Interactive Simplex-Meshes



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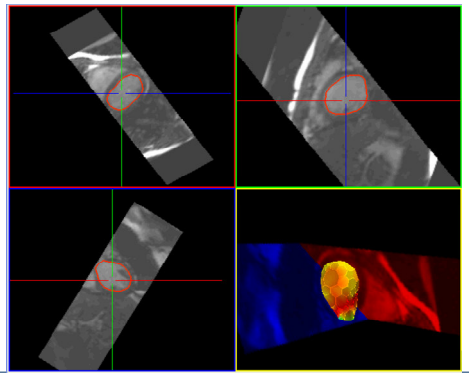
Data with geometry frame and support for 3D+t data



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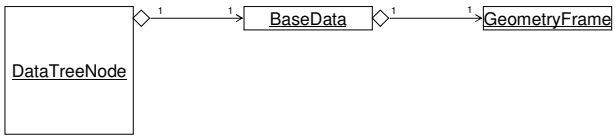
The nodes of the data-tree




```
// creating an iterator to the data-tree
mitk::DataTreePreOrderIterator
        iteratorToTree(tree);
// adding nodes to the data-tree
iteratorToTree.Add(anImageNode);
iteratorToTree.Add(aSurfaceNode);
iteratorToTree.Add(anotherImageNode);
iteratorToTree.Add(aPlaneNode);
```

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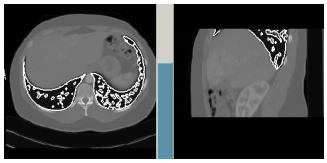
Rendering the data-tree



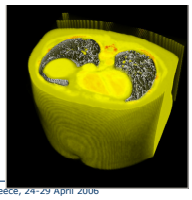
RenderWindows:

- **single** RenderWindow class
- **different types** of views
  - ➔ 2D/3D
  - ➔ special views definable (e.g., for AR)

```
renderer->SetMapperID(mitk::BaseRenderer::Standard3D);
```

- **reference** a (the) **data-tree**
  - ➔ **any number of views** on the same data:

```
renderer1->SetData(iteratorToTree);
renderer2->SetData(iteratorToTree);
...
```



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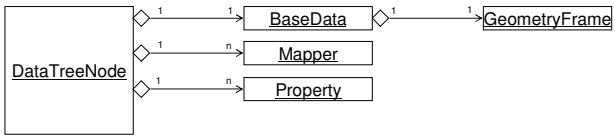
The nodes of the data-tree



Mappers: render the data into a renderwindow
Properties: define how to draw the data

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Data-tree – how to add a new data type

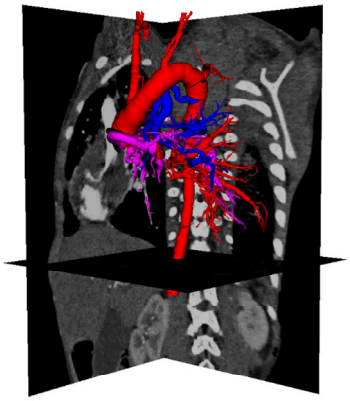
Extension for new data types:

➔ derive data class

➔ derive mapper

Example:

- attributed vessel graphs



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Rendering-Controllers

What is displayed in a view?

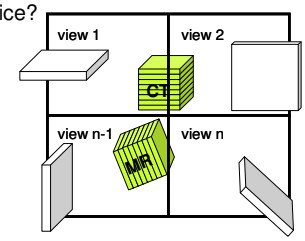
- Content is defined by the data tree
- But from which side, which slice?

For 3D views:

vtkCamera

For 2D views:

according to **geometry frame**!



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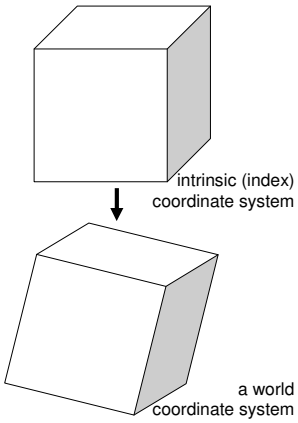
Geometry Frames

Geometry base-class holds:

- Axes-parallel **bounding-box** *in intrinsic ("index") coordinates* (e.g., in pixels/voxels)
- **Transform** to **a** *world-coordinate system* (in mm)
- **Live-span** of the data (in ms)
- FrameOfReferenceUID (DICOM coordinate-system ID)



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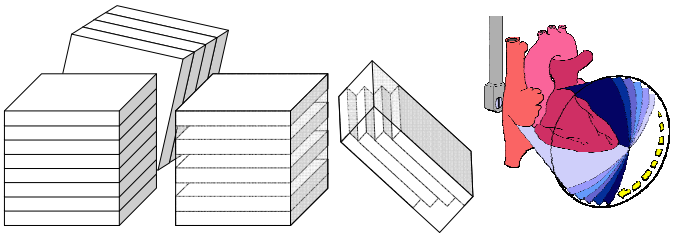
Sliced Geometry Frames

Sub-classes describe data *composed of slices* according to their internal organization.



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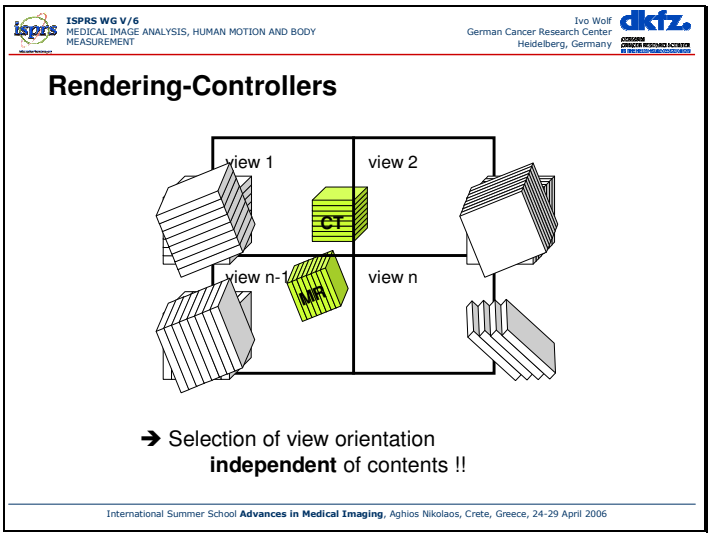
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Rendering-Controllers
view 1
view 2
CT
view n-1
MPR
view n
➔ Selection of view orientation
independent of contents !!
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Rendering the data-tree

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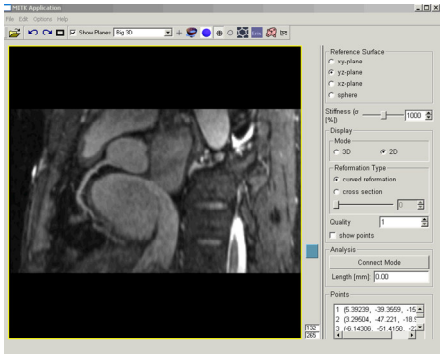
Geometry independent interaction: interaction on curved reformats



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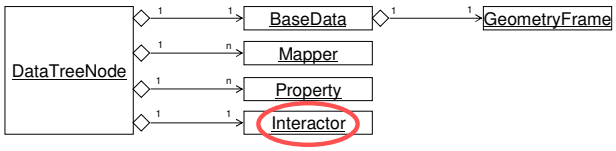
Interactors



Interactors:

- ➔ behavior defined in state-machines
- ➔ undo-/redo concept
- ➔ dimension-independent definition: (often) identical interaction code for 2D and 3D

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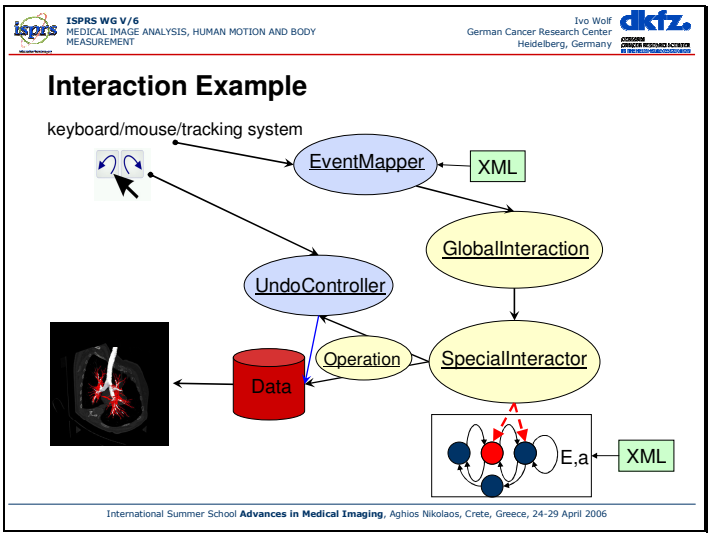
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Interaction Example
keyboard/mouse/tracking system
EventMapper
XML
GlobalInteraction
UndoController
Operation
SpecialInteractor
Data
E,a
XML
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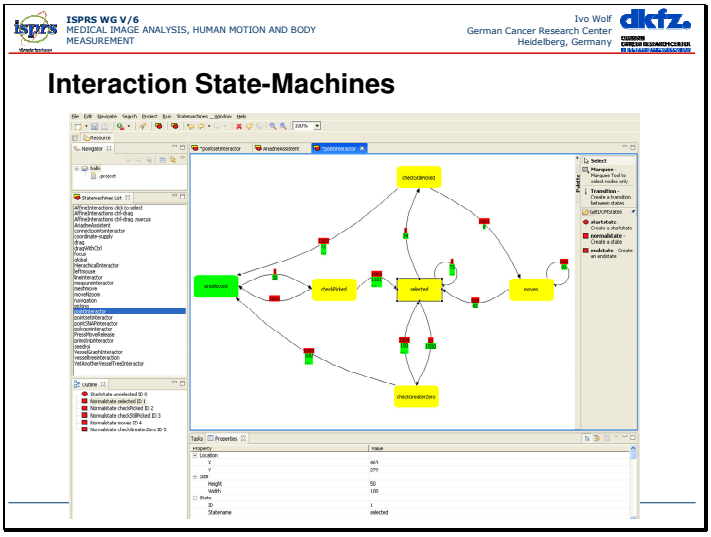
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Interaction State-Machines

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MEDICAL IMAGE ANALYSIS, HUMAN MOTION AND BODY MEASUREMENT

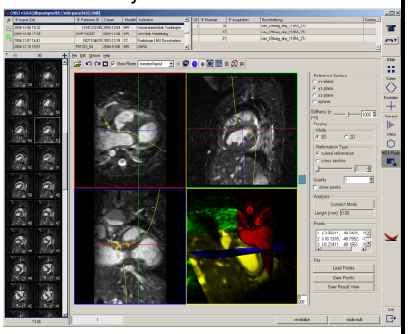
Ivo Wolf
German Cancer Research Center
Heidelberg, Germany

Integration into Clinical Setting

PlugIn integration into Chili® telemedicine system:

- PACS
- Connection to modalities
- DICOM import/export
- DICOM "unification"
- Data transfer
- Management of results from image processing
- Tele-radiology

➔ facilitates clinical integration



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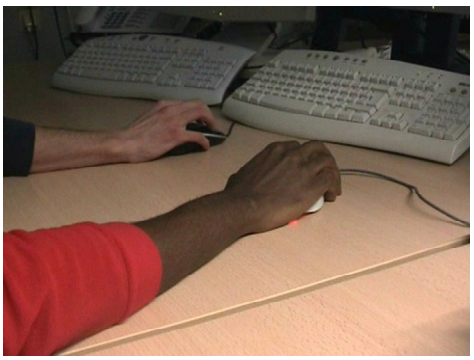
Teleconferencing



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Operation planning in Liver Surgery

Support for:
- liver tumor resection planning
- living donor liver transplantation (LDLT)

Planning based on patient individual anatomy:
- Vessel extraction and visualization
- Calculation of resection proposals
- Volumetry of organ and grafts

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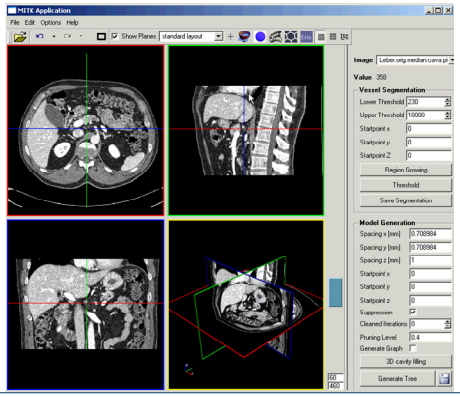
Liver Surgery Planning



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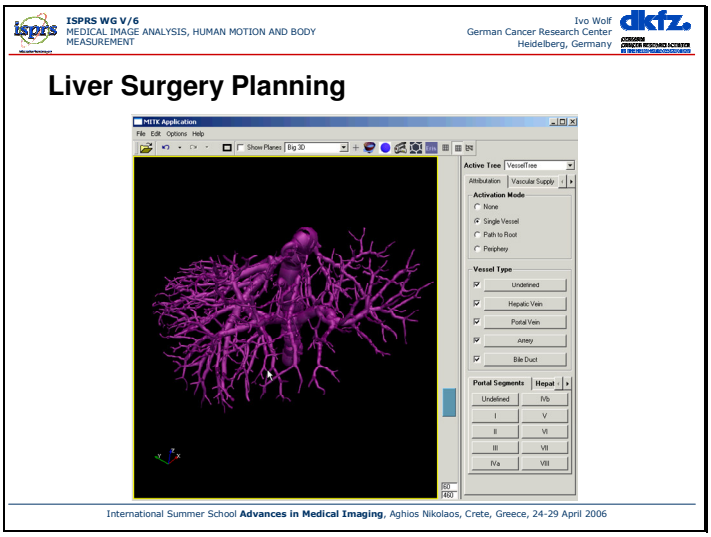
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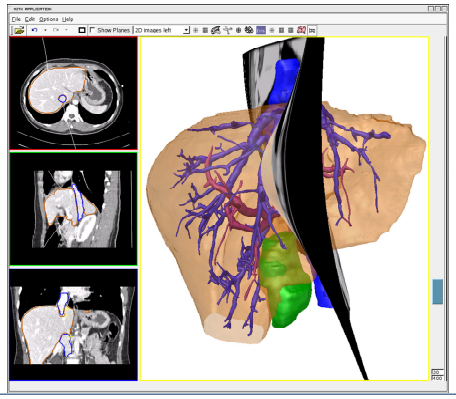

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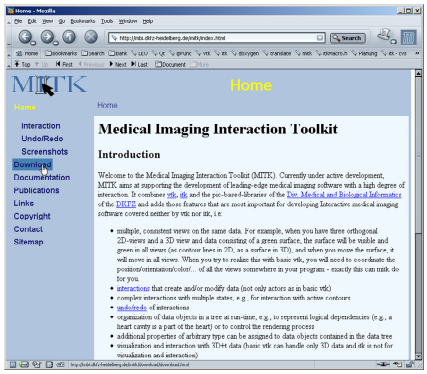
www.mitk.org

Download options:
- anonymous cvs
- zipped archive (v 0.6 in May)



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MITK – Summary

- Supports development of interactive systems from the *toolkit level*
- ➔ Toolkit, not an application or development environment
- Re-use of ITK/VTK code and concepts
- Coordination of visualizations and interactions
- Improved 2D support (compared to basic VTK)
- Adds more high-level interaction capabilities
- Support for 3D+t data
- Different layers of hidden complexity
- Facilitates re-use of high-level modules

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Thank you !

www.itk.org

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