Advances in Pulmonary Image Registration

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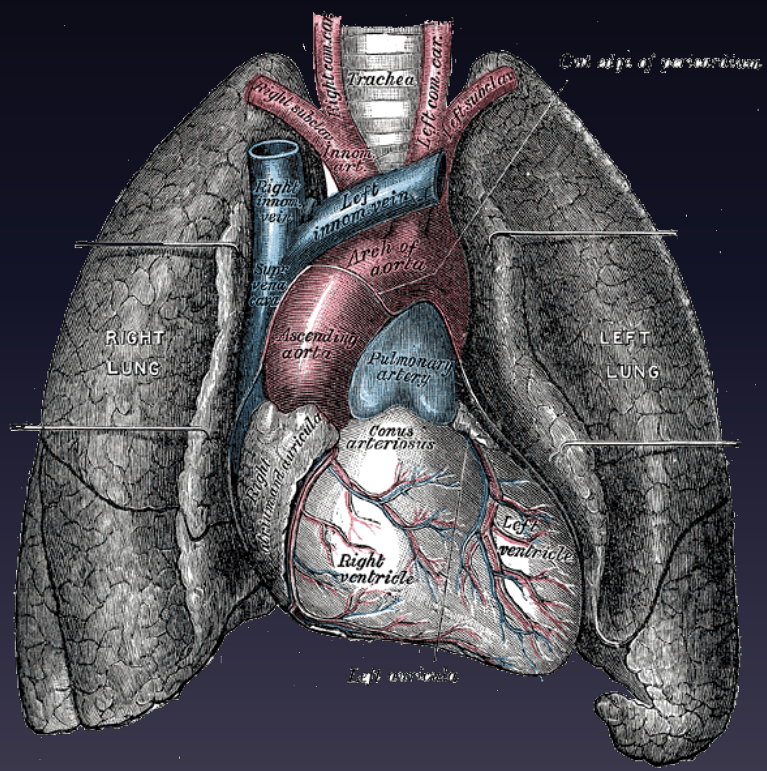
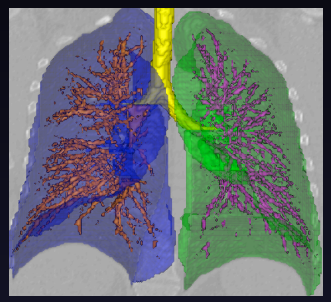
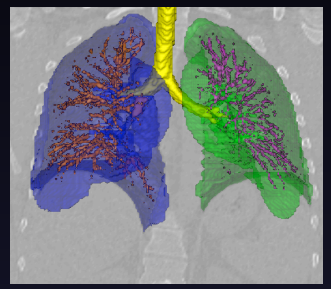
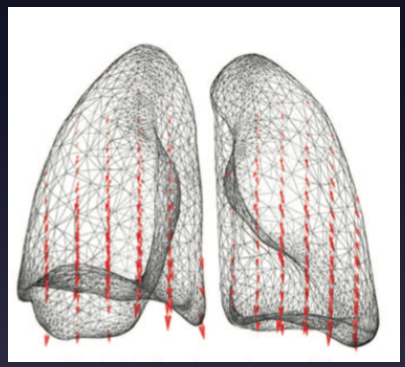
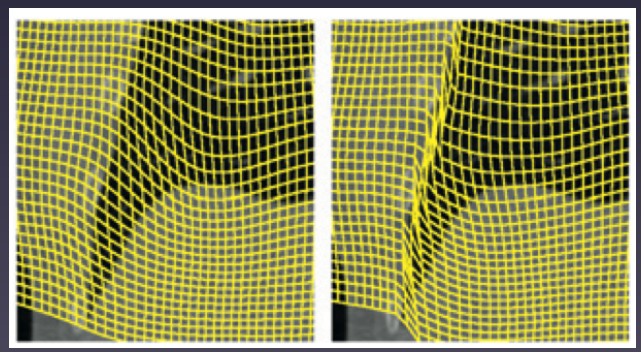
Nuances of pulmonary image registration

- Anatomy
  - sliding interface lung/chest wall
  - discontinuous lobes
  - tubular blood vessels
  - branching airways
- Modality
  - CT
  - ^{1}H MRI
  - hyperpolarized gas MRI
- Application
  - kinematics
  - radiotherapy treatment planning
  - treatment characterization



Lung-specific approaches

- Features
  - landmarks
  - point sets
  - currents
- Sliding conditions
  - Multiple B-splines
  - Piecewise diffeomorphisms
- Customized FEM models

EMPIRE10 Challenge

- 31 competitors
- Pre-competition: 20 scan pairs
- On-site: 10 scan pairs
- Evaluation criteria:
  - lung boundary alignment,
  - fissure correspondence,
  - landmark distance, and
  - biological plausibility.

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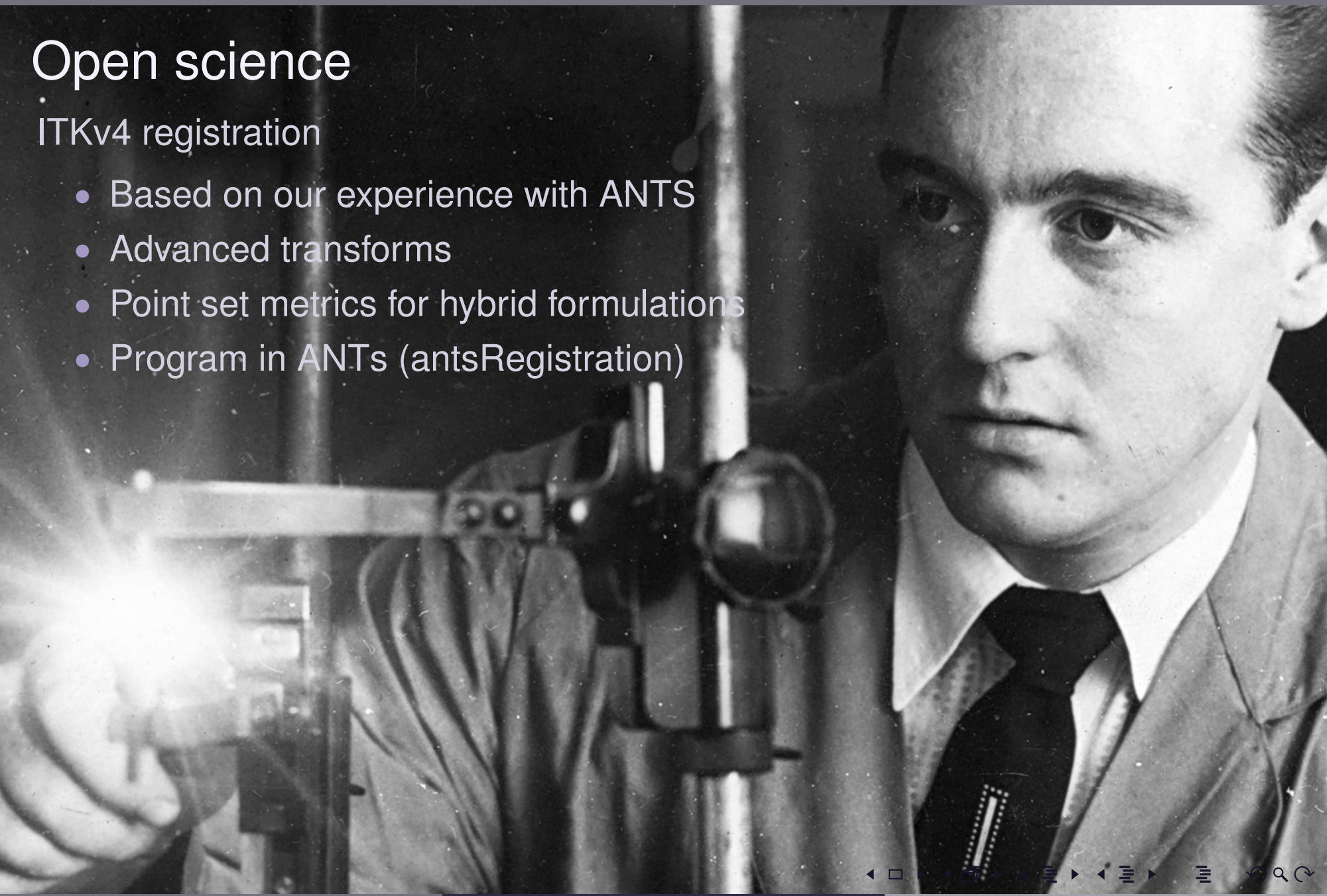
- Top current competitors:
  - picsl gsyn
  - CMS
  - MetaReg (ANTSNifElx)
  - MIC + Fraunhoer MEVIS Lübeck
  - ISI@UMCU
  - MetaReg (NifElx)
  - Nifty Reggers
  - elastix_smooth
  - IMI Lübeck Diffeomorph

K. Murphy et al., *Evaluation of registration methods on thoracic CT: The EMPIRE10 Challenge*, IEEE Trans Med Imaging 30(11):1901–1920 (2011).

Open science

ITKv4 registration

- Based on our experience with ANTS
- Advanced transforms
- Point set metrics for hybrid formulations
- Program in ANTs (antsRegistration)



antsRegistration

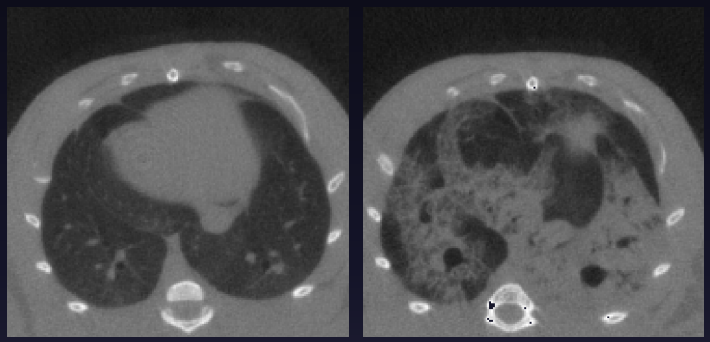
```
COMMAND:
     antsRegistration

OPTIONS:
     -d, --dimensionality 2/3
     -o, --output outputTransformPrefix
                 [outputTransformPrefix,<outputWarpedImage>,<outputInverseWarpedImage>]
     -a, --write-composite-transform 1/(0)
     -n, --interpolation Linear
                         NearestNeighbor
                         MultiLabel[<sigma=imageSpacing>,<alpha=4.0>]
                         Gaussian[<sigma=imageSpacing>,<alpha=1.0>]
                         BSpline[<order=3>]
                         CosineWindowedSinc
                         WelchWindowedSinc
                         HammingWindowedSinc
                         LanczosWindowedSinc
     -q, --initial-fixed-transform initialTransform
                                   [initialTransform,<useInverse>]
                                   [fixedImage,movingImage,useCenterOfMass]
     -p, --print-similarity-measure-interval <unsignedIntegerValue>
     -v, --write-interval-volumes <unsignedIntegerValue>
     -z, --collapse-output-transforms (1)/0
     -r, --initial-moving-transform initialTransform
                                    [initialTransform,<useInverse>]
                                    [fixedImage,movingImage,useCenterOfMass]
     -m, --metric CC[fixedImage,movingImage,metricWeight,radius,...]
                  MI[fixedImage,movingImage,metricWeight,numberOfBins,...]
                  Mattes[fixedImage,movingImage,metricWeight,numberOfBins,...]
                  MeanSquares[fixedImage,movingImage,metricWeight,...]
                  Demons[fixedImage,movingImage,metricWeight,...]
                  GC[fixedImage,movingImage,metricWeight,...]
```

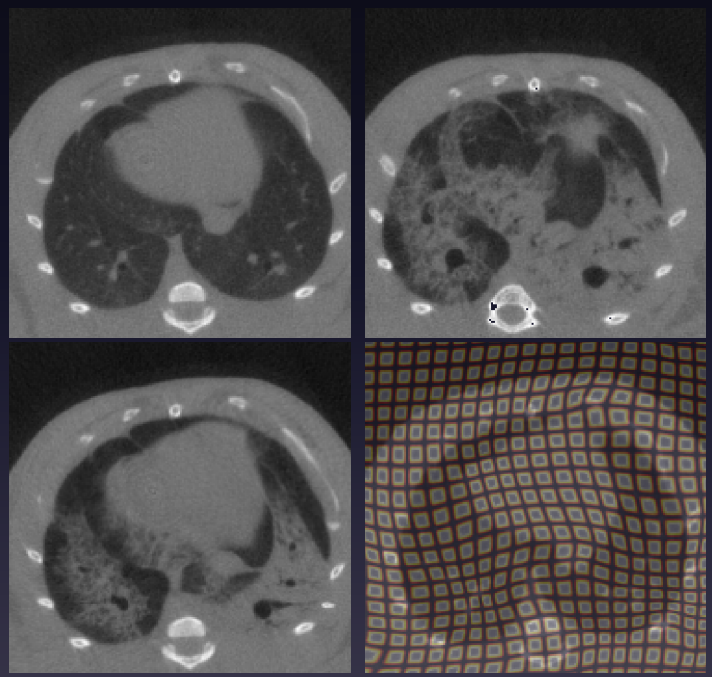
antsRegistration (cont.)

```
-t, --transform Rigid[gradientStep]
                Affine[gradientStep]
                CompositeAffine[gradientStep]
                Similarity[gradientStep]
                Translation[gradientStep]
                BSpline[gradientStep,meshSizeAtBaseLevel]
                GaussianDisplacementField[gradientStep,updateFieldVarianceInVoxelSpace,...]
                BSplineDisplacementField[gradientStep,updateFieldMeshSizeAtBaseLevel,...]
                TimeVaryingVelocityField[gradientStep,numberOfTimeIndices,...]
                TimeVaryingBSplineVelocityField[gradientStep,velocityFieldMeshSize,...]
                SyN[gradientStep,updateFieldVarianceInVoxelSpace,totalFieldVarianceInVoxelSpace]
                BSplineSyN[gradientStep,updateFieldMeshSizeAtBaseLevel,...]
                Exponential[gradientStep,updateFieldVarianceInVoxelSpace,...]
                BSplineExponential[gradientStep,updateFieldMeshSizeAtBaseLevel,...]
-c, --convergence MxNxO
                  [MxNxO,<convergenceThreshold=1e-6>,<convergenceWindowSize=10>]
-s, --smoothing-sigmas MxNxO...
-f, --shrink-factors MxNxO...
-u, --use-histogram-matching
-l, --use-estimate-learning-rate-once
-w, --winsorize-image-intensities [lowerQuantile,upperQuantile]
-x, --masks [fixedImageMask,movingImageMask]
-h
--help
```

Example registration



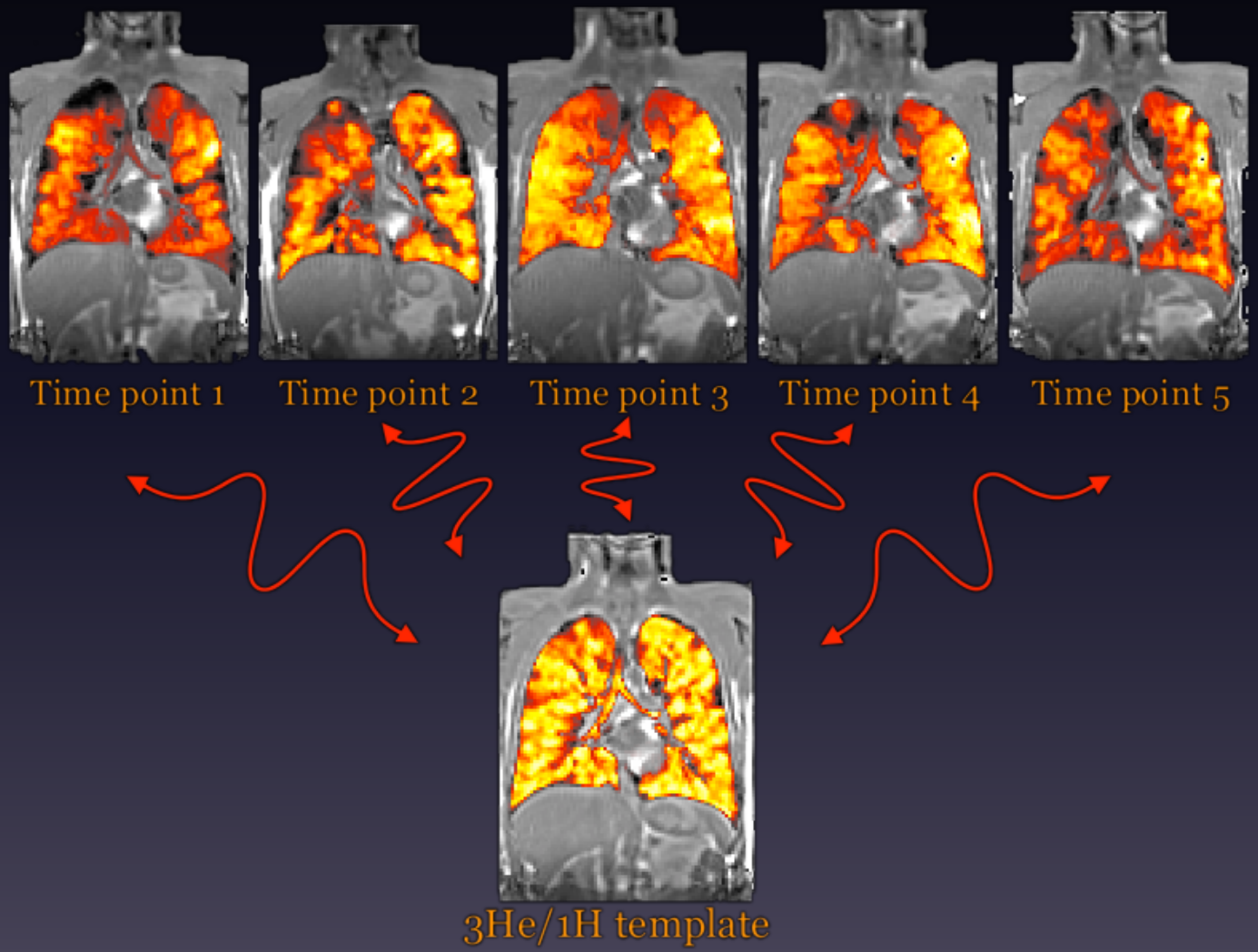
Example registration



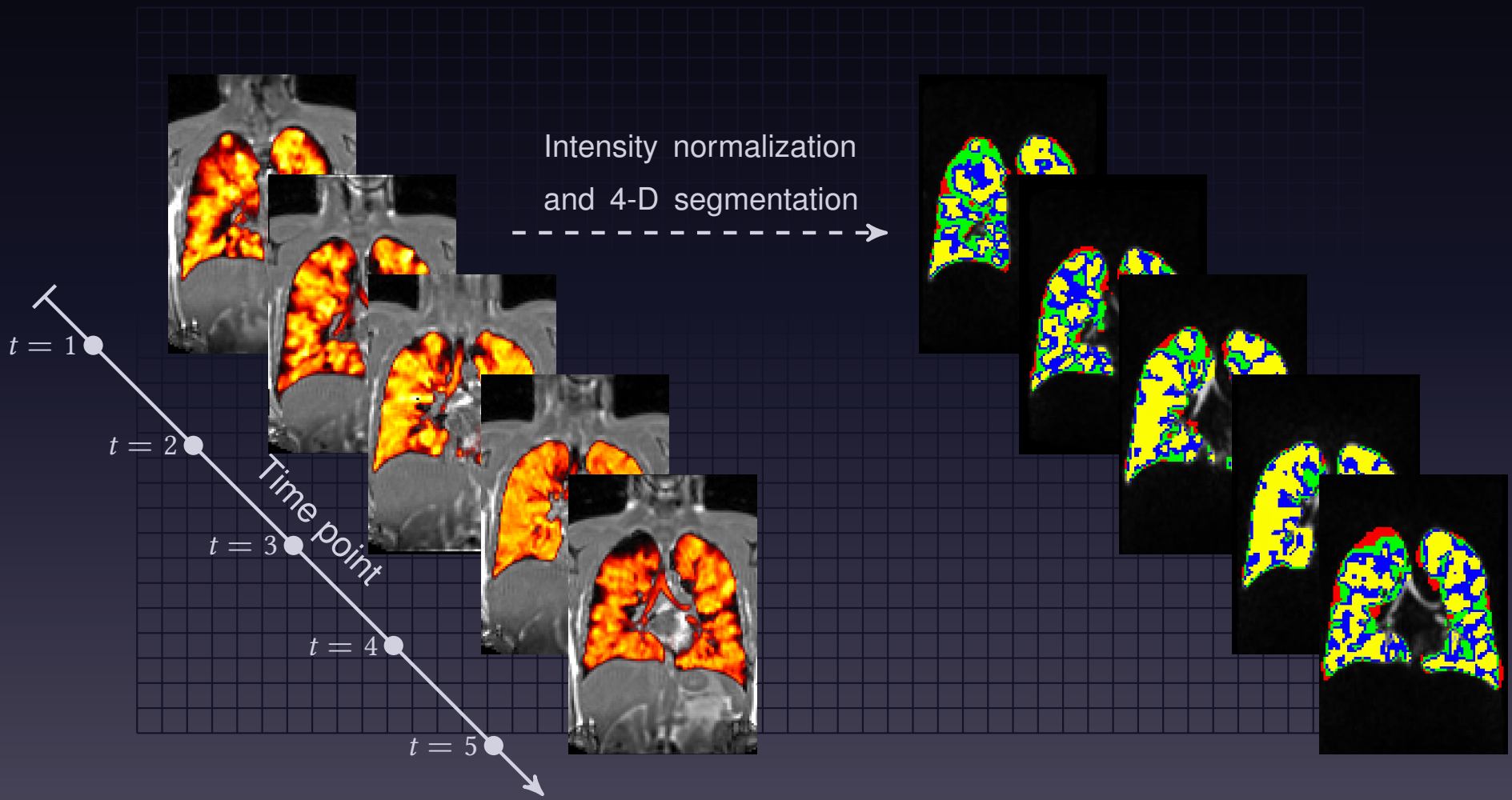
```
${ANTsPATH}antsRegistration -d 3 \
  -r [${fixed},${moving},1] \
  -m MI[${fixed},${moving},1,32,Regular,0.25] \
  -t Rigid[0.1] \
  -f 8x4x2x1 \
  -s 3x2x1x0 \
  -c [500x200x100x20,1e-6,10] \
  -m CC[${fixed},${moving1},1,4] \
  -m MSQ[${fixedDist},${moving1Dist},0.1] \
  -t BSplineSyN[0.1,10x10x11,0x0x0] \
  -f 6x4x2x1 \
  -s 3x2x1x0 \
  -c [70x50x40x10,1e-8,10] \
  -o ${fixedPrefix}x${moving1Prefix}_
```

N. J. Tustison, et al. “Voxel-Based Longitudinal Analysis of Pulmonary Ventilation MRI”

He3/H1 longitudinal template

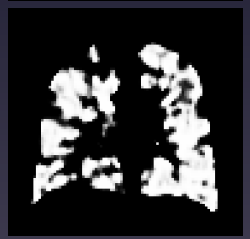


Longitudinal segmentation



Expected ventilation



$l = 1$

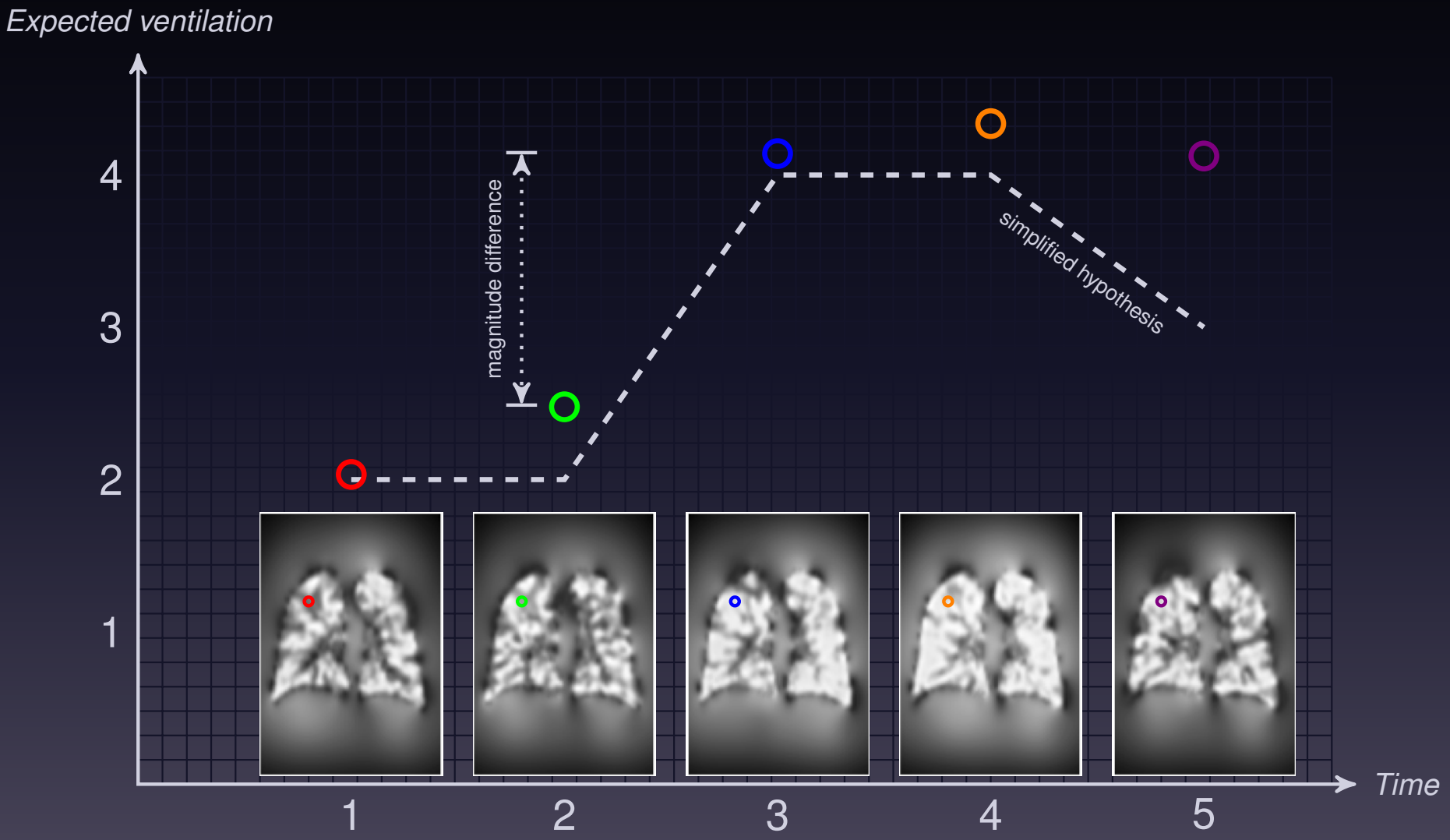
$l = 2$

$l = 3$

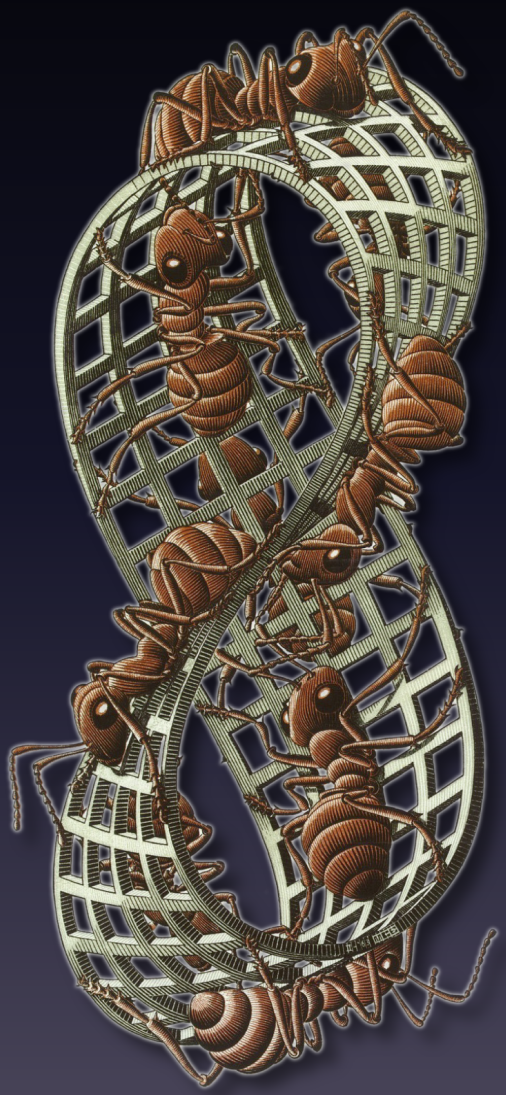
$l = 4$

$$EV_v = \sum_{l=1}^{4} l \times \Pr(l|I_v) \longrightarrow$$

Correlation analysis



Subjects 1–4



Further information

- http://www.itk.org
- http://www.picsl.upenn.edu/ANTs