ITK v4 Registration Refactoring

Feb 2, 2011

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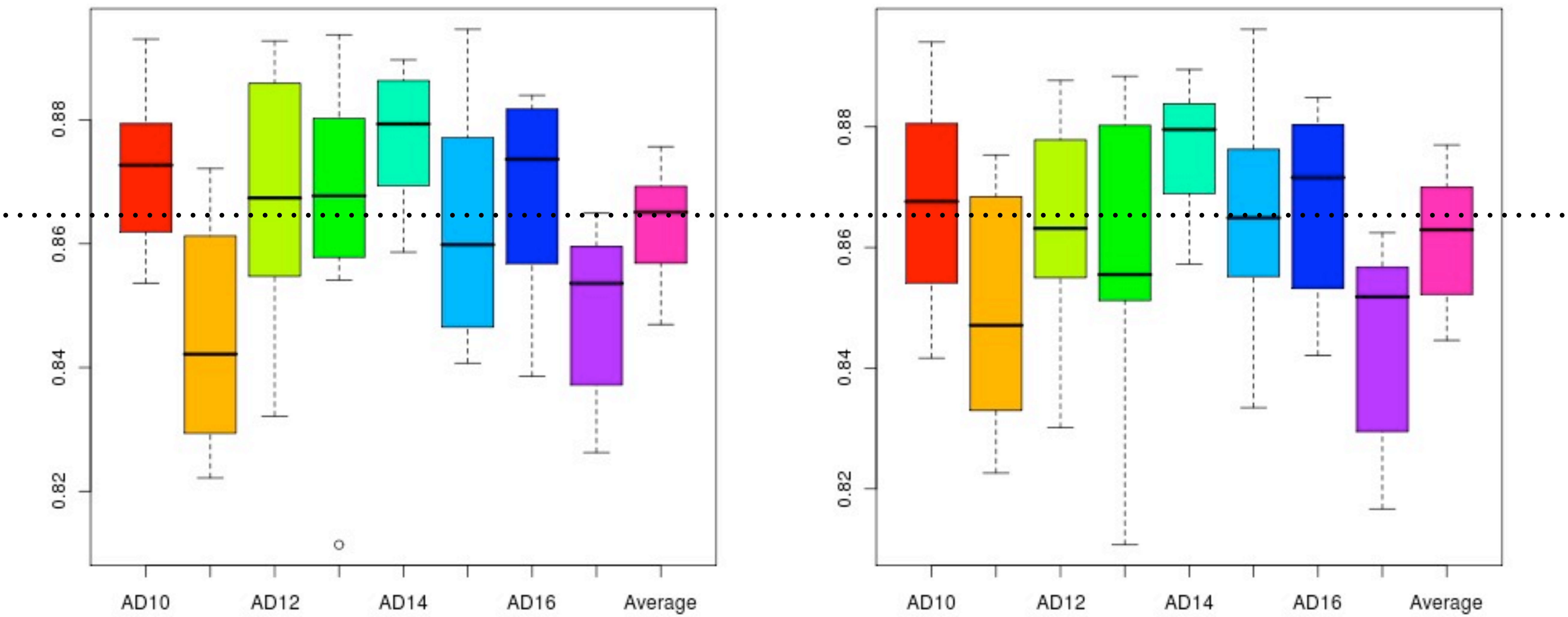
- New problems: interesting data that existing approaches do not easily handle (i.e. use cases).
- Slicer: big projects that we want to support. Kilian asks "why is resampling taking longer than registration?"
- New theory: interesting ideas we should be able to easily implement. E.g. LDDMM, longitudinal mapping, multivariate problems ...

ITK Mattes MI vs FSL correlation ratio

Evaluate brain overlap in neuroimages



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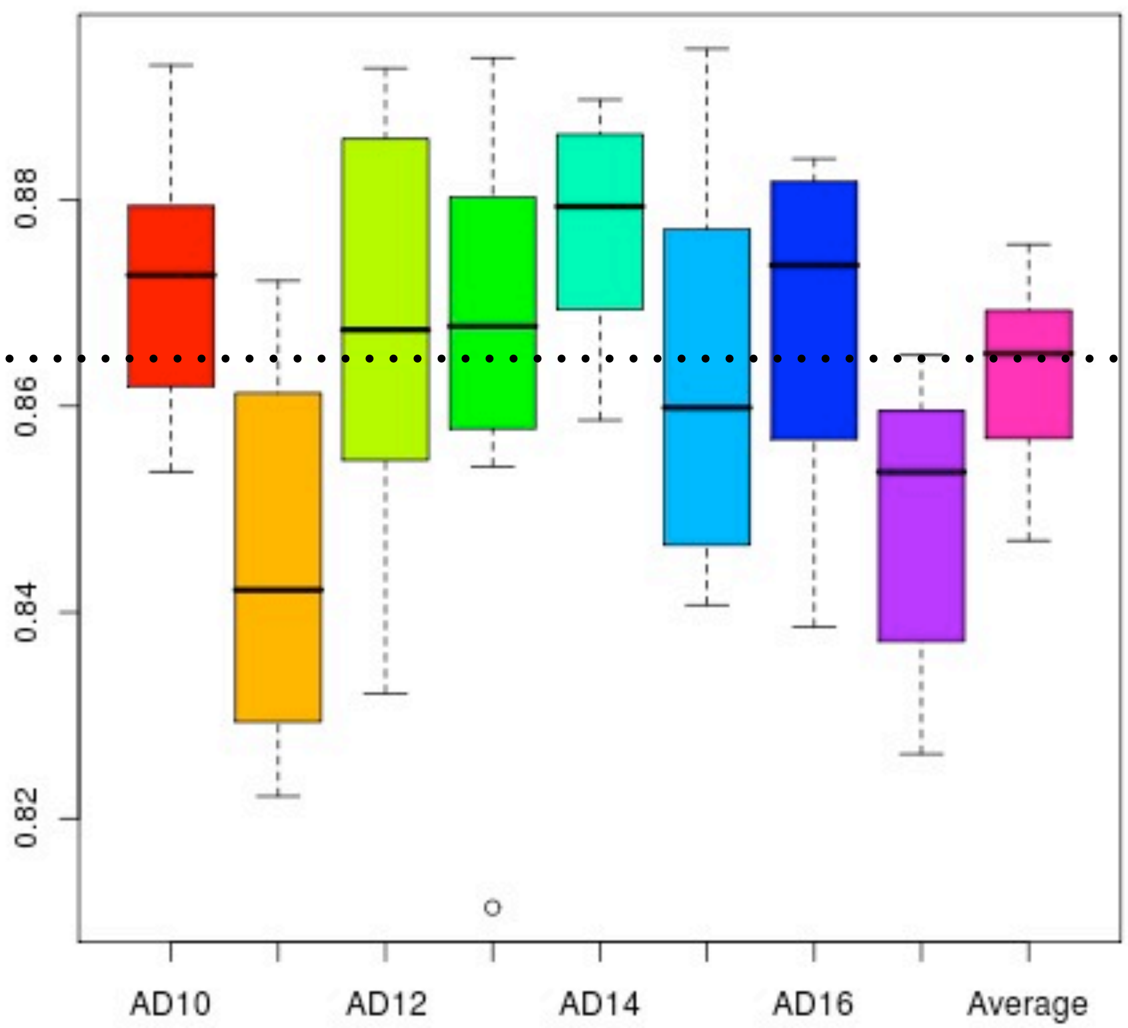

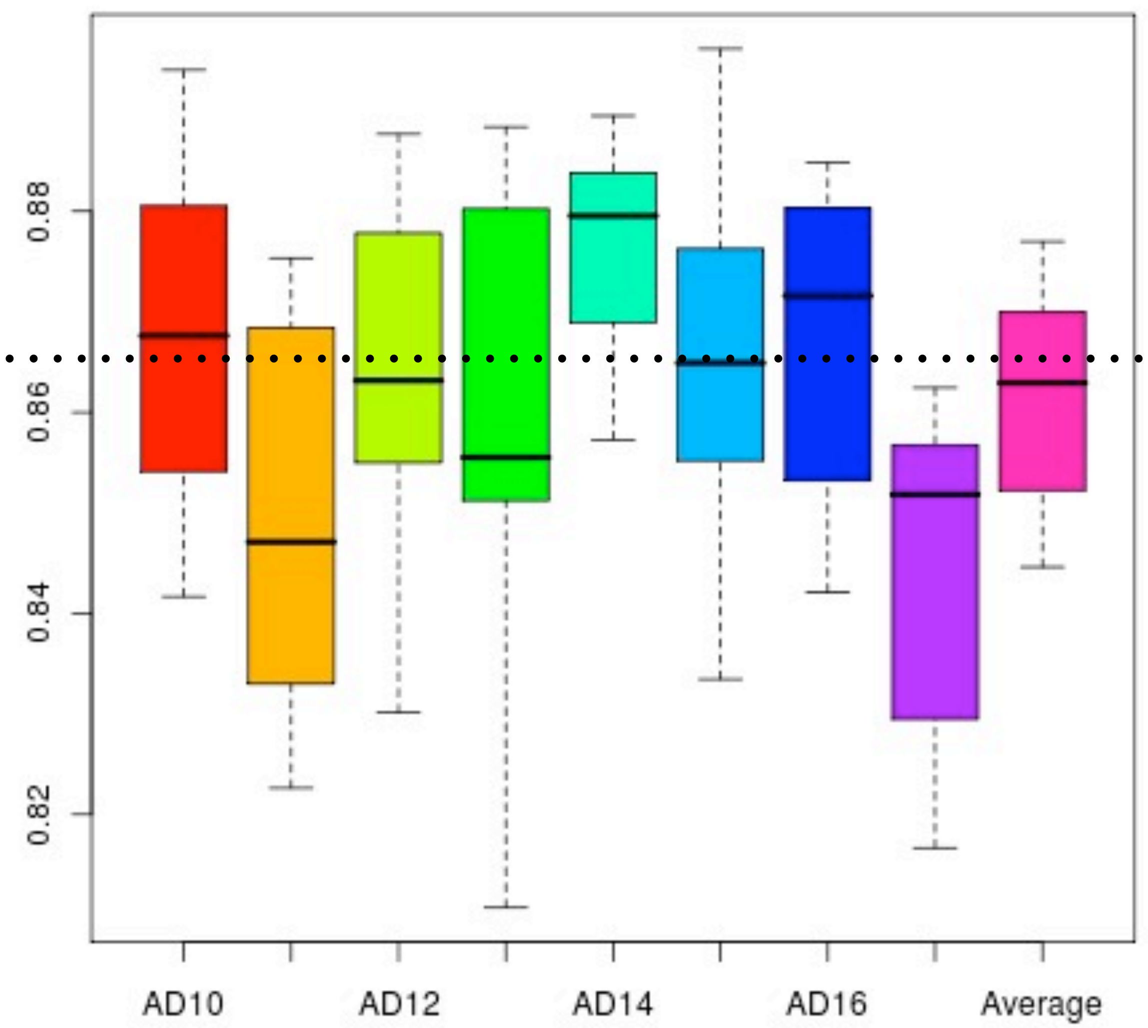

Default ANTs parameters
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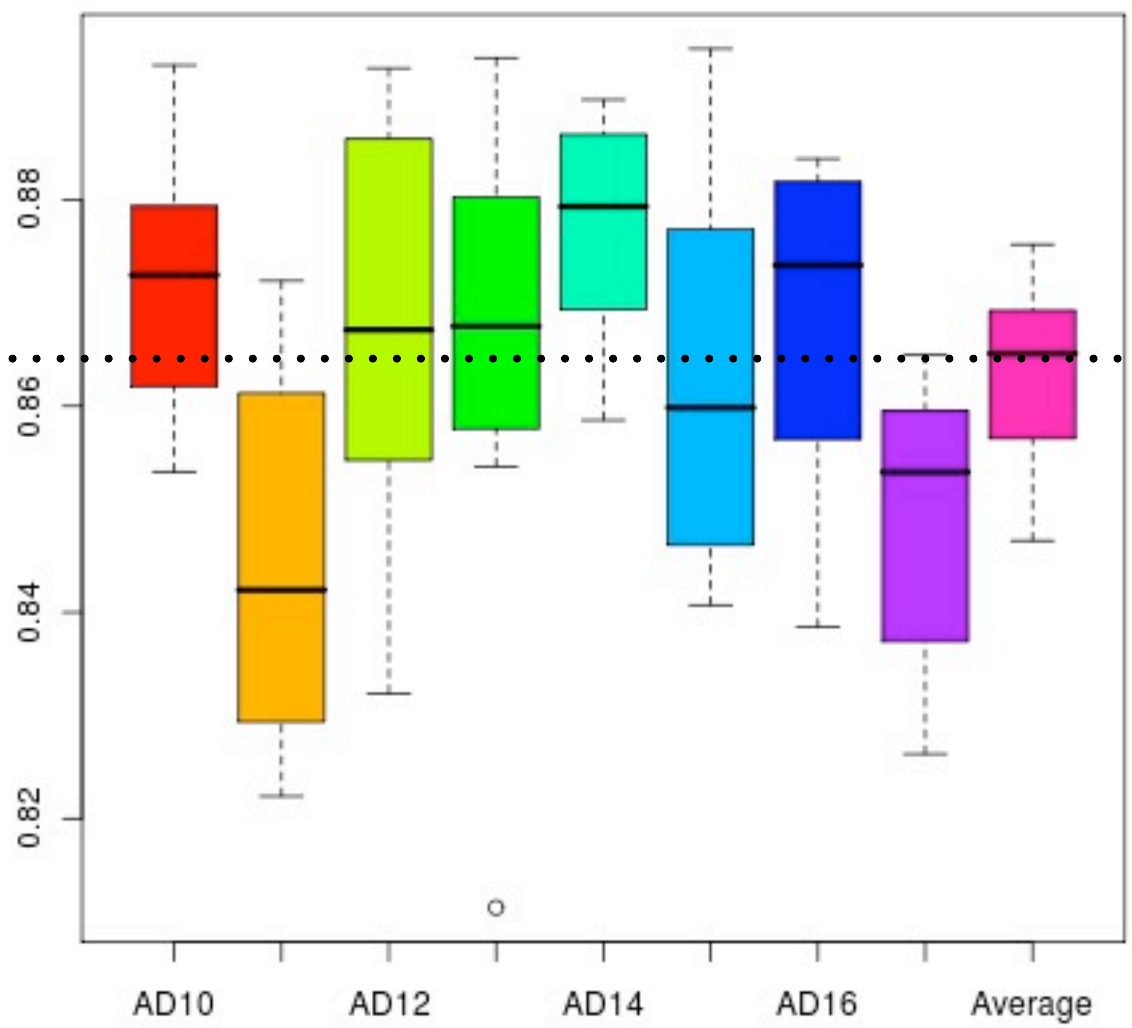

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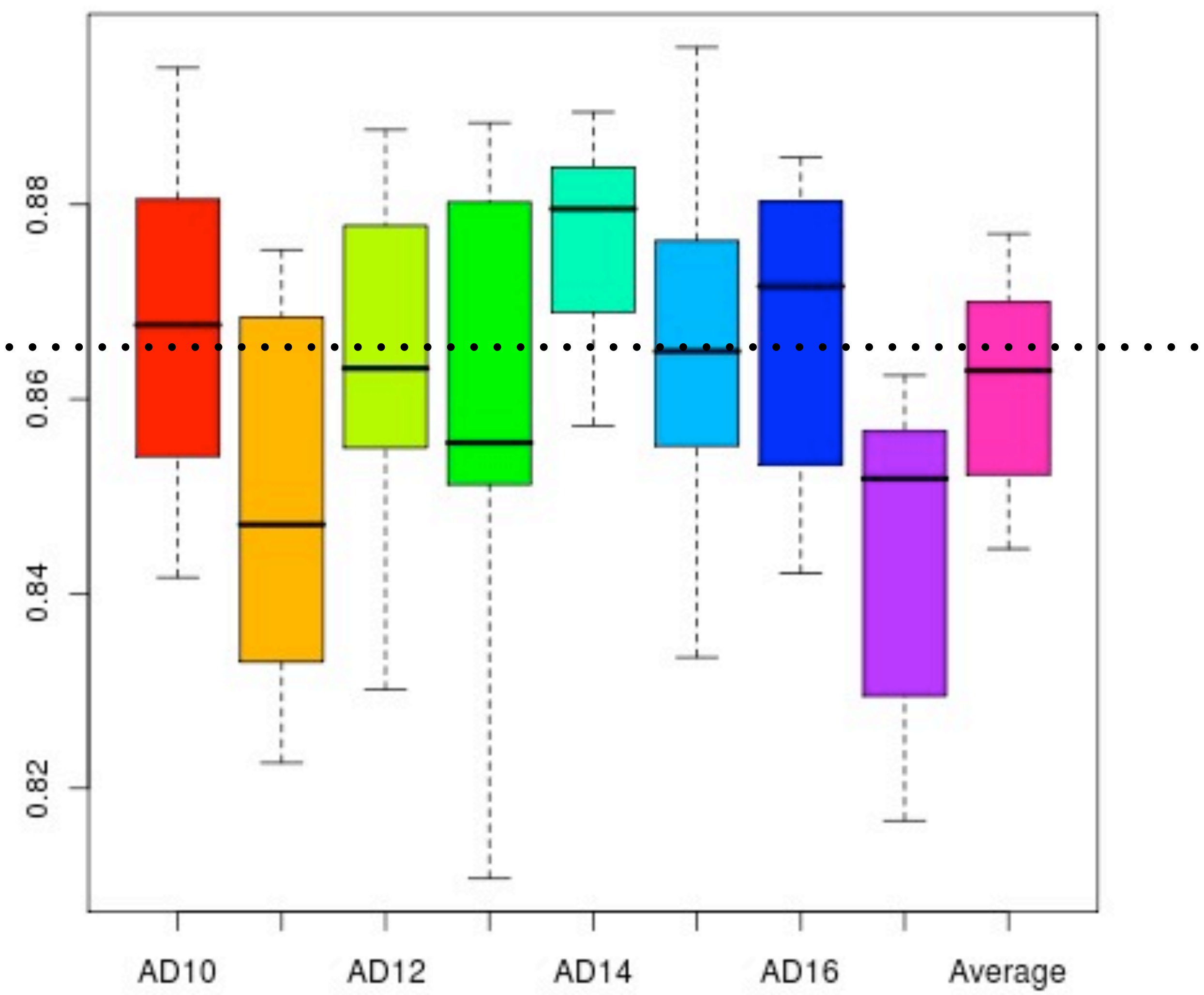

Default FSL parameters and optimization.

Biased registration

A B

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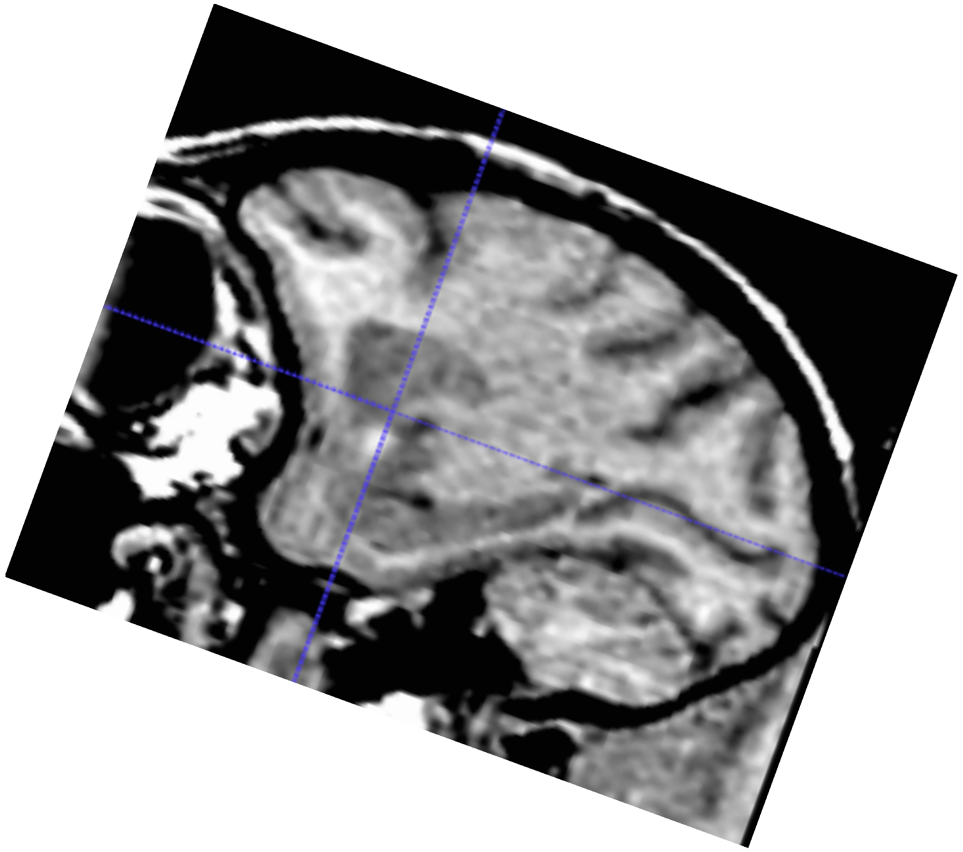

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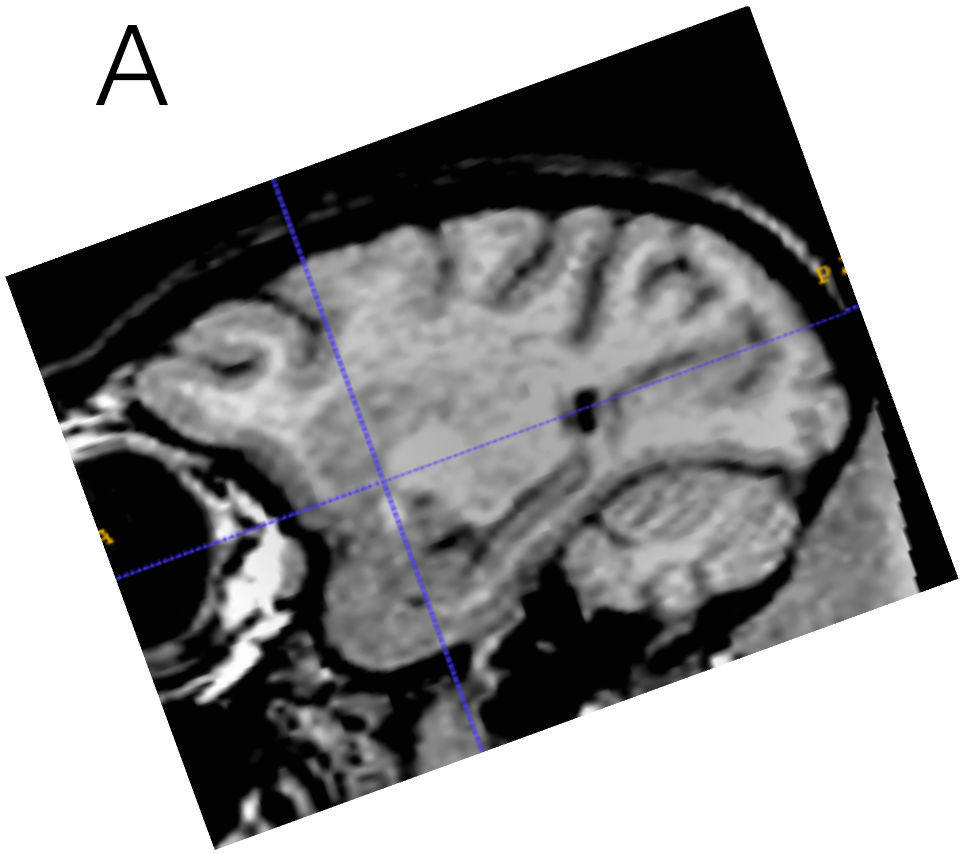

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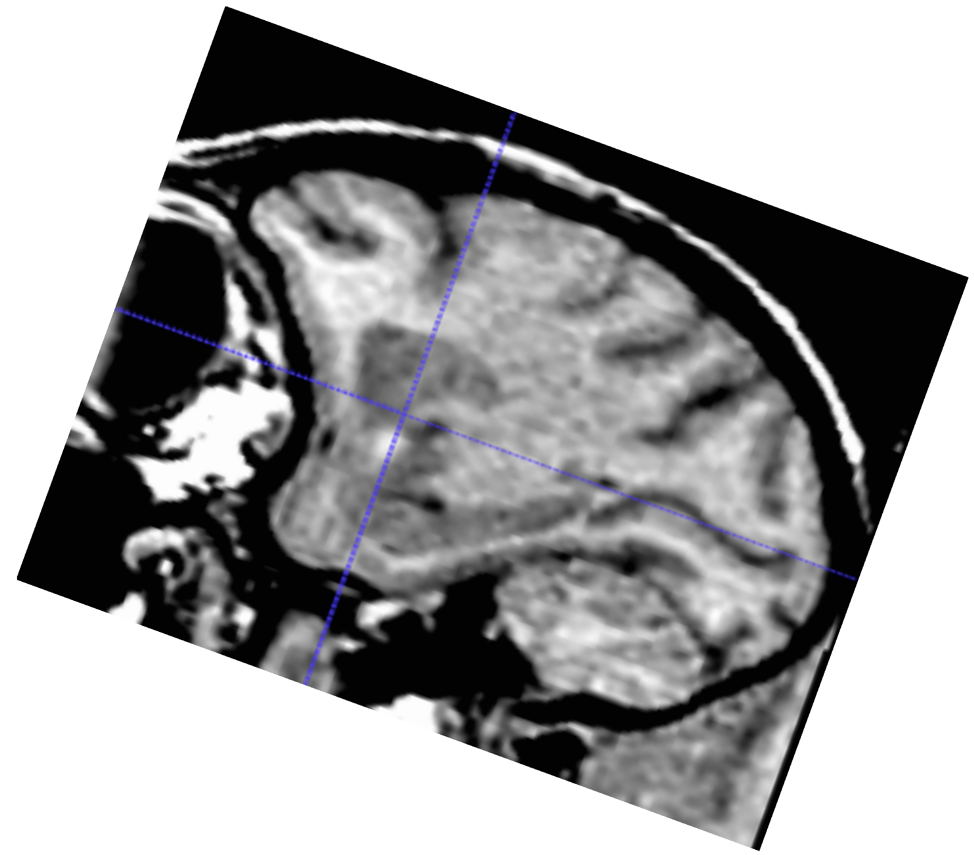

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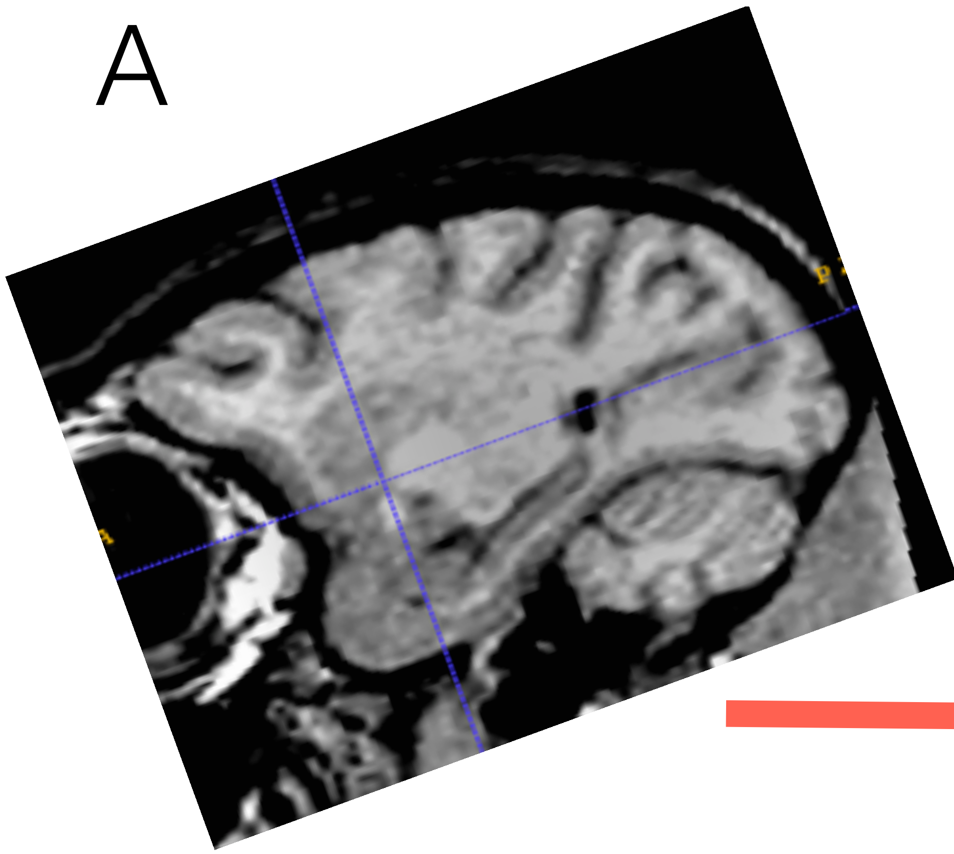

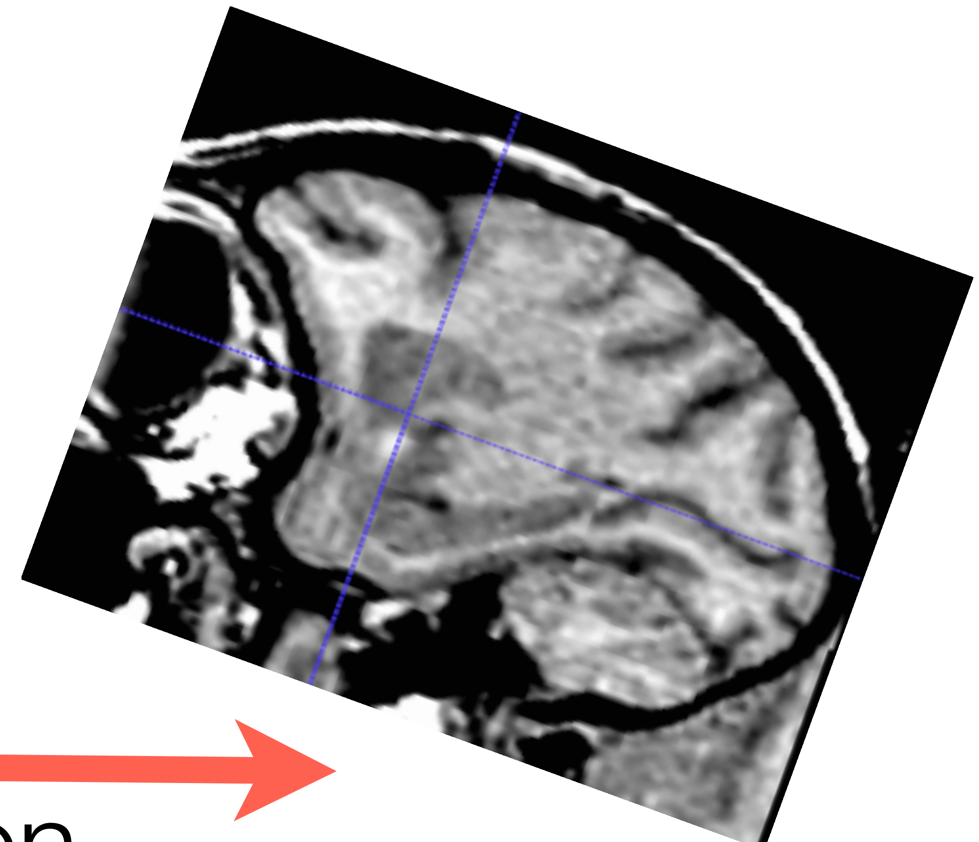

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Registration

Unbiased registration

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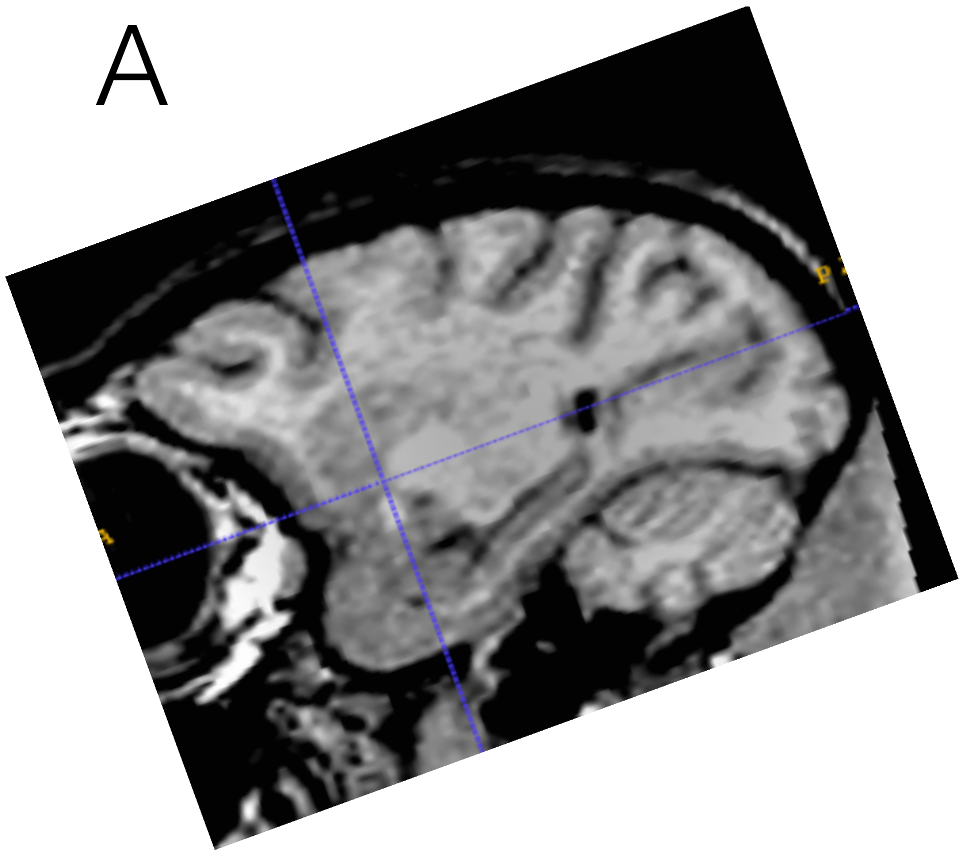

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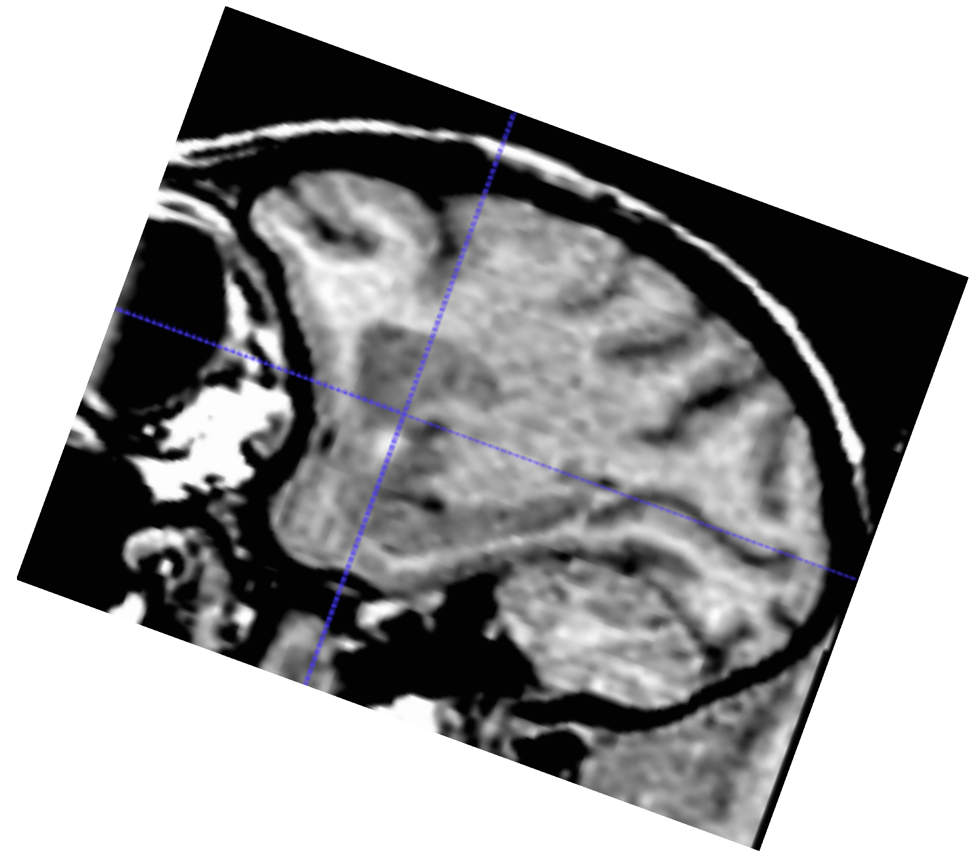

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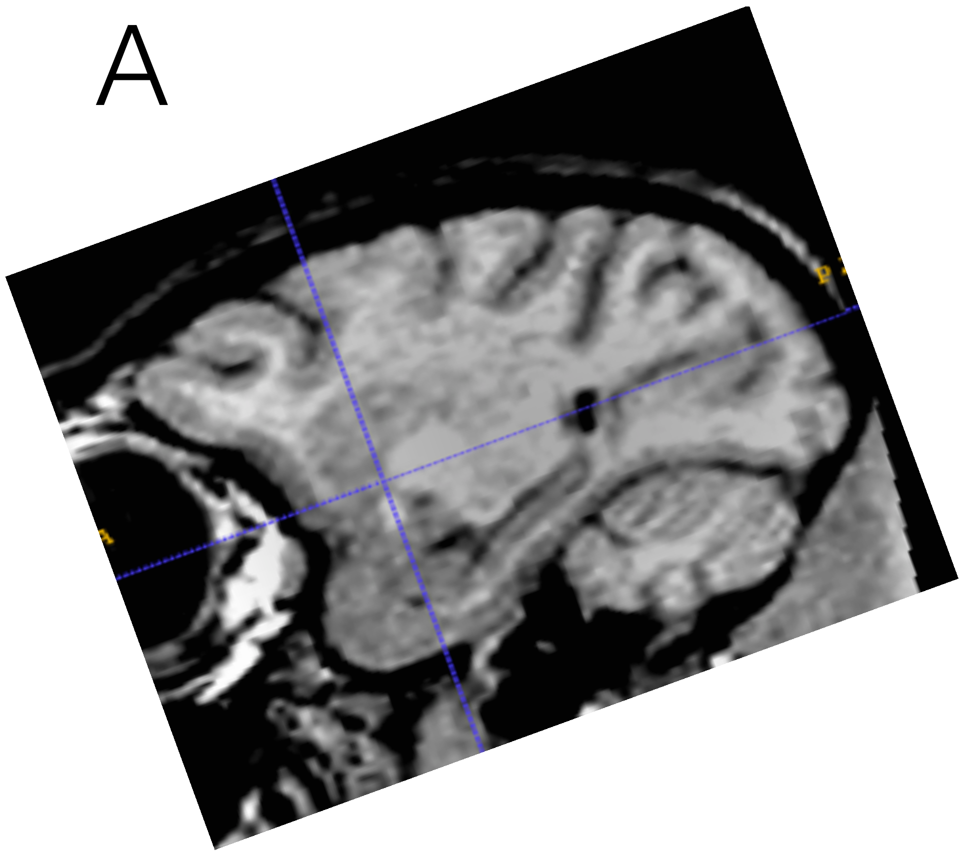

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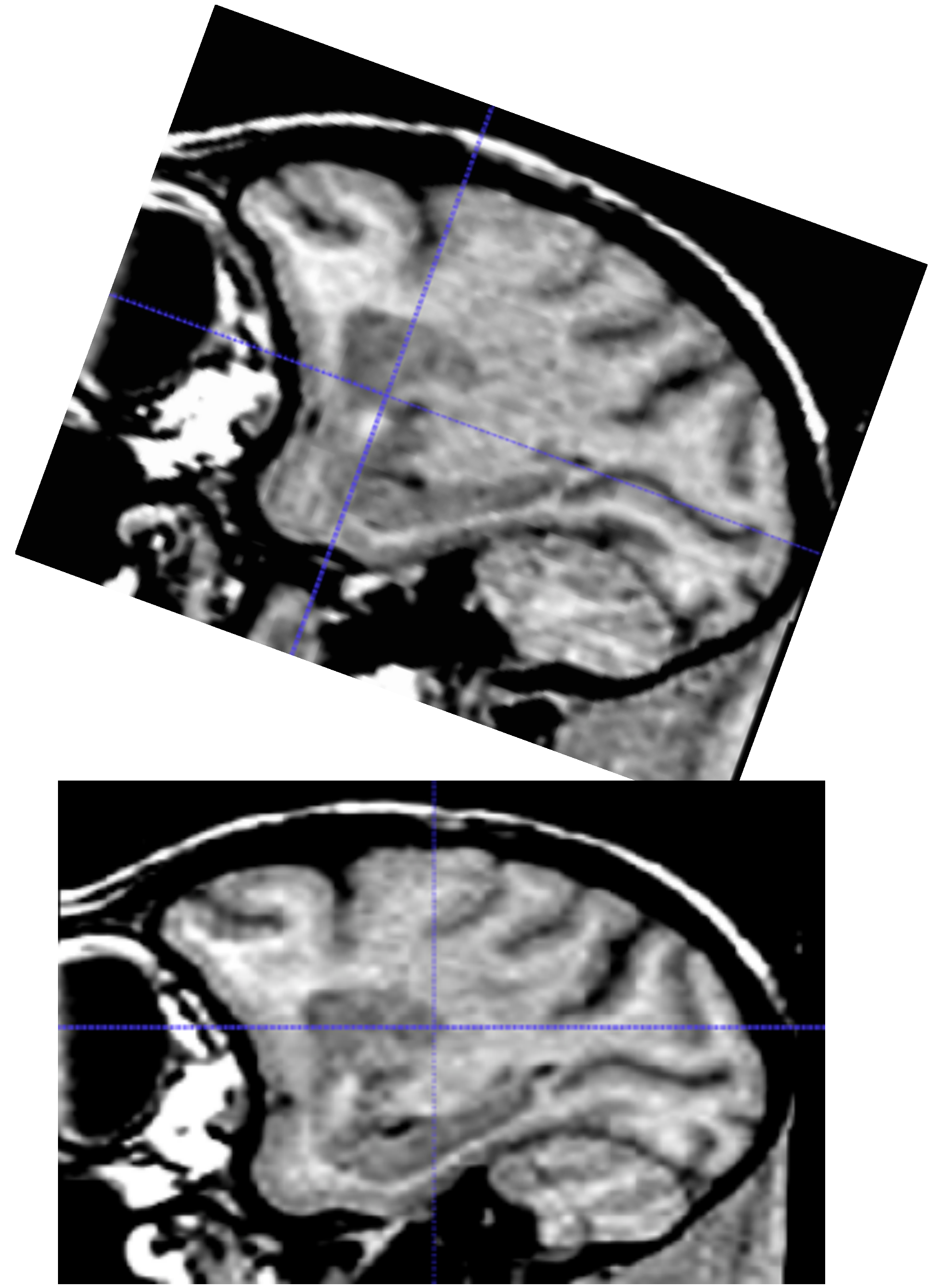

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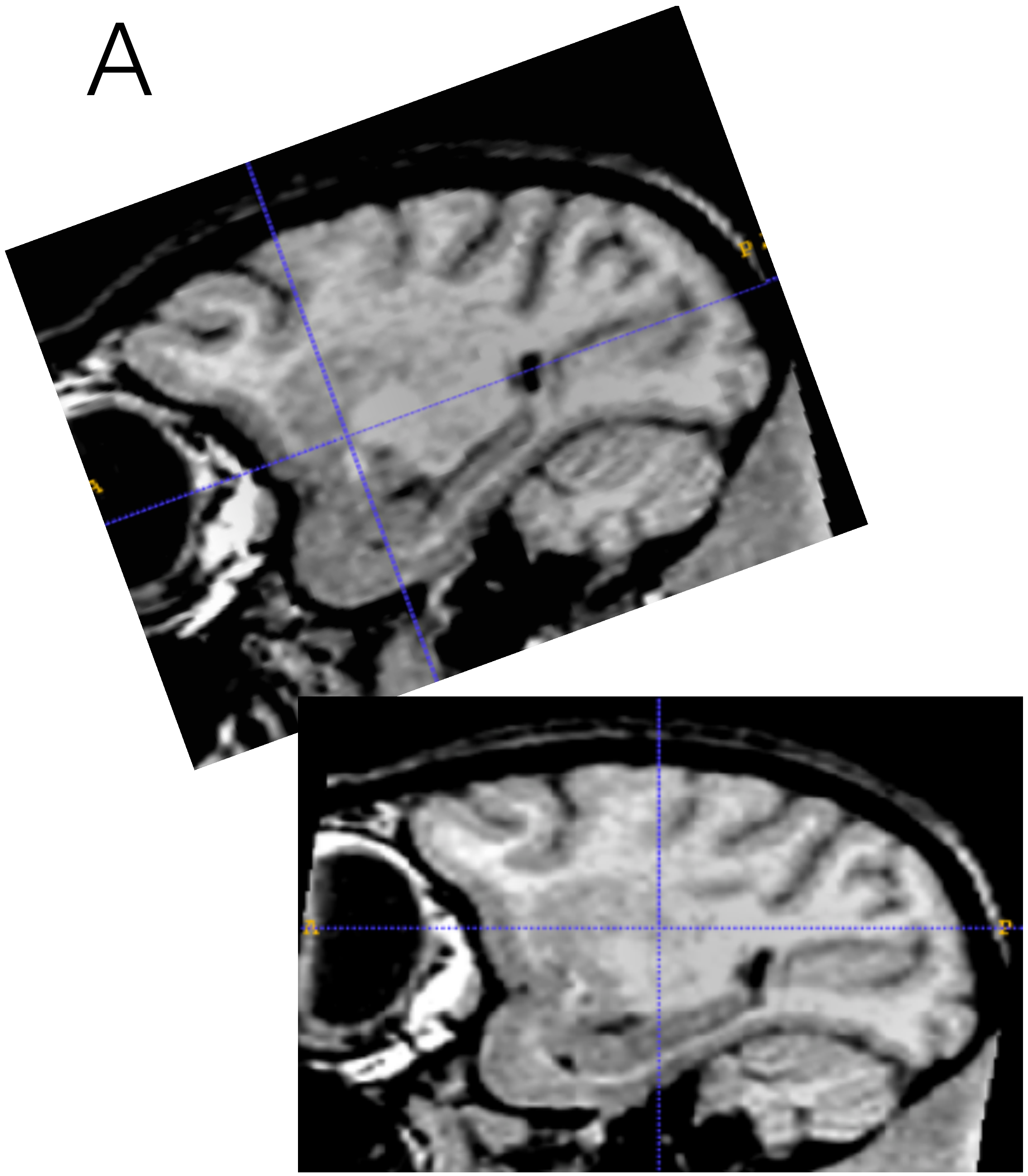

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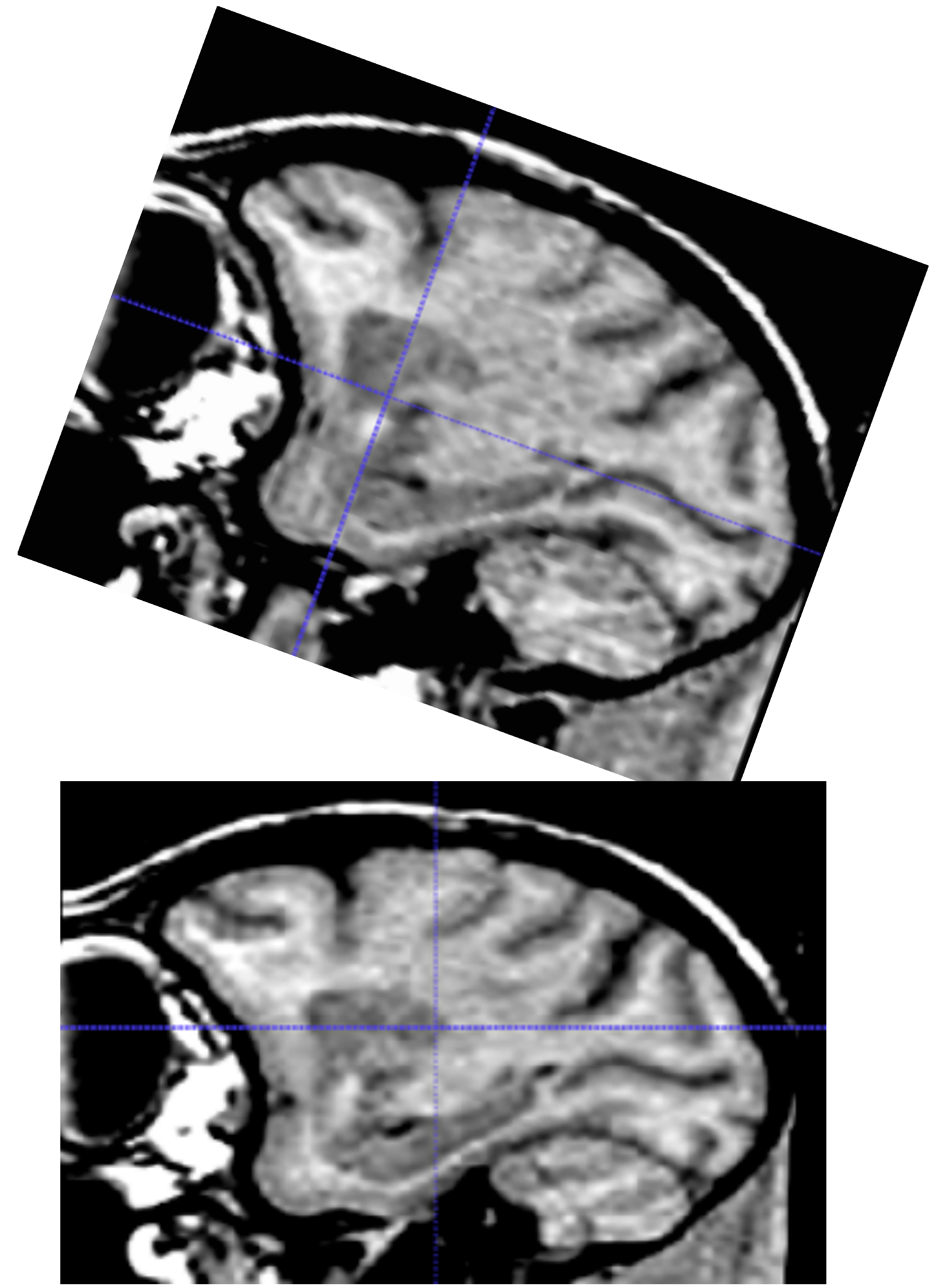

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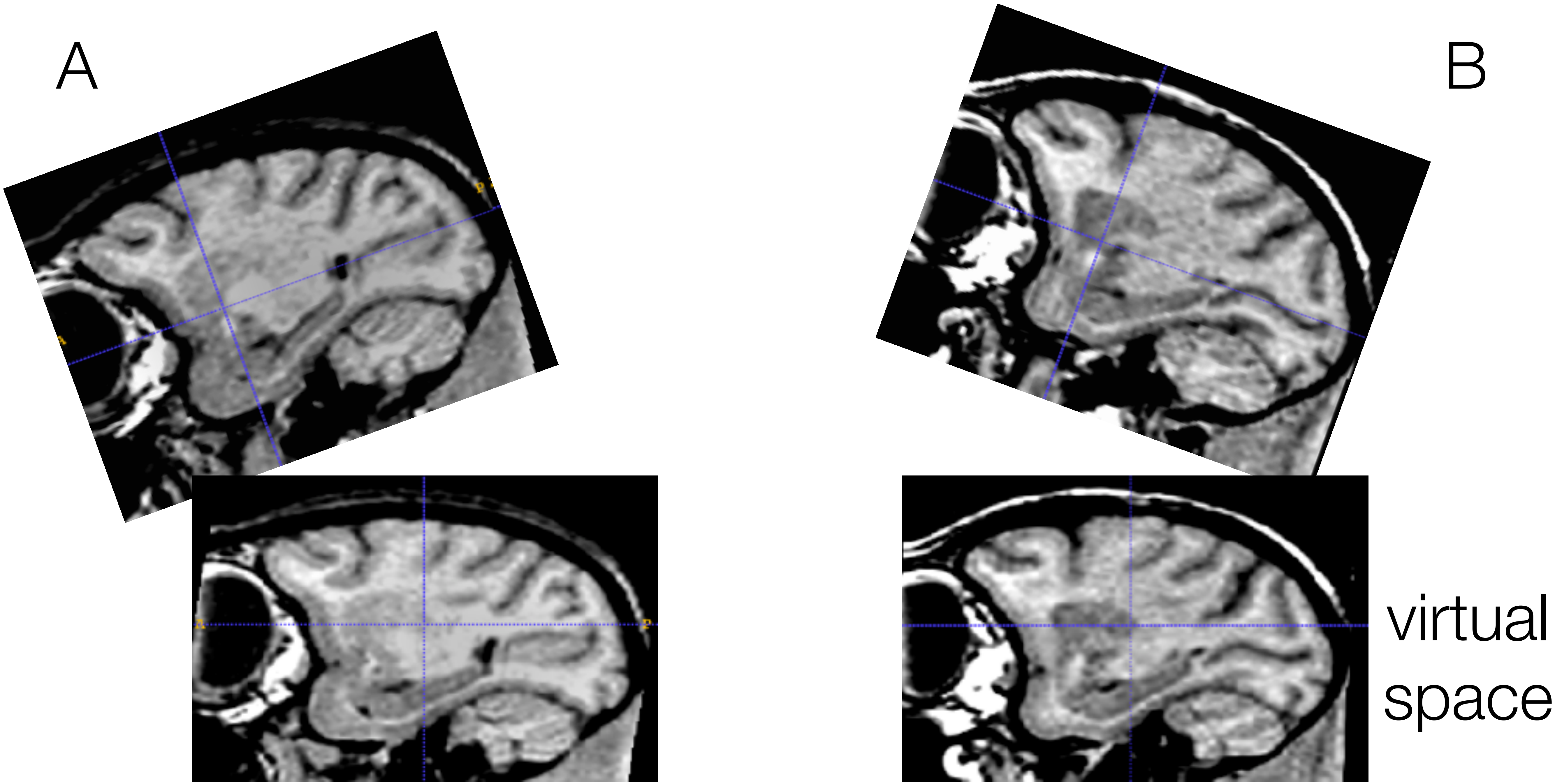

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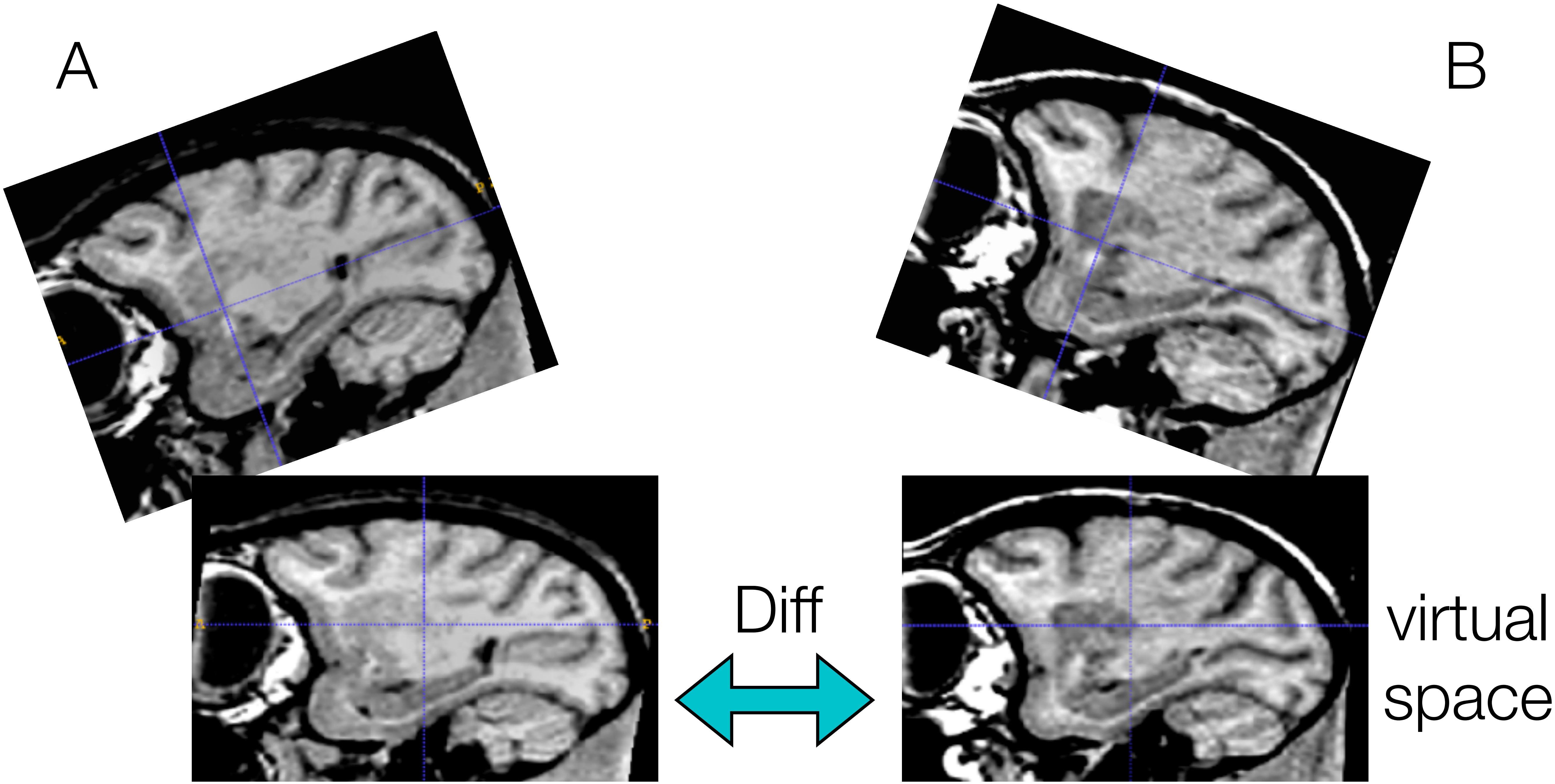

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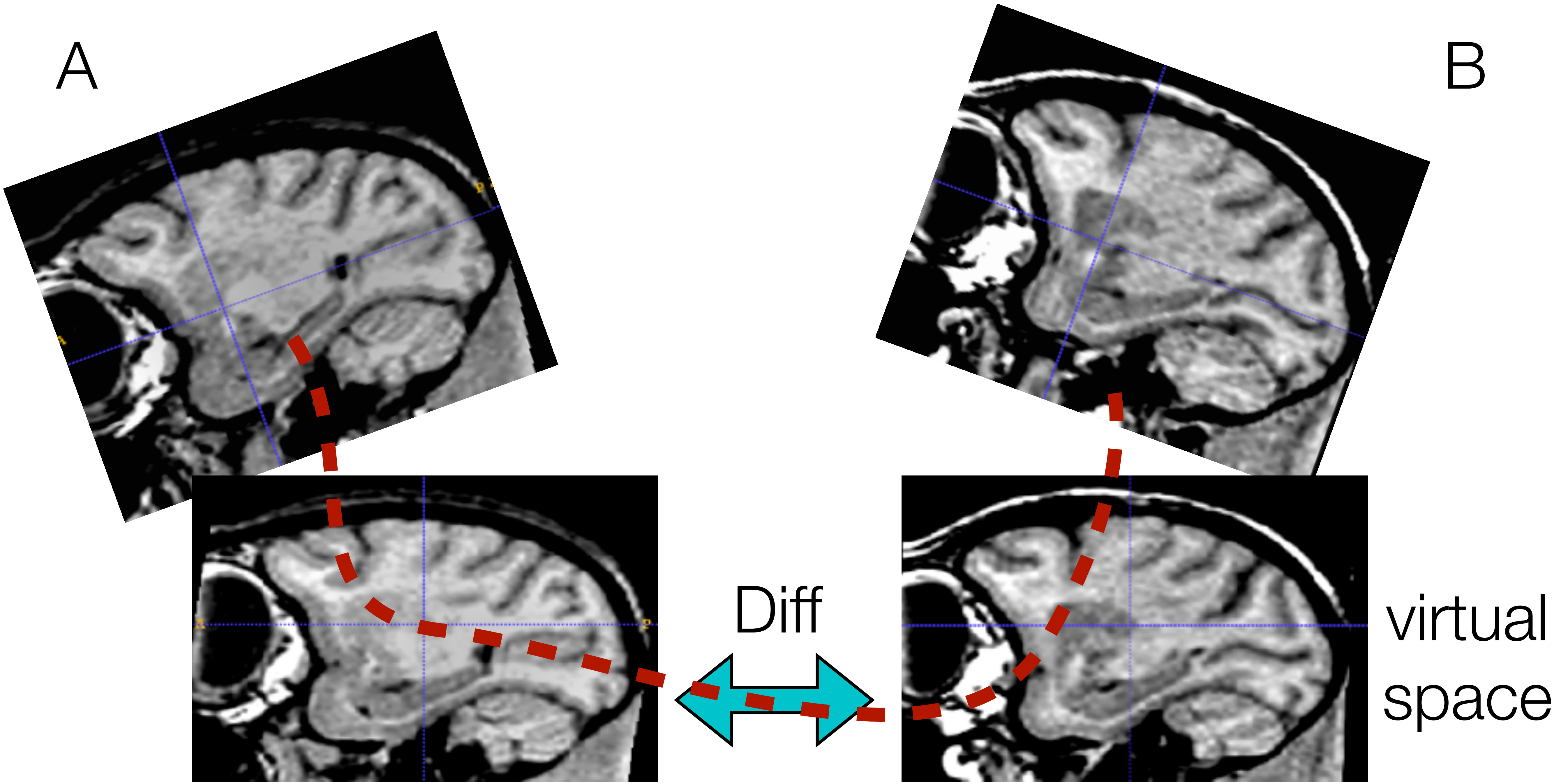

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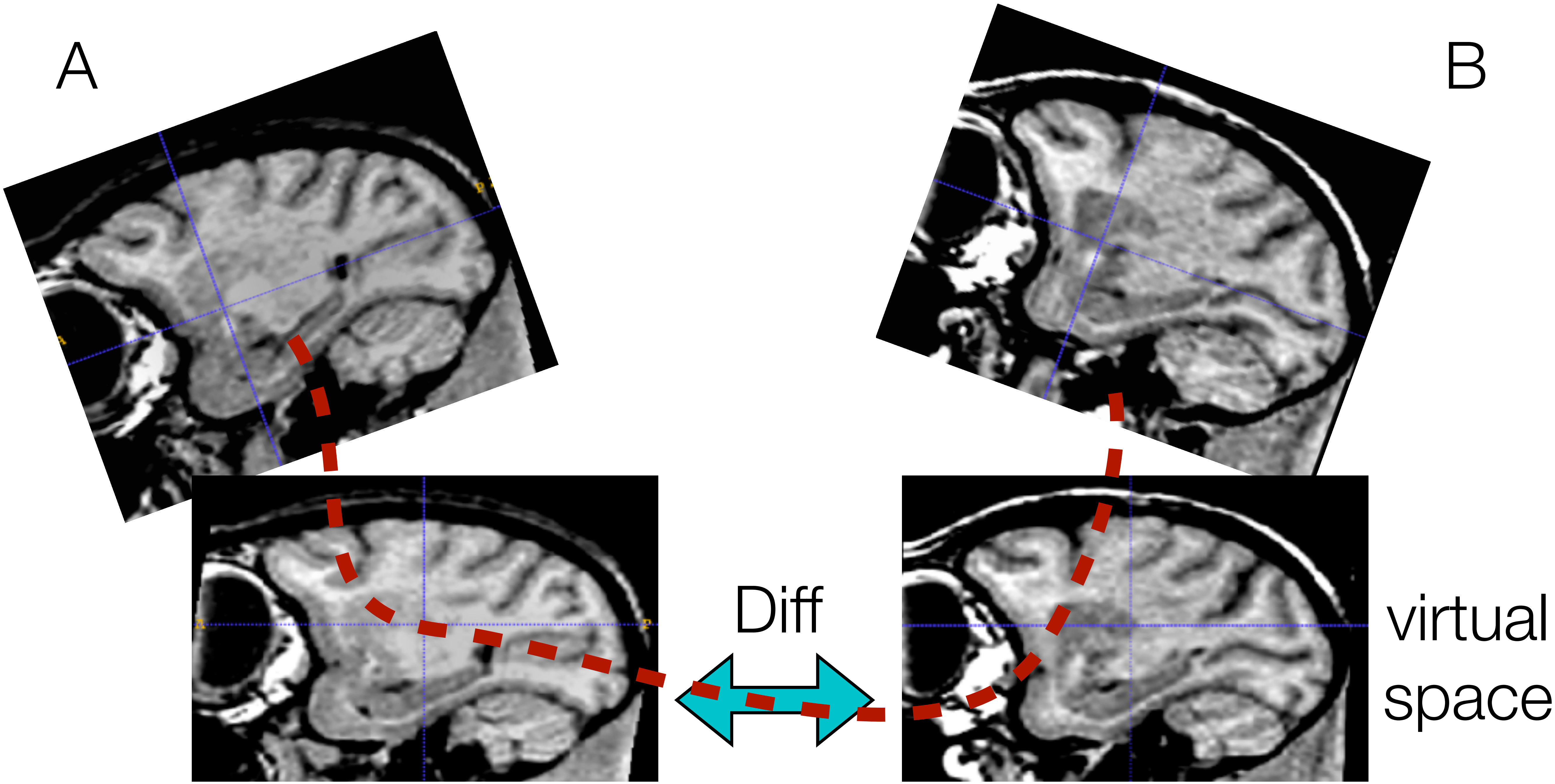
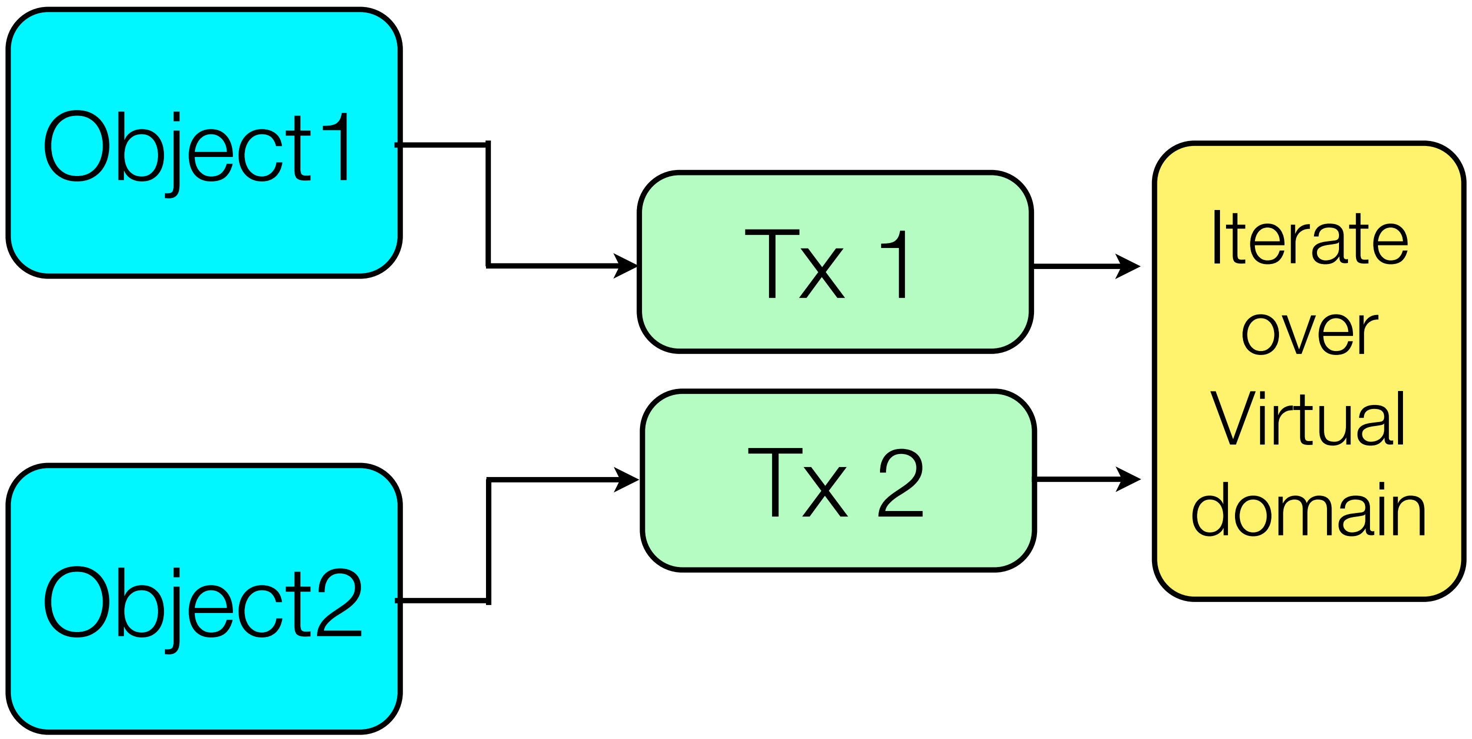


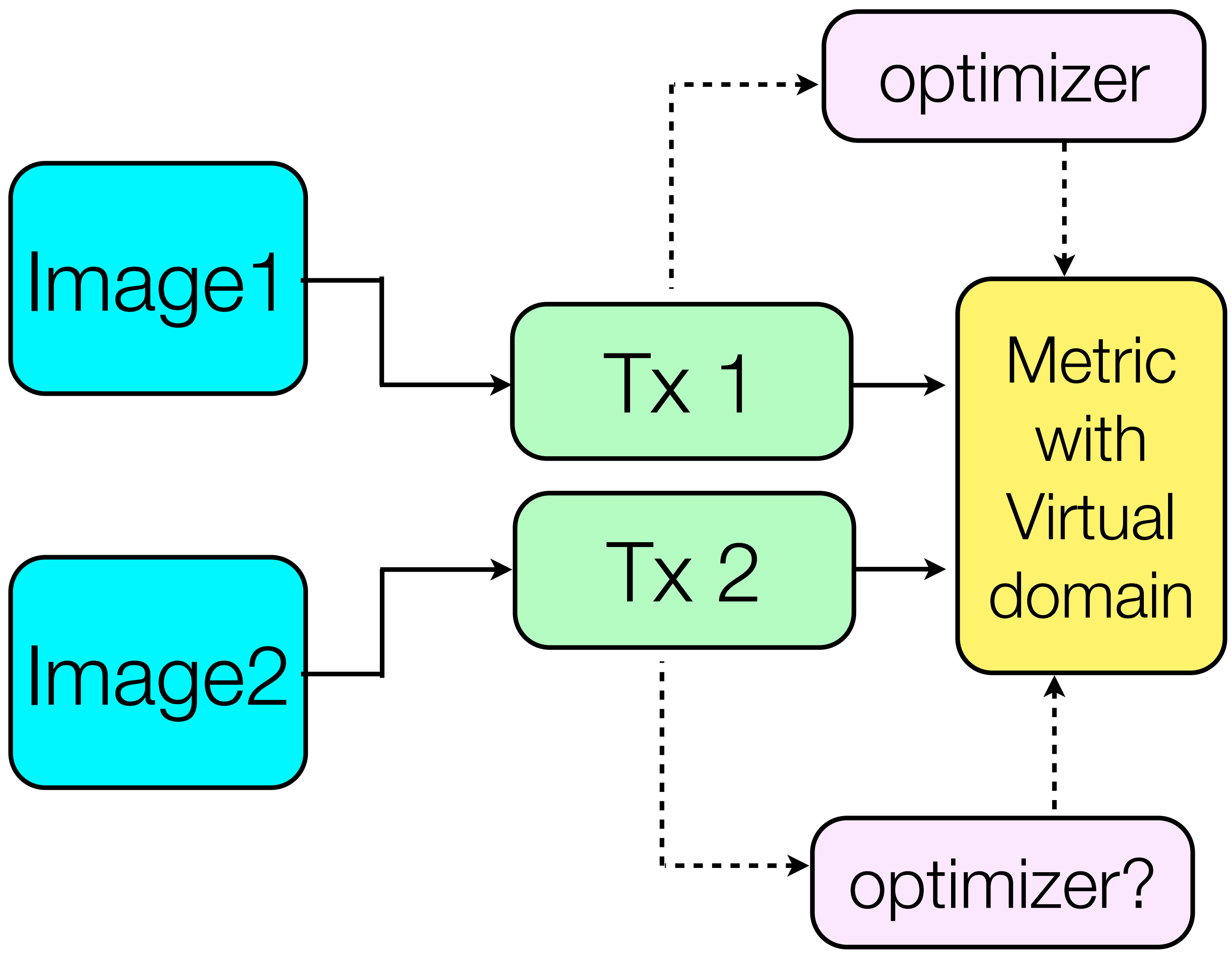
Important for longitudinal studies (Yushkevich, et al, 2010)

Object to object metric



Requires a generic iterator type.

Registration machinery object



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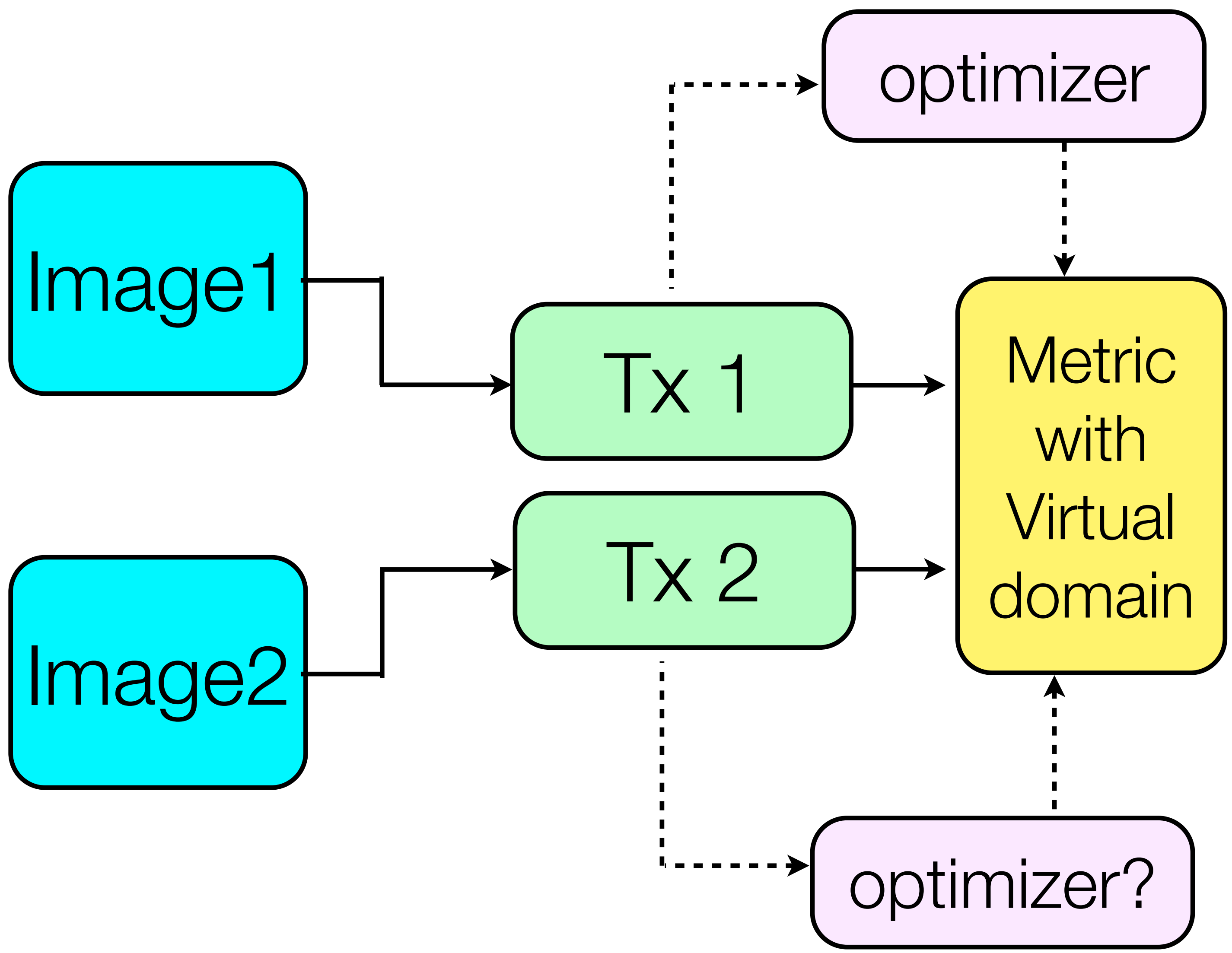

Virtual domain a critical component. Downsampling, more.

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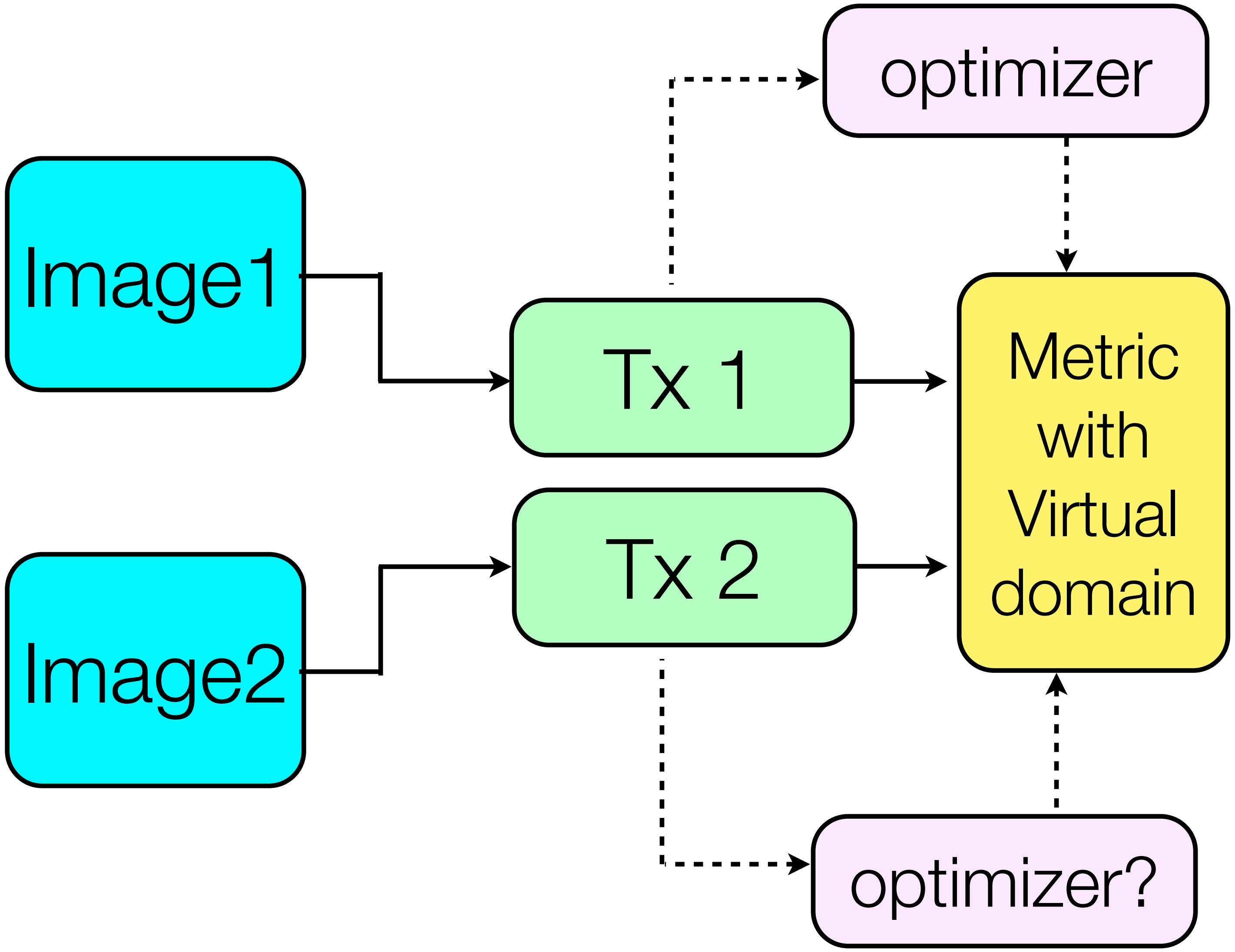

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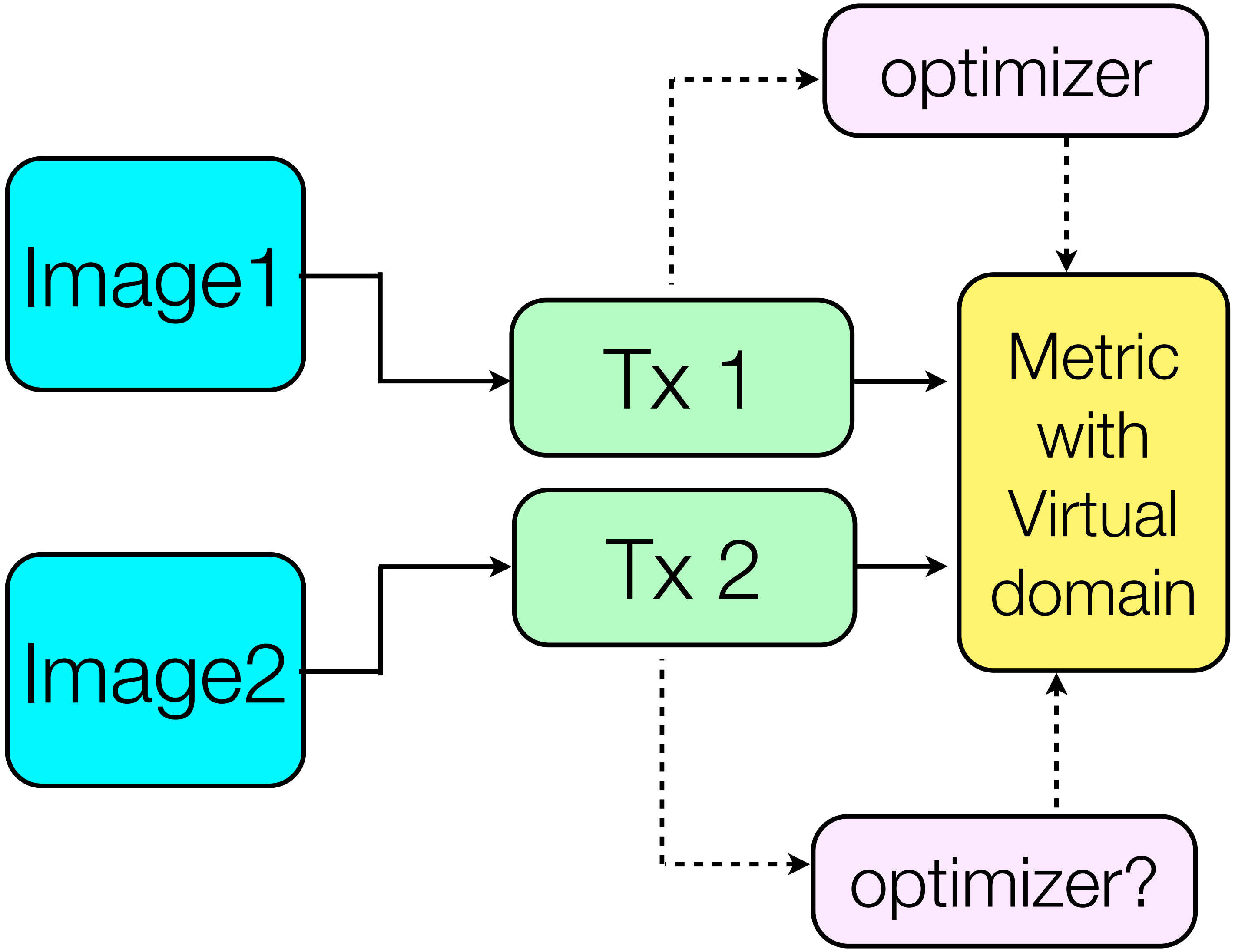

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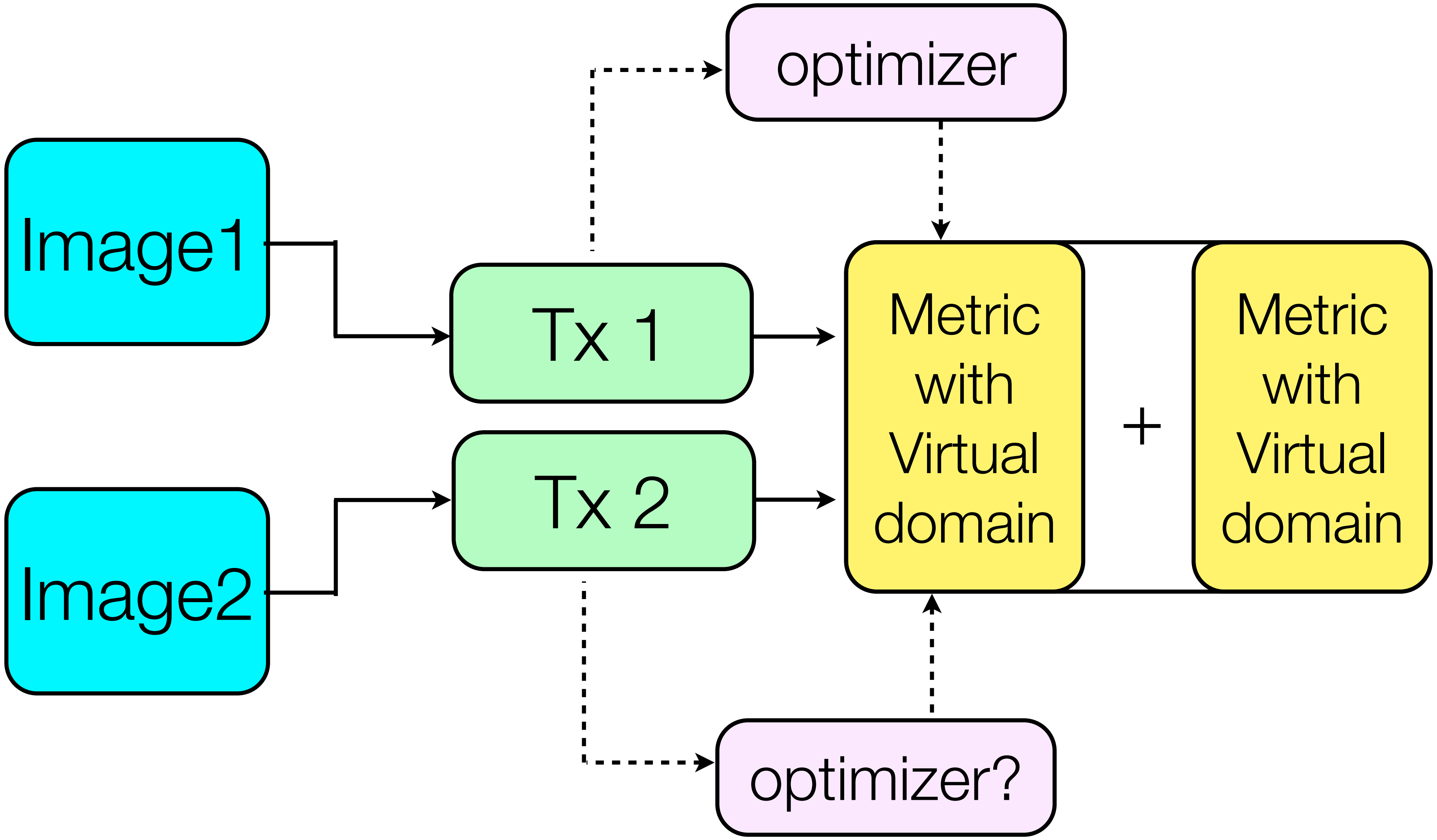

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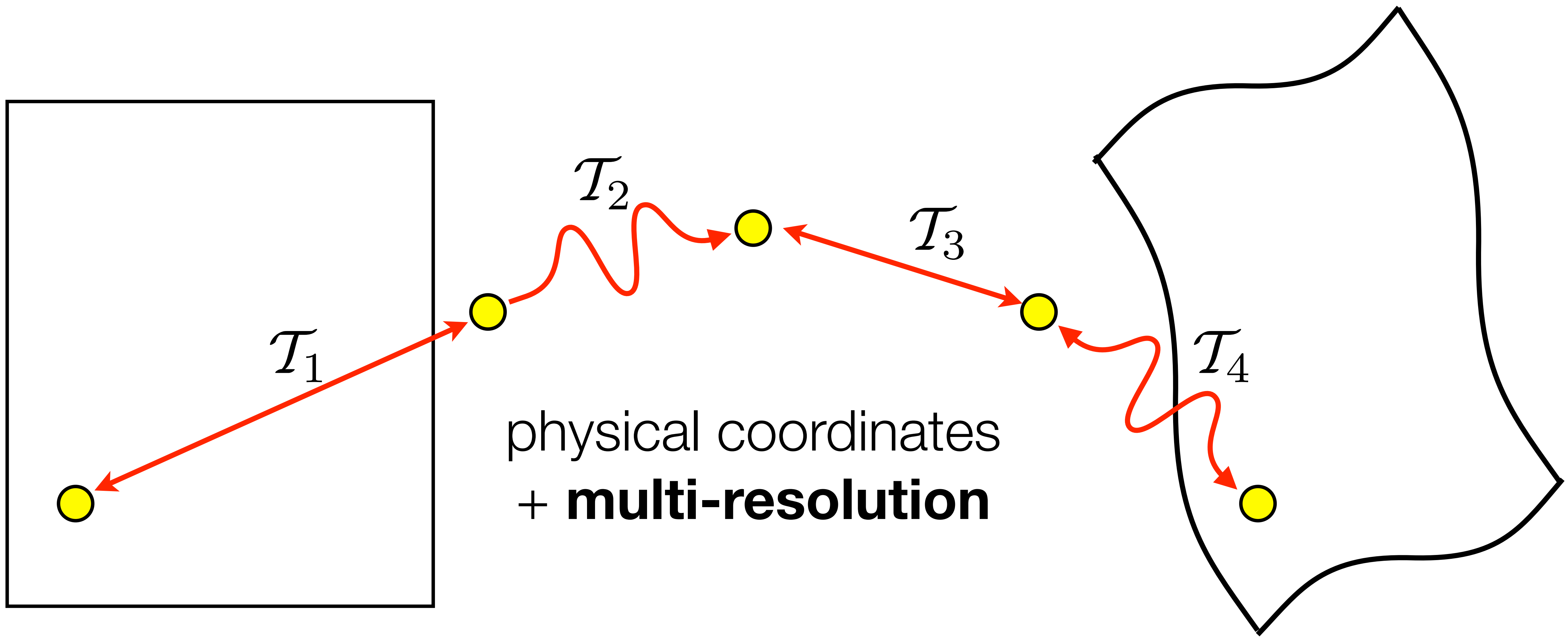
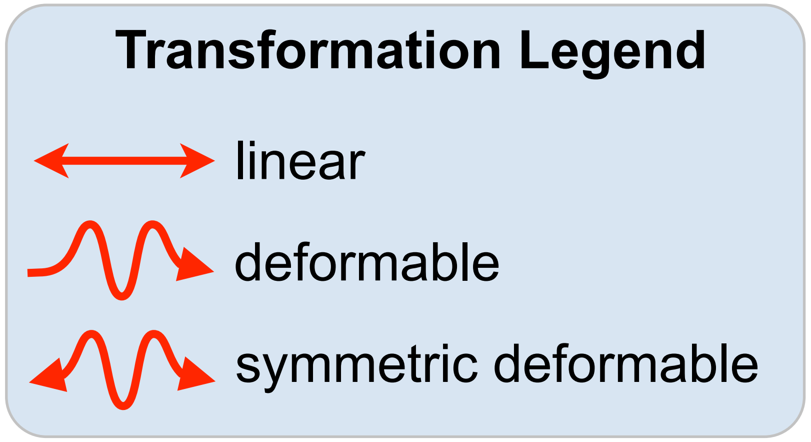
Composite transform



$$\mathcal{T} = \mathcal{T}_1 \circ \mathcal{T}_2 \circ \mathcal{T}_3 \circ \mathcal{T}_4$$



Accompanied by composite I/O.
Details need to be worked out.

Deformable transformation objects

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./ITK/Code/Review/itkDeformationFieldTransform.h

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Should therefore remove WarpImageFilter

This helps us unify the PDE and linear registration frameworks.

Registration machinery code 1

```
typedef itk::Transform<double,ImageDimension>  TransformType;
typedef itk::IdentityTransform<double,ImageDimension>  IdentityTransformType;
typedef itk::CompositeTransform<double,ImageDimension>  CompositeTransformType;
typedef itk::TranslationTransform<double,ImageDimension>  TranslationTransformType;
typedef itk::DeformationFieldTransform<double,ImageDimension>  DeformationTransformTy
typedef DeformationTransformType::DeformationFieldType FieldType;
IdentityTransformType::Pointer transformF = IdentityTransformType::New();
DeformationTransformType::Pointer transformM1 = DeformationTransformType::New();
TranslationTransformType::Pointer transformM2 = TranslationTransformType::New();
TranslationTransformType::Pointer transformM3 = TranslationTransformType::New();
CompositeTransformType::Pointer transformM = CompositeTransformType::New();
```

Registration machinery code 2

```
typedef itk::DemonsImageToImageMetric<ImageType, ImageType> ObjectMetric
ObjectMetricType::Pointer objectMetric = ObjectMetricType::New();

/** Set up the virtual reference space */
objectMetric->SetVirtualDomainSpacing(fixed_image->GetSpacing());
objectMetric->SetVirtualDomainSize(fixed_image->GetLargestPossibleRegion
objectMetric->SetVirtualDomainOrigin(fixed_image->GetOrigin());
objectMetric->SetVirtualDomainDirection(fixed_image->GetDirection());
```

Registration machinery code 3

```
transformM1->SetDeformationField(field);
transformM1->SetInverseDeformationField(field);

transformM->AddTransform(transformM1);
transformM->AddTransform(transformM2);

/** Define the input images and their transforms */
objectMetric->SetFixedImage(fixed_image);
objectMetric->SetMovingImage(moving_image);
objectMetric->SetFixedImageTransform(transformF);
objectMetric->SetMovingImageTransform(transformM);

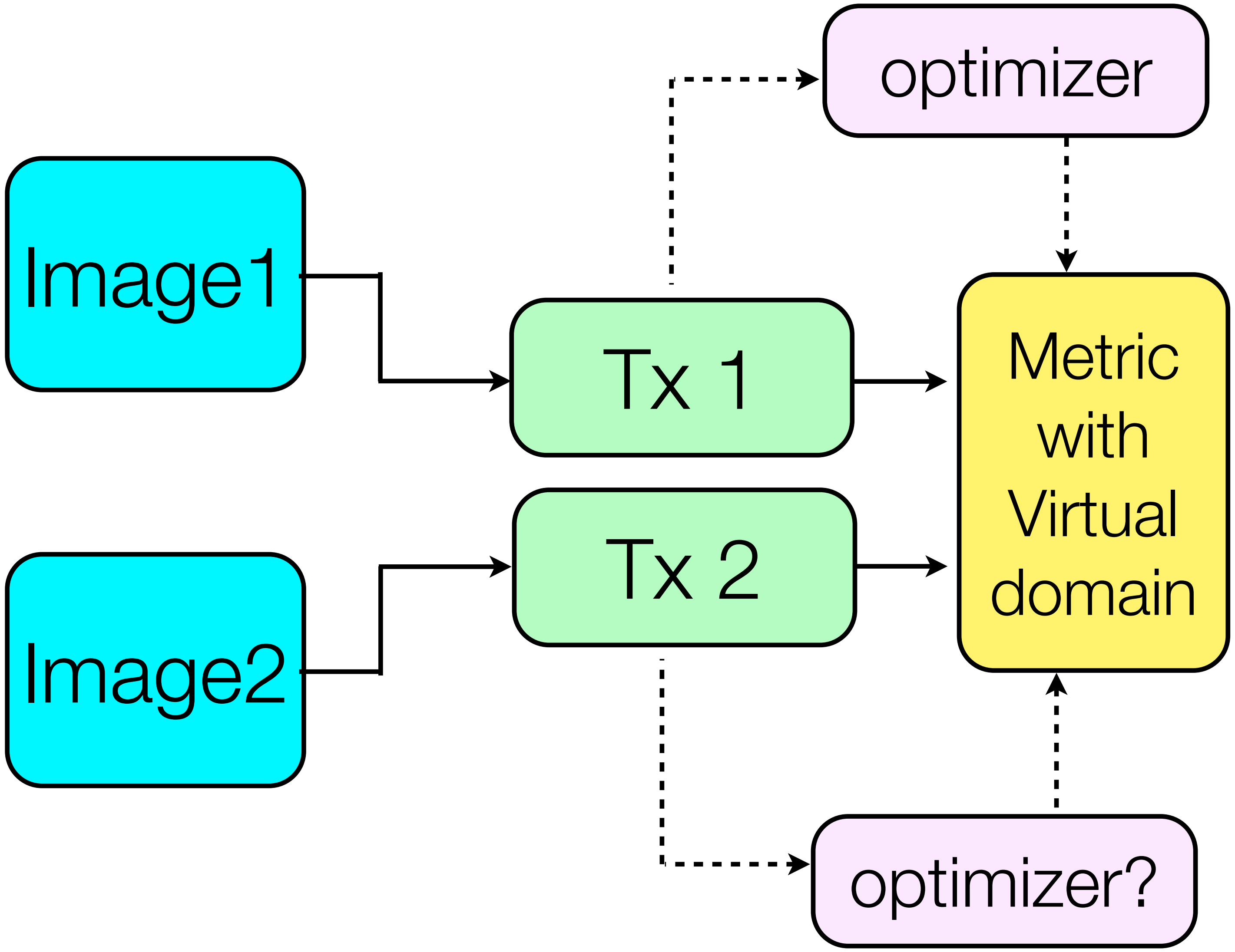
/** Compute one iteration of the metric */
objectMetric->ComputeMetricAndDerivative();
```

Object to object metric code

```
this->m_VirtualImage->TransformIndexToPhysicalPoint(ItV.GetIndex(),mappedPoint);

// Use generic transform to compute mapped position
mappedFixedPoint = this->m_FixedImageTransform->TransformPoint(mappedPoint);
mappedMovingPoint = this->m_MovingImageTransform->TransformPoint(mappedPoint);
if ( !this->m_FixedInterpolator->IsInsideBuffer(mappedFixedPoint) ||
     !this->m_MovingInterpolator->IsInsideBuffer(mappedMovingPoint) )
  sampleOk=false;
if ( sampleOk )
  {
    double metricval=this->ComputeLocalContributionToMetricAndDerivative(mappedFixedPoint,ma
```

Automated parameter setting



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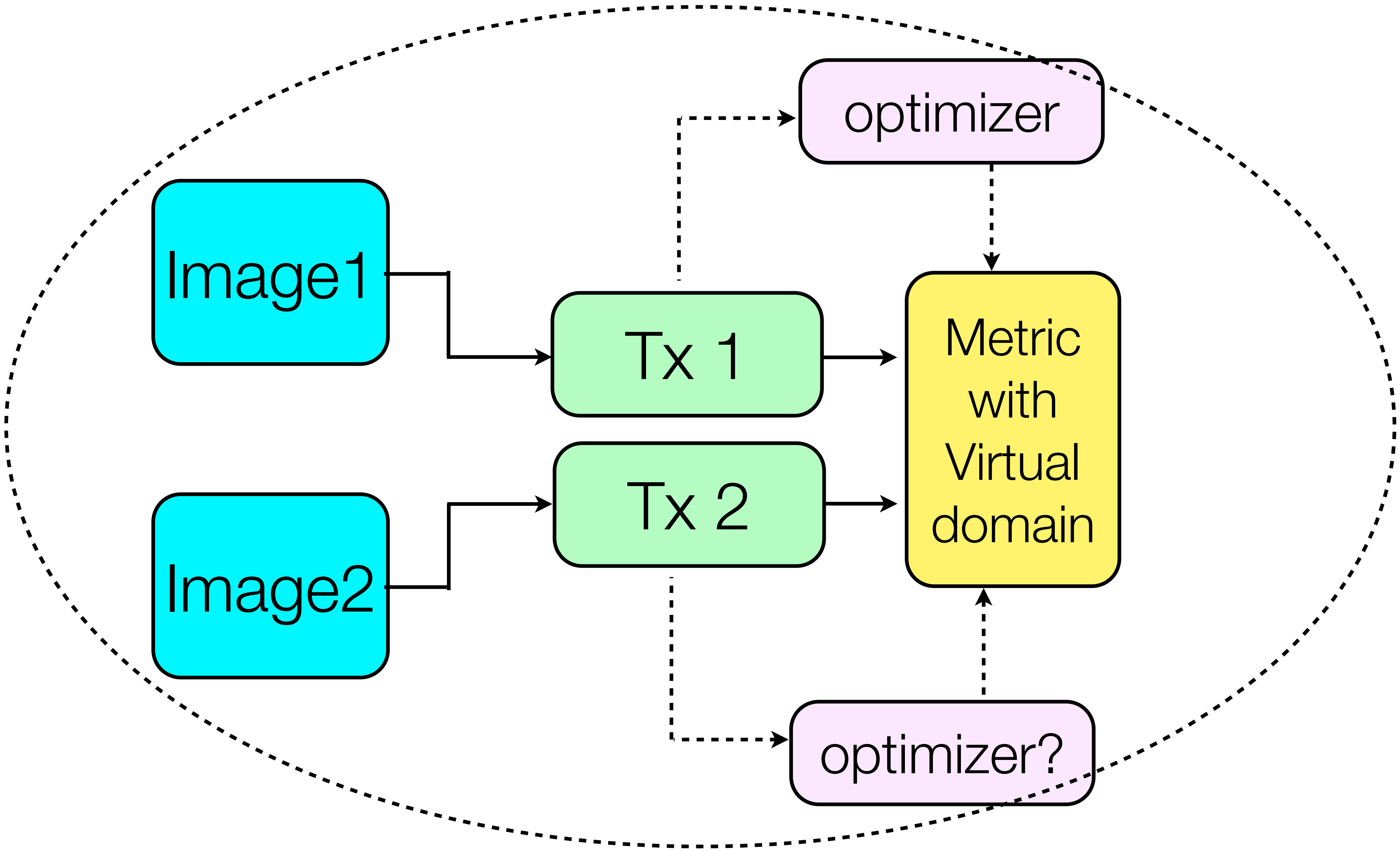

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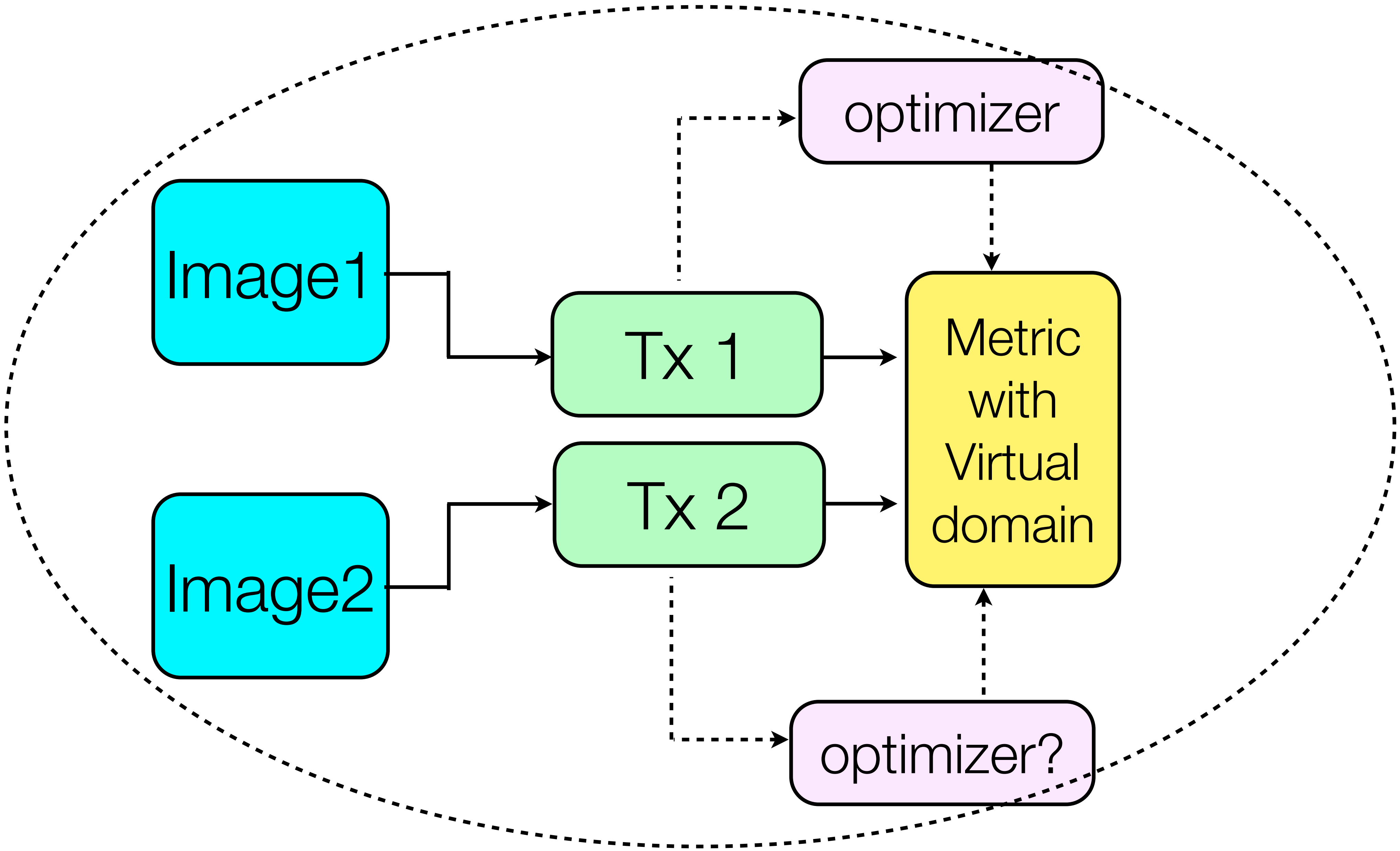
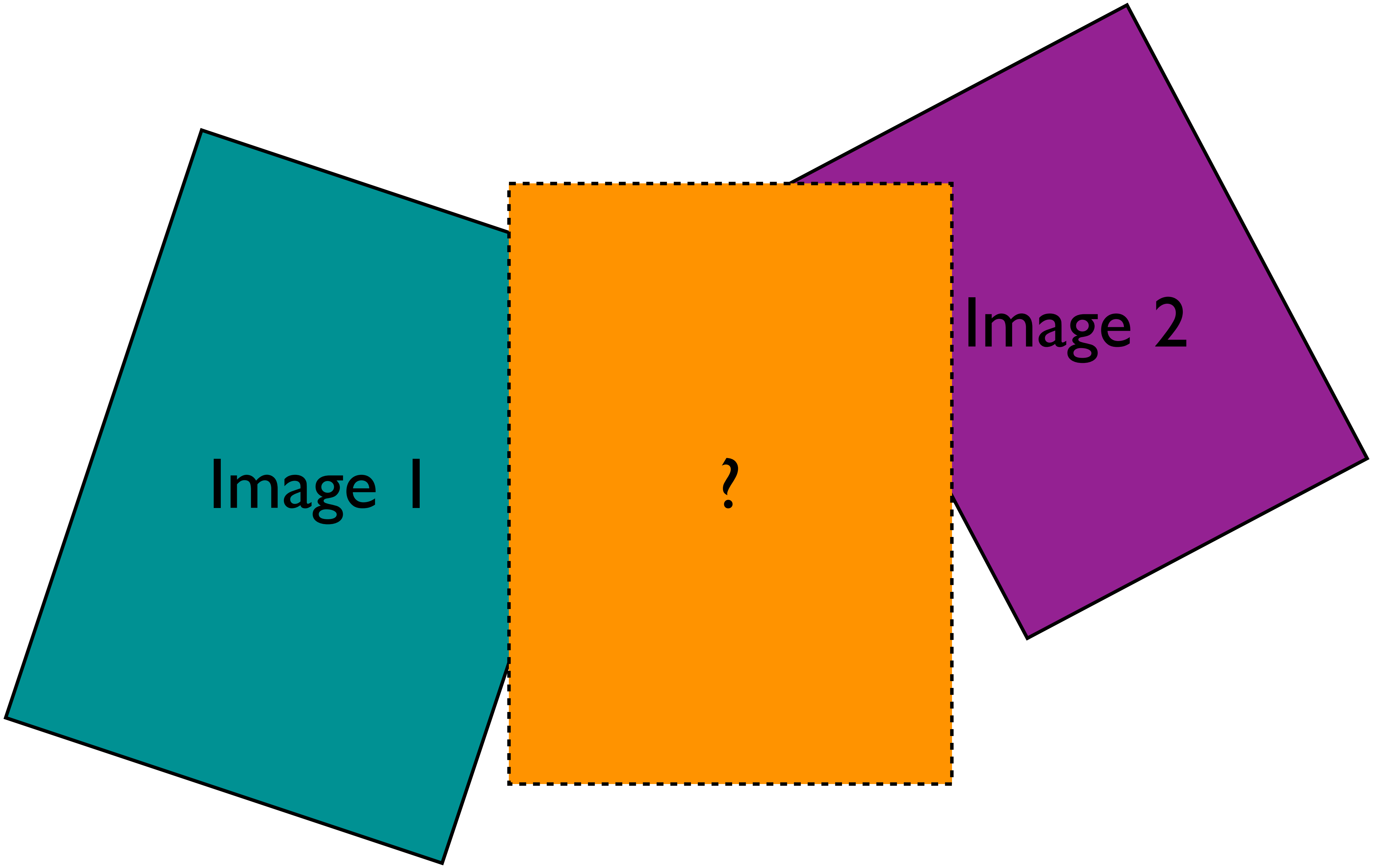


Takes the registration machinery object as input and sets the optimizer parameters according to a TBD algorithm.

Virtual space initializer



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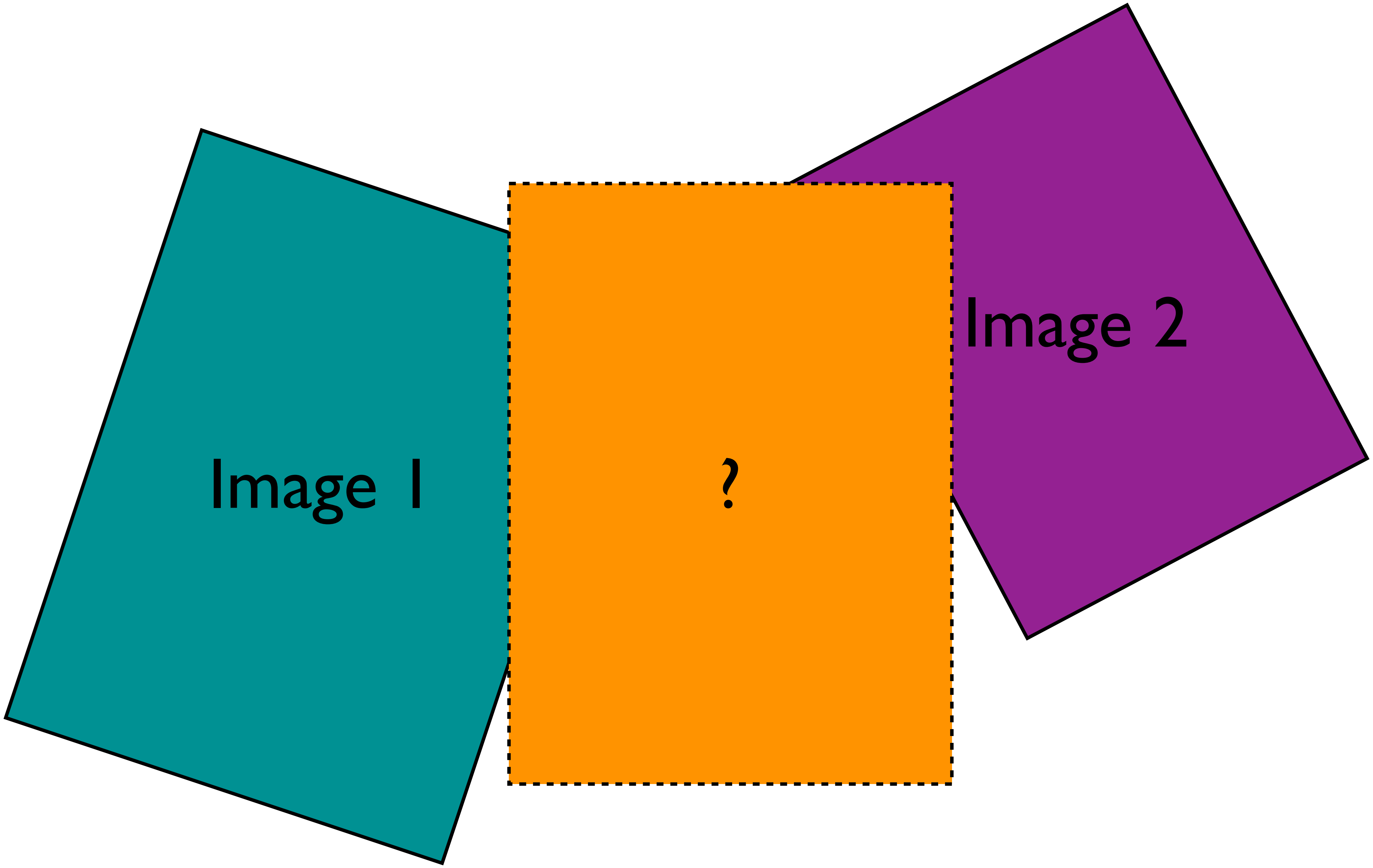

what is the best “average domain”?

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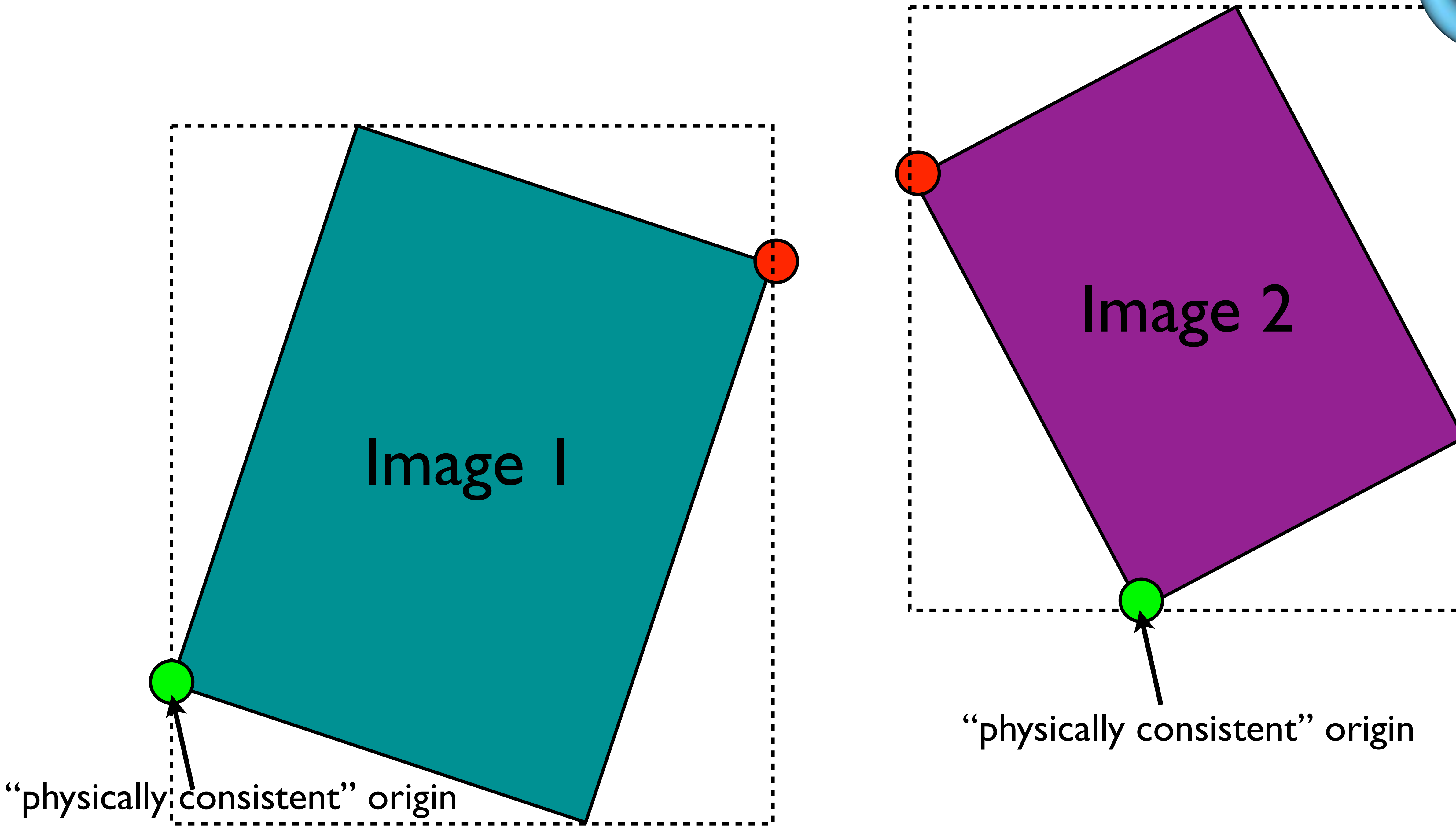

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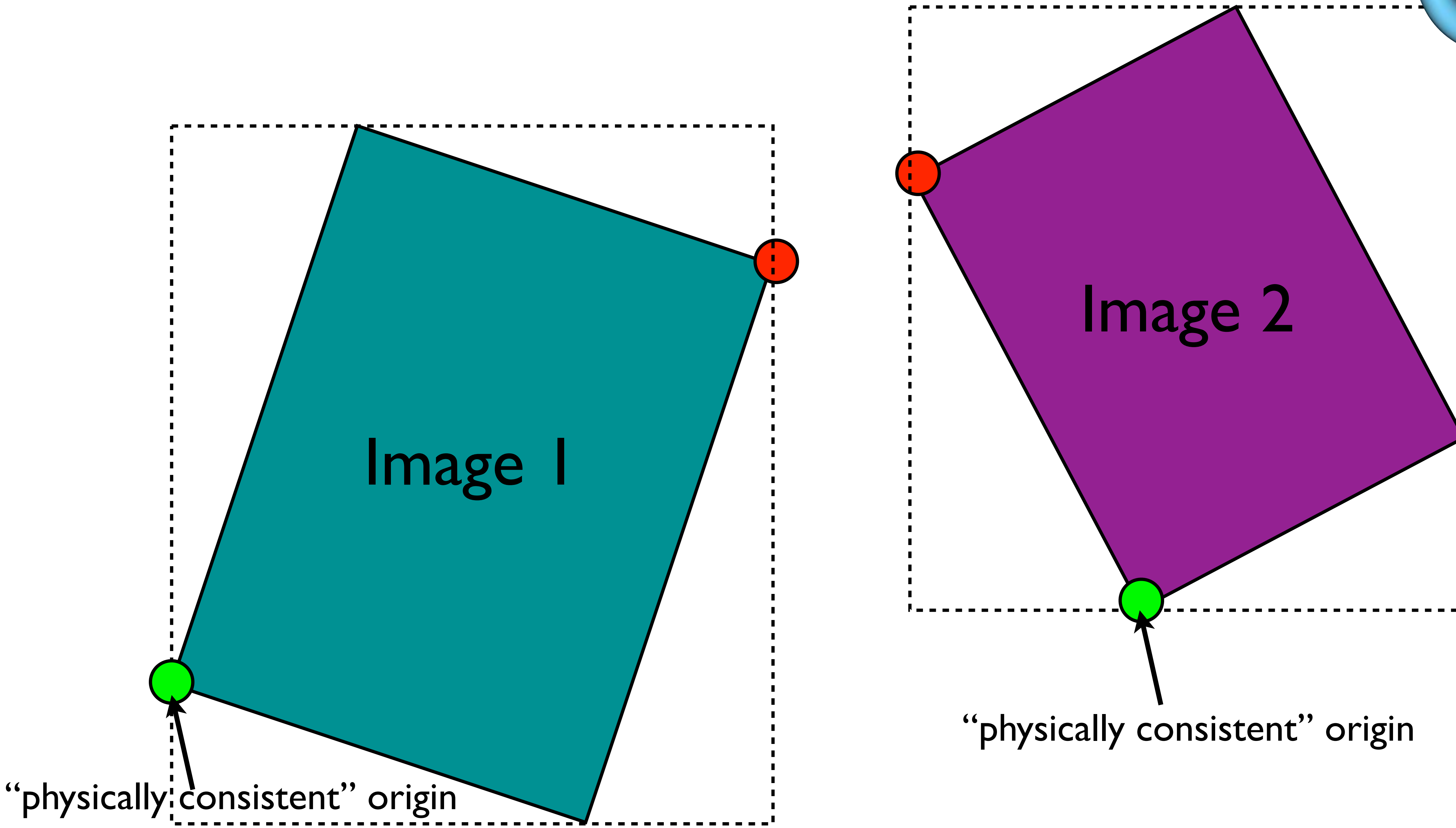

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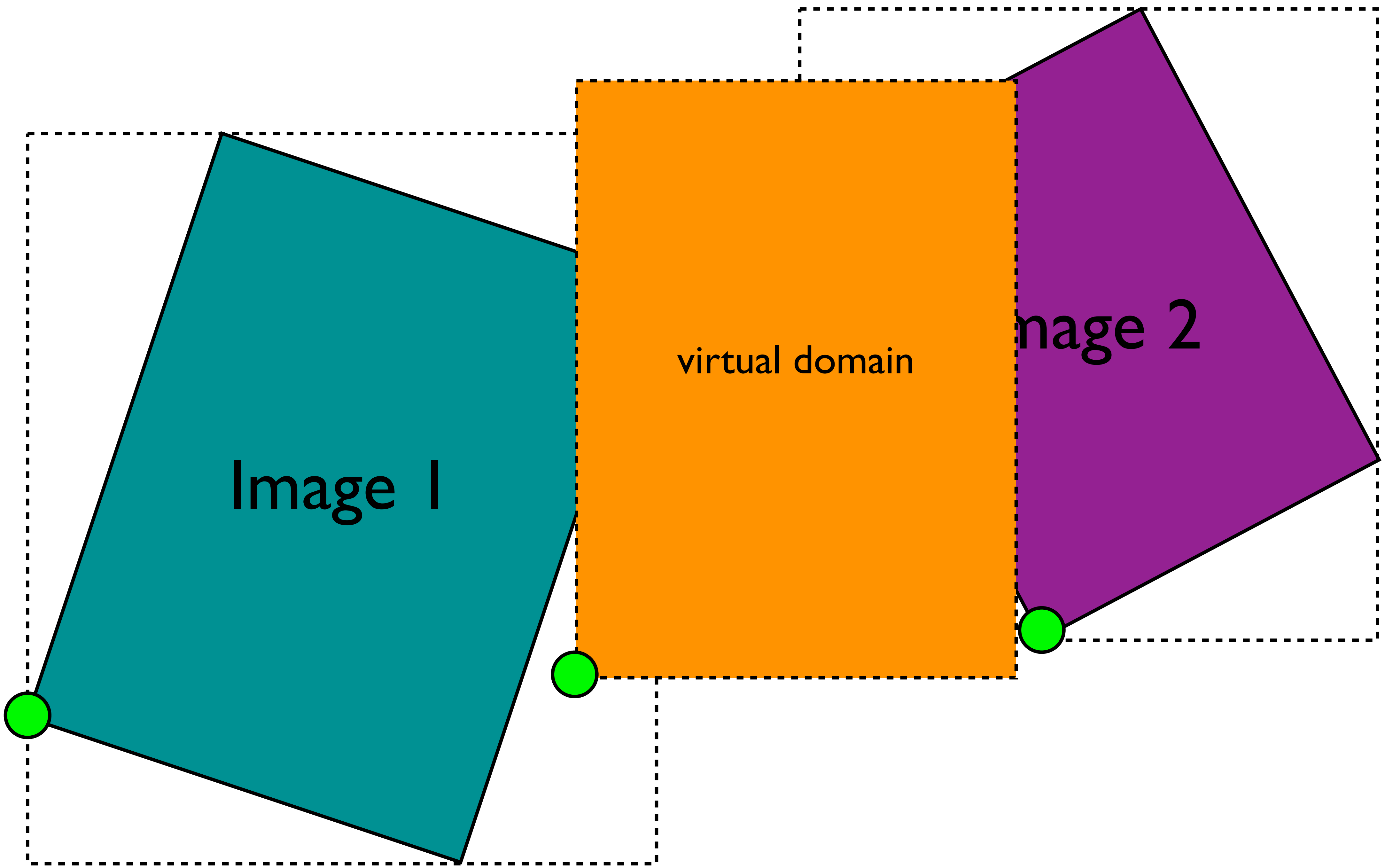

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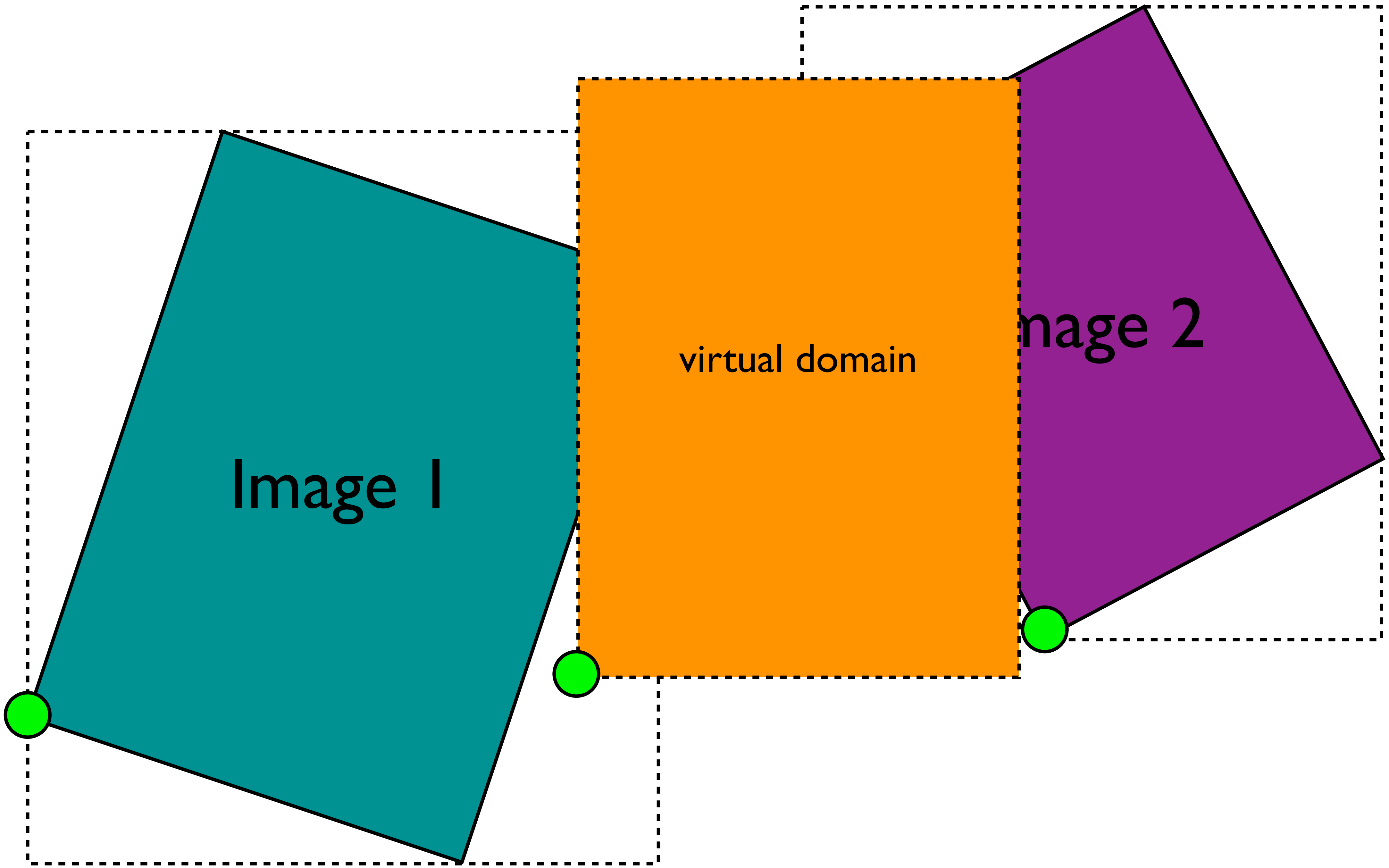

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Changes to transform + metric

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Revised framework supports dense metric computation with or without use of Jacobian

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Critical for efficient deformable registration

Neighborhood correlation metric

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Sliding window implementation of both metric and derivative.

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Independent metric development needs to be unified.

Transducer function (@ github)

$$E(\phi, \mathbf{I}, \mathbf{J}) = \sum_i \lambda_i S_i(\phi, I_i, J_i)$$

$$\phi \in Diff_0$$

$$S_i \in \{\ MI,\ CC,\ \|\cdot\|^2,$$

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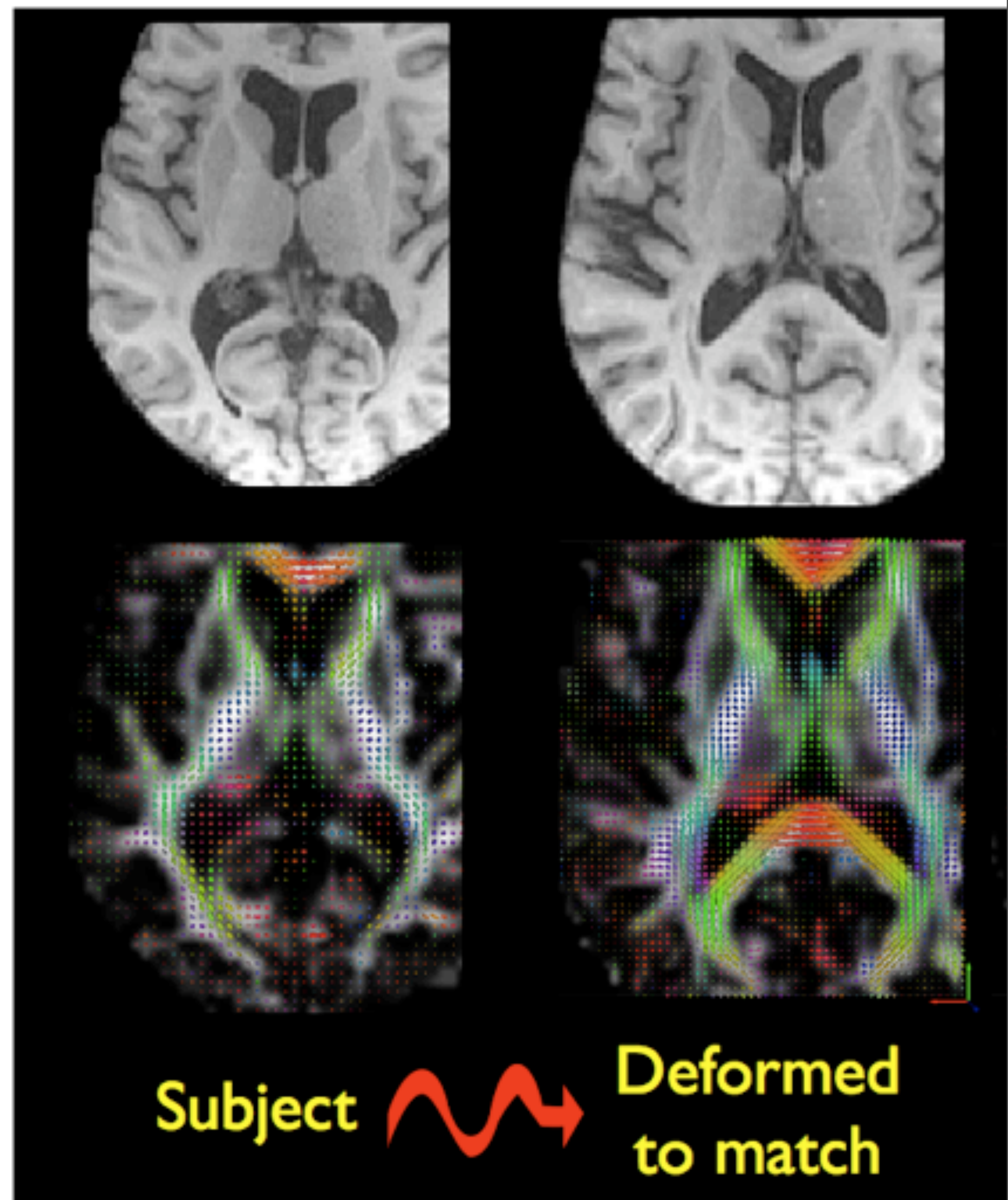
$$\phi T = (D\phi)T(\phi)$$



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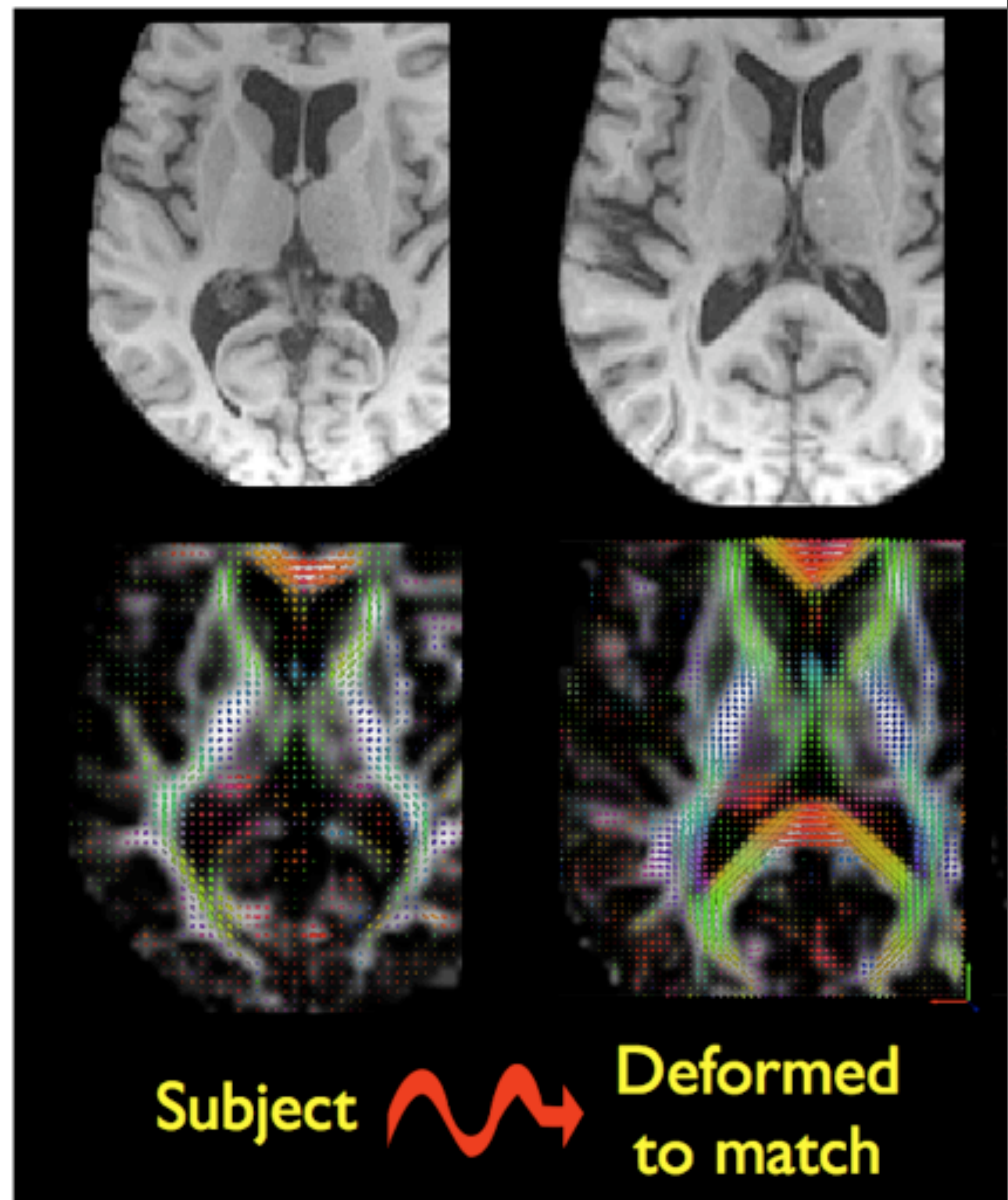

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Need to make efficient for the case when Transducer=Identity

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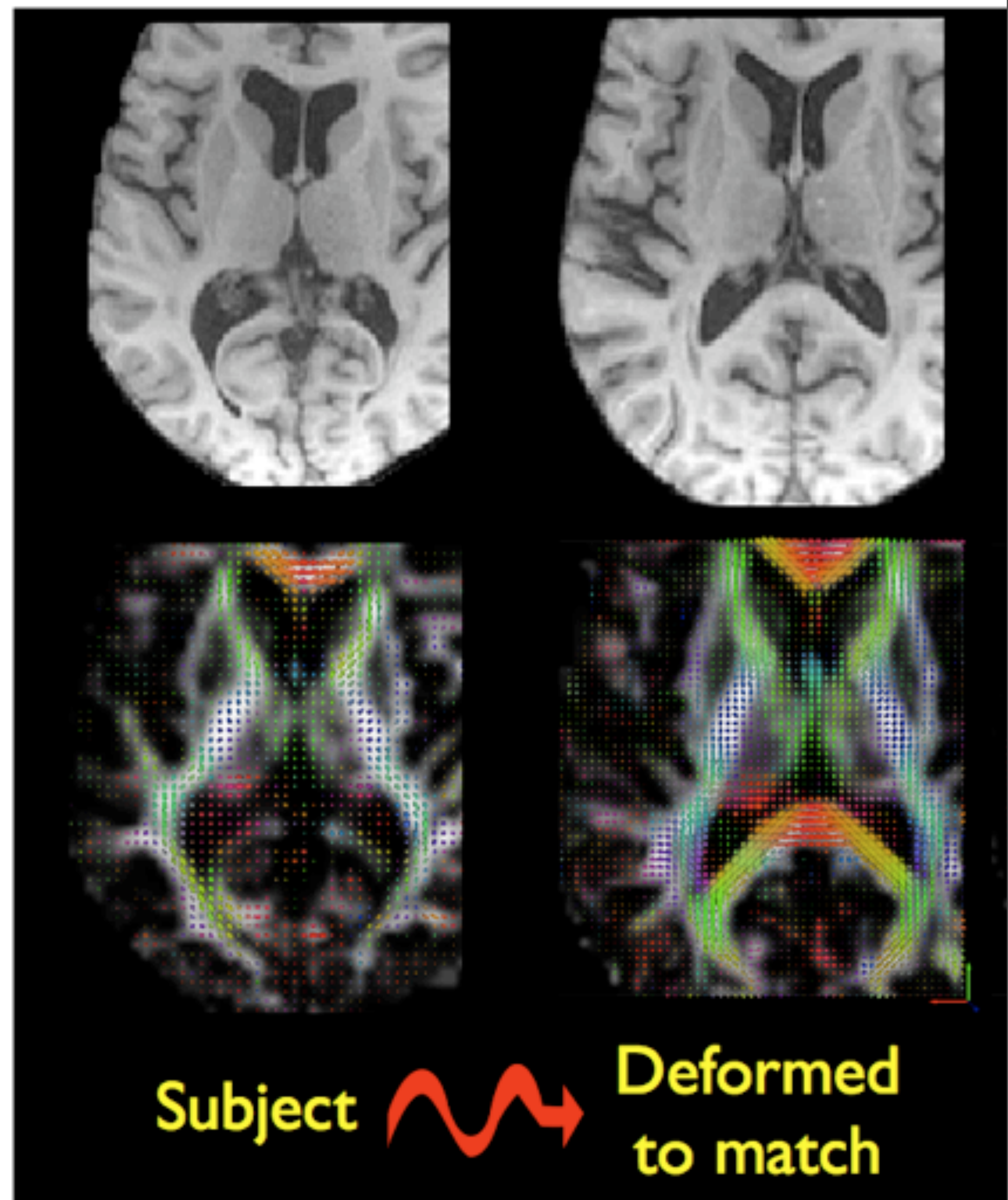

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- Rename these transforms?

B-spline transform domain

itkBSplineDeformableTransform (lines 179-187)

```
// Set the valid region
// If the grid spans the interval [start, last].
// The valid interval for evaluation is [start+offset, last-offset]
// when spline order is even.
// The valid interval for evaluation is [start+offset, last-offset)
// when spline order is odd.
// Where offset = floor(spline / 2 ).
// Note that the last pixel is not included in the valid region
// with odd spline orders.
```

B-spline transform domain

itkBSplineDeformableTransform (lines 179-187)

```
// Set the valid region
// If the grid spans the interval [start, last].
// The valid interval for evaluation is [start+offset, last-offset]
// when spline order is even.
// The valid interval for evaluation is [start+offset, last-offset)
// when spline order is odd.
// Where offset = floor(spline / 2 ).
// Note that the last pixel is not included in the valid region
// with odd spline orders.
```

This is slightly different from what I understand about B-spline domains.

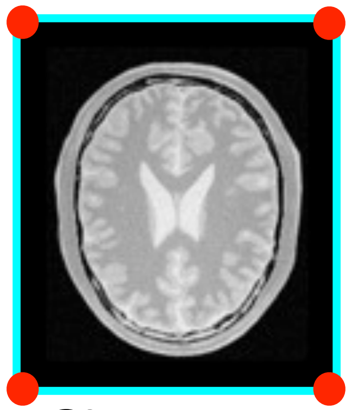
Single element domains with c.p. grid

C^0 splines
SplineOrder = 1

C^2 splines
SplineOrder = 3

C^1 splines
SplineOrder = 2

Single element domains with c.p. grid



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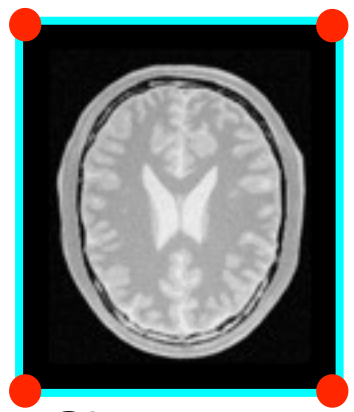
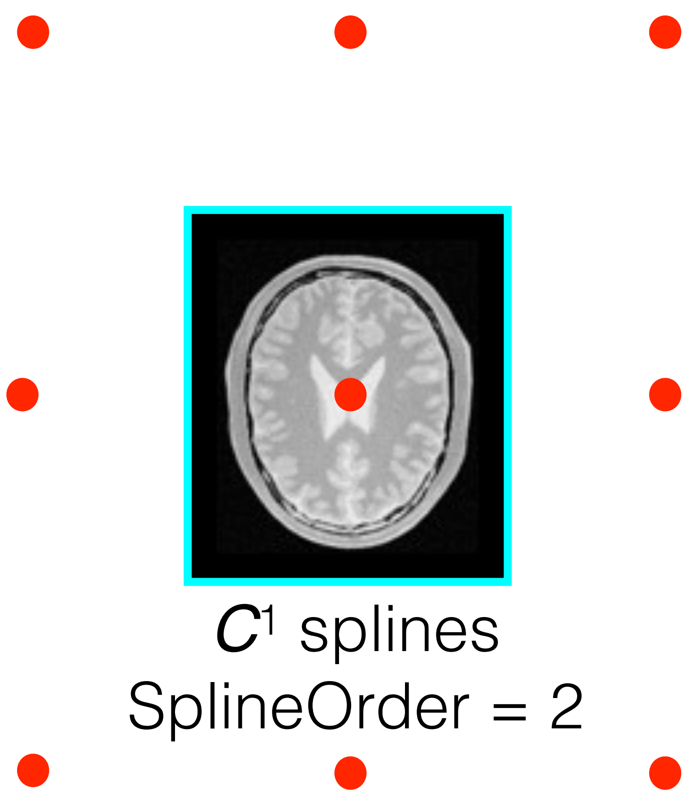


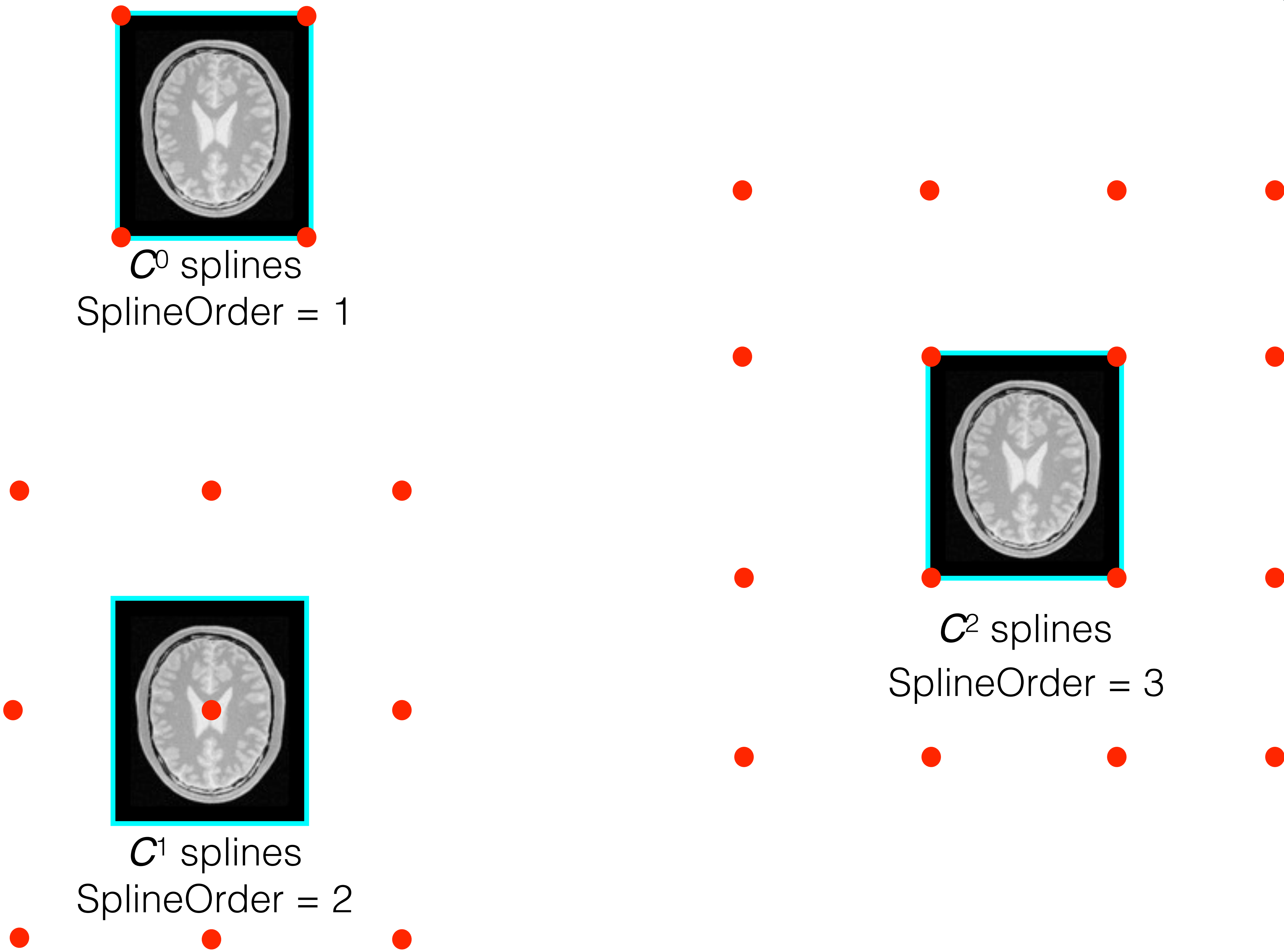
C^0 splines
SplineOrder = 1



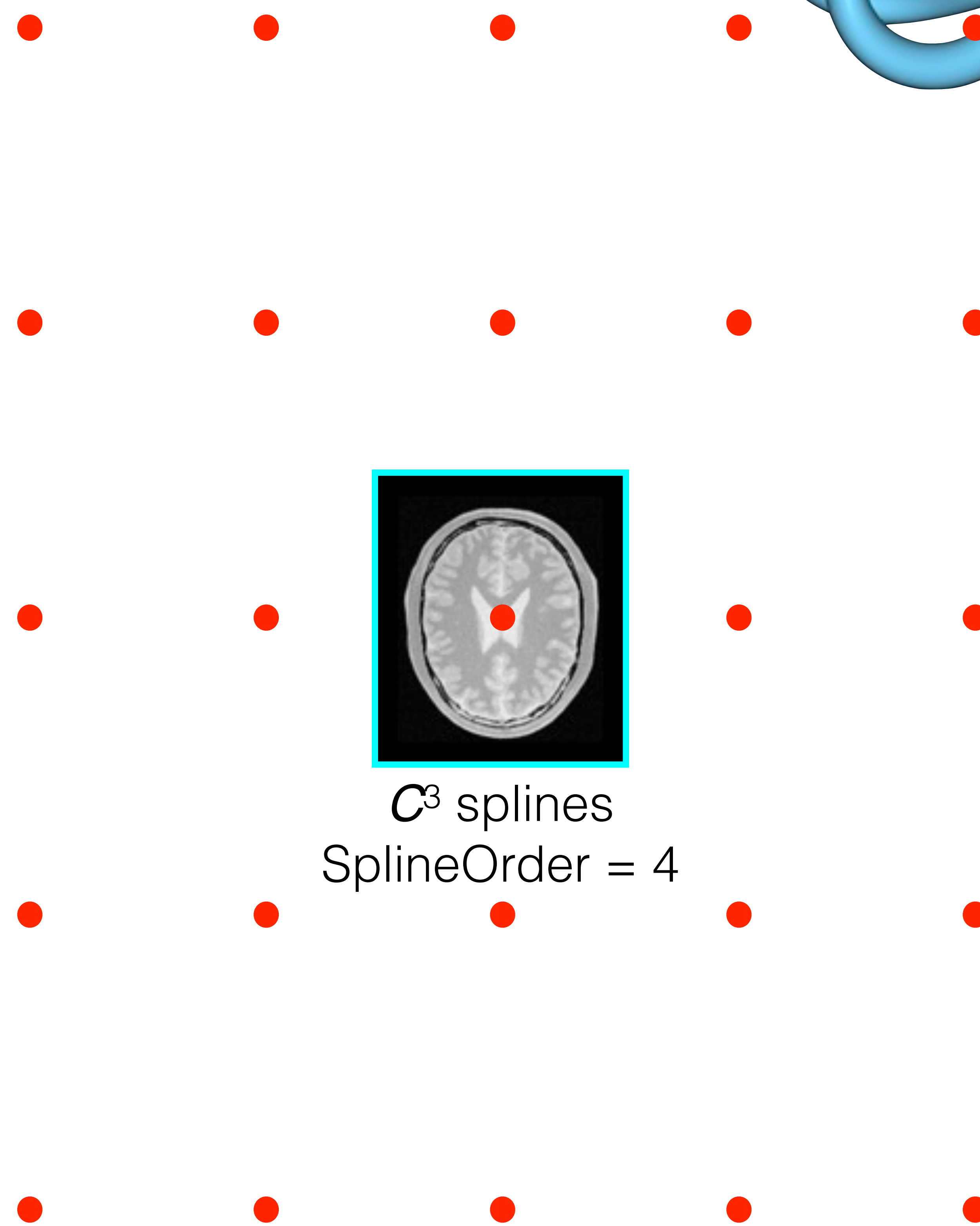
C^1 splines
SplineOrder = 2

C^2 splines
SplineOrder = 3

Single element domains with c.p. grid

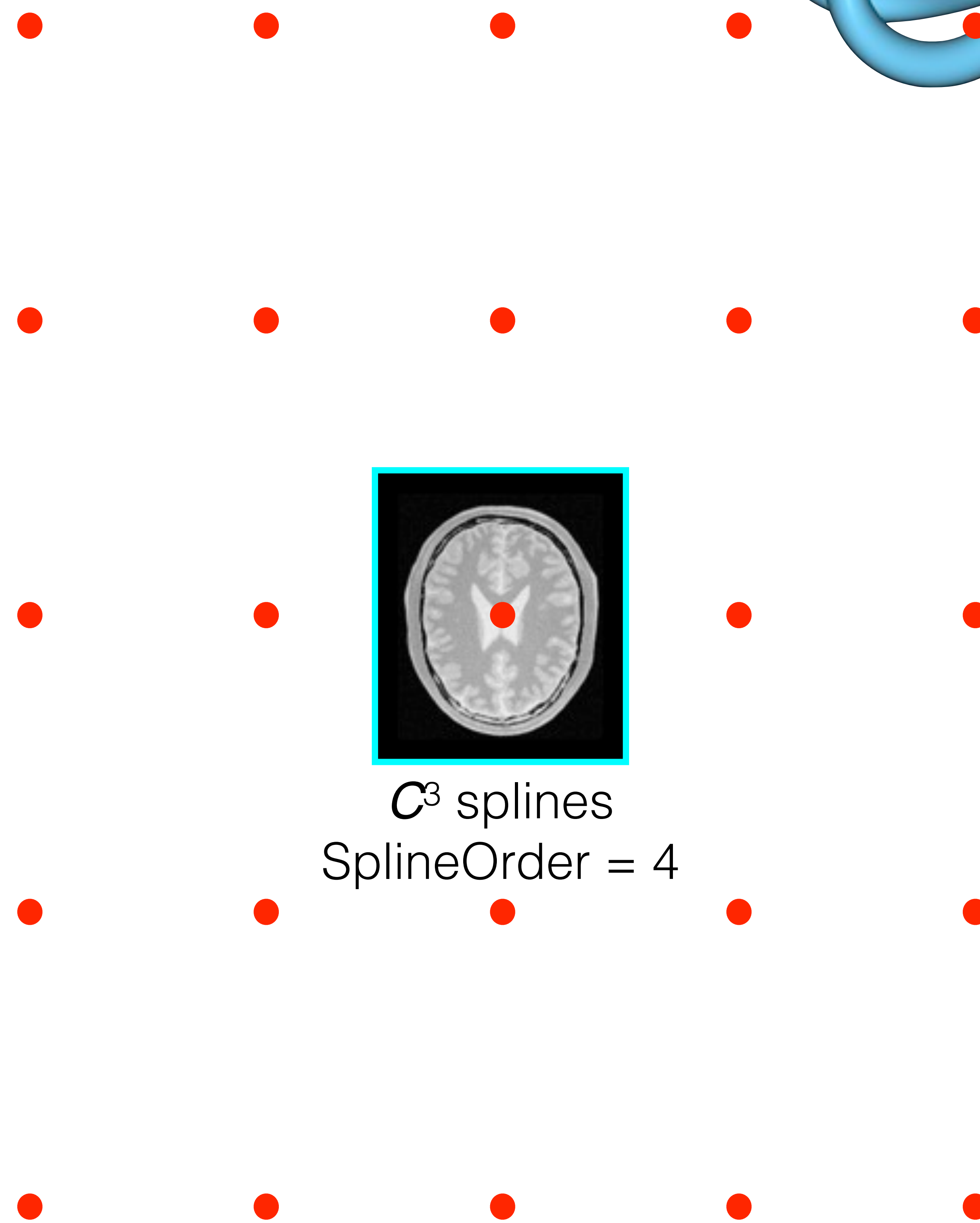


Domain summary



Domain summary

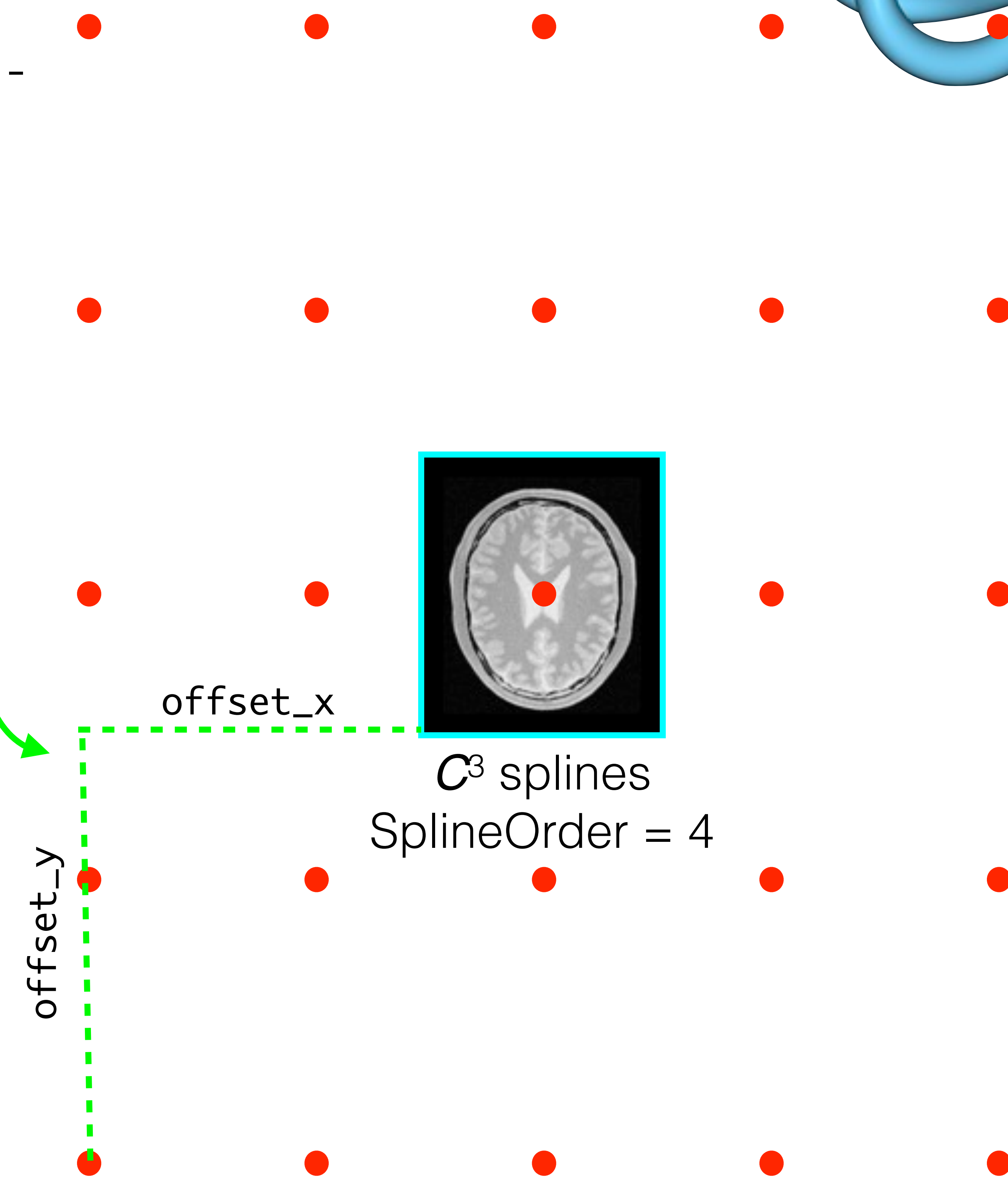
```
meshSize[d] = numberOfControlPoints[d] -
SplineOrder
```



Domain summary

`meshSize[d] = numberOfControlPoints[d] - SplineOrder`

`offset[d] = 0.5 * (SplineOrder - 1 ) * gridSpacing[d]`



Domain summary

```
meshSize[d] = numberOfControlPoints[d] -
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```

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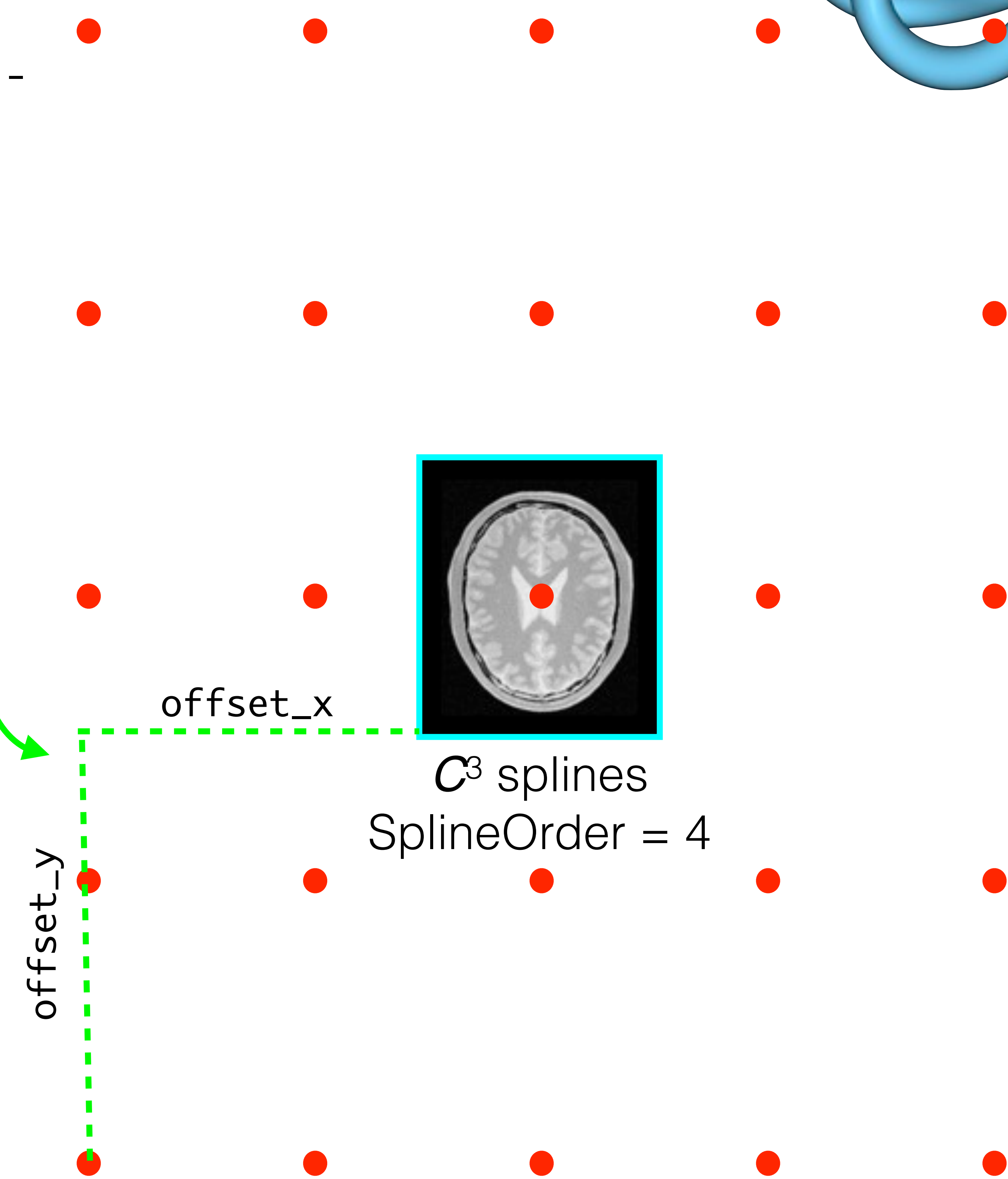
```

control point grid is
centered on the domain



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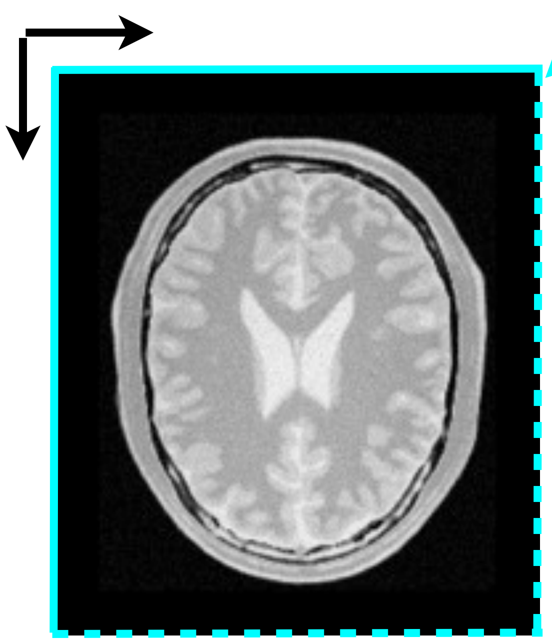
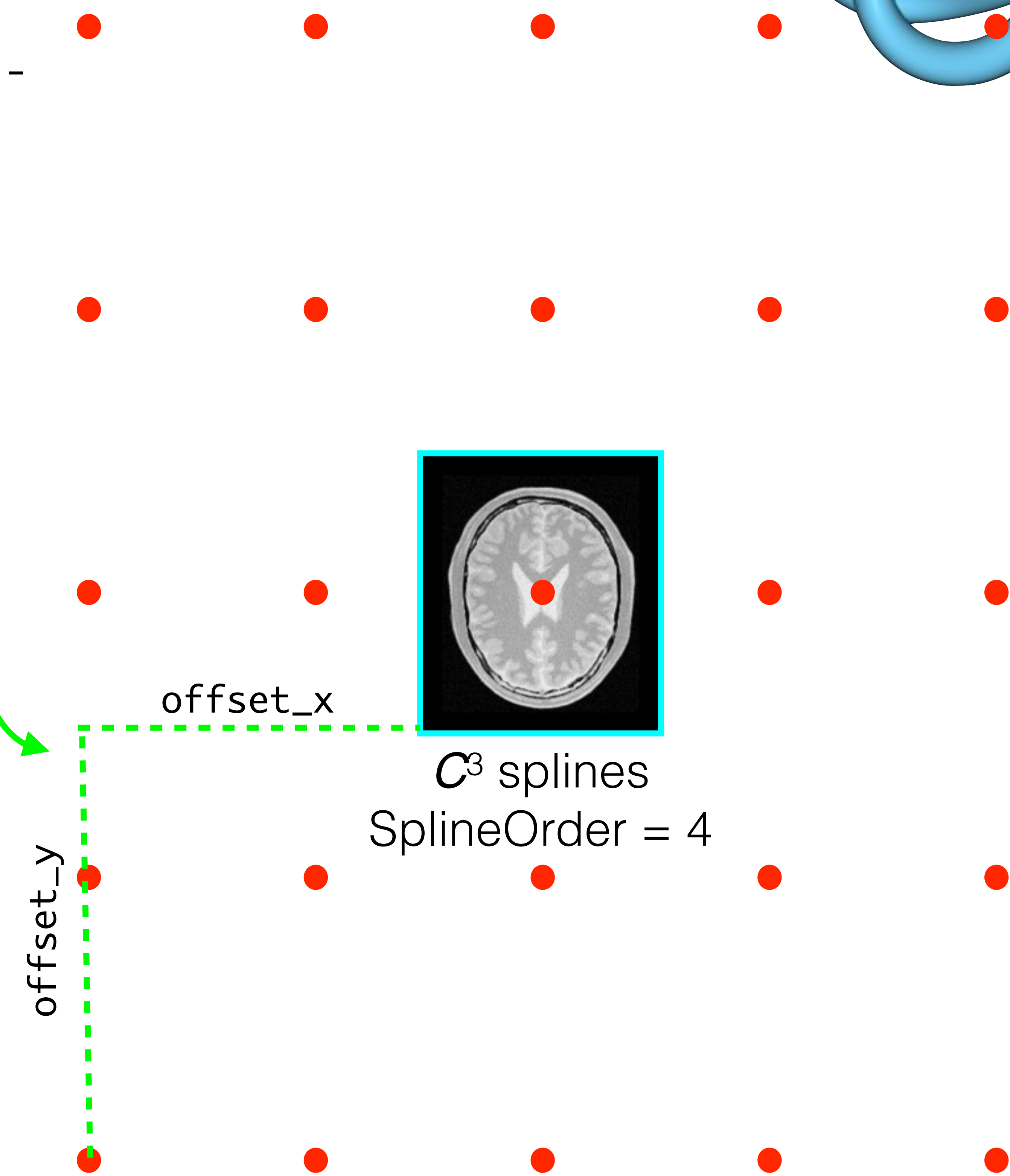
The domain interval is right
open-ended, i.e.





B-spline transform domain changes

Proposed interface change:

```
transform->SetTransformDomainOrigin( origin );
transform->SetTransformDomainPhysicalDimensions( dimensions );
transform->SetTransformDomainDirection( direction );
transform->SetTransformDomainMeshSize( meshSize );
```

This seems to me a much more B-spline-novice friendly interface as the B-spline domain is continuous over a certain finite domain and a typical user can intuit a uniform, rectilinear mesh uniformly placed over that domain of interest (perhaps more FEM-like?).

```
OLD
transform->SetControlPointGridSpacing( something )
transform->SetControlPointGridOrigin( something )
etc
```

B-spline transform initializer

These changes would seemingly obviate the need for a transform initializer except for a “bug” pointed out by Hans Johnson. Since the number of control points in a specific direction directly influences the regularization in the direction, it’s important that the B-spline control point grid is placed relative to the image ***as it resides in physical space***.

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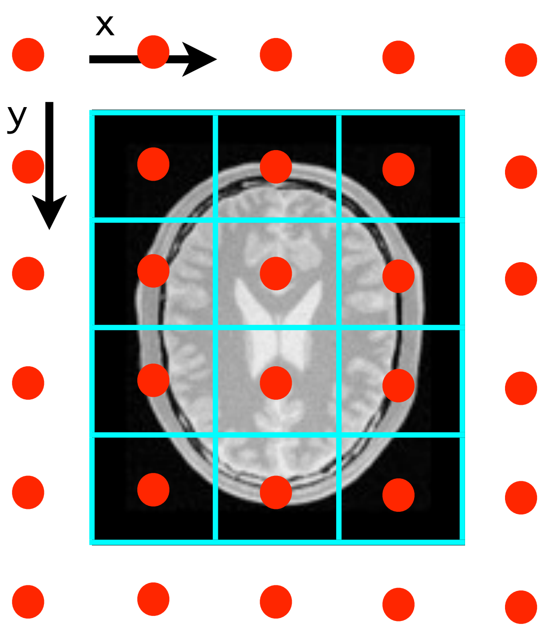

3x4 mesh, quadratic splines, isotropic regularization

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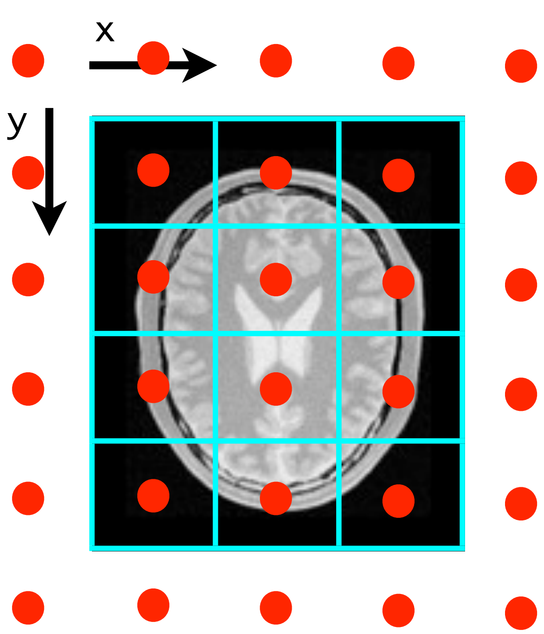

`3x4 mesh, quadratic splines, isotropic regularization`

`itkPermuteAxesImageFilter`

direction cosines change but the image resides in physical space precisely as before

→

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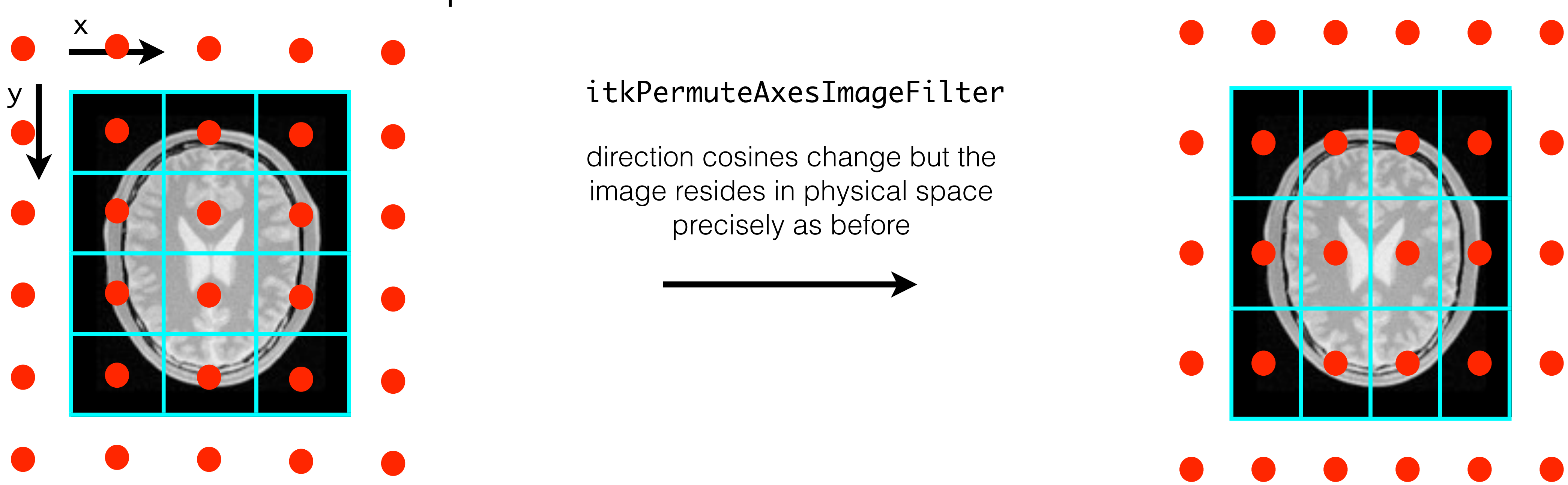

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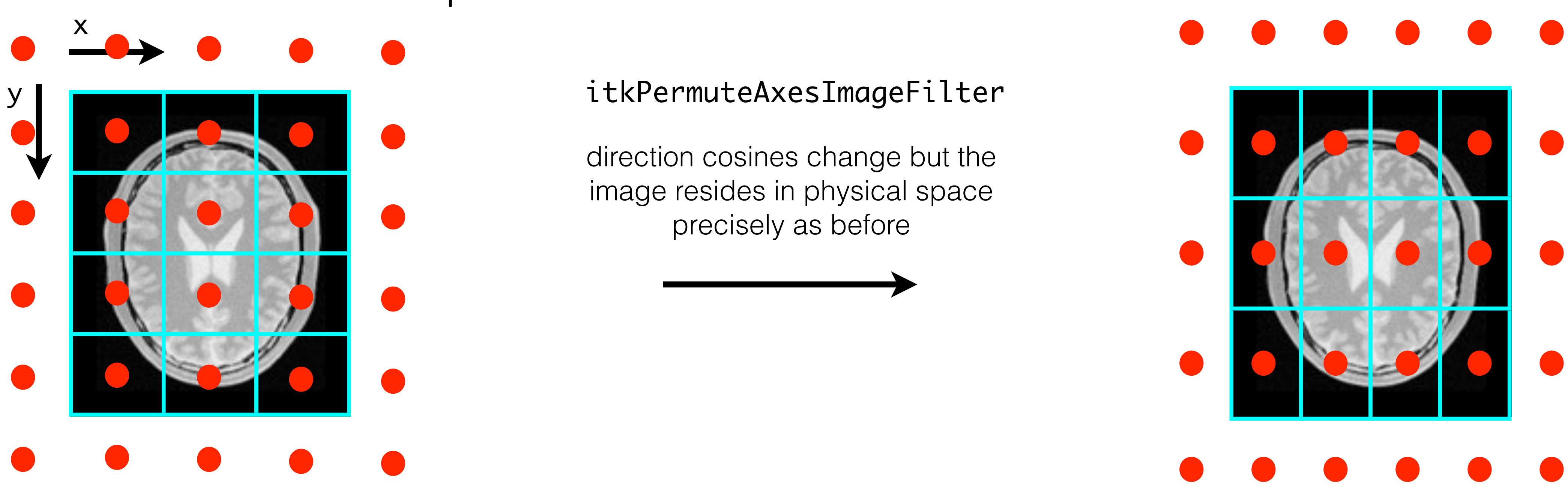


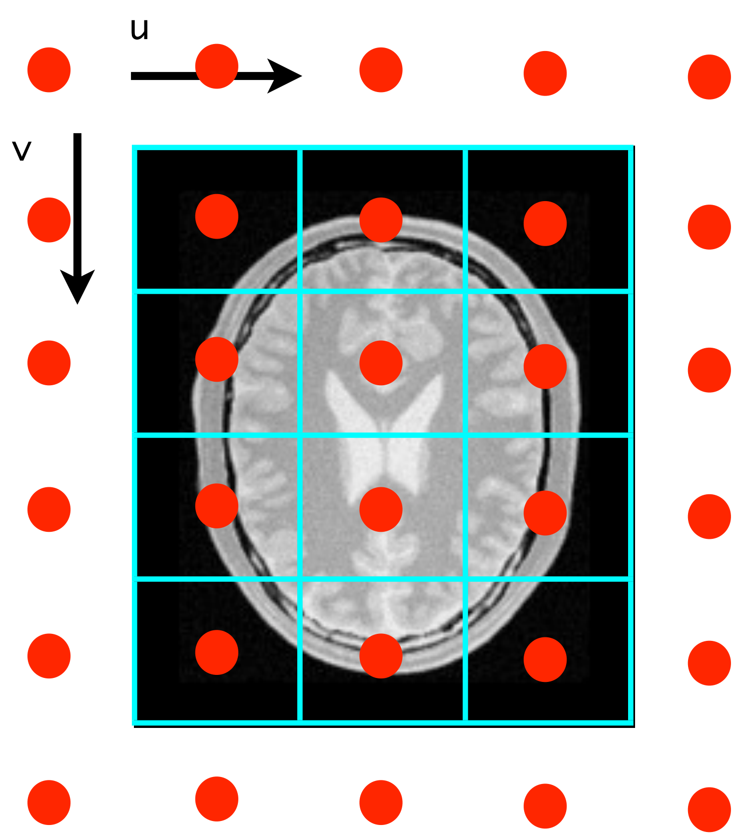
`3x4 mesh, quadratic splines, isotropic regularization`

`4x3 mesh, quadratic splines, anisotropic regularization`

To remedy this, we have introduced a new B-spline transform initializer which takes the n-D fixed image and calculates its location and pose based on the location of its 2^D corners.

B-spline deformation field transform

One of the other B-spline related issues we are hoping to address is the time it takes to perform image registration. Currently, various sampling strategies and large memory overhead are used to trim down the time it takes to perform registration. The following is another possibility.



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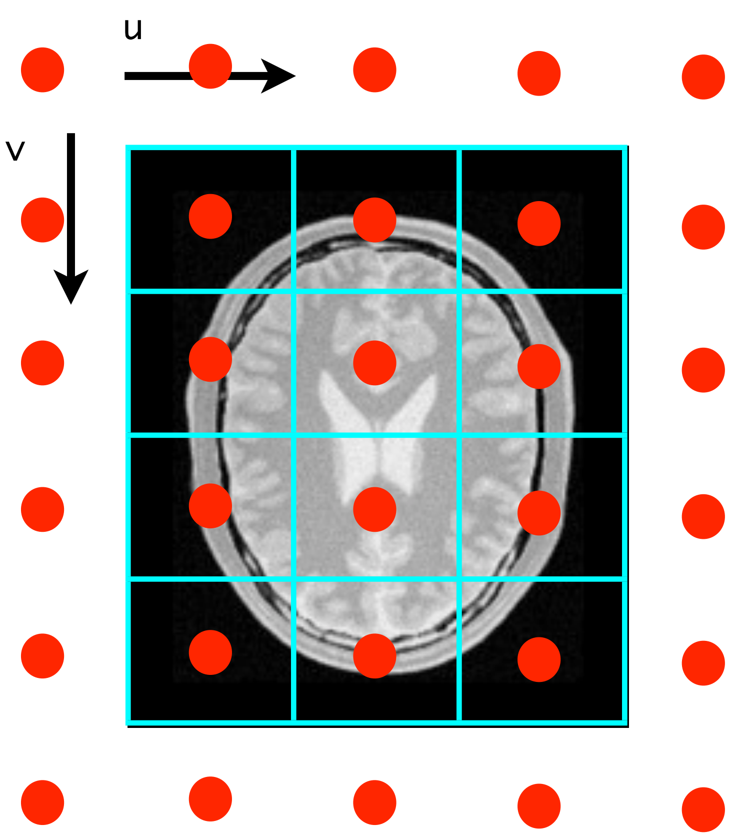

This is how the B-spline transform is currently evaluated via the transform point function:

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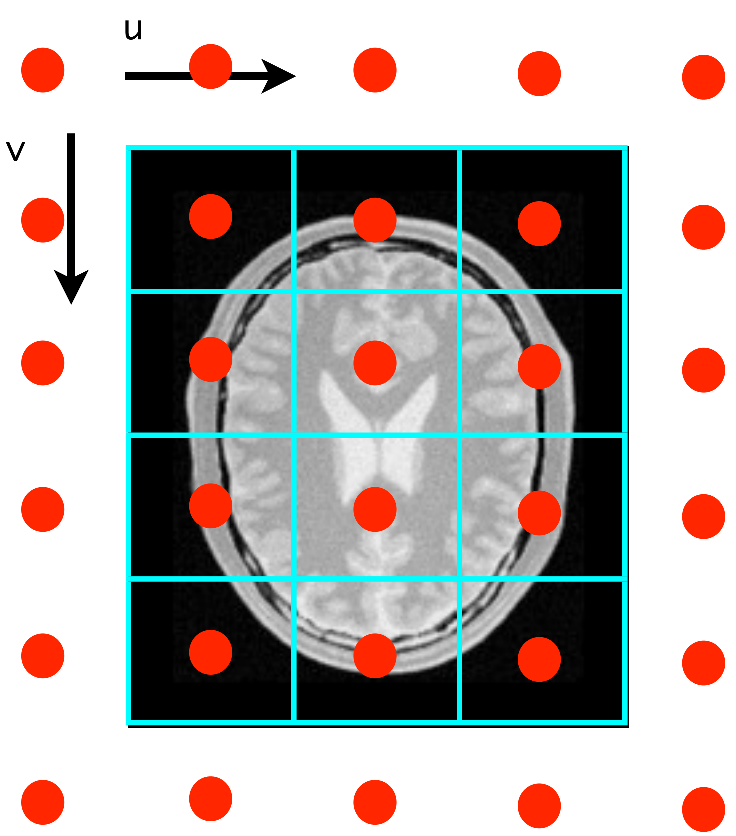

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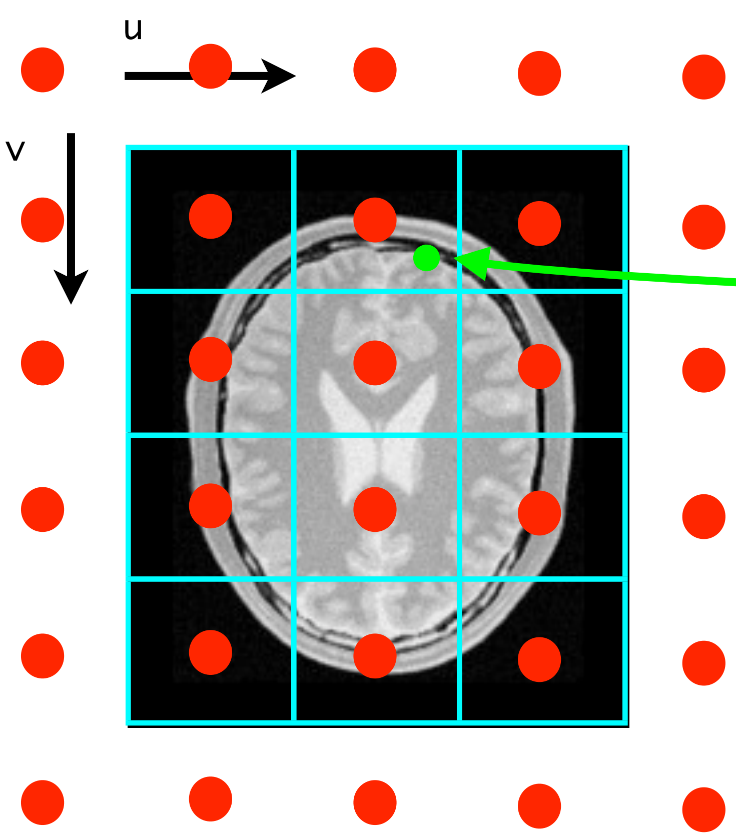

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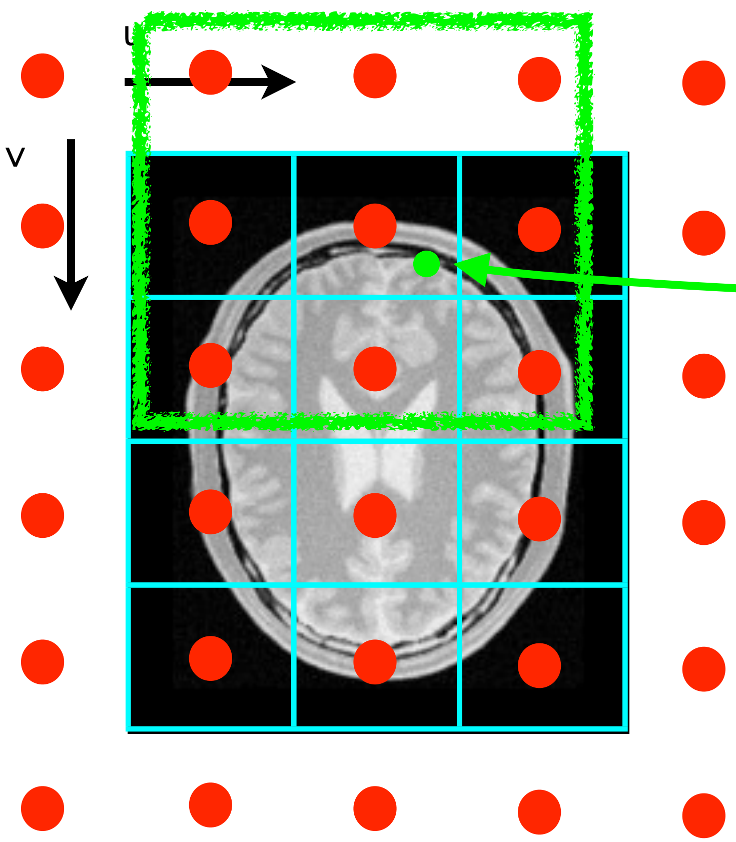

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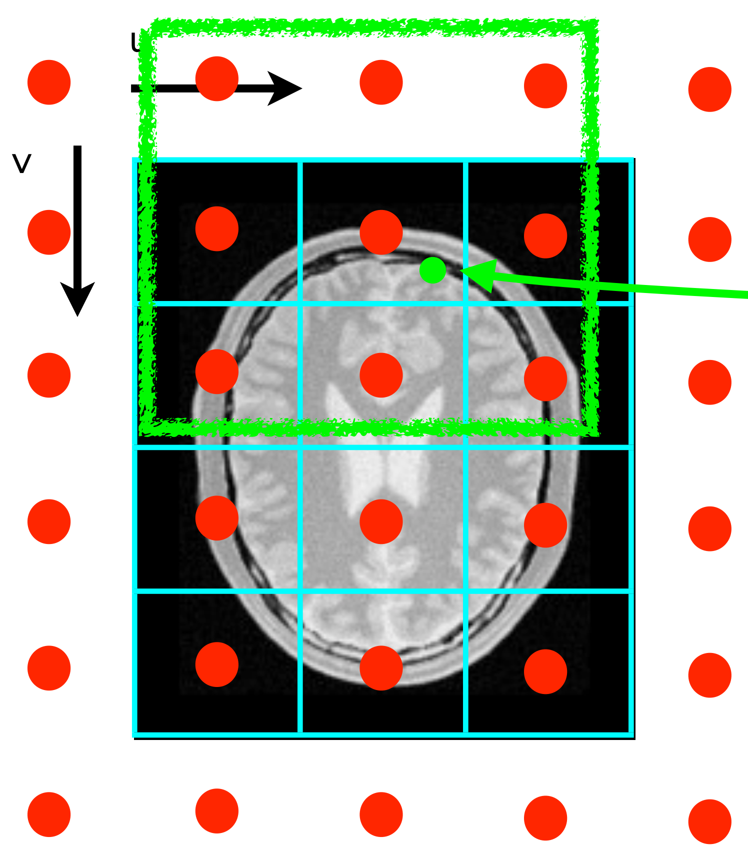

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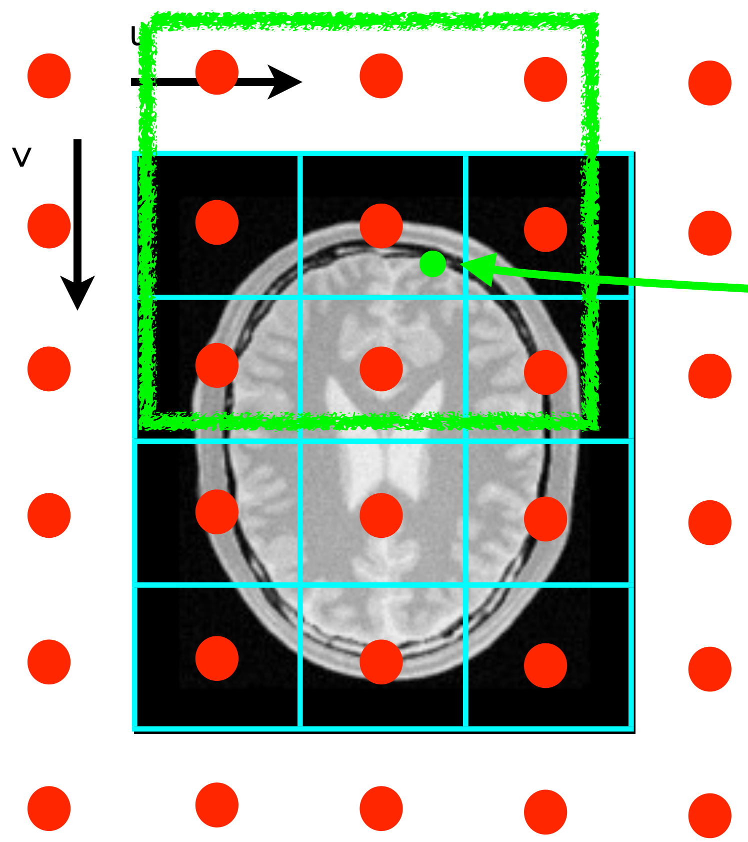

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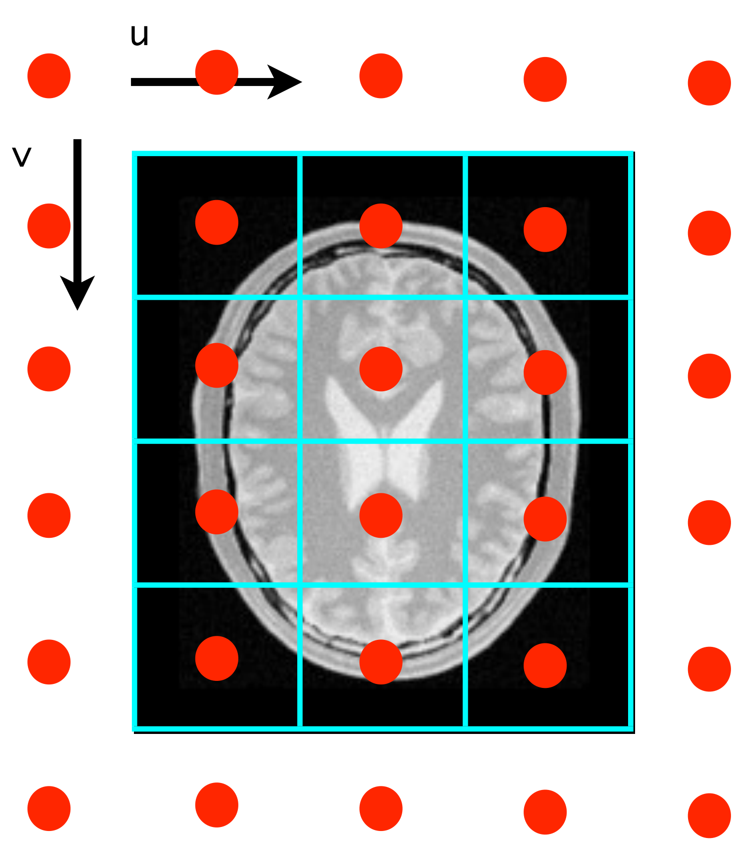
Most commonly people use cubic B-splines in 3-D which means that for *each* input point, one has to calculate **4x4x4=64** B-spline weights! Storing the weights is currently used but this is a huge memory cost alternative.

B-spline deformation field transform

Fortunately there is a faster way which we currently use in ANTs for our DMFFD image registration. It is also used in our previous ITK contributions (itkBSplineScatteredDataPointSetToImageFilter, itkBSplineControlPointImageFilter). We do not have to resort to a large memory overhead and we can also sample the metric at each voxel in the entire image with speeds comparable to a Demon's type implementation.



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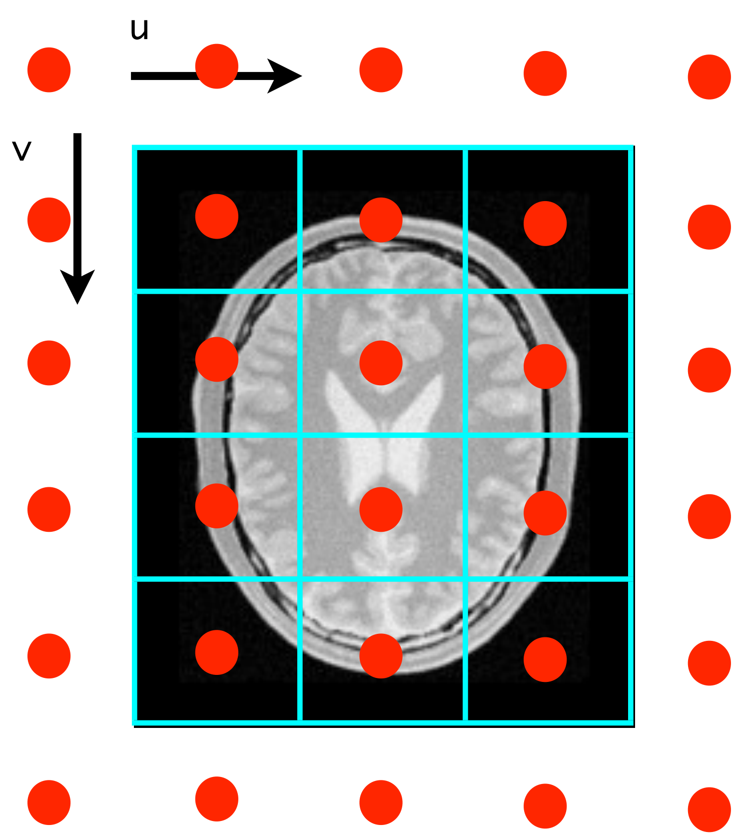

Suppose instead of evaluating individual points, we sample the transform in its entirety as an `itkImageIterator` would traverse the image. To see what would that give us, we look at the actual B-spline equation.

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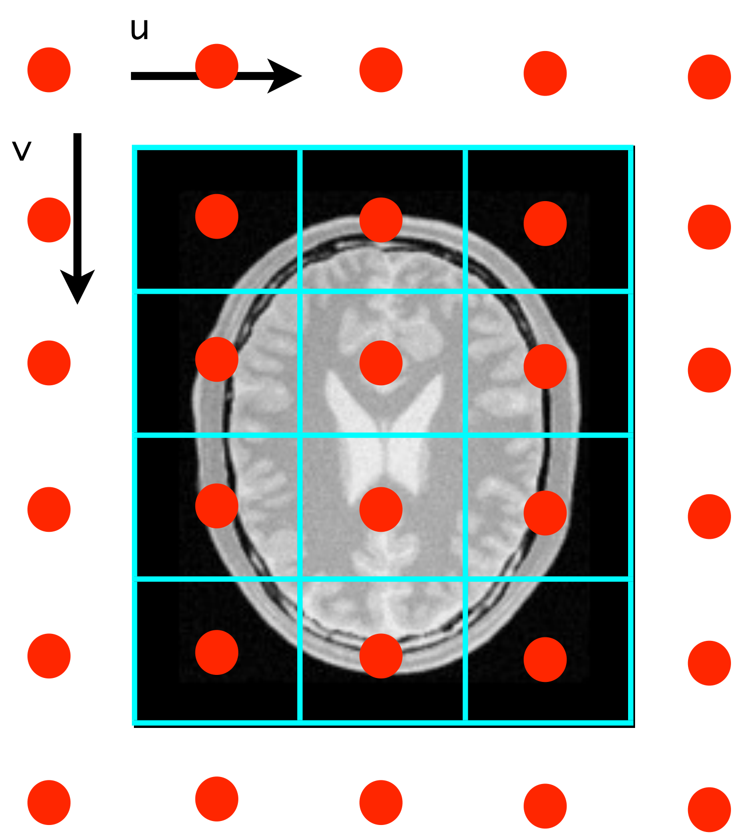

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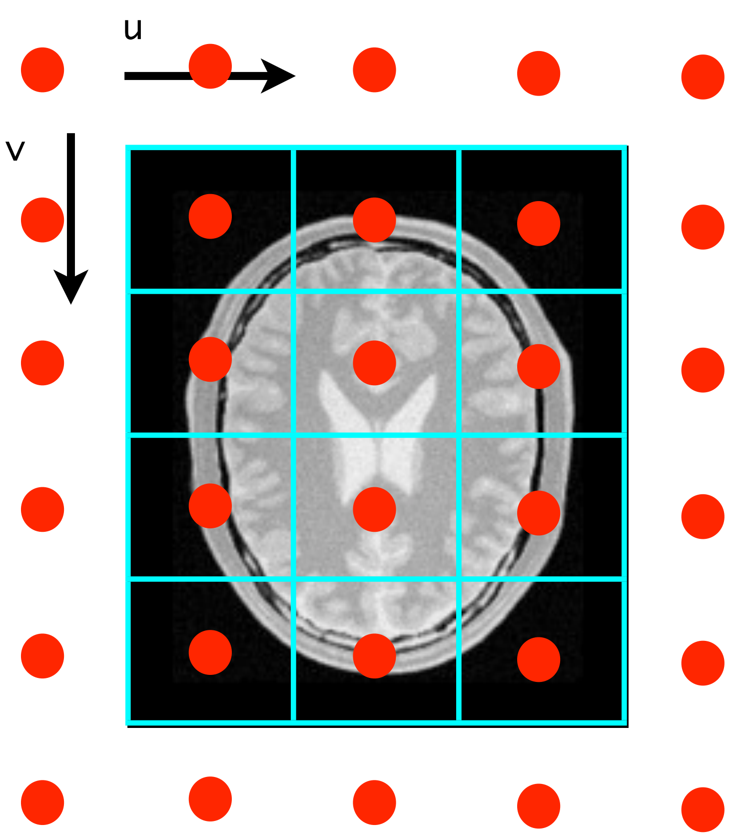

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Since ***v*** is constant along the direction of the first image axis, the weight $B_i(u)$ is also constant so the term in green above can be "collapsed" such that for the entire length of the image sampling where ***v*** is constant, we only have to evaluate a 1-D B-spline with the set of ϕ_i' serving as "pseudo-control" points. This relationship is recursive and extends to ***n***-D. In fact, as mentioned, this is what we do in itkBSplineScatteredDataPointSetToImageFilter. This would also facilitate contributing our own DMFFD-brand of B-spline image registration which is also multi-threaded so Jacobian calculations are much faster.

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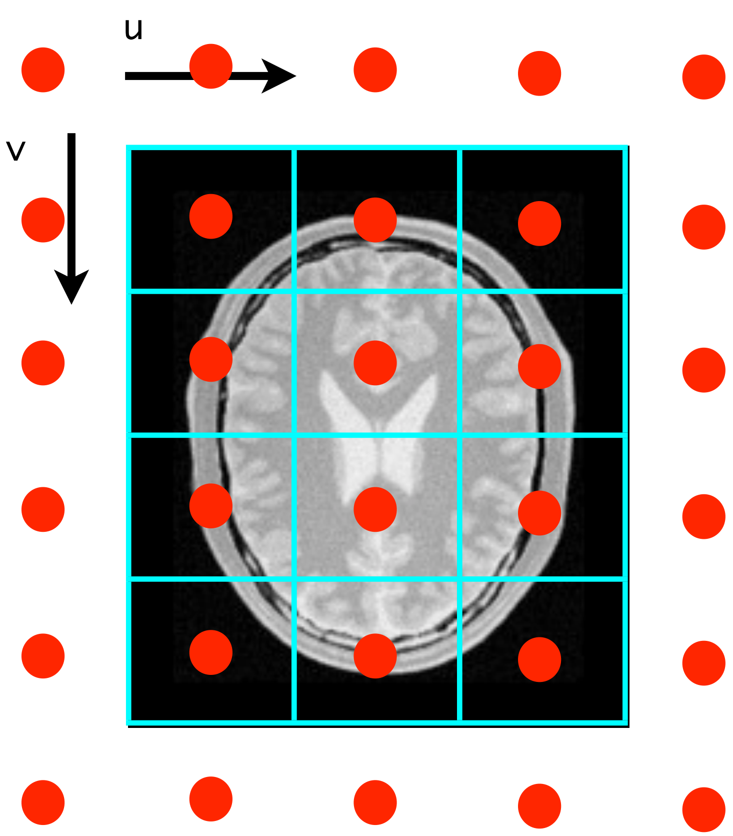

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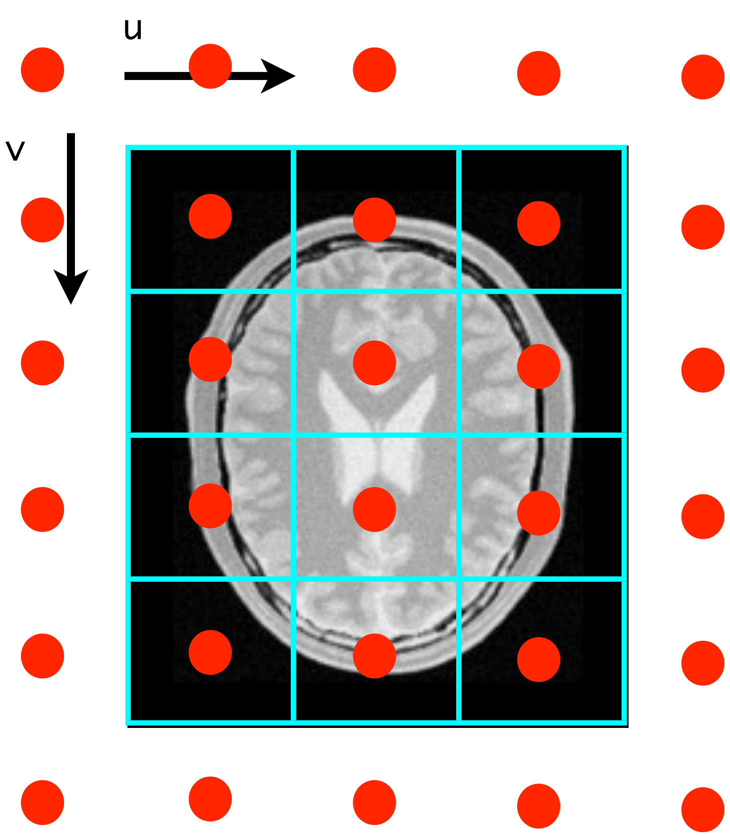

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- Still need to work on DTI. How much interest?

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Is currently in Gerrit.

Pipeline: 4D Processing + SCCA