# Statistical analysis of neuronal connectivity in patients with Gilles de la Tourette syndrome

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# *Purpose of the Project*

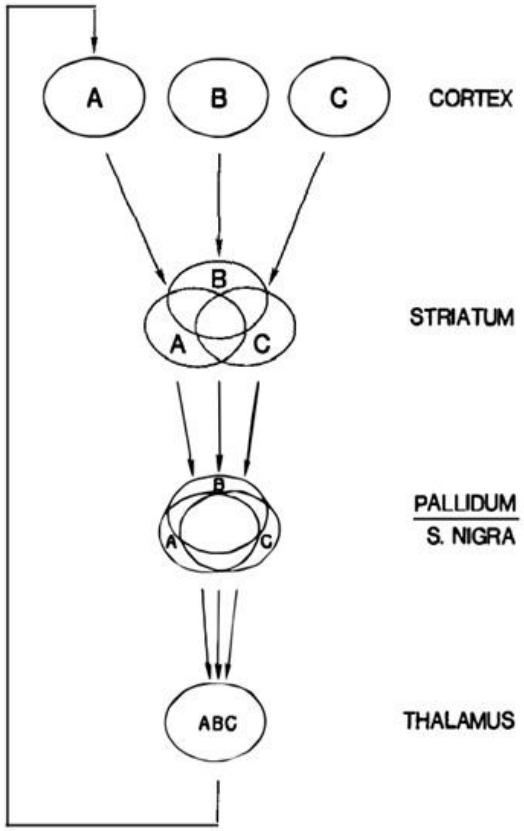
Study differences concerning *shape* and *organization* between cerebral anatomical configurations of 27 controls and 47 patients subject to *Gilles de la Tourette syndrome* in order to test the hypothesis presented in Worbe et al.

***Gilles de la Tourette syndrome***:

- Multiple motor tics and at least one vocal tic.
- Tics occur many times everyday for at least one year.
- Onset before 18 years old.
- No drugs or any other general medical condition.

# *Purpose of the Project*

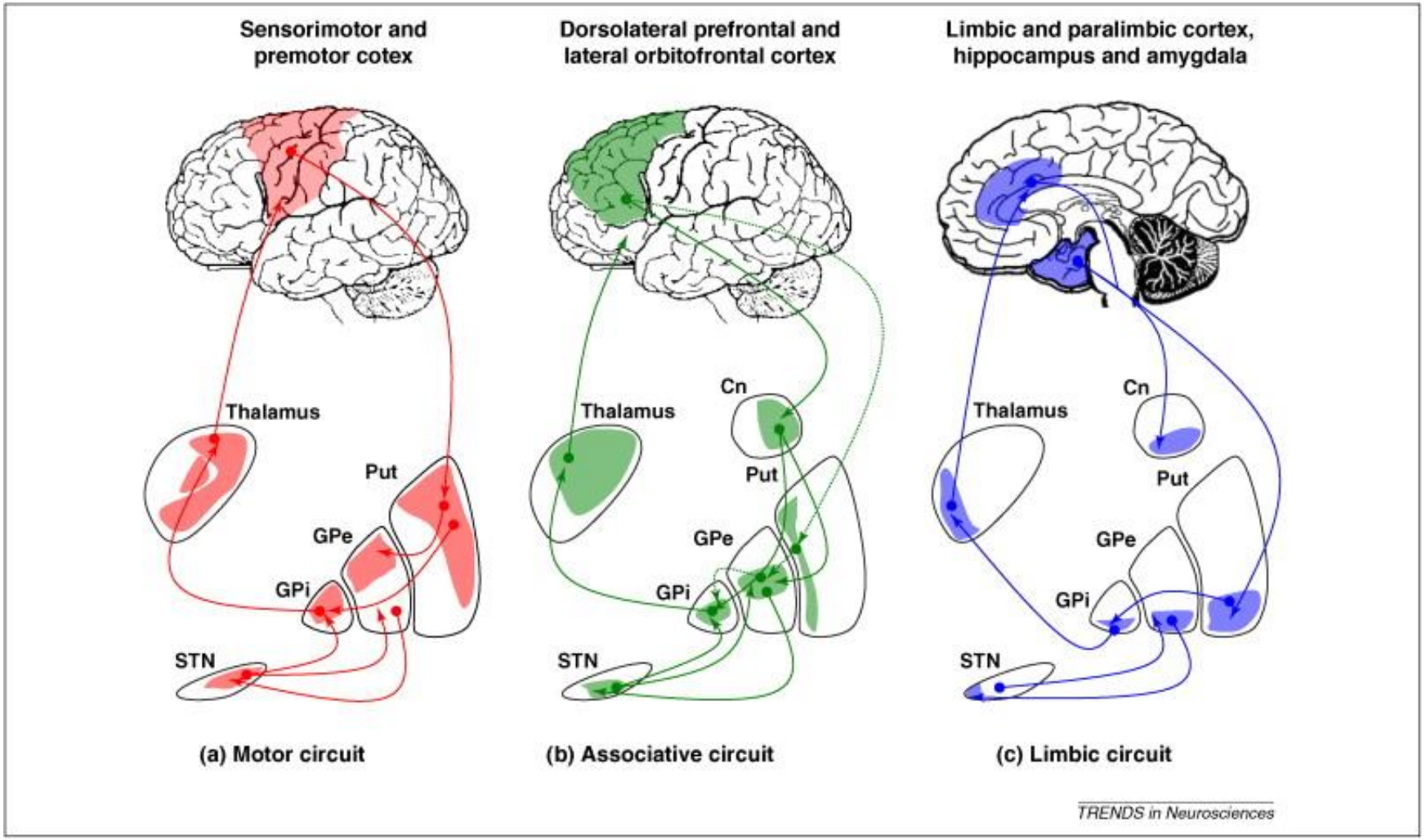
Worbe's hypothesis: *"Gilles de la Tourette syndrome is associated with dysfunctions of the cortico-striato-thalamo-cortical circuits."*




Multiple inputs from several functionally related cortical areas (A,B,C) are "funneled" back through the basal ganglia and thalamus to a particular area of the cortical surface.

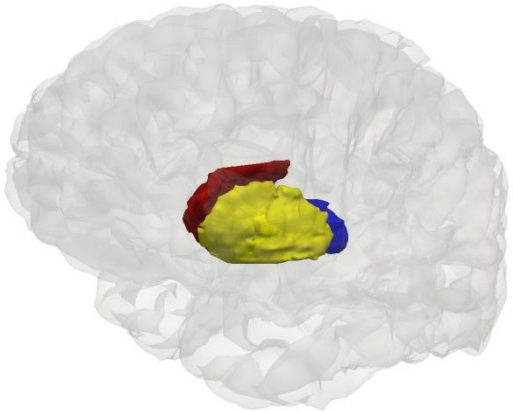
*Alexander et al.* – Parallel organization of functionally… - Ann. Rev. Neurosci.- *1986*

# *Purpose of the Project*

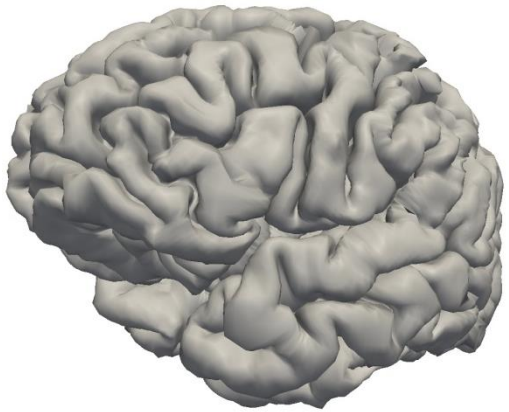



Krack *et al.* – Deep brain stimulation… - Trends in Neuroscience - *2010*

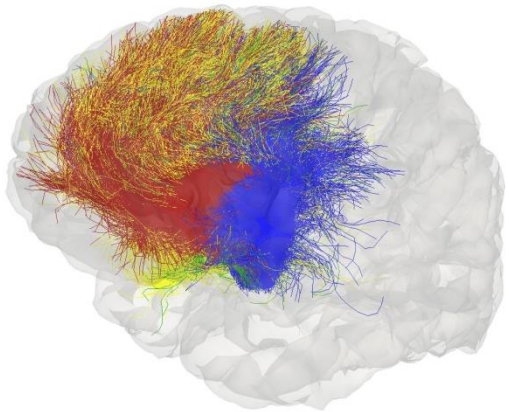
# Gilles de la Tourette syndrome



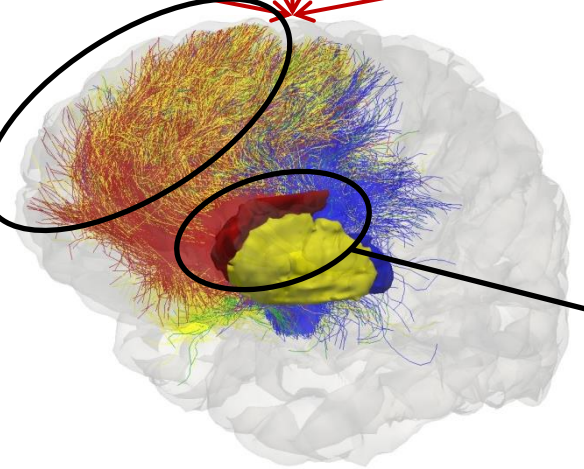
Sub-cortical Structures

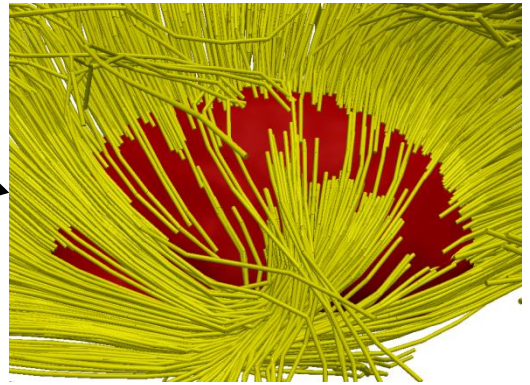


Cortical Surface

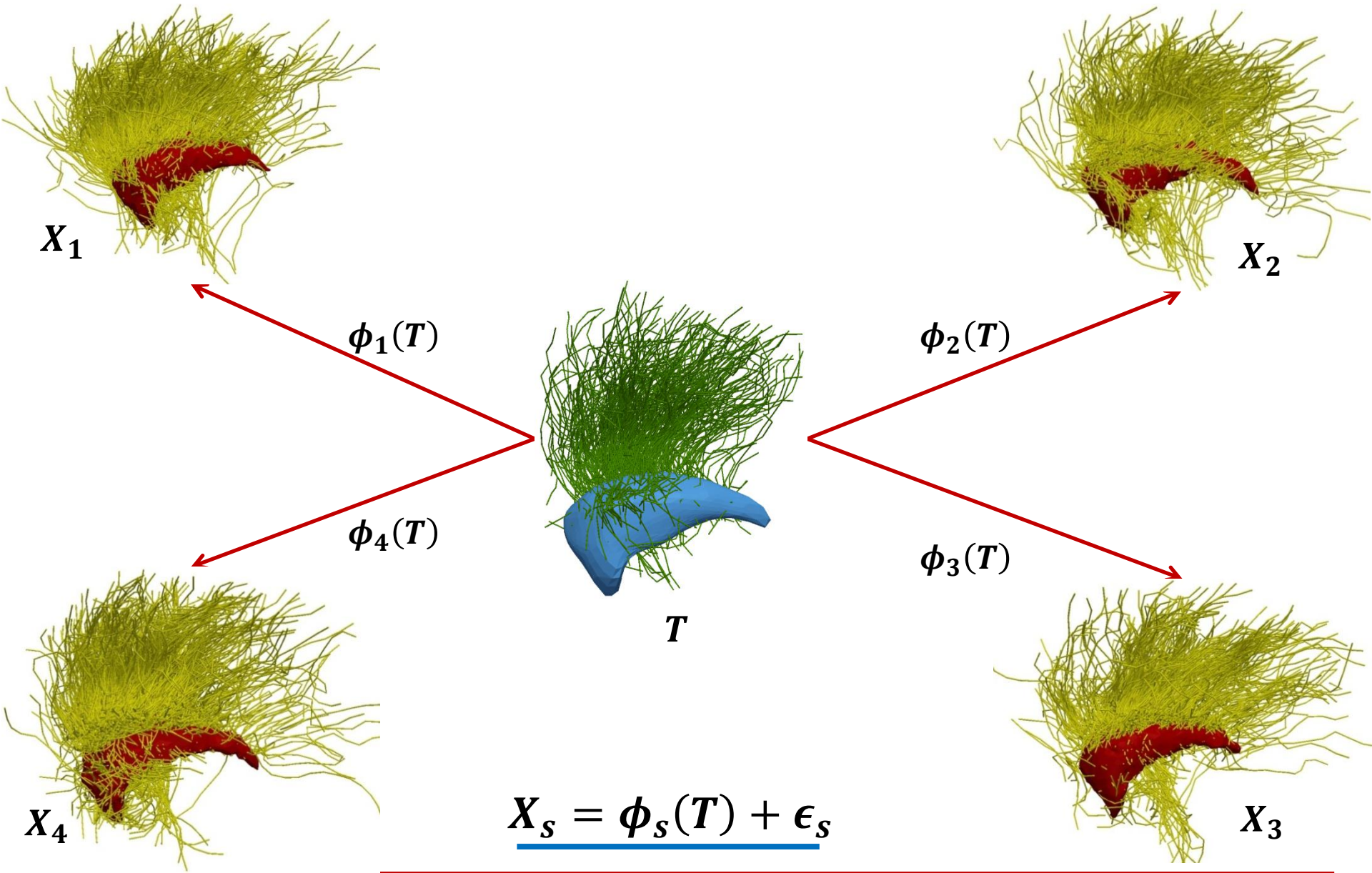


Fiber bundles





# Atlas Construction



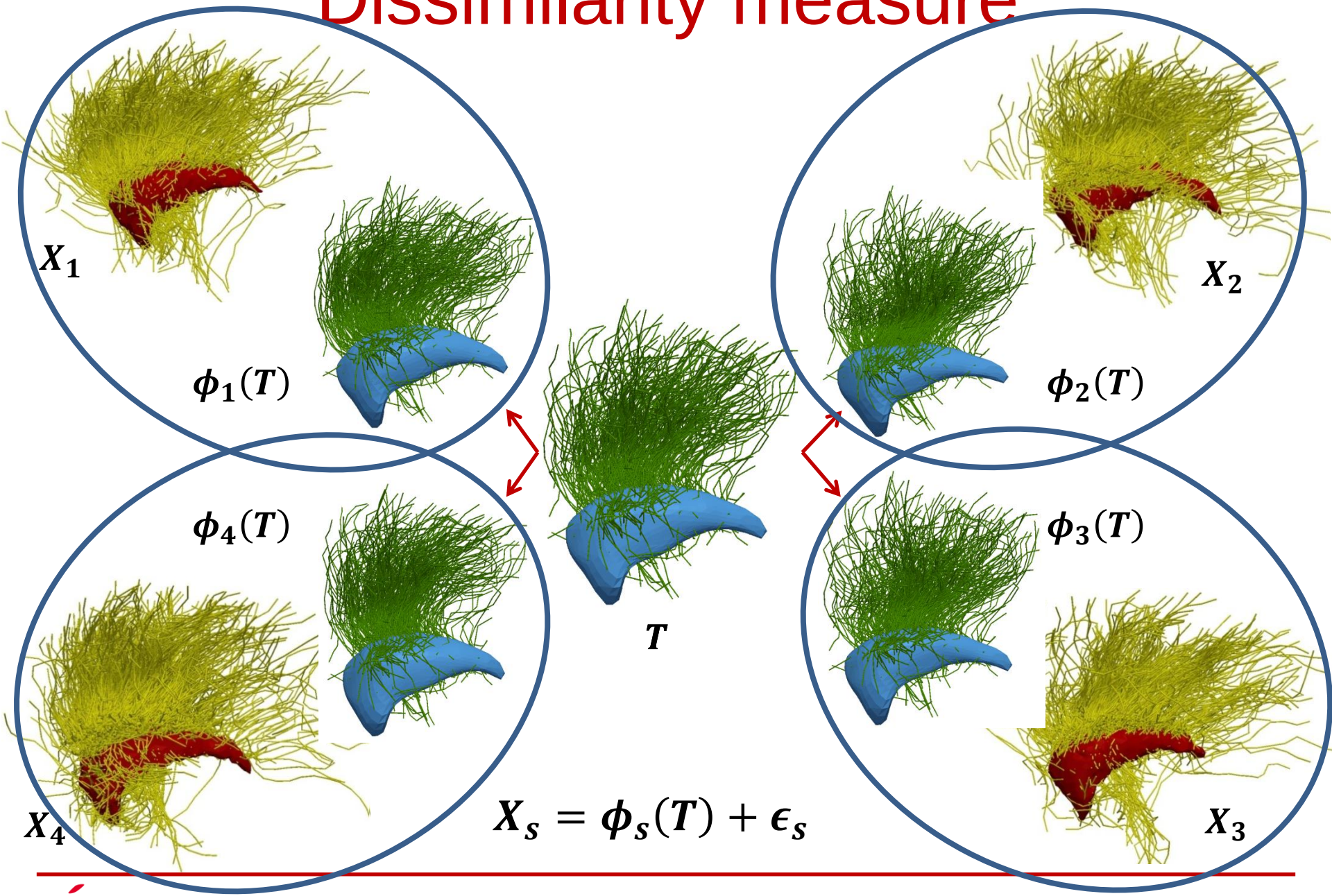

$$X_s = \phi_s(T) + \epsilon_s$$

# Atlas Construction

$$E(\boldsymbol{T}, \{\phi_s\}) = \sum_{s=1}^{N} \frac{1}{2\sigma_\epsilon^2} D(\phi_s(\boldsymbol{T}), \boldsymbol{X}_s) + Reg(\phi_s)$$

- Template
- Deformations
- Dissimilarity measure

# Dissimilarity measure

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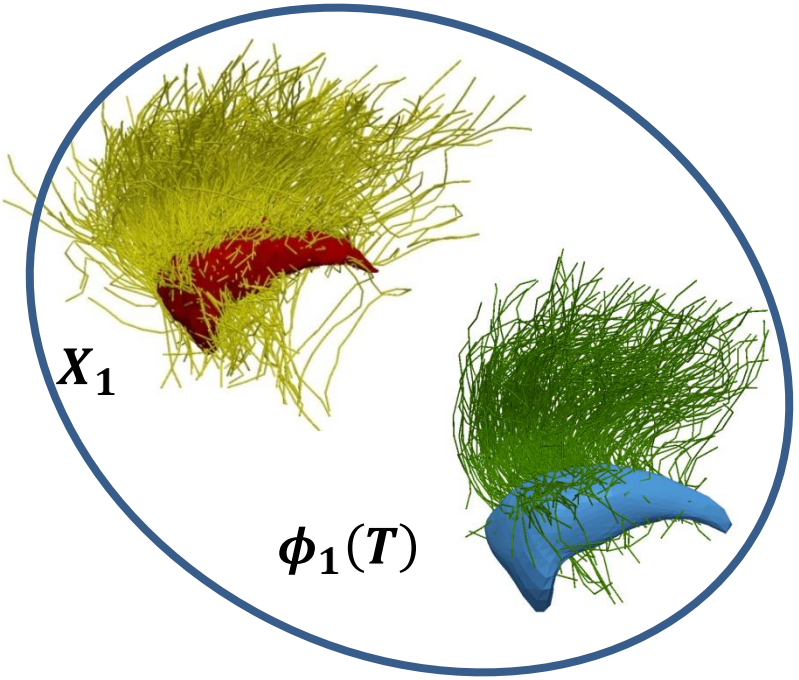


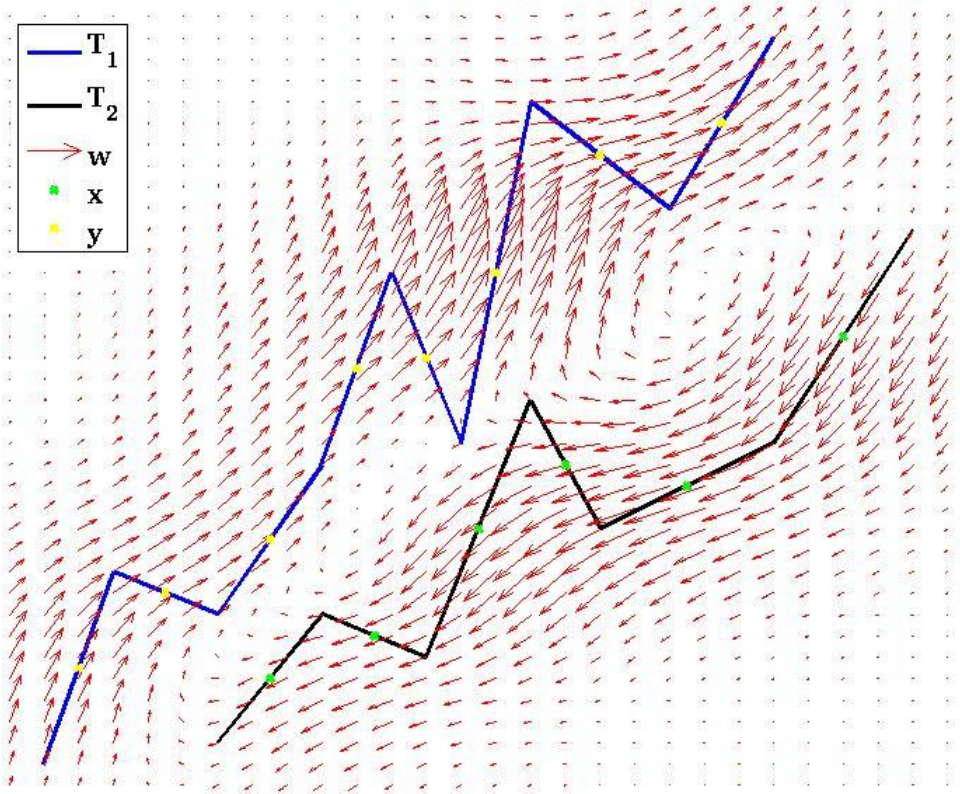

## Currents

1. For both surfaces and curves
2. No need of point or fiber correspondences
3. Robust to different sampling
4. Global geometrical differences

*Glaunès et al. –*
Surface matching via currents –
*IPMI - (2006)*

# Dissimilarity measure

The framework of **Currents** can represent both curves and surfaces and it doesn't need point or fiber correspondence.



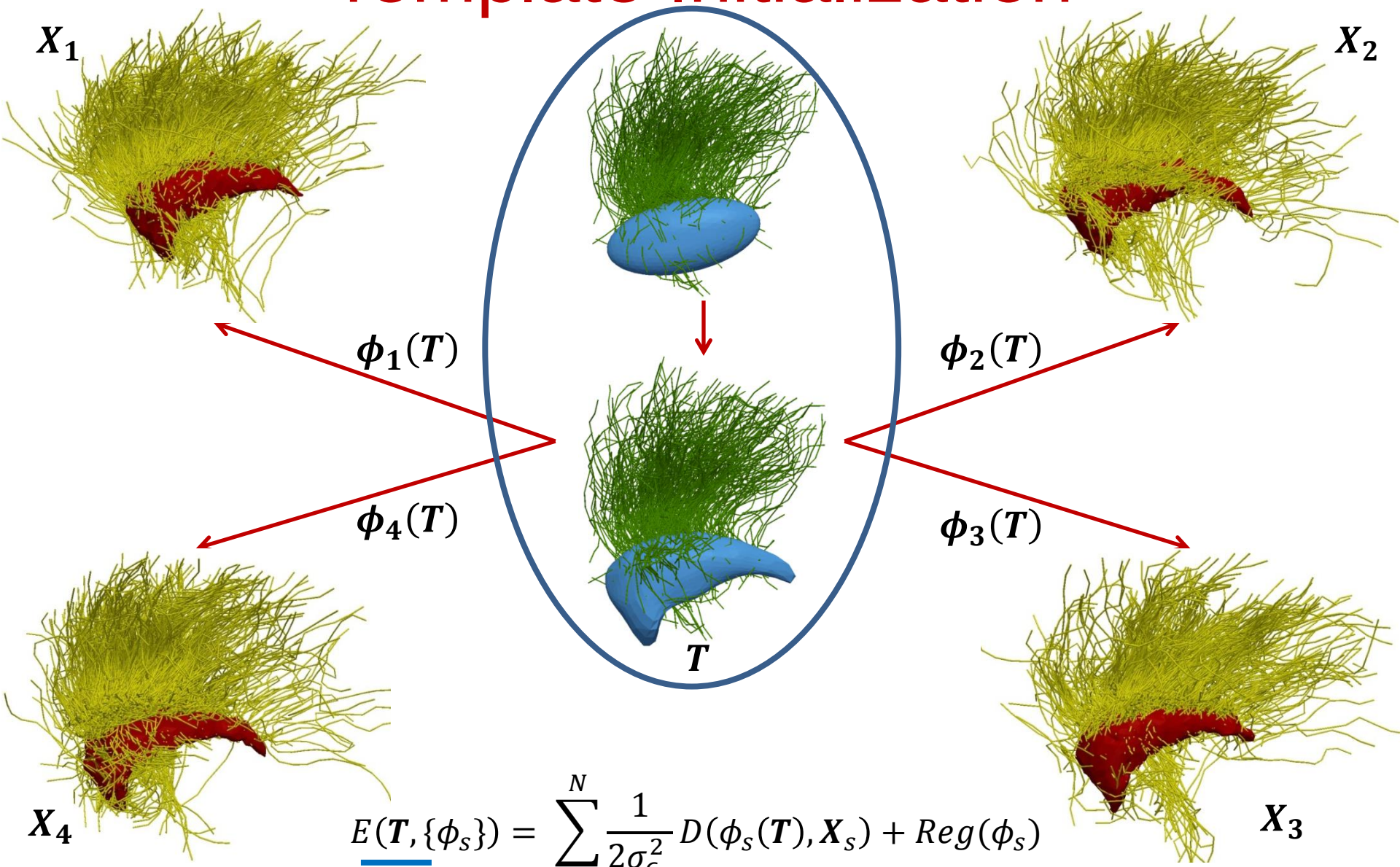

Characterize an object via its response to probing vector field

$$T_1(w) = \int_{T_1} w(t)^T \alpha(t) dt \sim \sum_i w(x_i)^T \alpha_i$$

$$w(x_i) = \sum_k K^W(x_i, y_j)\beta_j$$

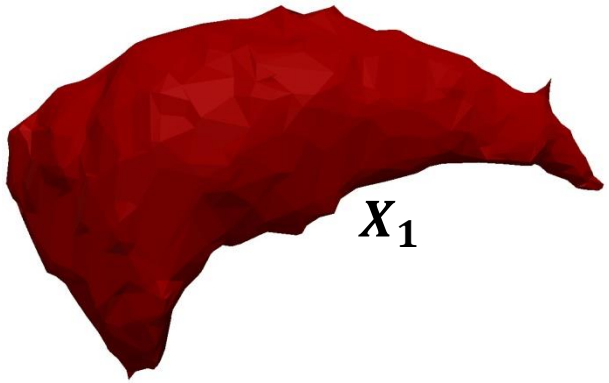
$$\langle T_1, T_2 \rangle_{W*} = \sum_i \sum_j \beta_j^T K^W(y_j, x_i)\alpha_i$$

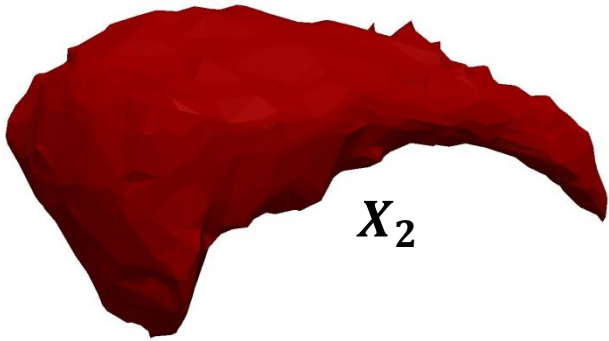
# Template Initialization

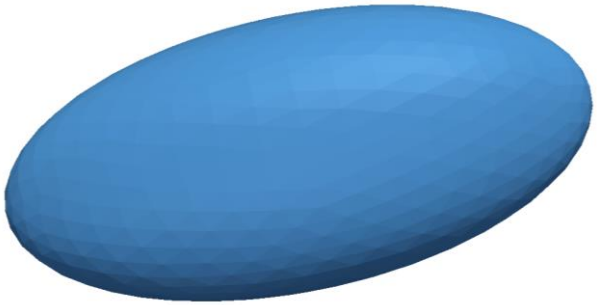



$$E(\boldsymbol{T}, \{\phi_s\}) = \sum_{s=1}^{N} \frac{1}{2\sigma_\epsilon^2} D(\phi_s(\boldsymbol{T}), \boldsymbol{X}_s) + Reg(\phi_s)$$

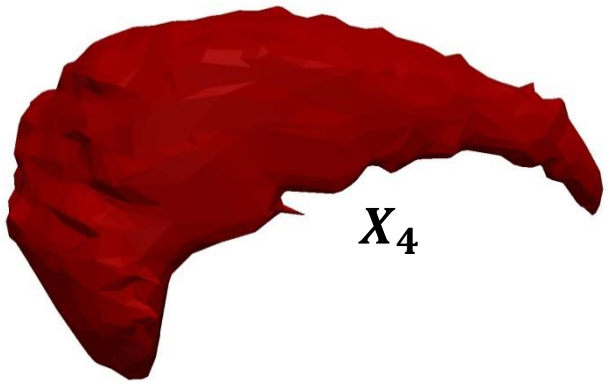
# Template Initialization

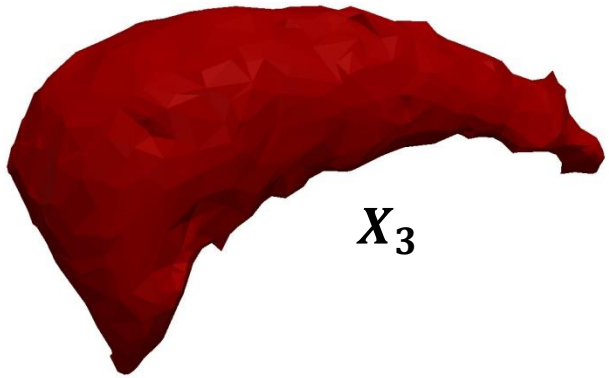


*Durrleman et al.* – Topology Preserving Atlas Construction… - MICCAI 2012 *(2012)*



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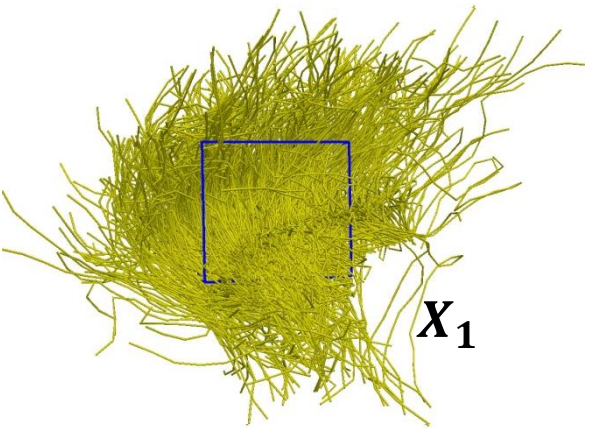


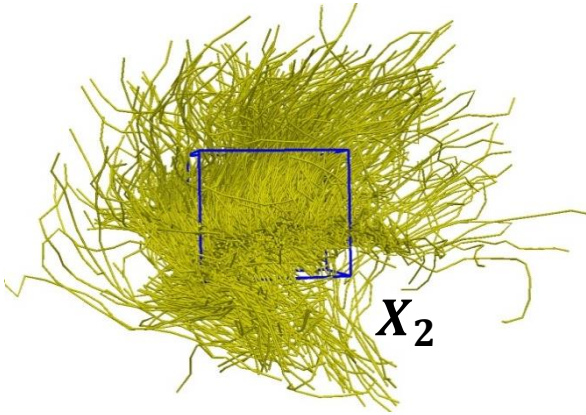


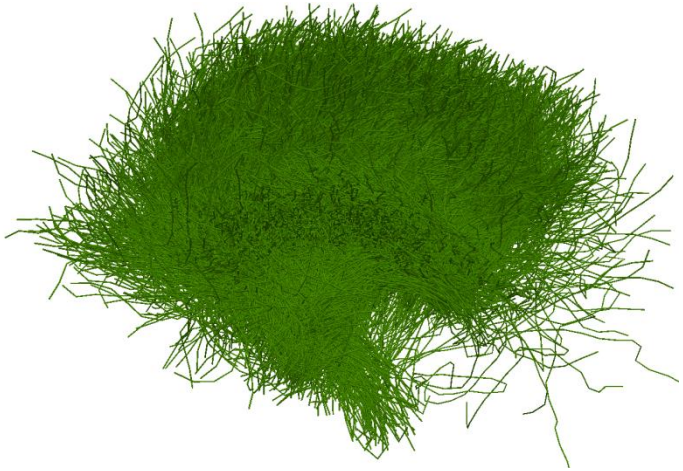

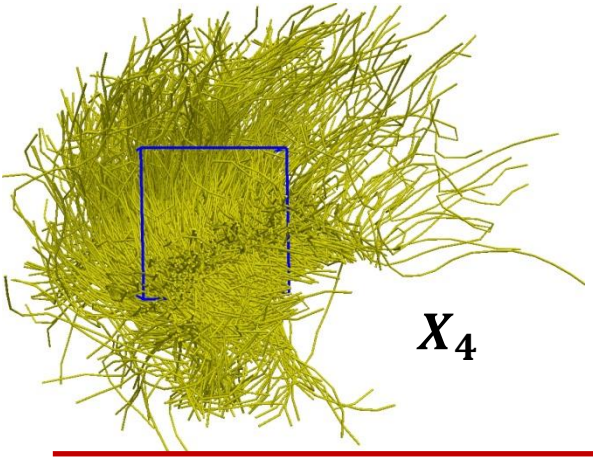


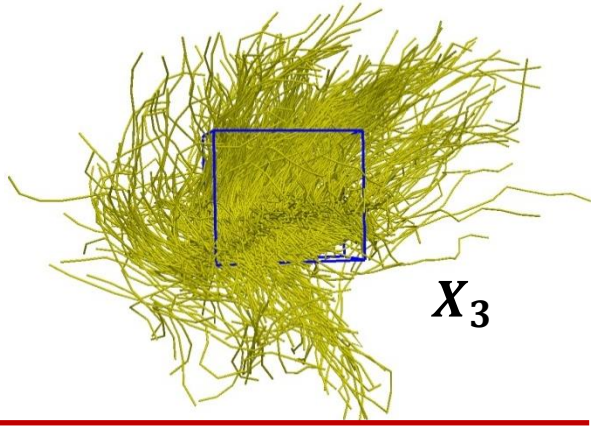

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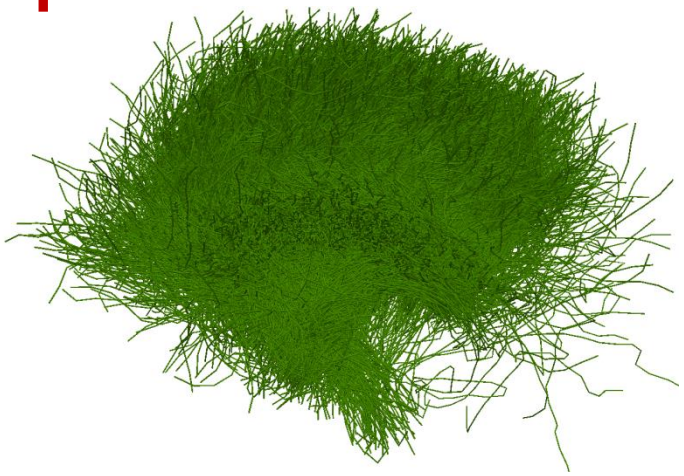
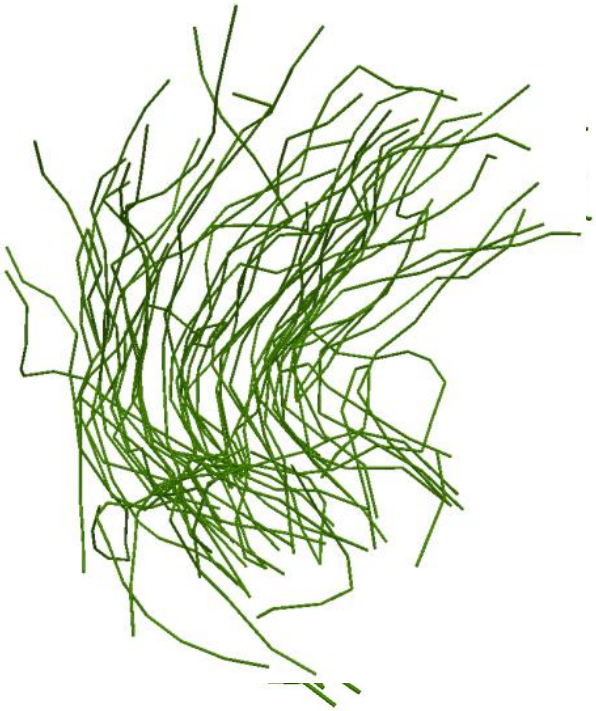


$T$

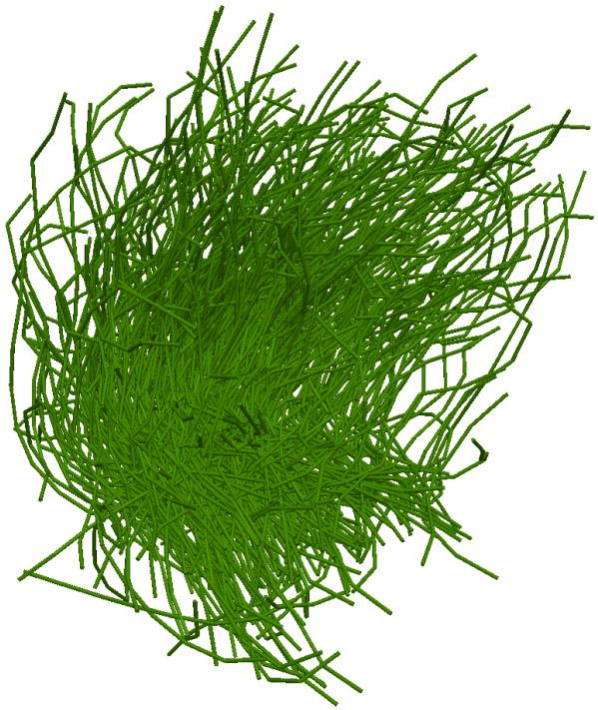
# Template Initialization

$$I^* = \underset{I_k}{\operatorname{argmin}} \|T - I_k\|^2_{W_*}$$

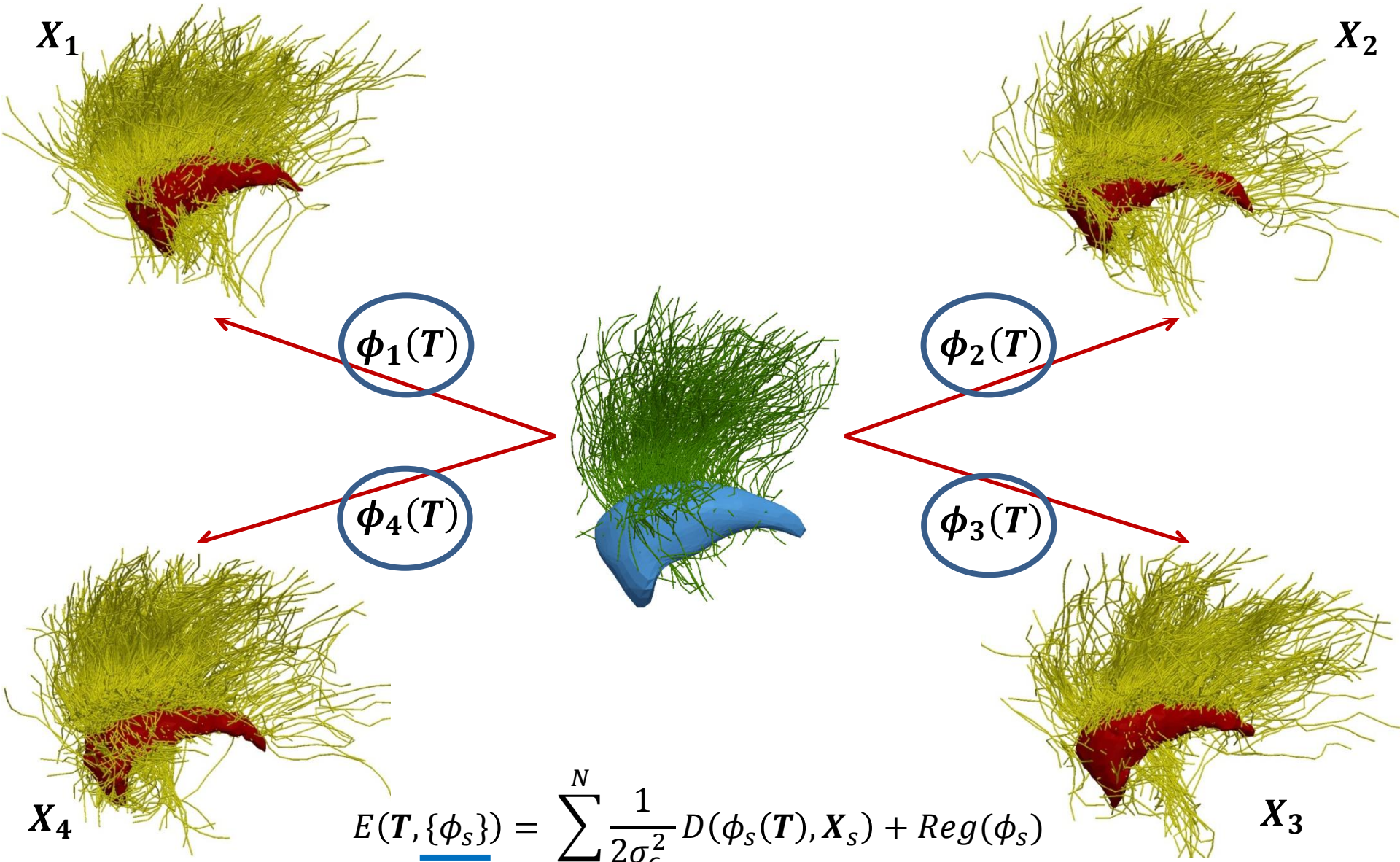


# Template Initialization

$$I^* = \underset{I_k}{\operatorname{argmin}} \|T - I_k\|^2_{W_*}$$



# Deformations




$$E(\boldsymbol{T}, \{\phi_s\}) = \sum_{s=1}^{N} \frac{1}{2\sigma_\epsilon^2} D(\phi_s(\boldsymbol{T}), \boldsymbol{X}_s) + Reg(\phi_s)$$

# Deformations

- Enables a global description of the whole brain preserving the underlying organization of structures

  ↳ *One single diffeomorphism for the whole 3D space*

- Captures local non-linear variations

  ↳ *Framework of diffeomorphism*

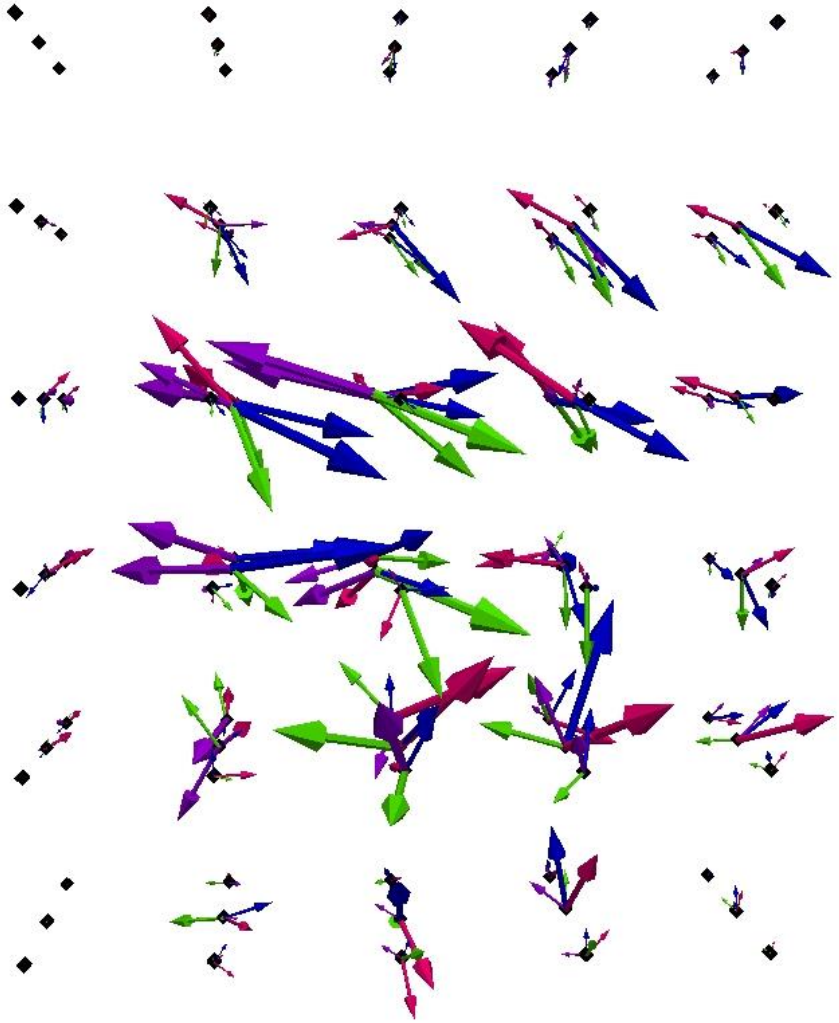
- Low dimension parameterization

  ↳ *New control point formulation*

*Durrleman et al.* – Topology Preserving Atlas Construction… - MICCAI 2012 *(2012)*

# Deformations

The whole 3D space is deformed by a single diffeomorphism



Position of point x at time t → $\phi_t(x) = x + \int_0^t v_s(\phi_s(x))ds$

time-varying vector field

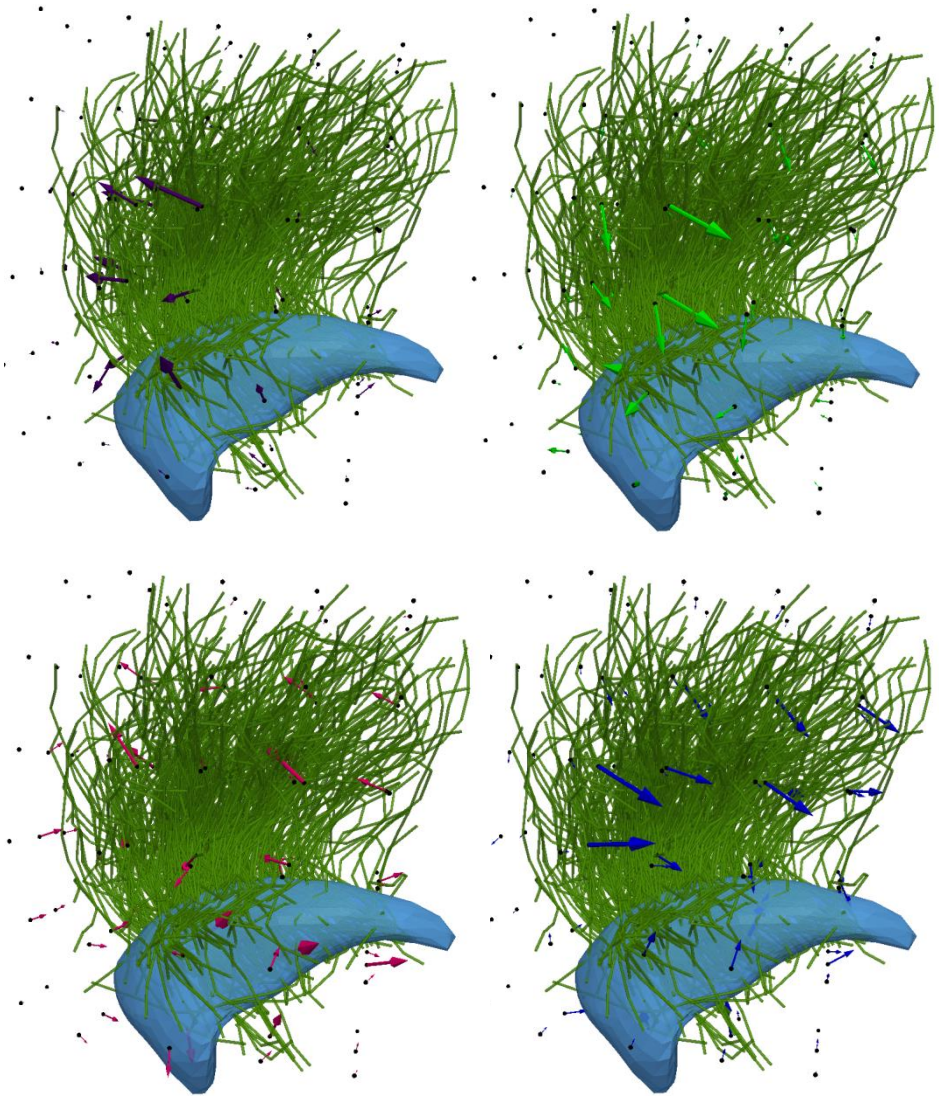
$$v_t(x(t)) = \sum_{p=1}^{C_p} K\left(x(t), c_p(t)\right)\alpha_p^i(t)$$

Momenta

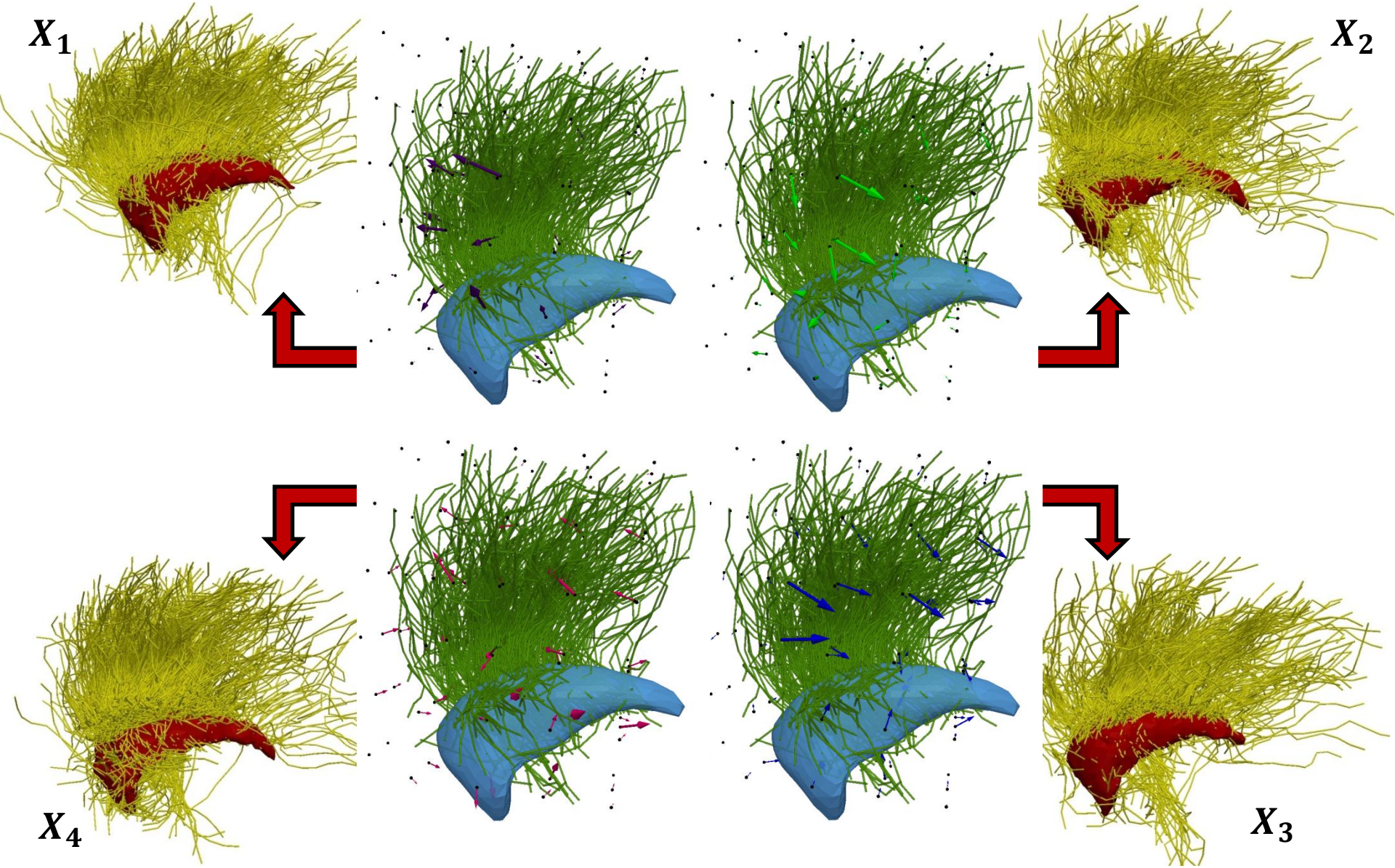
Control point

$\{\boldsymbol{\alpha^i(0)}\}$ → **Deformation parameters** → **Linear Statistics**

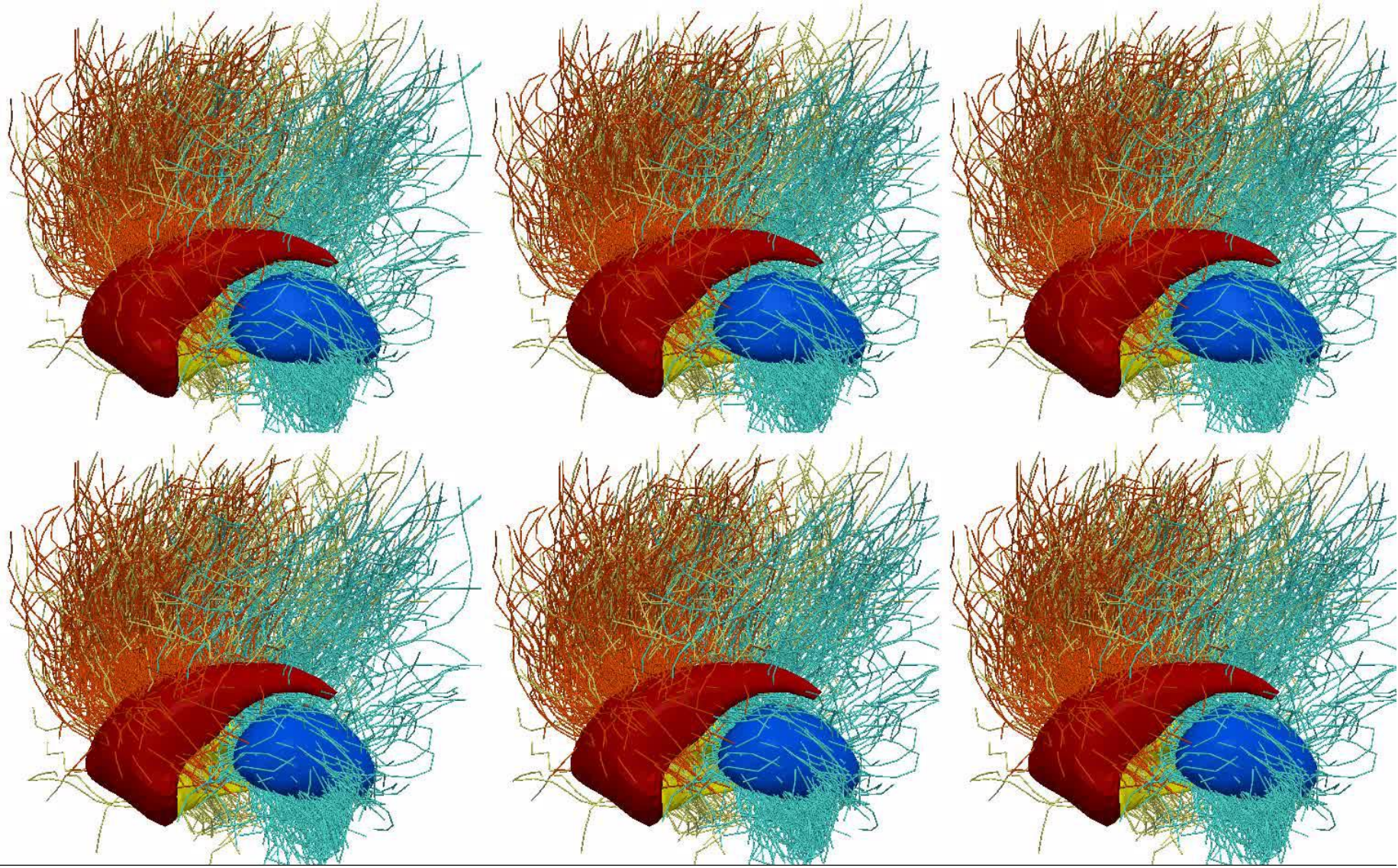
# Deformations



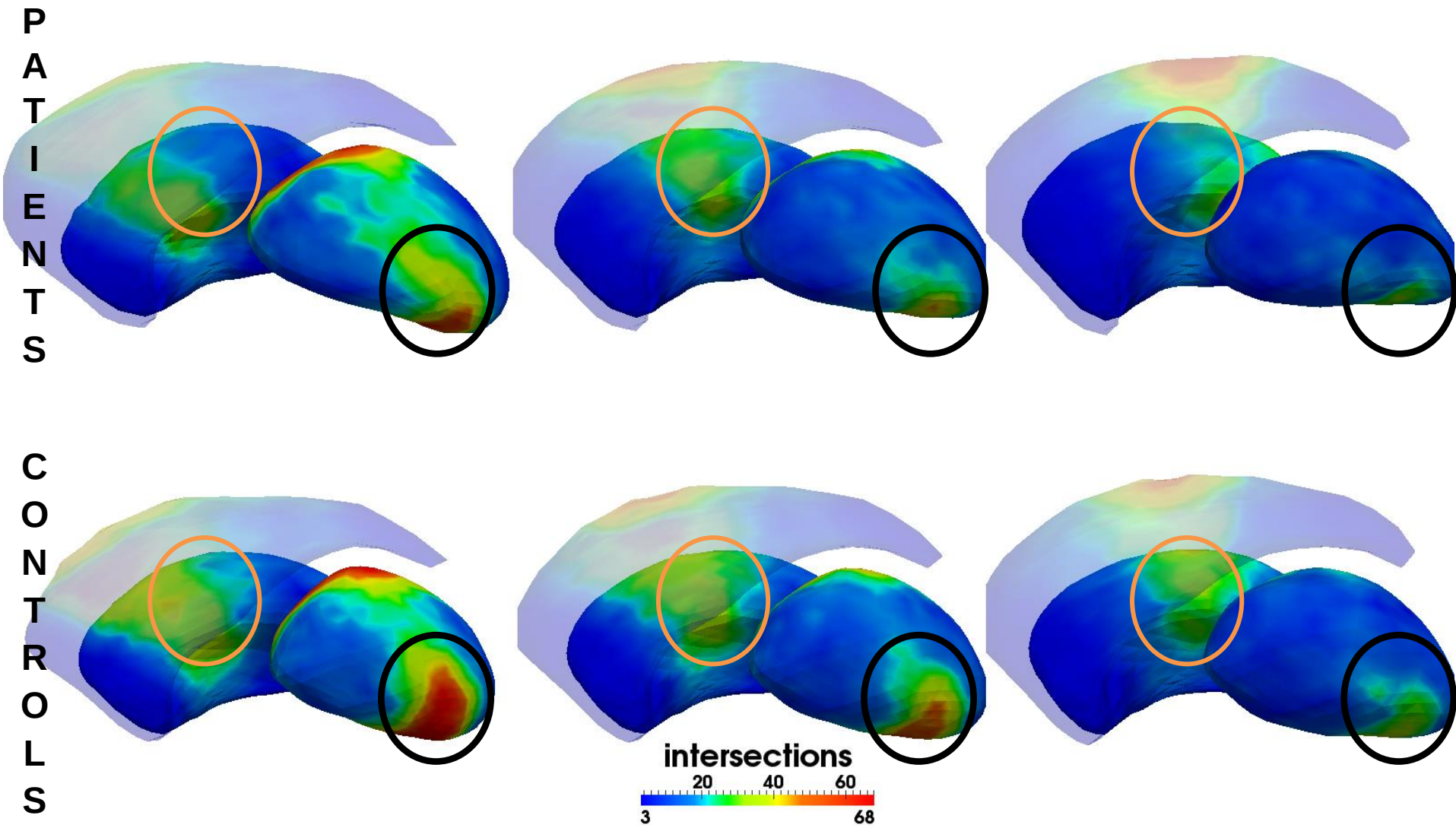
# Deformations



# PCA – first mode



# First mode


PATIENTS
CONTROLS
intersections
20
40
60
3
68
- 2σ
Updated template
+ 2σ

# Conclusions

- New multi-object atlas construction method based on *currents* for shape complexes
- Joint analysis of white matter tracts and gray matter surfaces preserving spatial organization of the structures
- Fiber bundles template with anatomically correct topology
- Limited number of deformation parameters well suited for linear statistical analysis

# Perspectives

- Include the cortical surface into our analysis
- Decrease the computational time of the process using a GPU-CUDA code
- Find a suitable statistical test to highlight few important differences between the two populations

# Deformetrica

- Software for the statistical analysis of 2D and 3D shape data: curves, surfaces, images, point clouds
- Multi-object registration and atlas construction
- Different kinds of deformation: rigid, affine, diffeomorphism
- Longitudinal analysis
- GPU implementation (under construction, Alexandre Routier)
- Bayesian Framework (under construction, Pietro Gori)
- Multi-scale analysis (under construction, Barbara Gris)

# Acknowledgments

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- Dr Olivier Colliot (PhD)
- Professor Nicholas Ayache (PhD)
- Dr Stanley Durrleman (PhD)

# Thank You for your attention!