Visualization of Effective Connectivity of the Brain

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Outline

1. Background
2. Motivation
   - Why another visualization?
   - Possible alternatives
   - Summarizing requirements
   - Goal
3. Our approach
   - Fiber-tract selection
   - Volumetric fiber-tract representation
   - Effective connectivity animation
   - Plugging it together
4. Results and further work

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Anatomical Connectivity

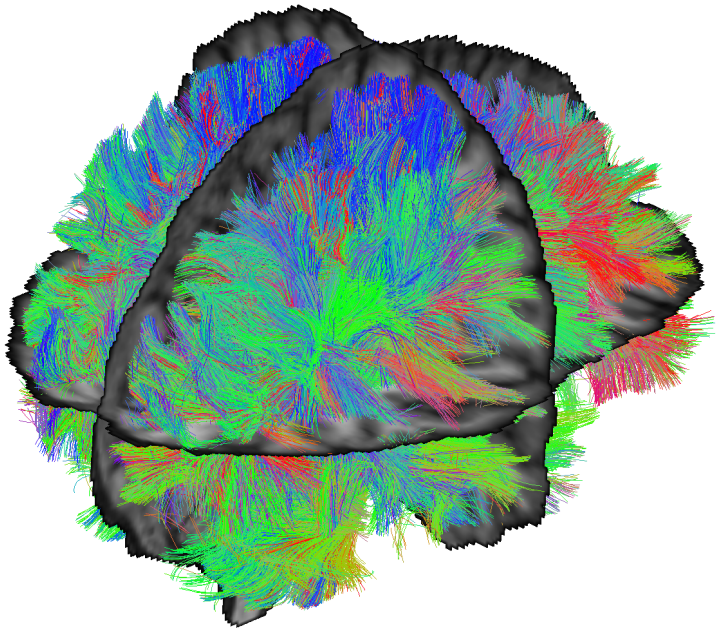

Figure: Fiber-tracts representing nerve-bundles

- Measured using DW-MRI
- Describes anatomical structure of the brain
- Fiber-tracts

Functional Connectivity

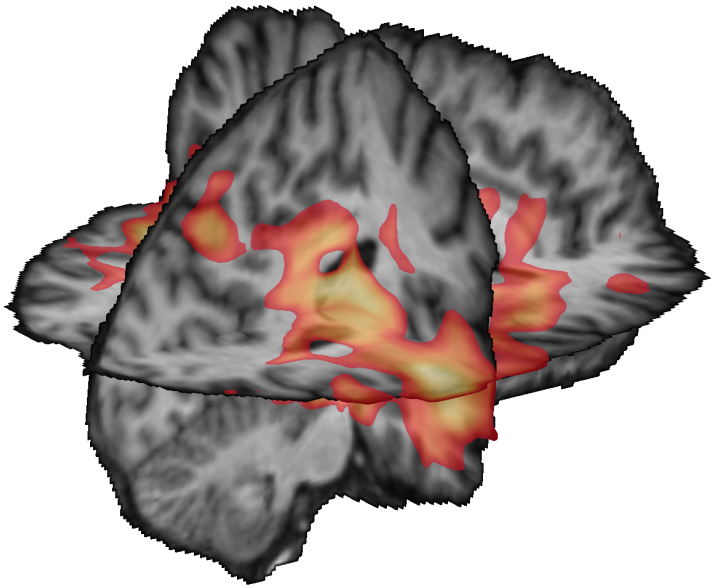

Figure: fMRI scan as color-mapping on anatomical slices

- Measured using fMRI
- Reveals activations in brain on certain stimulus

Effective Connectivity I

- Anatomical Connectivity + Functional Connectivity = Effective Connectivity?

Effective Connectivity I

- Anatomical Connectivity + Functional Connectivity = Effective Connectivity?
  - No!
- It is a model
  - Explains causal relation of measured data
  - Input is graph of involved regions and stimuli

Effective Connectivity II

- Describes the information transfer between two regions A and B of the brain
- Regions are connected anatomically (fiber tracts)
- Two values exists per pair
  - For $A \rightarrow B$ and for $B \rightarrow A$
  - Big hurdle for simultaneous visualization
- Related work:

[FHP03] K.J. Friston, L. Harrison, and W. Penny.
Dynamic causal modelling.
NeuroImage, 19(4):1273 – 1302, 2003.

[MGL94] A. R. McIntosh and F. Gonzalez-Lima.
Structural equation modeling and its application to network analysis in functional brain imaging.
Human Brain Mapping, 2(1-2):2–22, 1994.

[STK+09] Klaas Enno Stephan, Marc Tittgemeyer, Thomas R. Knösche, Rosalyn J. Moran, and Karl J. Friston.
Tractography-based priors for dynamic causal models.
NeuroImage, 47(4):1628 – 1638, 2009.

Effective Connectivity III

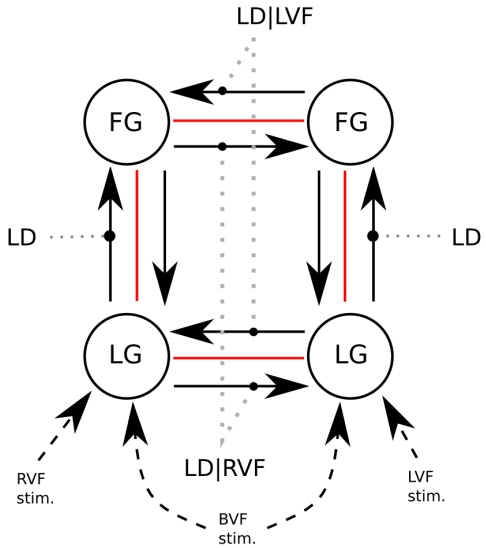

Figure: Graph showing the modelling

- From the visualization point of view it is a graph
  - Weighted and directed
  - Not necessarily planar
  - Nodes = regions
  - Edges = anatomical connection
  - Weights = effective connectivity

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The problem with 2D graphs I

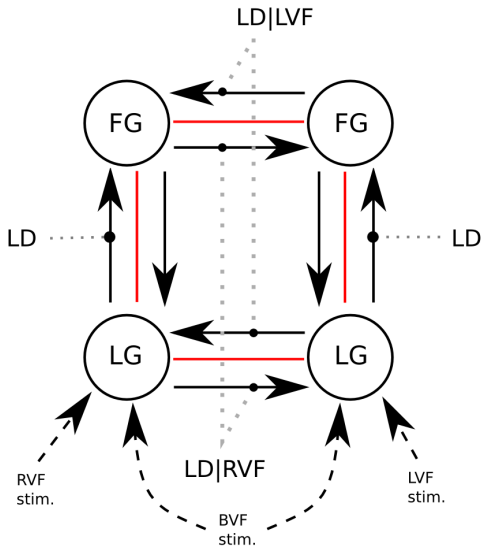


Figure: Graph showing the modelling

- Can these graphs help to:
  - Understand the structure-function relationship?
  - Verify models with measured data?

The problem with 2D graphs II

- Growing model complexity means
  - No 2D layout possible matching anatomical structure in some projection
  - No anatomical structure of connection

Possible alternatives I

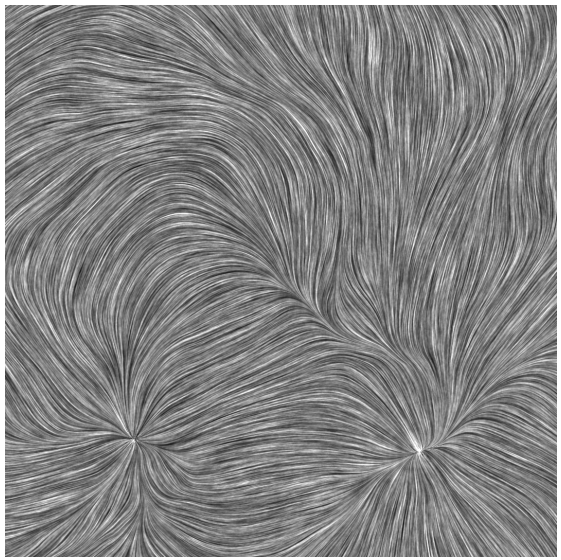


Figure: Line Integral Convolution

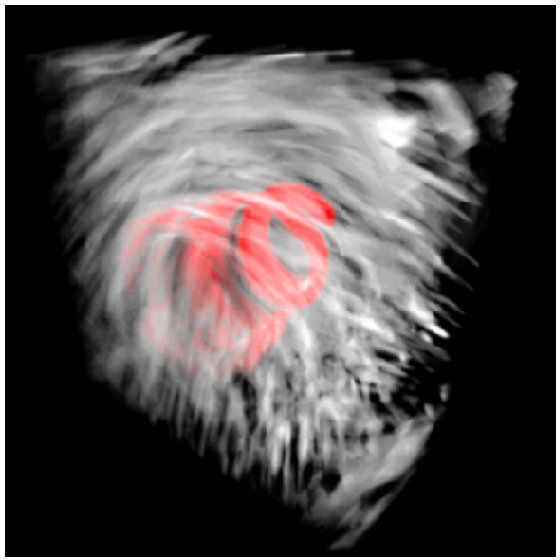


Figure: GPU based advection

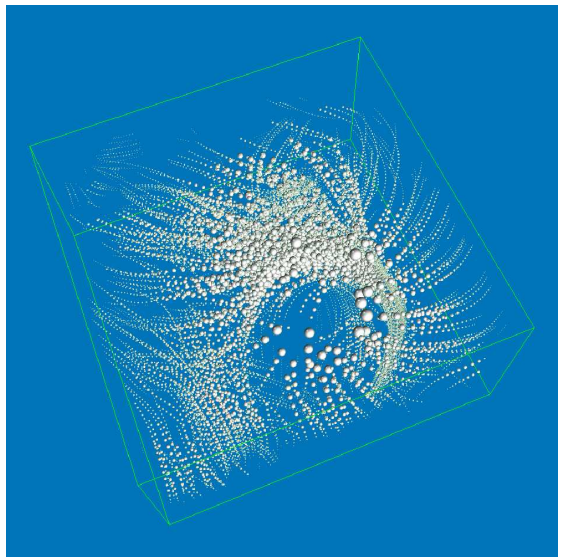


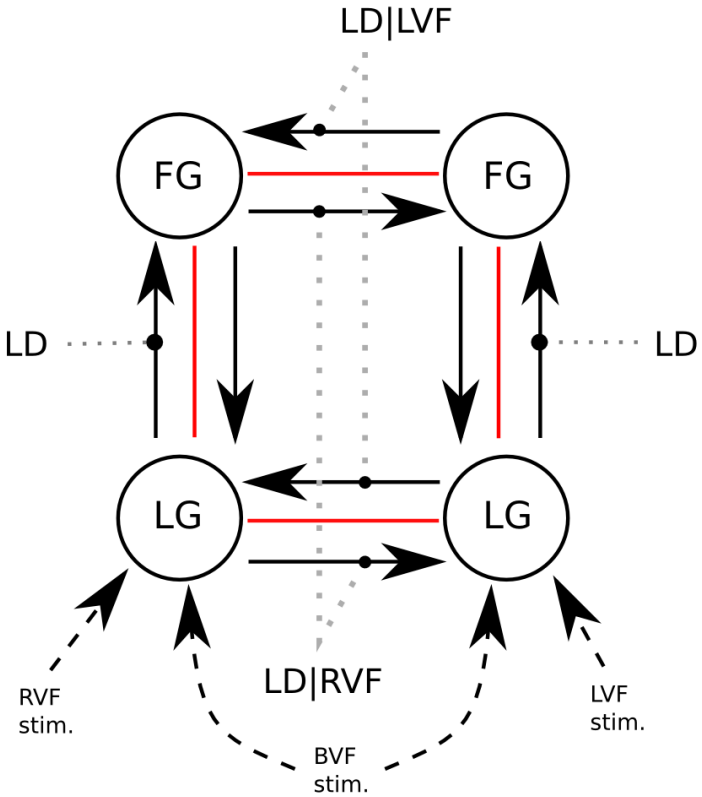
Figure: Particle animation

- Problem: only one direction, no weighting (besides color-coding).

Requirements

- Embedded visualization into the 3D domain
- Anatomical context, especially the fiber-tracts
- Selective browsing of large graphs in 3D
- Relative visualization of both effective connectivities on one connection
- Illustrative and appealing visualization
- Exploit the metaphor of moving information packages

Goal


LD|LVF
FG
FG
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LG
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RVF
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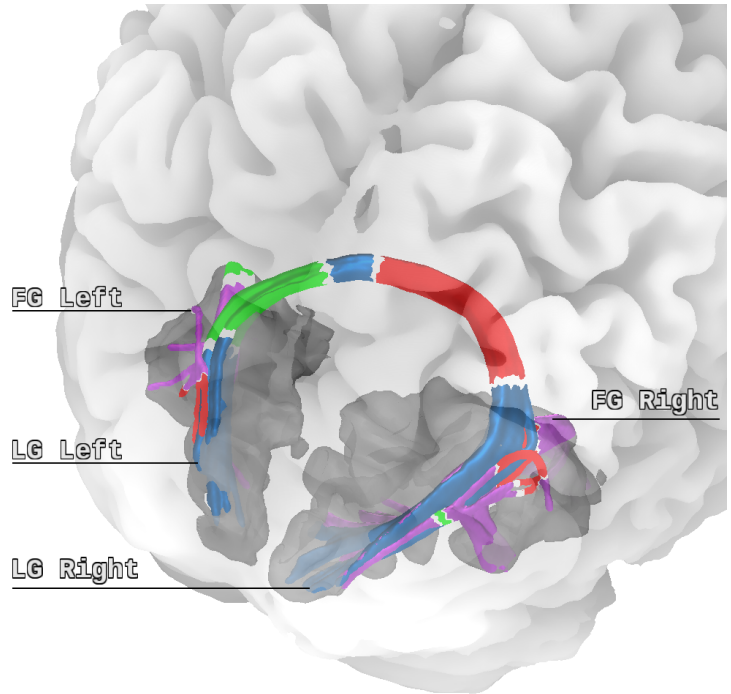
LD|RVF
BVF
stim.
LVF
stim.


FG Left
FG Right
LG Left
LG Right

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Fiber-tract selection

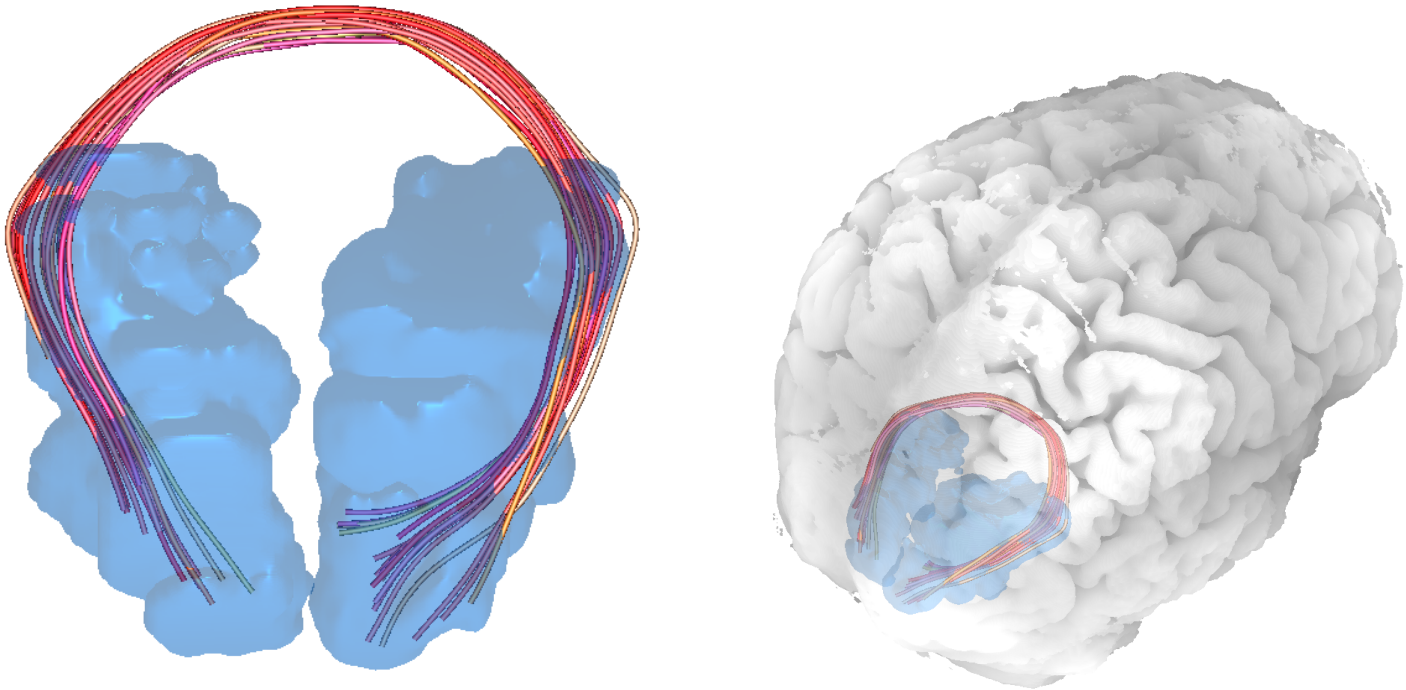


Figure: Selecting involved fiber-tracts using two masks for LGl and LGr.

Volumetric fiber-tract representation I

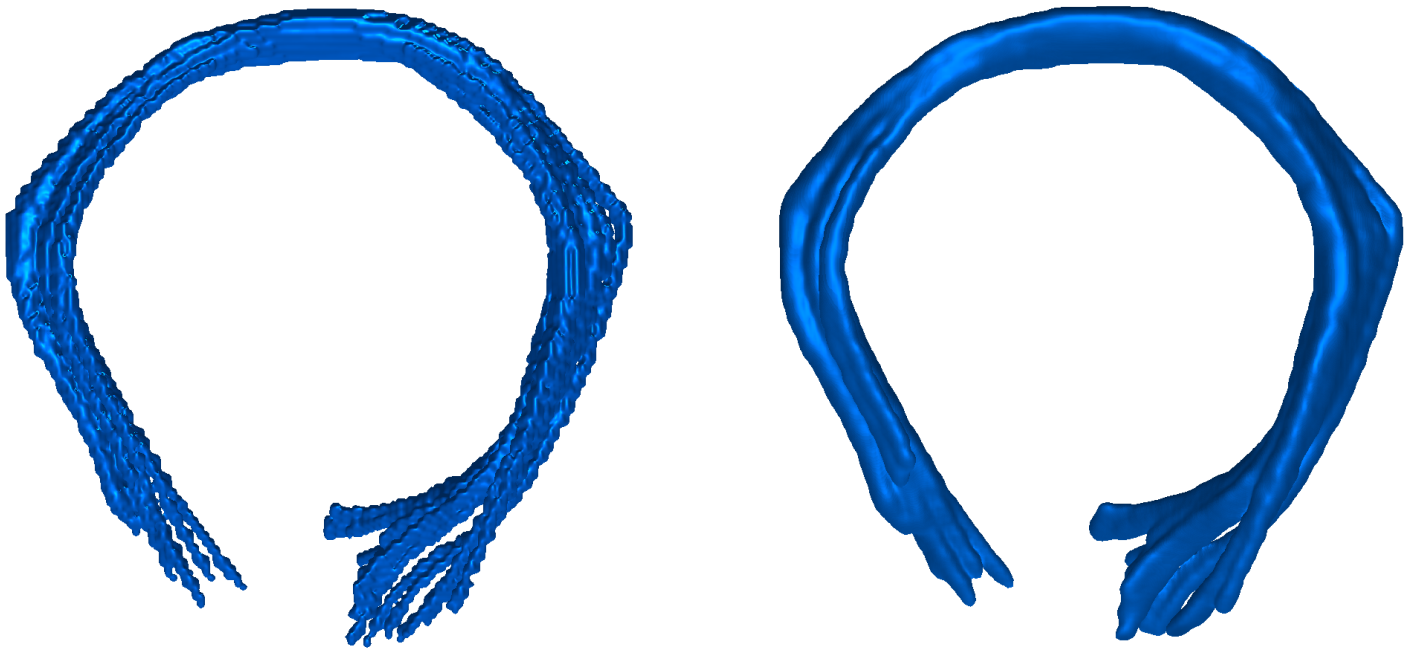


Figure: The bundle gets voxelized and filtered with a gauss kernel to smooth the jagged surface.

Volumetric fiber-tract representation II

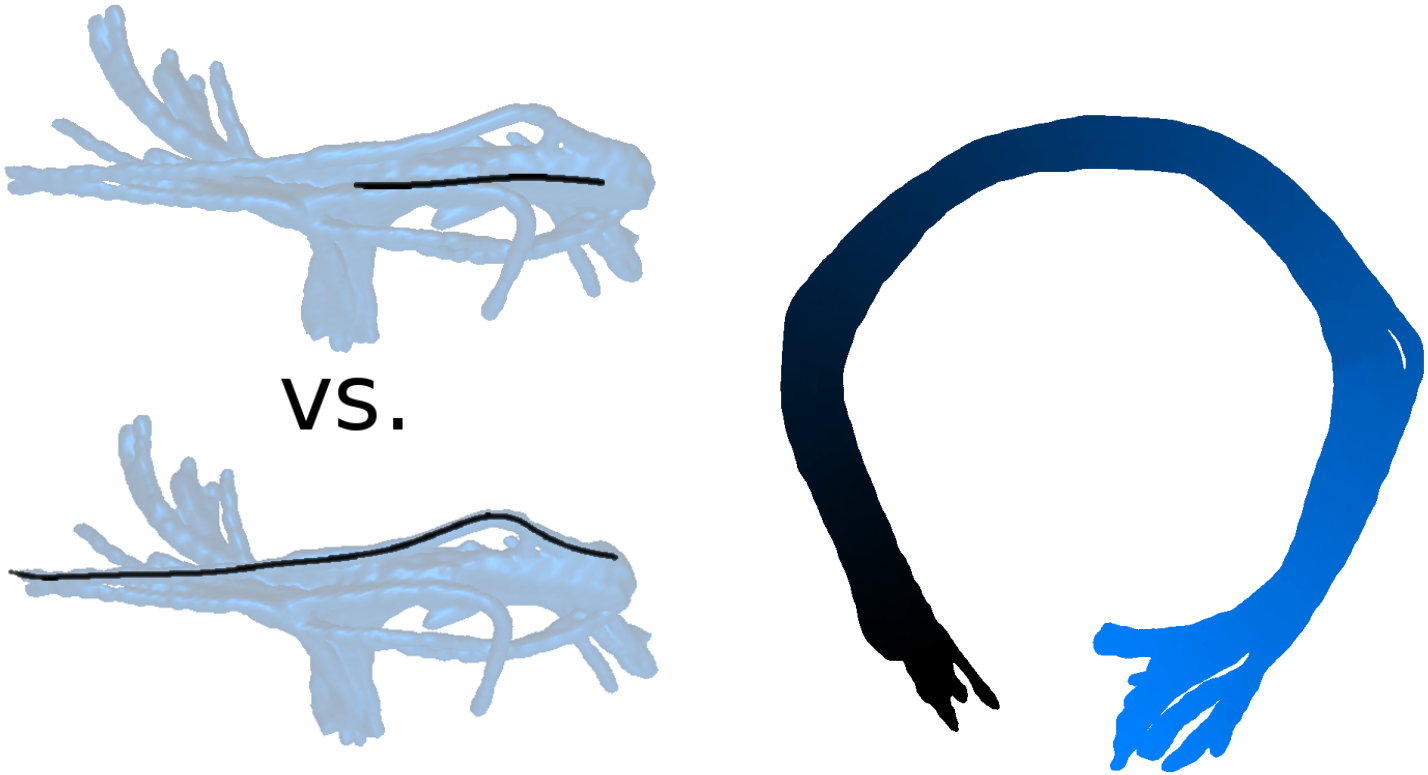


Figure: Parameterization of the volume along the so called center line or longest fiber-tract.

Effective connectivity animation

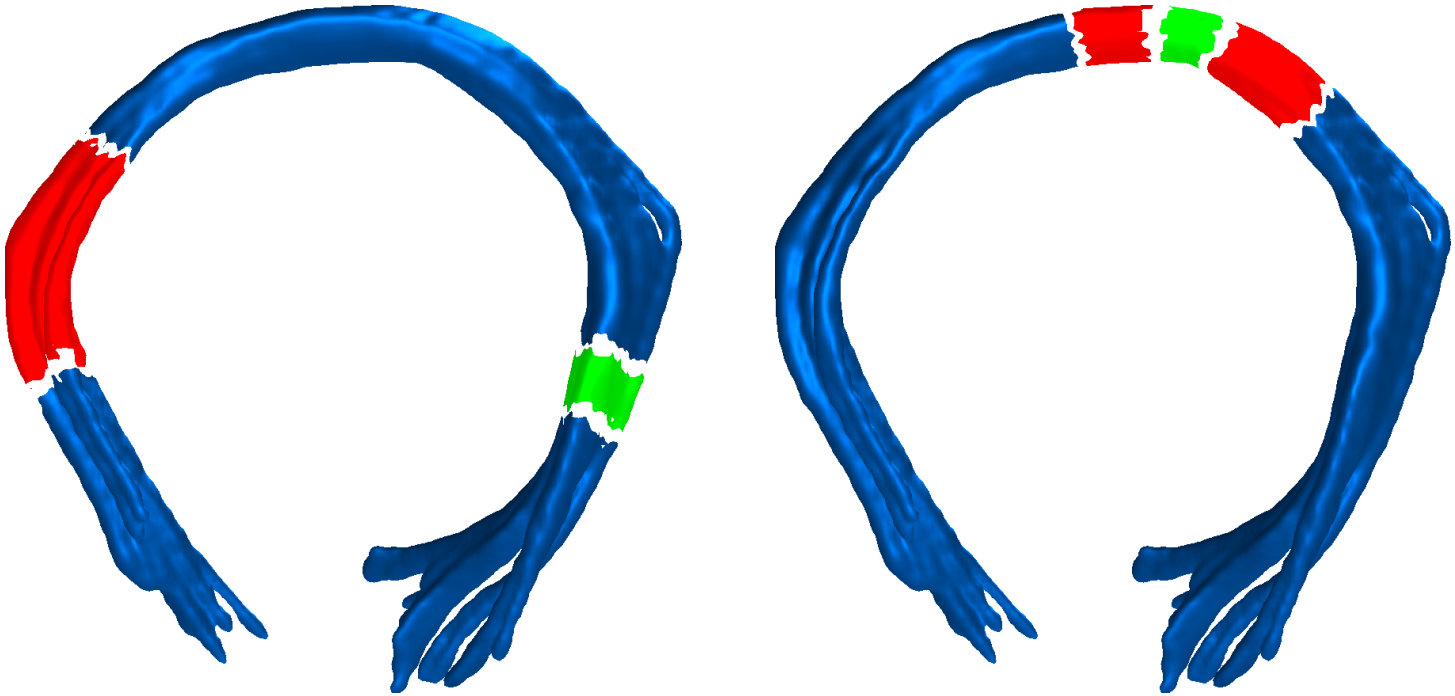
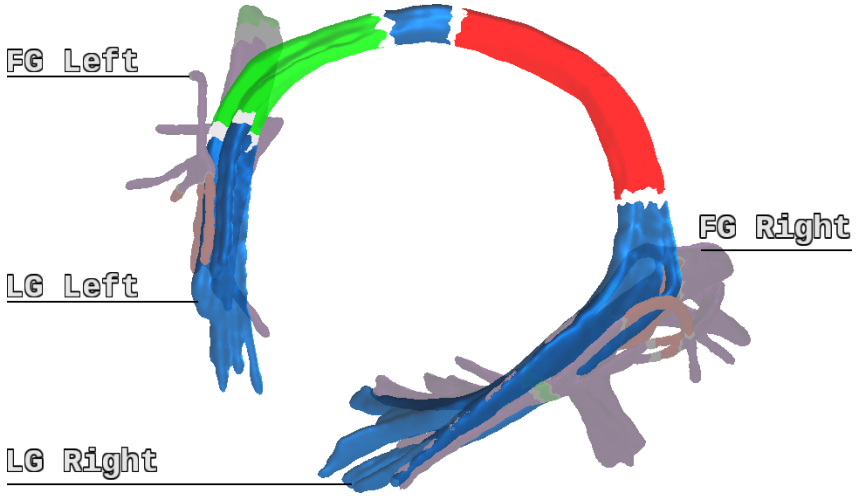


Figure: Two beams of different size representing information packages, a metaphor for effective connectivity strength.

Labeling and context



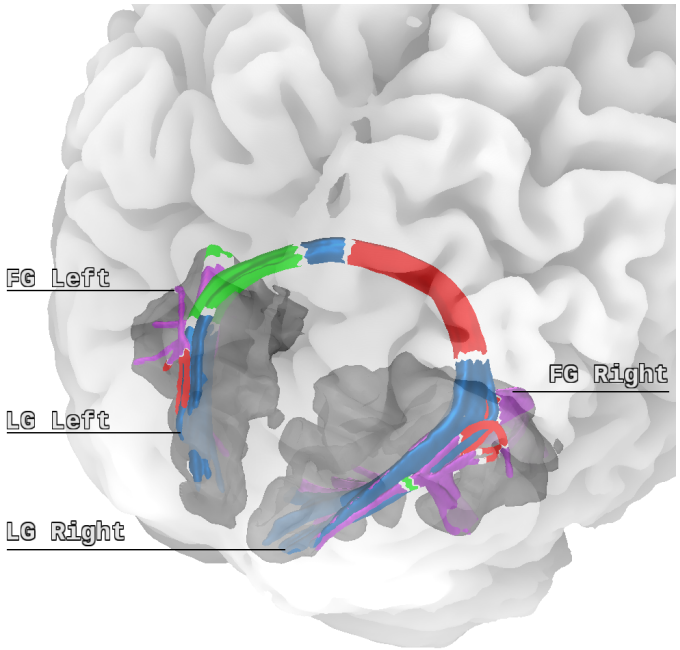


Figure: Labeling of each connecting and embedding it into some anatomical context.

Video

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Results

- Embedded in its anatomical context
- Focus and context principles
- Both effective connectivity values on one connection
- Relative sizes for comparability of multiple connections
- Illustrative and metaphoric character

Problems and Further Work

- Animation?
  - Evaluation of other animations and color-codings
- Scaling problems and relative sizes
  - Evaluation of scaling schemes
- Visual clutter
  - Addition of easier browsing tools
  - Evaluation of large connectivity graphs

Thank You for listening

Questions?