TRR295 workshop "Computational Models"
“OSS-DBS within Lead-DBS”

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Why OSS-DBS

- Advanced E-field modeling:
  - tissue dispersiveness and capacitance,
  - conductivity tensors
  - adaptive mesh refinement
- Cable equations
- Supports pathway activation modeling
- For the theory, refer to *https://doi.org/10.1371/journal.pcbi.1008023*

Why not:

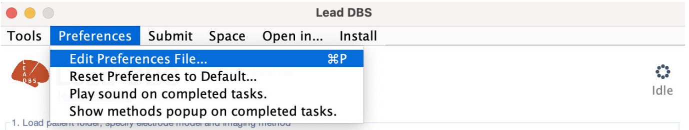
- Computationally demanding (do not run on your old laptop)
- Advanced simulations require understanding of model parameters

Overview

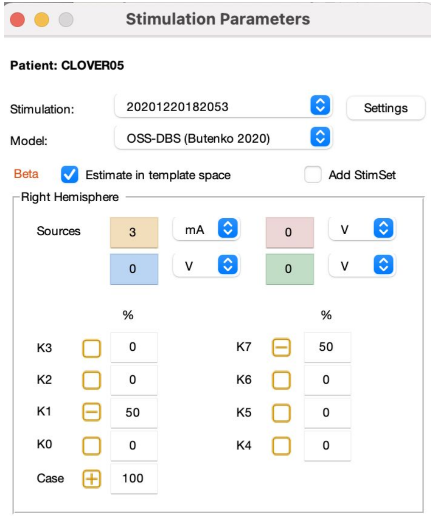
- Installation
- Setting up in Lead-DBS
    - *VTA approximation*
    - *Pathway activation modeling (PAM)*
    - *Multiple protocols*
- OSS-DBS GUI
- OSS-DBS terminal

Installation

OSS-DBS is distributed as an external library in Lead-DBS



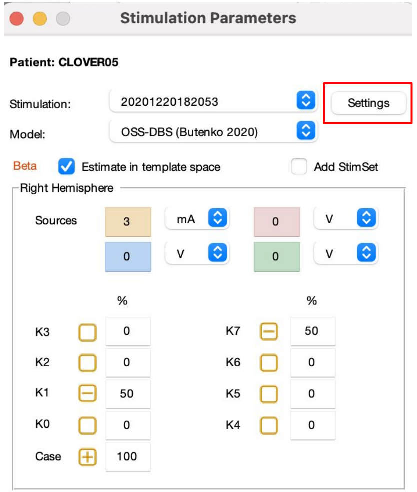
- *git clone --branch develop --single-branch https://github.com/netstim/leaddbs.git*
- Merge the data folder and request DTI and connectome files from us
- DTI data in *'lead-dbs-folder'/templates/space/MNI_ICBM_2009b_NLIN_ASYM/*
- Enable development environment
- In MATLAB command line, run *ea_checkOSSDBSInstall*
- *Windows* and *macOS* users should install *Docker Desktop* and provide corresponding permissions
- Ubuntu users should follow instructions on page 4 of OSS-DBS tutorial *ext_libs/OSS-DBS/OSS-DBS - Lead-DBS - tutorial.pdf*

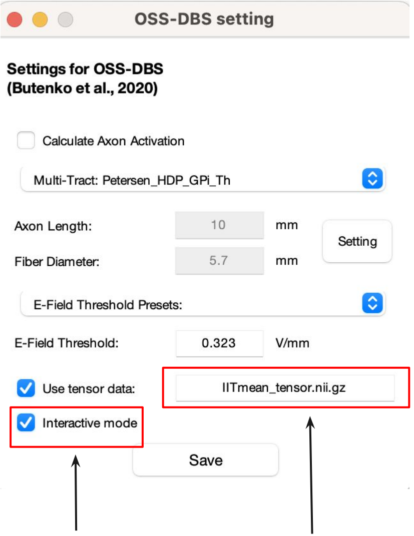


Setting up in Lead-DBS

Required minimum for non-experts

- Template or native space
- Source settings either in Lead-DBS or OSS-DBS
- Currently supports one source, support for multiple upon request
- Use *settings* to specify the simulation setup





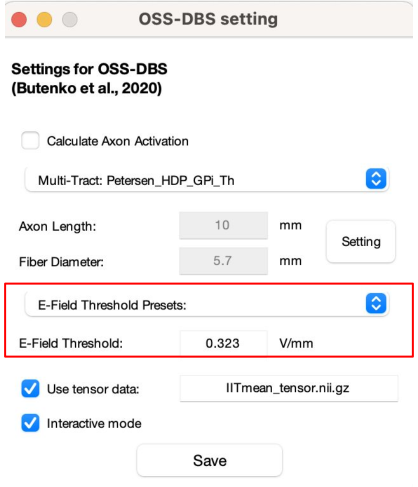
Check if OSS-DBS GUI will be used

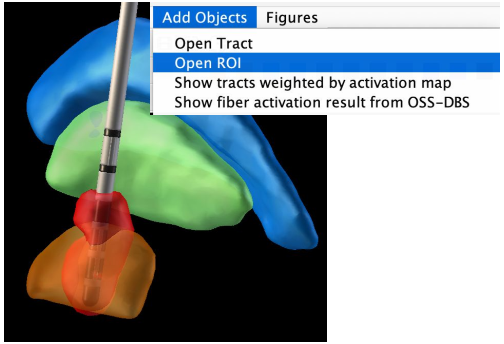
External DTI data

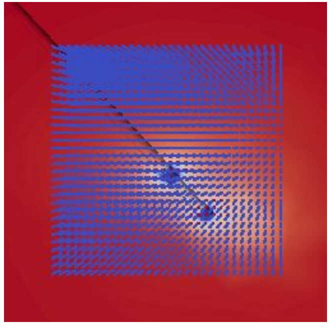
Setting up in Lead-DBS: VTA approximation

Standard approach of VTA approximation by |E|-threshold is supported

- VTA is seeded with MRI resolution
- Maximum |E| during the pulse
- Rattay's function upon request
- Directional VTA in development





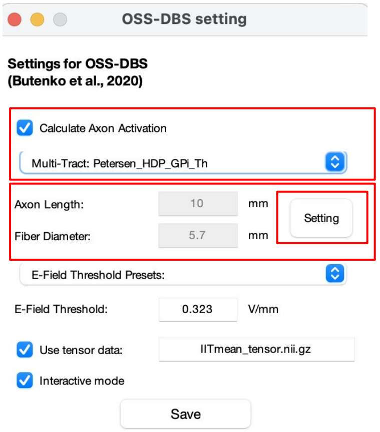


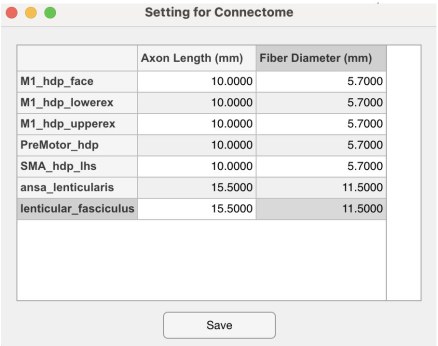
Setting up in Lead-DBS: PAM

Activation of 'realistic' axons

Choose a connectome/pathway

If one pathway, settings here





	Axon Length (mm)	Fiber Diameter (mm)
M1_hdp_face	10.0000	5.7000
M1_hdp_lowerex	10.0000	5.7000
M1_hdp_upperex	10.0000	5.7000
PreMotor_hdp	10.0000	5.7000
SMA_hdp_lhs	10.0000	5.7000
ansa_lenticularis	15.5000	11.5000
lenticular_fasciculus	15.5000	11.5000

- Within one pathway, the same morphology
- When modeling one pathway, store a file with fibers as *'lead-dbs-folder'/connectomes/dMRI/'pathway_name'/data.mat*
- When modeling multiple pathways, store them as *.../dMRI_MultiTract/'connectome_name'/'pathway_name.mat'*
- Fibers are pre-filtered using intentionally exaggerated Kuncel VTA
- Example of a fiber file: *https://github.com/SFB-ELAINE/OSS-DBS/blob/67a30ac26b300e7517b5c302912d7130c126db45/OSS_platform/Example_fibers.mat*

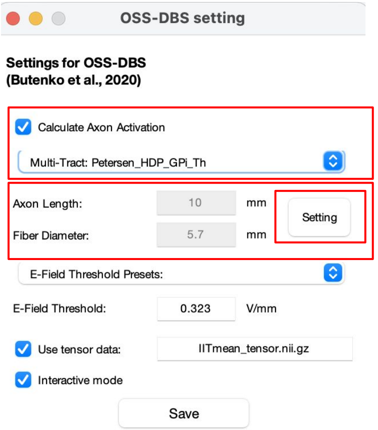
Setting up in Lead-DBS: PAM

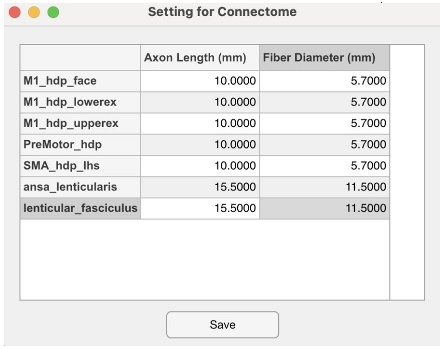
Activation of 'realistic' axons

- Axons are centered around active contacts
- Axon length: limit for long fibers to reduce computational costs
- Fiber diameter: educated guess
- Axon model: McIntyre's mammalian axon (or classic McNeal's)

Choose a connectome/pathway

If one pathway, settings here





	Axon Length (mm)	Fiber Diameter (mm)
M1_hdp_face	10.0000	5.7000
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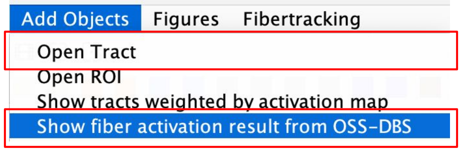
SMA_hdp_lhs	10.0000	5.7000
ansa_lenticularis	15.5000	11.5000
lenticular_fasciculus	15.5000	11.5000

Setting up in Lead-DBS: PAM

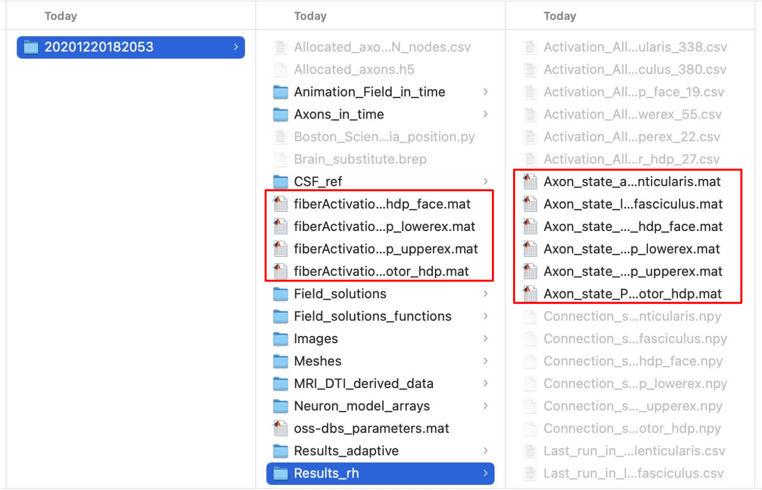
Activation of ‘realistic’ axons

Show fiber/axon status



Show fibers /axons

- Purple - damaged, red - activated (i.e. AP in response to the DBS pulse)
- Damaged due to the intersection with the electrode, encapsulation and CSF
- Activation is also stored in Network_state.h5 file (dataset for each projection)
- Fiber activation is displayed automatically



Setting up in Lead-DBS: PAM

Activation of 'realistic' axons

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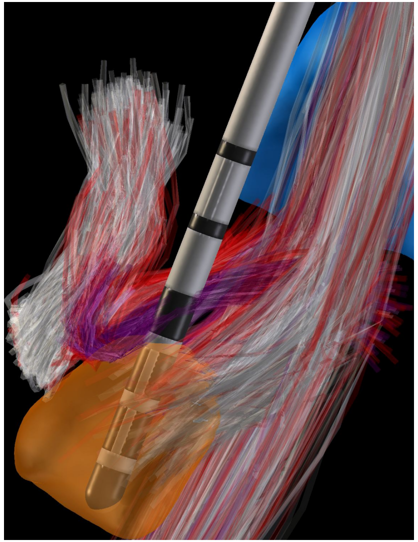
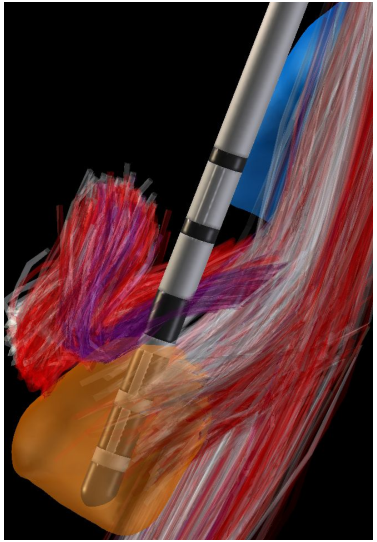


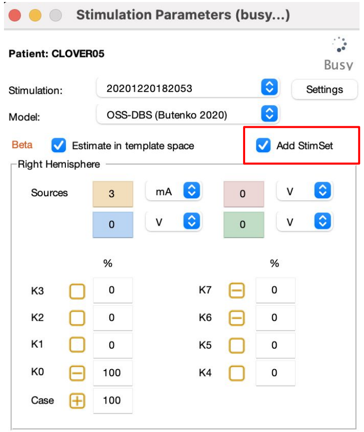


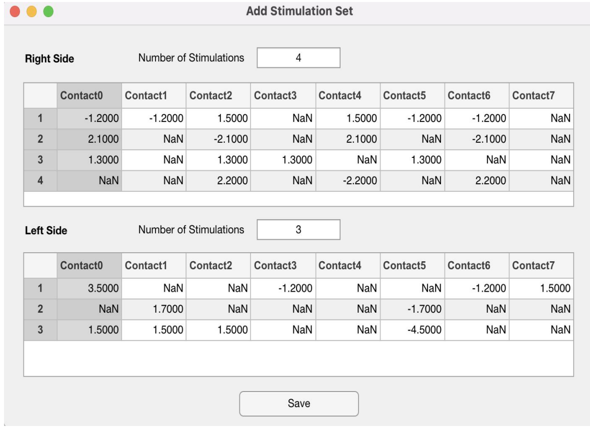
Setting up in Lead-DBS: Multiple protocols

Field superposition instead of recalculations

$$\nabla \cdot \Big[\big(\sigma(\mathbf{r},\omega) + j\omega\epsilon(\mathbf{r},\omega)\big)\nabla\phi\Big] = 0$$

- Linearity of Laplace's equation allows to 'combine' and scale solutions (el. potential distribution) for each active contact
- Straight-forward for constant current mode
- StimSet input in mA(!)
- Use case grounding
- Superposition of |E| suffers from discretization inaccuracies





Setting up in Lead-DBS: Multiple protocols

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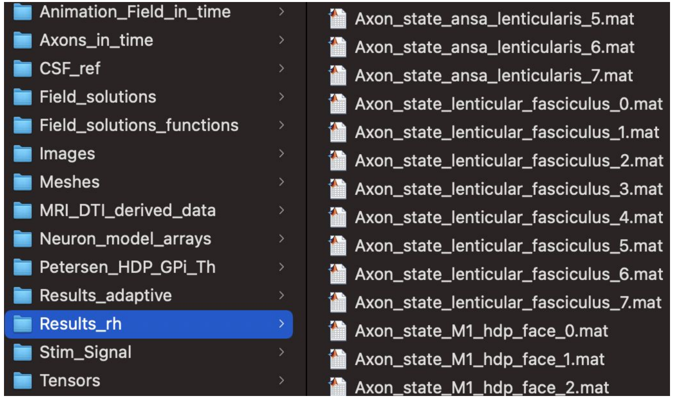
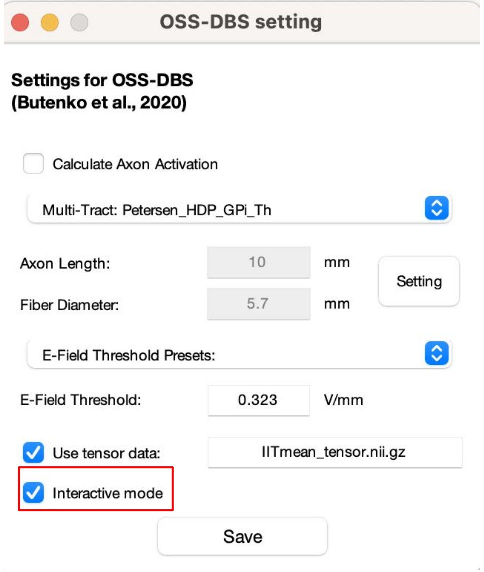


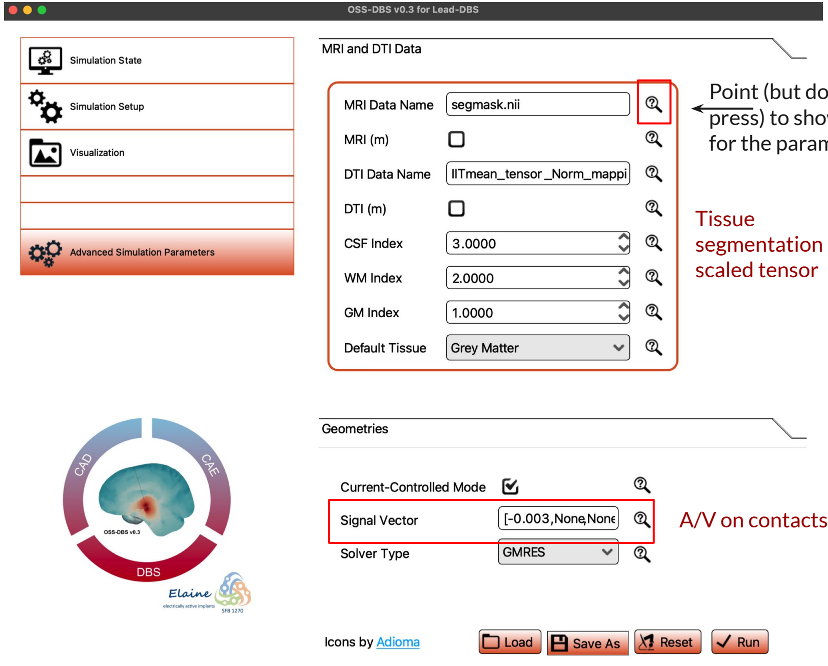
OSS-DBS GUI

Deeper understanding of the model

- Opens anyway, but waits for the input if interactive mode



Lead-DBS input →



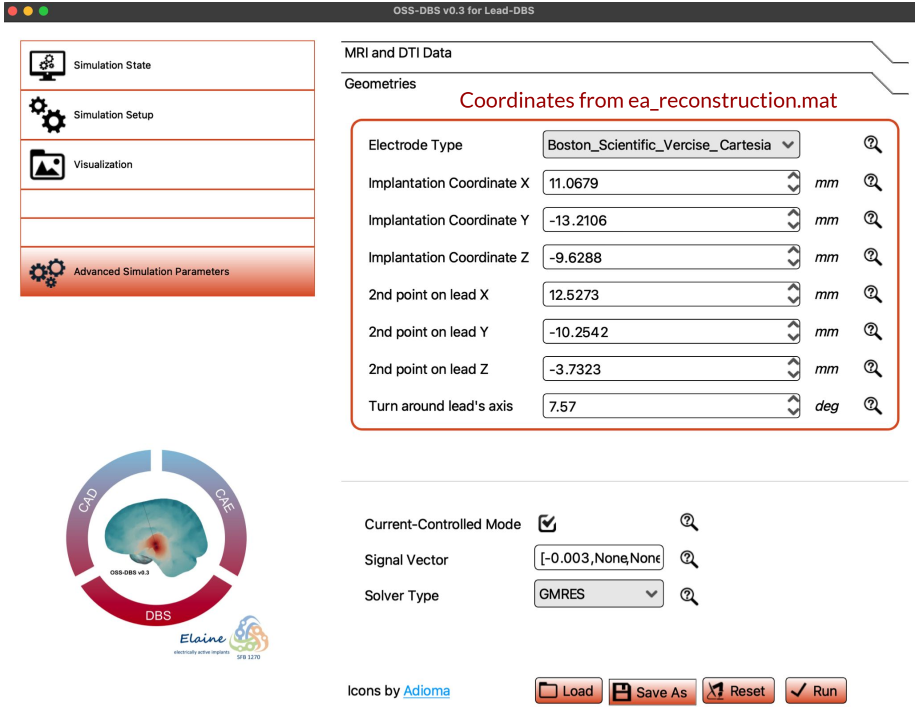
Point (but do not press) to show a tip for the parameter

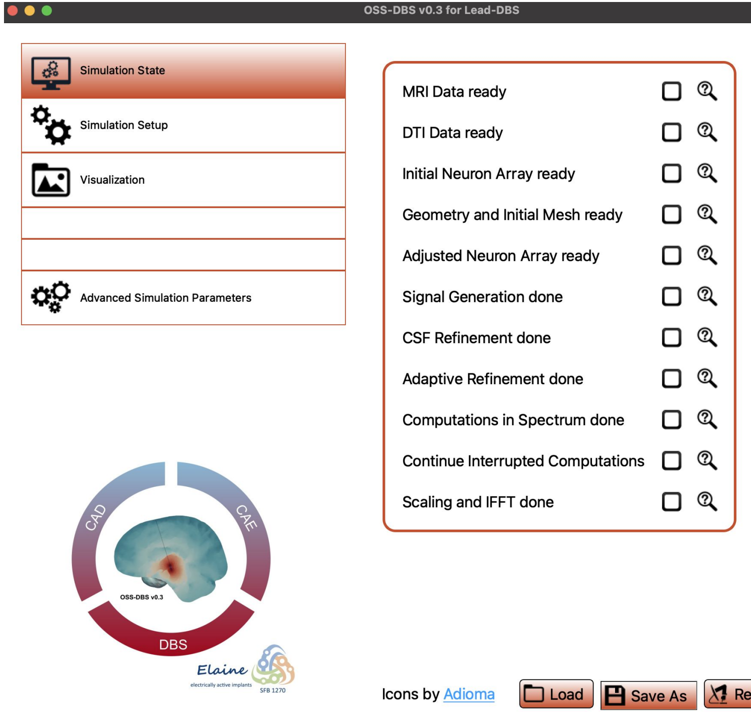
Tissue segmentation and scaled tensor

A/V on contacts

OSS-DBS GUI

Deeper understanding of the model





Skipping steps if interrupted

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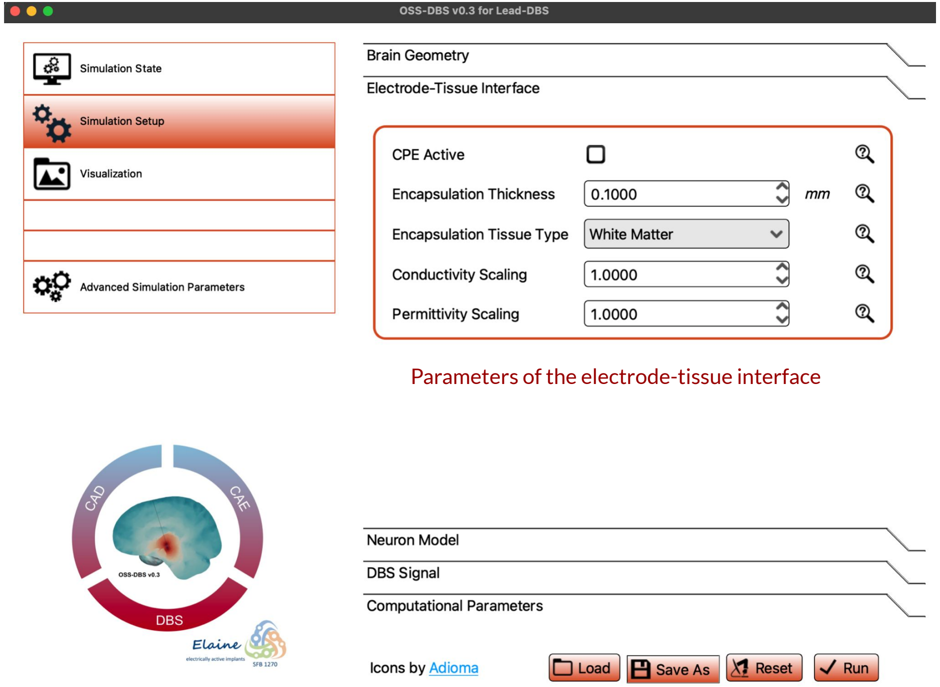
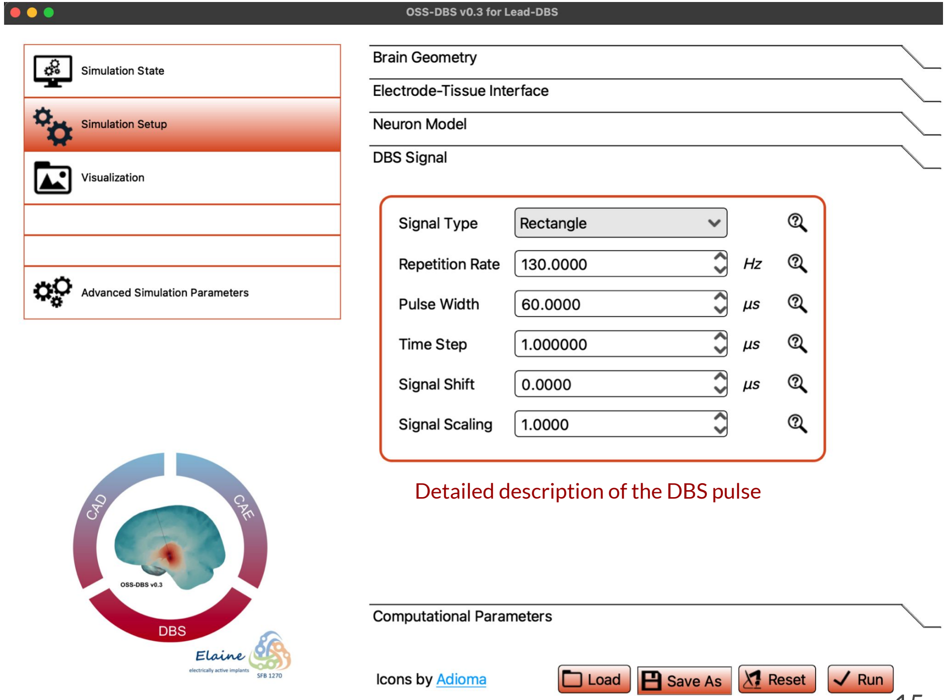
OSS-DBS GUI

Deeper understanding of the model



Parameters of the electrode-tissue interface

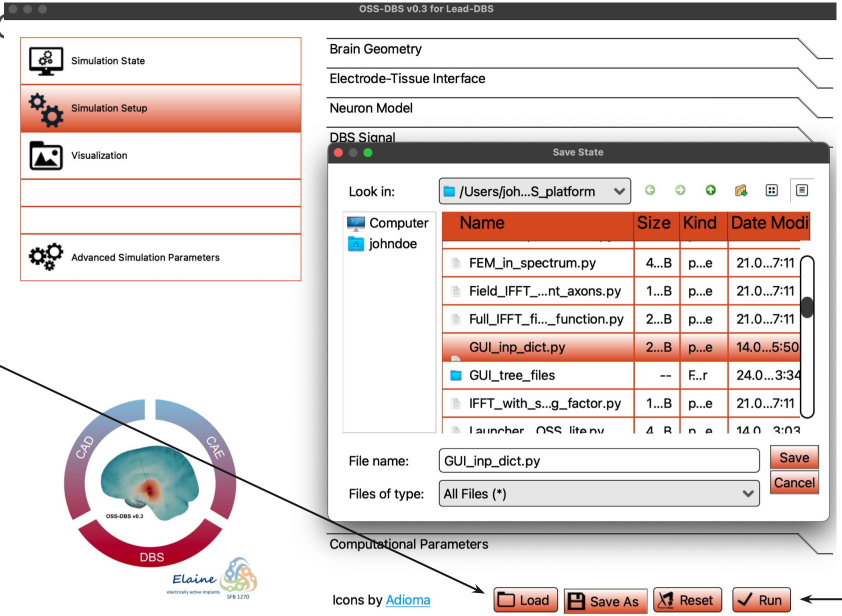


Detailed description of the DBS pulse

OSS-DBS GUI

Deeper understanding of the model

- Input configuration is stored as a python dictionary GUI_inp_dict.py in *ext_libs/OSS-DBS/C*



Load a preconfigured simulation

Resave your configuration as this file to use in the simulation or save in another .py file for future

Instead of using GUI, you can modify entries of the dictionary directly (for advanced users)

Launch a simulation in a Docker container

OSS-DBS outputs

Behind the scenes

- Various outputs and intermediate files are stored in patient folders
- Can be rather large (depending on the neuron array)
- What is interesting: *Tensors/*, *Images/*, *Field_solutions/*
- Status files: *success_rh*, *skip_rh*, *fail_rh* (same with *_lh*)

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OSS-DBS terminal

Behind the scenes

- Shows the simulation flow (but concisely)
- The starting point to trace errors
- Closes automatically if everything is fine
- Log files will be implemented

```
--- MRI meta data were loaded

--- DTI meta data were loaded

----- Adjusting neuron models to the geometry and MRI data -----
voxel_array_CSF is loaded
Points in CSF, encapsulation layer (and floating conductors) and outside (and intersecting with the electrode):
0 103 9
Adjusted neuron models can be visualized from Neuron_model_arrays/Vert_of_Neural_model_NEURON.csv in Paraview
Number of placed neuron models per population:  [ 98  97  98  85 500 410]
----- Adjustment of the neuron models took  0  min  11  s -----
Neuron models were adjusted and corresp. meta data were created

----- Generating DBS signal -----
Rectangle  with repetition rate  130.0  Hz and  0.06  ms pulse width
Max frequency in the spectrum:  500000.0

----- Signal generation took  0  min  1  s -----
Before ground ref:  554713
After ground ref:  554713
CSF and adaptive mesh refinement was skipped

----- Truncating the frequency spectrum -----
Number of frequencies after truncation with the octave method:  15
New frequency vector can be found in Stim_Signal/FR_vector_signal_octaves130.0.csv

----- Calculating electric field in the truncated frequency spectrum -----
```

OSS-DBS support

That is our job

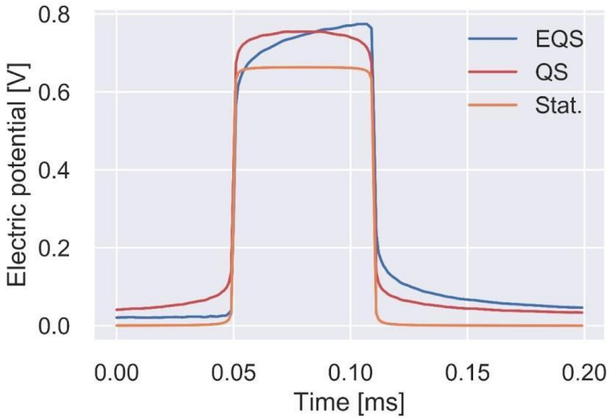
- Do not hesitate to contact us (*konstantin.butenko@uni-rostock.de, arash.golmohammadi@uni-rostock.de*)
- The software is rather new, not all features are implemented
- Cluster solution after summer
- Standalone version for fundamental research

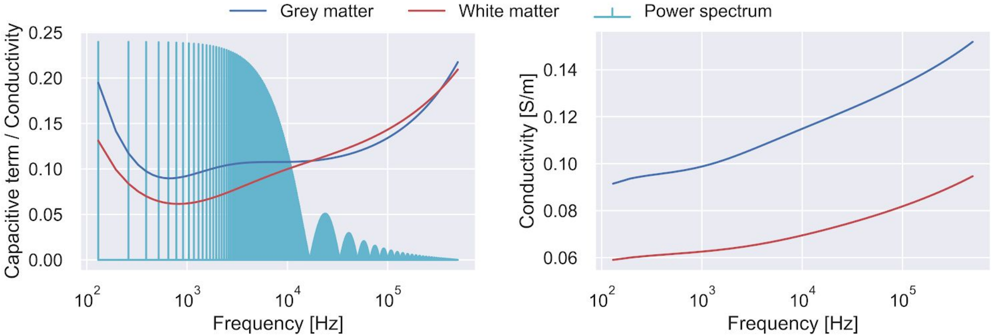
Appendix

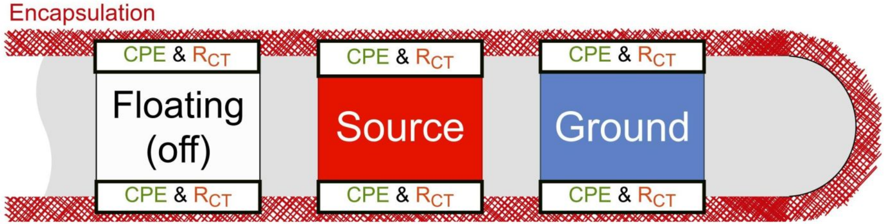
Butenko K, Bahls C, Schröder M, Köhling R, van Rienen U (2020) *OSS-DBS: Open-source simulation platform for deep brain stimulation with a comprehensive automated modeling*. PLoS Comput Biol 16(7): e1008023.
https://doi.org/10.1371/journal.pcbi.1008023

Field modeling

$$\nabla \cdot \Big[\big(\sigma(\mathbf{r},\omega) + j\omega\epsilon(\mathbf{r},\omega) \big) \nabla \phi \Big] = 0$$







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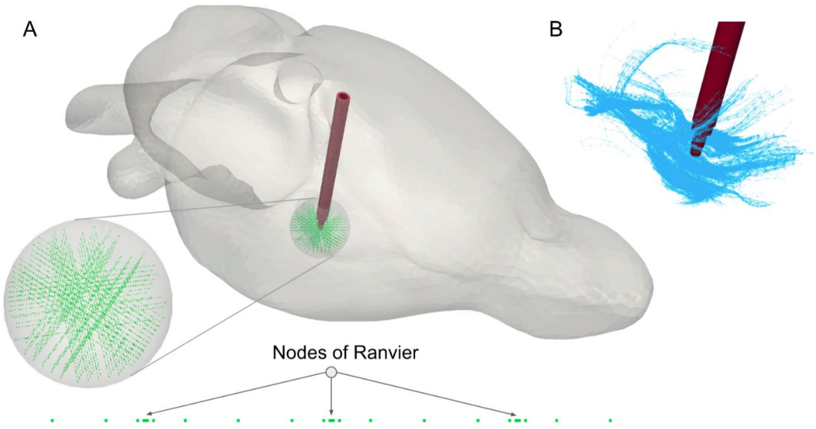
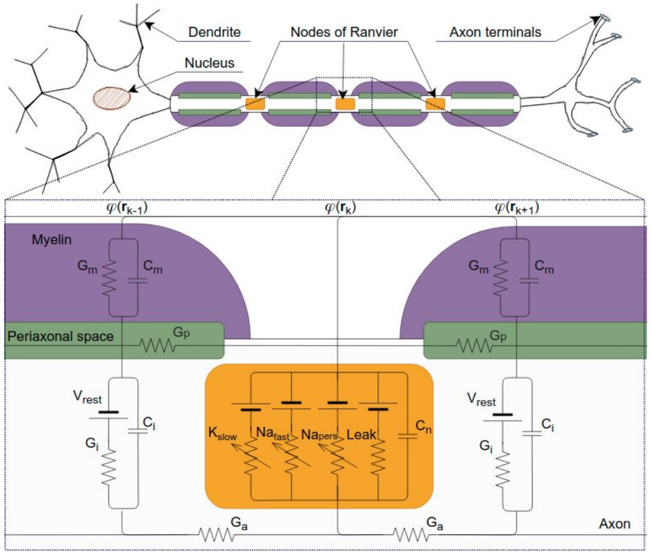
Neural activation





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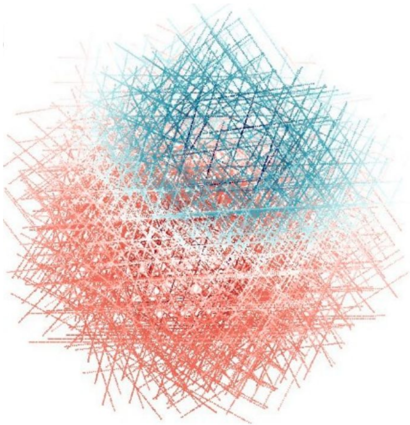
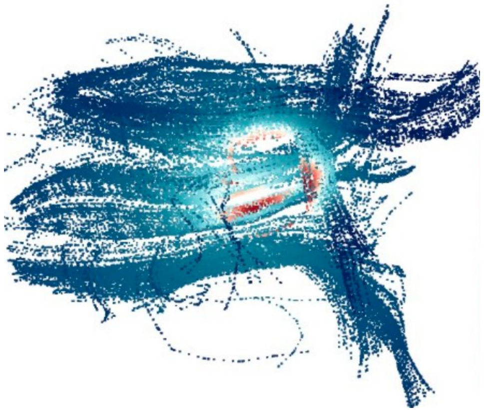
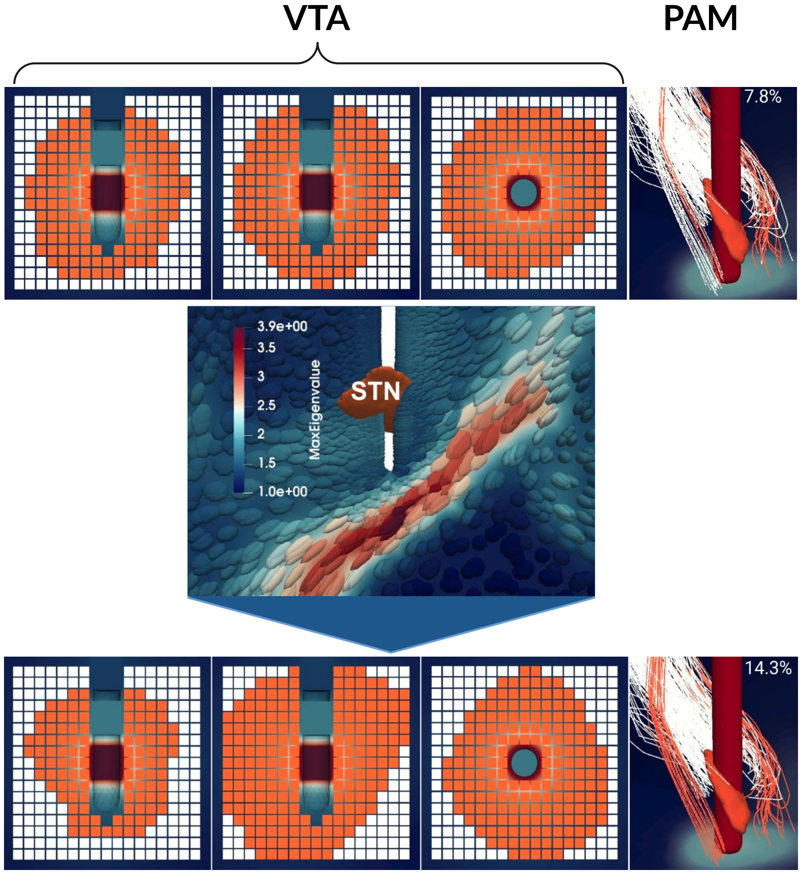




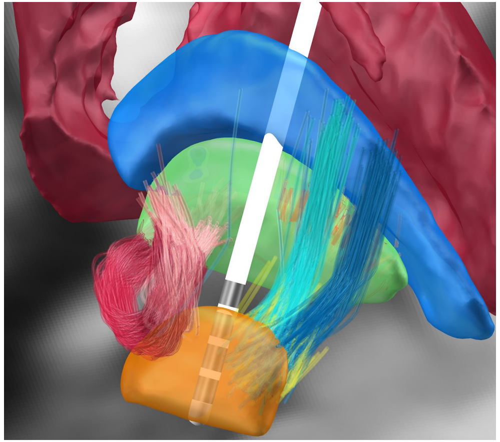


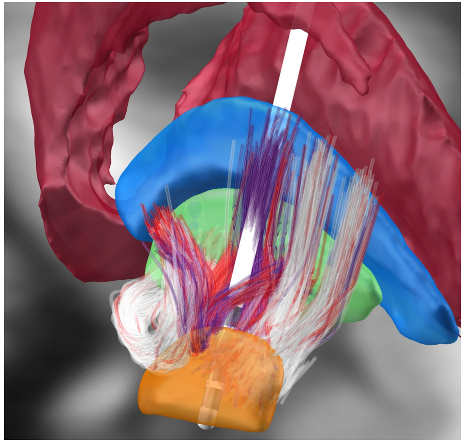
OSS-DBS & Lead-DBS

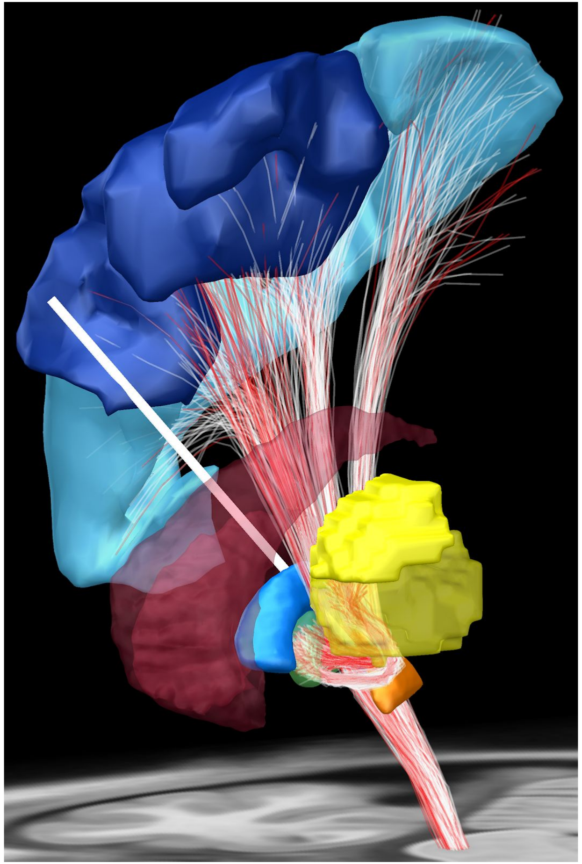
- Tailoring OSS-DBS and Lead-DBS *(Ningfei & Konstantin)* ✓
    - *Relatively simple deployment in Windows, macOS and Linux using Docker*
    - *Preferably in patient space (due to linearity assumption of electrode lead geometry)*
- Volume of Tissue Activated ✓
- Pathway Activation Modeling ✓
- Cluster version *(Ningfei)* ✓

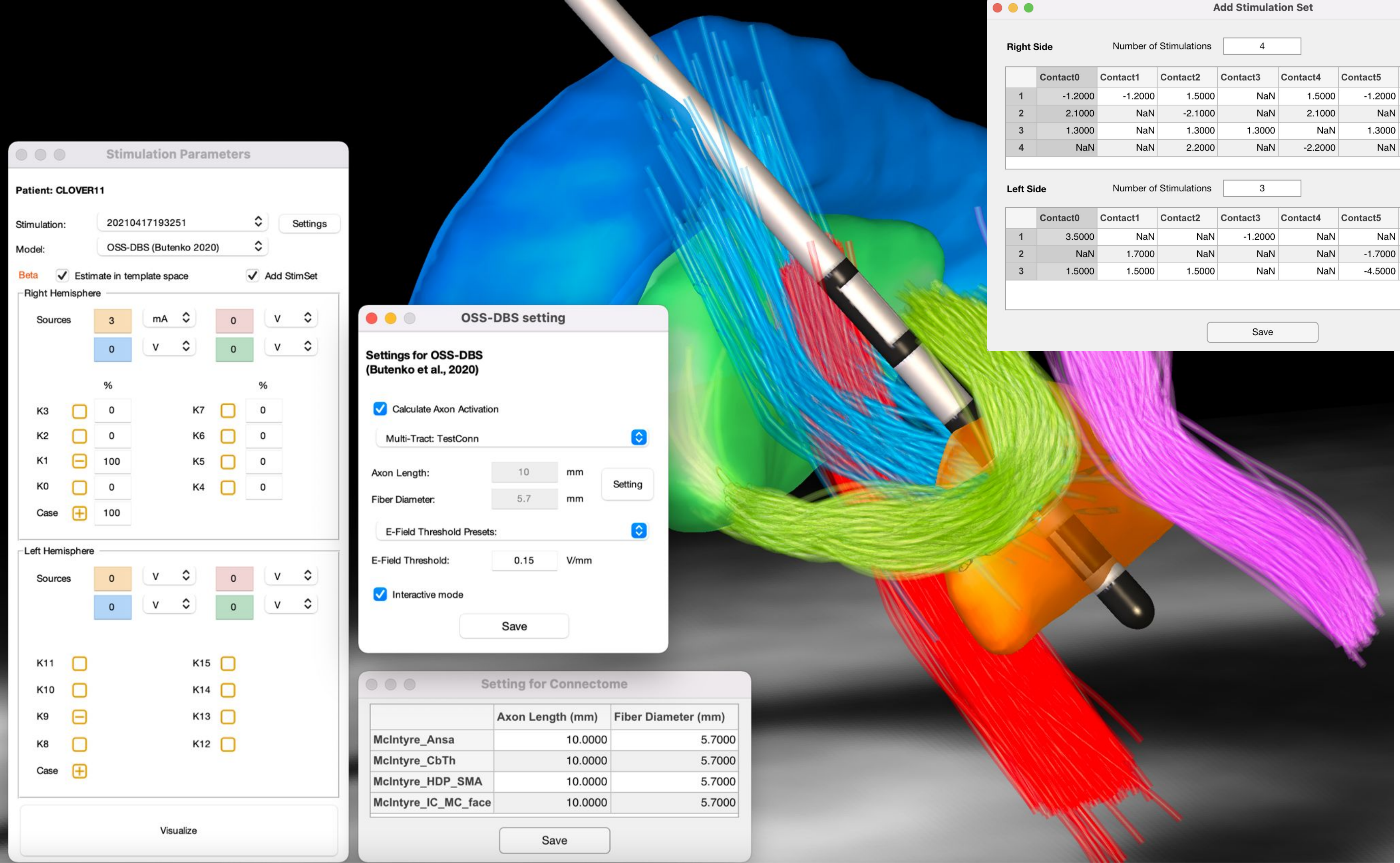
OSS-DBS & Lead-DBS

- Different morphology per projection in one simulation
- Axons near the lead are considered damaged








Add Stimulation Set
Right Side
Number of Stimulations
4
Contact0 Contact1 Contact2 Contact3 Contact4 Contact5 Contact6 Contact7
1 -1.2000 -1.2000 1.5000 NaN 1.5000 -1.2000 -1.2000 NaN
2 2.1000 NaN -2.1000 NaN 2.1000 NaN -2.1000 NaN
3 1.3000 NaN 1.3000 1.3000 NaN 1.3000 NaN NaN
4 NaN NaN 2.2000 NaN -2.2000 NaN 2.2000 NaN
Left Side
Number of Stimulations
3
Contact0 Contact1 Contact2 Contact3 Contact4 Contact5 Contact6 Contact7
1 3.5000 NaN NaN -1.2000 NaN NaN -1.2000 1.5000
2 NaN 1.7000 NaN NaN NaN -1.7000 NaN NaN
3 1.5000 1.5000 1.5000 NaN NaN -4.5000 NaN NaN
Save
Stimulation Parameters
Patient: CLOVER11
Stimulation:
20210417193251
Settings
Model:
OSS-DBS (Butenko 2020)
Beta
Estimate in template space
Add StimSet
Right Hemisphere
Sources
3
mA
0
V
0
V
0
V
%
%
K3 0
K2 0
K1 100
K0 0
Case 100
K7 0
K6 0
K5 0
K4 0
Left Hemisphere
Sources
0
V
0
V
0
V
0
V
K11
K10
K9
K8
Case
K15
K14
K13
K12
Visualize
OSS-DBS setting
Settings for OSS-DBS
(Butenko et al., 2020)
Calculate Axon Activation
Multi-Tract: TestConn
Axon Length: 10 mm
Fiber Diameter: 5.7 mm
Setting
E-Field Threshold Presets:
E-Field Threshold: 0.15 V/mm
Interactive mode
Save
Setting for Connectome
Axon Length (mm) Fiber Diameter (mm)
McIntyre_Ansa 10.0000 5.7000
McIntyre_CbTh 10.0000 5.7000
McIntyre_HDP_SMA 10.0000 5.7000
McIntyre_IC_MC_face 10.0000 5.7000
Save

Next Steps

- Patient-specific VCM
    - *In vivo conductivity measurements*
    - *Patient specific DWI*
- PAM
    - *Testing of PAM efficiency in clinics (e.g. IC activation monitored with EMG)*
    - *Fiber-to-projection classifier*
    - *Morphological analysis of relevant fibers*
- Active neuromodulation
    - *DBS pulse optimization*
- Computational model of Basal ganglia-thalamo-cortical network
    - *Early studies*

Conclusion

WP3: Advanced field modeling of stimulation effects

- **Experiment #1**: *Integration of OSS-DBS and Lead-DBS* ✓
  - Optimization and refinement
- **Experiment #2**: *Advanced computational model*
  - Devising patient-specific model
  - Detail analysis of fiber tracts
  - Automated tractography
  - Pulse optimization
  - Network effects