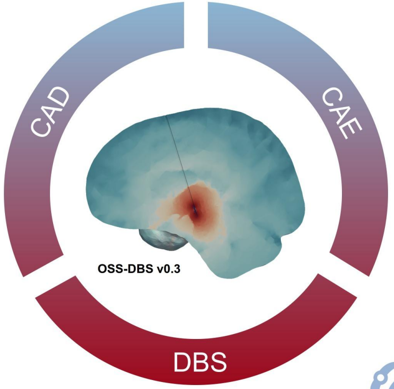
RETUNE
CRC TRR 295 Berlin–Würzburg

OSS-DBS: Quick Start

By Konstantin Butenko kbutenko@bwh.harvard.edu

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
- Example of use https://doi.org/10.1016/j.nicl.2022.103185



Elaine
electrically active implants
SFB 1270

Why not:

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

Overview

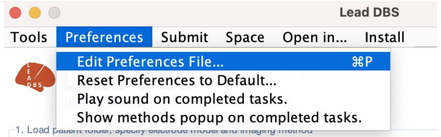
- Installation
- Setting up in Lead-DBS
  - *VTA approximation*
  - *Pathway activation modeling (PAM)*
  - *Multiple protocols*
- OSS-DBS GUI
- OSS-DBS terminal

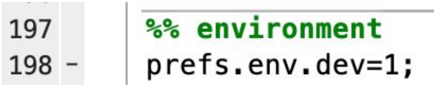
Installation

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

And runs within *Docker* (can be thought as a virtual environment)

- Install *Docker*
  - *Windows* and *macOS* users should install *Docker Desktop* and provide corresponding permissions
  - *Linux* users are referred to https://docs.docker.com/desktop/install/linux-install/ , make sure you install the appropriate version
- Enable development environment in *Preferences File*
- In MATLAB command line, run *ea_checkOSSDBSInstall*
  - Follow prompted suggestions, you might need to update *pip*


Lead DBS
Tools
Preferences
Submit
Space
Open in...
Install
Edit Preferences File... ⌘P
Reset Preferences to Default...
Play sound on completed tasks.
Show methods popup on completed tasks.
1. Load patient folder, specify electrode model and imaging method



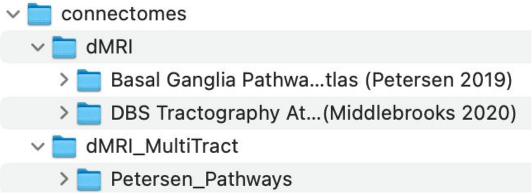
```
%% environment
prefs.env.dev=1;
```

Installation

Without Lead-DBS installation routines (for confident Linux users)

- Install *Docker* following https://docs.docker.com/desktop/install/linux-install/
- Install/update *pip*, run `python3 -m pip install PyQt5` and `python3 -m pip install h5py`
  - I had to re-install some *PyQt5* dependencies on *Ubuntu 22.04*
- Create a docker group, add your user and reboot
  - `sudo groupadd docker`
  - `sudo usermod -aG docker <USERNAME>`
- Pull the docker image `sudo docker pull ningfei/oss-dbs:latest`
- Open a terminal in *leaddbs/.../ext_libs/OSS-DBS/* and run the following to allow non sudo execution of docker container
  - `docker build --build-arg UID=$(id -u) --build-arg GID=$(id -g) -t ningfei/oss-dbs:custom -f custom.Dockerfile .`
- Run OSS-DBS with the following command
  - `docker run --name OSS_docker --volume <OSS-DBS path>:/opt/OSS-DBS --volume <patient stim folder path>:/opt/Patient --cap-add=SYS_PTRACE -it --rm <docker image>`
  - E.g. for a test patient *pBK:* `docker run --name OSS_docker --volume ~/Documents/leaddbs/ext_libs/OSS-DBS:/opt/OSS-DBS --volume ~/Documents/Data/pBK:/opt/Patient --cap-add=SYS_PTRACE -it --rm ningfei/oss-dbs:custom`

Additional files



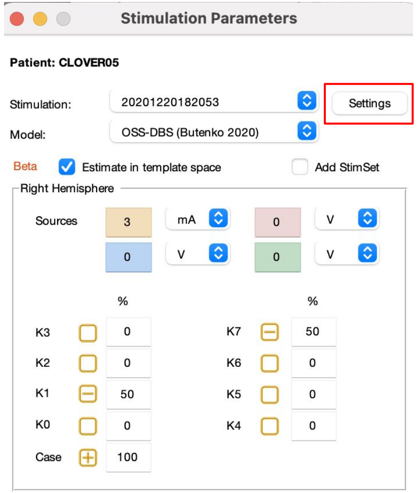
- connectomes
  - dMRI
    - Basal Ganglia Pathwa...tlas (Petersen 2019)
    - DBS Tractography At...(Middlebrooks 2020)
  - dMRI_MultiTract
    - Petersen_Pathways

- Lead-DBS *data* folder (*templates/…*) contains tensor data for MNI space (*IITMeanTensor.nii.gz* & *IITMeanTensor_NormMapping.nii.gz*)
- Advance users can use custom DTI data
- Fiber atlases are stored as *'lead-dbs-folder'/connectomes/dMRI/'atlas_name'/data.mat*
- Pathway atlases are stored as *'lead-dbs-folder'/connectomes/dMRI_MultiTract/'connectome_name'/'pathway_name.mat'*
- Example of a fiber atlas: [*https://github.com/SFB-ELAINE/OSS-DBS/blob/67a30ac26b300e7517b5c302912d7130c126db45/OSS_platform/Example_fibers.mat*](https://github.com/SFB-ELAINE/OSS-DBS/blob/67a30ac26b300e7517b5c302912d7130c126db45/OSS_platform/Example_fibers.mat)
- Contact us for connectomes, we have plenty!

Setting up in Lead-DBS

Required minimum for non-experts

- Template or native space (the latter is preferred)
- Source settings either in Lead-DBS or OSS-DBS (the latter is easier)
- Use *settings* to specify the simulation setup



Patient: CLOVER05

Stimulation: 20201220182053 Settings

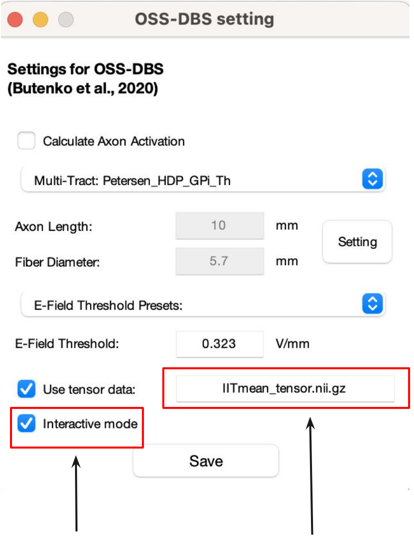
Model: OSS-DBS (Butenko 2020)

Beta ☑ Estimate in template space □ Add StimSet

Right Hemisphere

Sources 3 mA 0 V
0 V 0 V

	%			%
K3	0		K7	50
K2	0		K6	0
K1	50		K5	0
K0	0		K4	0
Case	100			



Settings for OSS-DBS (Butenko et al., 2020)

□ Calculate Axon Activation

Multi-Tract: Petersen_HDP_GPi_Th

Axon Length: 10 mm

Fiber Diameter: 5.7 mm

Setting

E-Field Threshold Presets:

E-Field Threshold: 0.323 V/mm

☑ Use tensor data: IITmean_tensor.nii.gz

☑ Interactive mode

Save

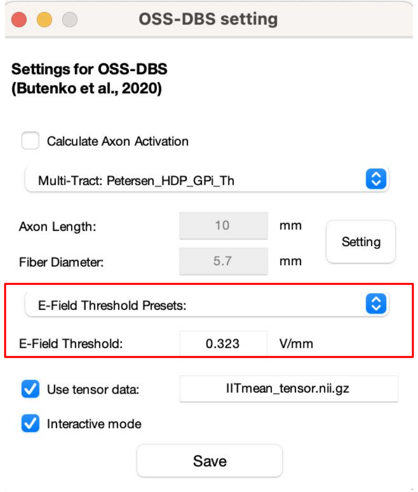
Check if OSS-DBS GUI will be used

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



OSS-DBS setting

Settings for OSS-DBS (Butenko et al., 2020)

☐ Calculate Axon Activation

Multi-Tract: Petersen_HDP_GPi_Th

Axon Length: 10 mm

Fiber Diameter: 5.7 mm

Setting

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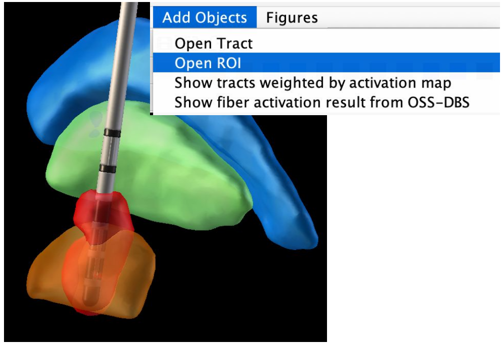
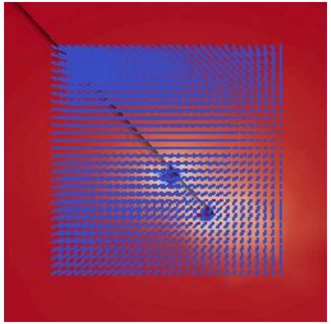
☑ Interactive mode

Save


Add Objects
Figures
Open Tract
Open ROI
Show tracts weighted by activation map
Show fiber activation result from OSS-DBS



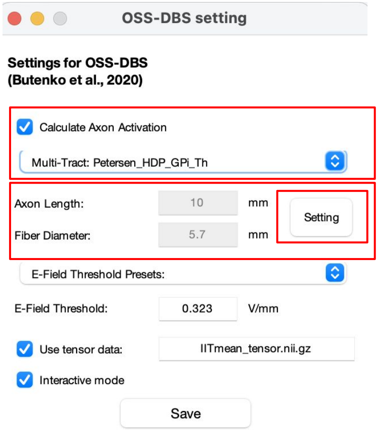
Setting up in Lead-DBS: PAM

Activation of 'realistic' axons

- The same morphology within one pathway
- 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'*
  - **IMPORTANT:** Review *'Setting'* when modeling multiple pathways!
- Fibers are pre-filtered using intentionally exaggerated Kuncel VTA

Choose a connectome/pathway →

If one pathway, settings here →



OSS-DBS setting

Settings for OSS-DBS (Butenko et al., 2020)

☑ Calculate Axon Activation

Multi-Tract: Petersen_HDP_GPi_Th

Axon Length: 10 mm

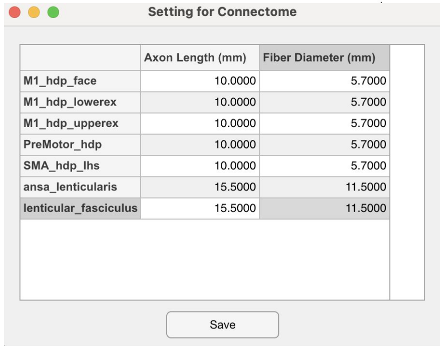
Fiber Diameter: 5.7 mm

E-Field Threshold Presets:

E-Field Threshold: 0.323 V/mm

☑ Use tensor data: IITmean_tensor.nii.gz

☑ Interactive mode



Setting for Connectome

	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

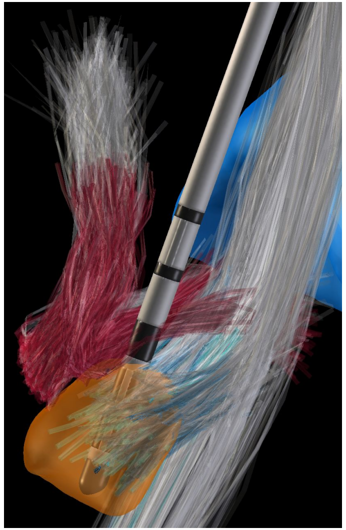
Setting up in Lead-DBS: PAM

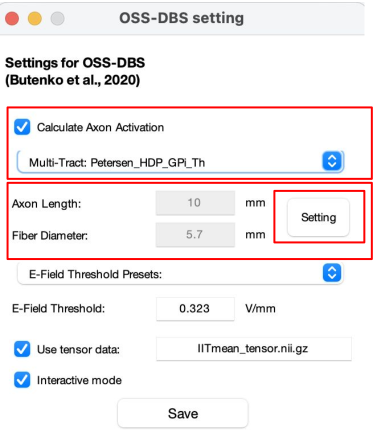
Activation of 'realistic' axons

- Axons are seeded 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 model upon request)

Choose a connectome/pathway →

If one pathway, settings here →





OSS-DBS setting

Settings for OSS-DBS (Butenko et al., 2020)

☑ Calculate Axon Activation

Multi-Tract: Petersen_HDP_GPi_Th

Axon Length: 10 mm

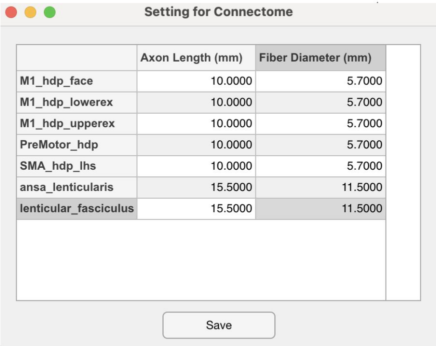
Fiber Diameter: 5.7 mm

E-Field Threshold Presets:

E-Field Threshold: 0.323 V/mm

☑ Use tensor data: IITmean_tensor.nii.gz

☑ Interactive mode

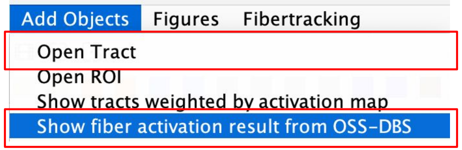


Setting for Connectome

	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

Setting up in Lead-DBS: PAM

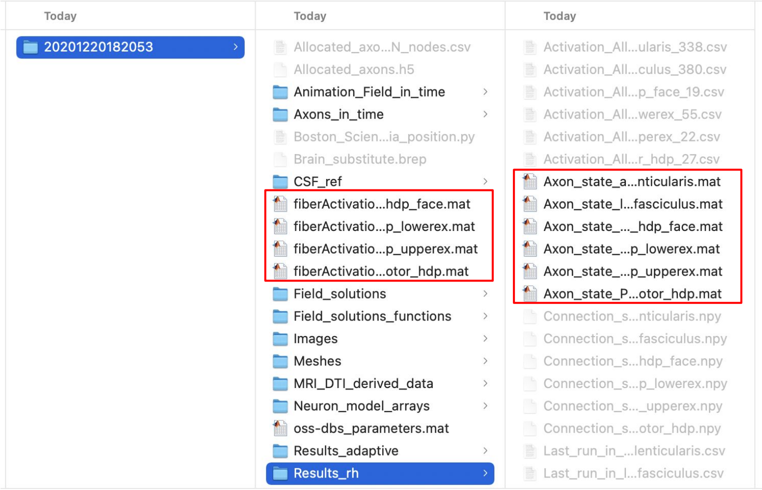
Activation of ‘realistic’ axons


Add Objects
Figures
Fibertracking
Open Tract
Open ROI
Show tracts weighted by activation map
Show fiber activation result from OSS-DBS

Show fibers /axons

Show fiber/axon status

- 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 in electrode-scene



Today

20201220182053

Today

Allocated_axo...N_nodes.csv
Allocated_axons.h5
Animation_Field_in_time
Axons_in_time
Boston_Scien...ia_position.py
Brain_substitute.brep
CSF_ref
fiberActivatio...hdp_face.mat
fiberActivatio...p_lowerex.mat
fiberActivatio...p_upperex.mat
fiberActivatio...otor_hdp.mat
Field_solutions
Field_solutions_functions
Images
Meshes
MRI_DTI_derived_data
Neuron_model_arrays
oss-dbs_parameters.mat
Results_adaptive
Results_rh

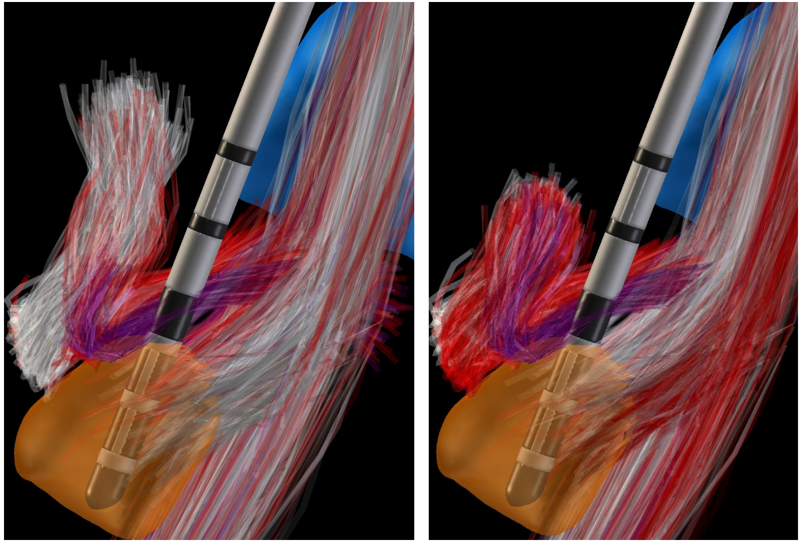
Today

Activation_All...ularis_338.csv
Activation_All...culus_380.csv
Activation_All...p_face_19.csv
Activation_All...werex_55.csv
Activation_All...perex_22.csv
Activation_All...r_hdp_27.csv
Axon_state_a...nticularis.mat
Axon_state_l...fasciculus.mat
Axon_state_..._hdp_face.mat
Axon_state_...p_lowerex.mat
Axon_state_...p_upperex.mat
Axon_state_P...otor_hdp.mat
Connection_s...nticularis.npy
Connection_s...fasciculus.npy
Connection_s...hdp_face.npy
Connection_s...p_lowerex.npy
Connection_s..._upperex.npy
Connection_s...otor_hdp.npy
Last_run_in_...lenticularis.csv
Last_run_in_l...fasciculus.csv

Setting up in Lead-DBS: PAM

Activation of ‘realistic’ 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

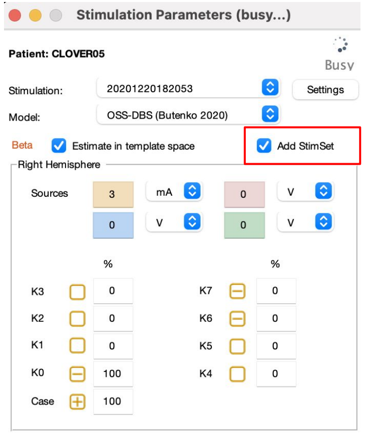


Setting up in Lead-DBS: Multiple protocols

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



Stimulation Parameters (busy...)

Patient: CLOVER05

Busy

Stimulation: 20201220182053

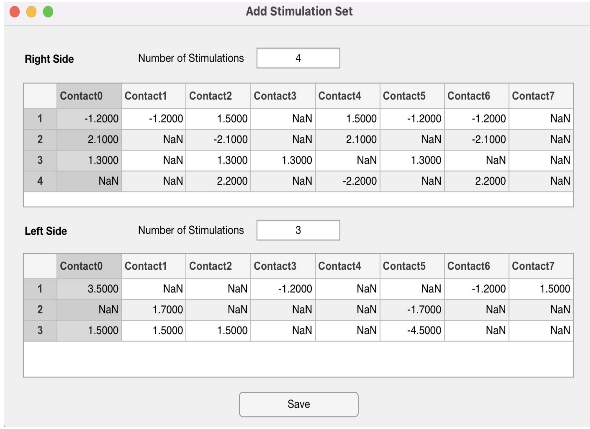
Model: OSS-DBS (Butenko 2020)

Beta ☑ Estimate in template space ☑ Add StimSet

Right Hemisphere

Sources	3	mA	0	V
	0	V	0	V

		%			%
K3	□	0	K7	⊟	0
K2	□	0	K6	⊟	0
K1	□	0	K5	□	0
K0	⊟	100	K4	□	0
Case	⊞	100			



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

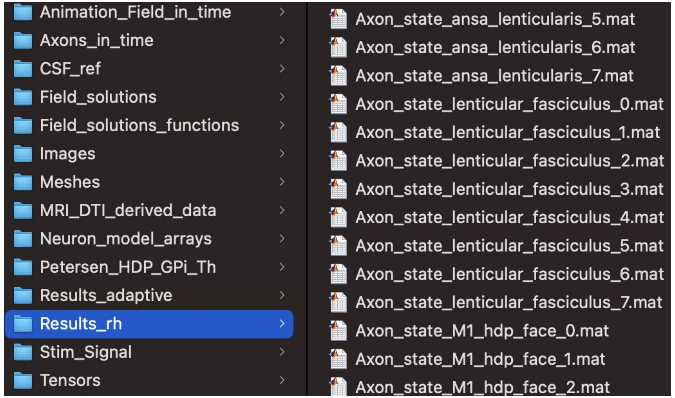
Left Side Number of Stimulations 3

	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

Setting up in Lead-DBS: Multiple protocols

Field superposition instead of recalculations

- 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

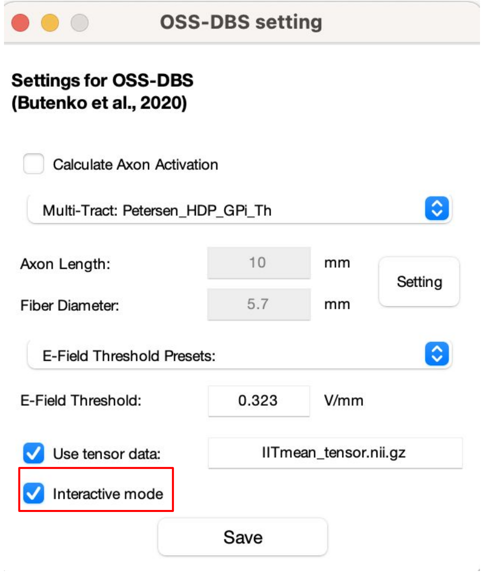


Animation_Field_in_time
Axons_in_time
CSF_ref
Field_solutions
Field_solutions_functions
Images
Meshes
MRI_DTI_derived_data
Neuron_model_arrays
Petersen_HDP_GPi_Th
Results_adaptive
Results_rh
Stim_Signal
Tensors

Axon_state_ansa_lenticularis_5.mat
Axon_state_ansa_lenticularis_6.mat
Axon_state_ansa_lenticularis_7.mat
Axon_state_lenticular_fasciculus_0.mat
Axon_state_lenticular_fasciculus_1.mat
Axon_state_lenticular_fasciculus_2.mat
Axon_state_lenticular_fasciculus_3.mat
Axon_state_lenticular_fasciculus_4.mat
Axon_state_lenticular_fasciculus_5.mat
Axon_state_lenticular_fasciculus_6.mat
Axon_state_lenticular_fasciculus_7.mat
Axon_state_M1_hdp_face_0.mat
Axon_state_M1_hdp_face_1.mat
Axon_state_M1_hdp_face_2.mat

OSS-DBS GUI

Allows to access more modeling parameters



OSS-DBS setting

Settings for OSS-DBS (Butenko et al., 2020)

□ Calculate Axon Activation

Multi-Tract: Petersen_HDP_GPi_Th

Axon Length: 10 mm

Fiber Diameter: 5.7 mm

Setting

E-Field Threshold Presets:

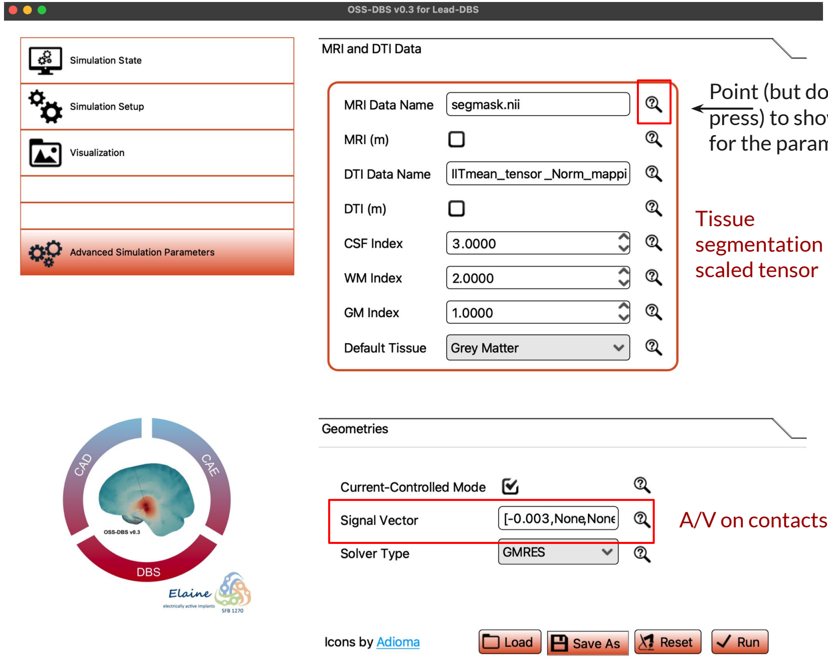
E-Field Threshold: 0.323 V/mm

☑ Use tensor data: IITmean_tensor.nii.gz

☑ Interactive mode

Save

Lead-DBS input →



OSS-DBS v0.3 for Lead-DBS

MRI and DTI Data

MRI Data Name: segmask.nii

MRI (m): □

DTI Data Name: IITmean_tensor_Norm_mappi

DTI (m): □

CSF Index: 3.0000

WM Index: 2.0000

GM Index: 1.0000

Default Tissue: Grey Matter

Geometries

Current-Controlled Mode ☑

Signal Vector: [-0.003,None,None

Solver Type: GMRES

Icons by Adioma

Load | Save As | Reset | ✓ Run

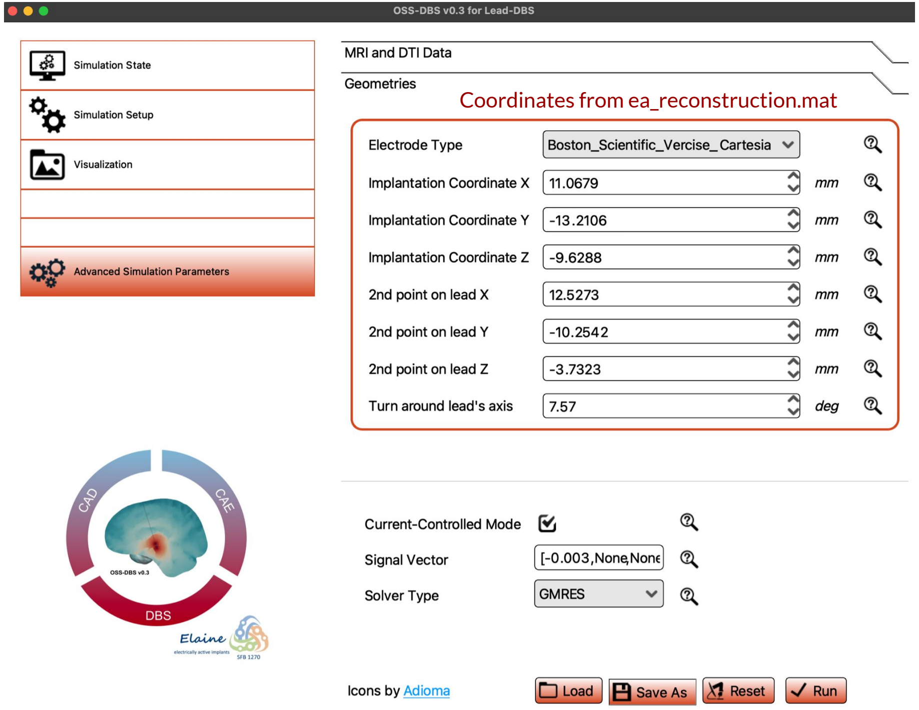
Point (but do not press) to show a tip for the parameter

Tissue segmentation and scaled tensor

A/V on contacts

OSS-DBS GUI

Deeper understanding of the model

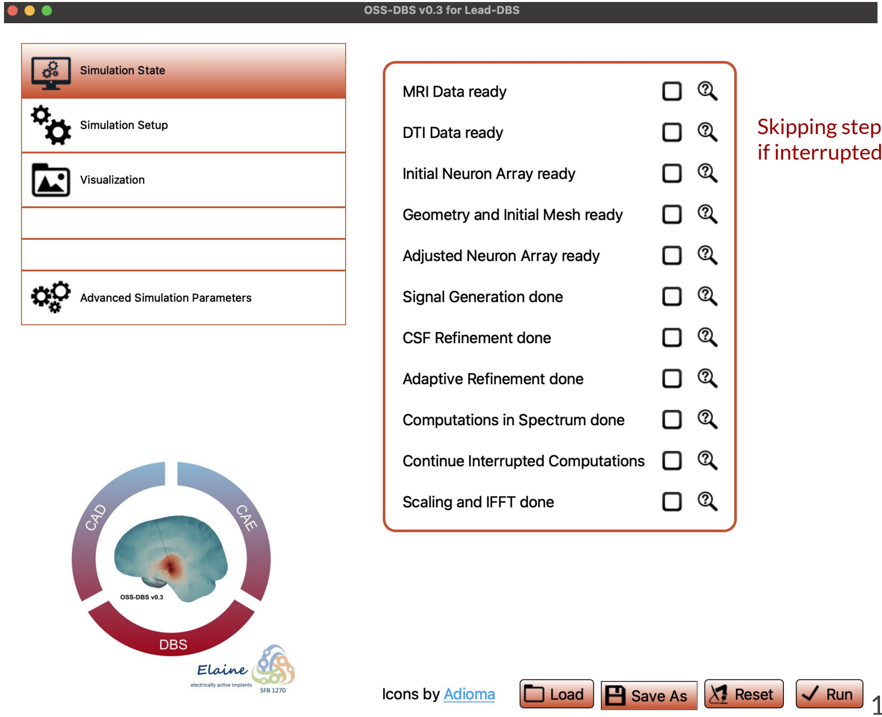


Coordinates from ea_reconstruction.mat

Electrode Type	Boston_Scientific_Vercise_Cartesia	
Implantation Coordinate X	11.0679	mm
Implantation Coordinate Y	-13.2106	mm
Implantation Coordinate Z	-9.6288	mm
2nd point on lead X	12.5273	mm
2nd point on lead Y	-10.2542	mm
2nd point on lead Z	-3.7323	mm
Turn around lead's axis	7.57	deg

Current-Controlled Mode	☑
Signal Vector	[-0.003,None,None
Solver Type	GMRES

Icons by Adioma



MRI Data ready	☐
DTI Data ready	☐
Initial Neuron Array ready	☐
Geometry and Initial Mesh ready	☐
Adjusted Neuron Array ready	☐
Signal Generation done	☐
CSF Refinement done	☐
Adaptive Refinement done	☐
Computations in Spectrum done	☐
Continue Interrupted Computations	☐
Scaling and IFFT done	☐

Skipping steps if interrupted

Icons by Adioma

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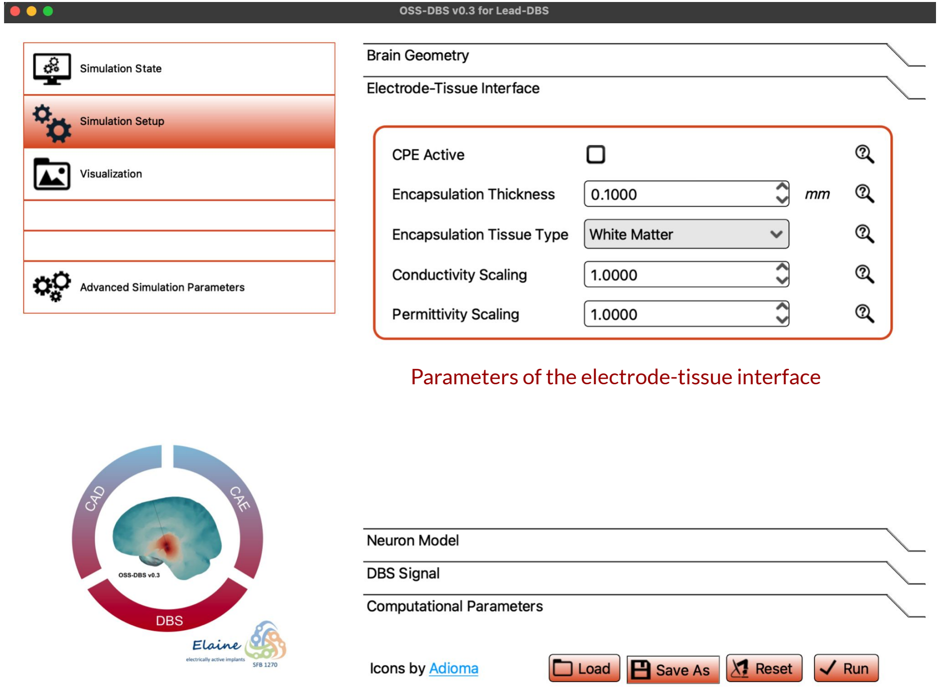
CRC TRR 295 Berlin-Würzburg

OSS-DBS GUI

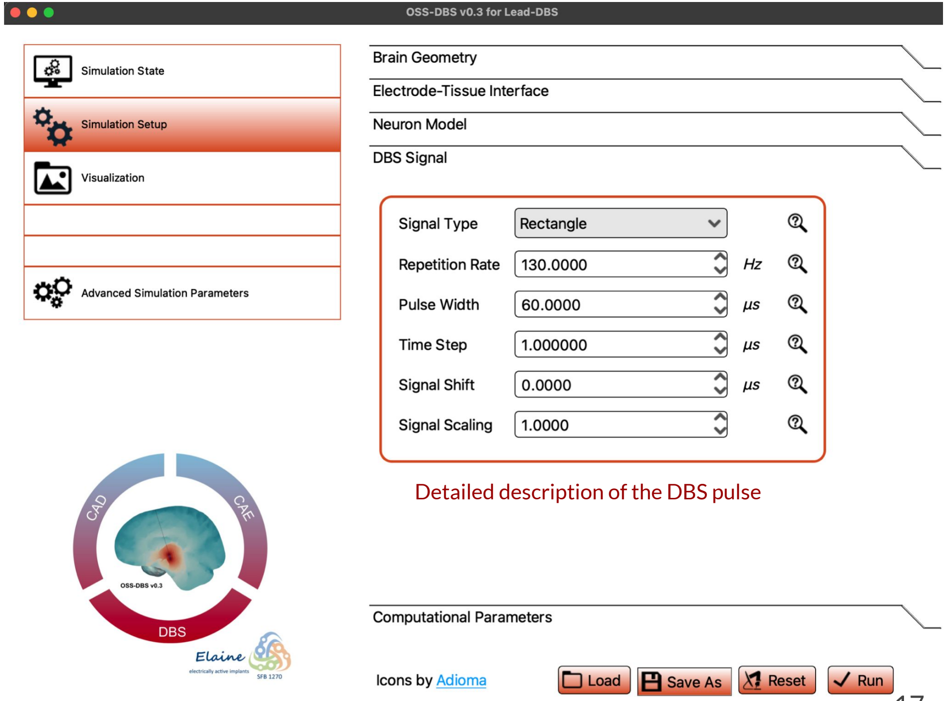
Deeper understanding of the model



CPE Active	☐	
Encapsulation Thickness	0.1000	mm
Encapsulation Tissue Type	White Matter	
Conductivity Scaling	1.0000	
Permittivity Scaling	1.0000	

Parameters of the electrode-tissue interface

Icons by Adioma



Signal Type	Rectangle	
Repetition Rate	130.0000	Hz
Pulse Width	60.0000	µs
Time Step	1.000000	µs
Signal Shift	0.0000	µs
Signal Scaling	1.0000	

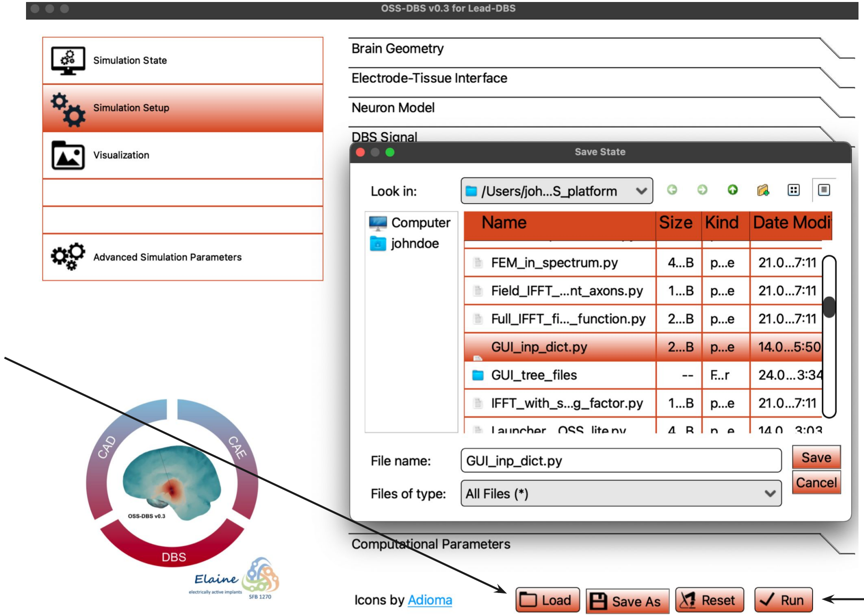
Detailed description of the DBS pulse

Icons by Adioma

OSS-DBS GUI

Deeper understanding of the model

- Input configuration is stored as a python dictionary GUI_inp_dict.py in *stim folder* of the patient



OSS-DBS v0.3 for Lead-DBS

Simulation State
Simulation Setup
Visualization
Advanced Simulation Parameters

Brain Geometry
Electrode-Tissue Interface
Neuron Model
DBS Signal
Computational Parameters

Save State

Look in: /Users/joh...S_platform

Computer
johndoe

Name	Size	Kind	Date Modi
FEM_in_spectrum.py	4...B	p...e	21.0...7:11
Field_IFFT_...nt_axons.py	1...B	p...e	21.0...7:11
Full_IFFT_fi..._function.py	2...B	p...e	21.0...7:11
GUI_inp_dict.py	2...B	p...e	14.0...5:50
GUI_tree_files	--	F...r	24.0...3:34
IFFT_with_s...g_factor.py	1...B	p...e	21.0...7:11
Launcher_OSS_lite.py	4...B	p...e	14.0...3:03

File name: GUI_inp_dict.py
Files of type: All Files (*)

Icons by Adioma

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

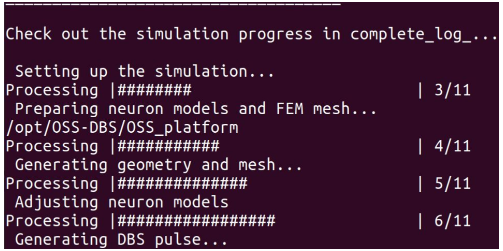
Behind the scene

- 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*)

OSS-DBS terminal

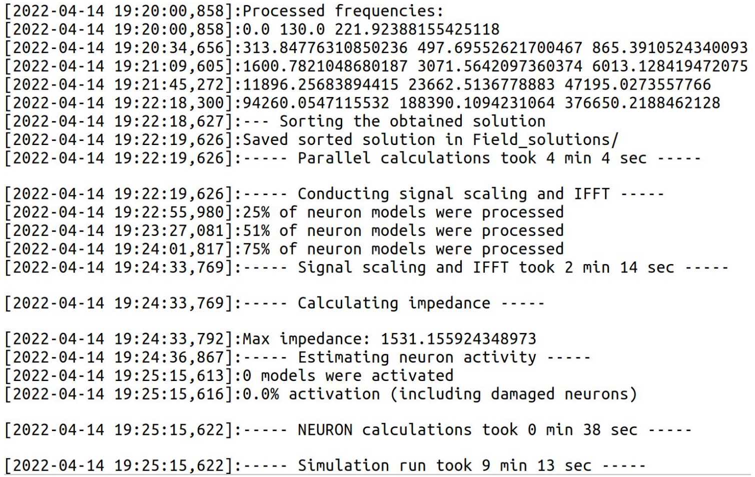
Behind the scenes

- Shows the simulation flow (but concisely)
- Closes automatically if everything is fine
- Log files are available in stim. Folders use them to report errors



```
Check out the simulation progress in complete_log_...

 Setting up the simulation...
Processing |########                        | 3/11
 Preparing neuron models and FEM mesh...
/opt/OSS-DBS/OSS_platform
Processing |###########                     | 4/11
 Generating geometry and mesh...
Processing |##############                  | 5/11
 Adjusting neuron models
Processing |#################               | 6/11
 Generating DBS pulse...
```



```
[2022-04-14 19:20:00,858]:Processed frequencies:
[2022-04-14 19:20:00,858]:0.0 130.0 221.92388155425118
[2022-04-14 19:20:34,656]:313.84776310850236 497.69552621700467 865.3910524340093
[2022-04-14 19:21:09,605]:1600.7821048680187 3071.5642097360374 6013.128419472075
[2022-04-14 19:21:45,272]:11896.25683894415 23662.5136778883 47195.0273557766
[2022-04-14 19:22:18,300]:94260.0547115532 188390.1094231064 376650.2188462128
[2022-04-14 19:22:18,627]:--- Sorting the obtained solution
[2022-04-14 19:22:19,626]:Saved sorted solution in Field_solutions/
[2022-04-14 19:22:19,626]:----- Parallel calculations took 4 min 4 sec -----

[2022-04-14 19:22:19,626]:----- Conducting signal scaling and IFFT -----
[2022-04-14 19:22:55,980]:25% of neuron models were processed
[2022-04-14 19:23:27,081]:51% of neuron models were processed
[2022-04-14 19:24:01,817]:75% of neuron models were processed
[2022-04-14 19:24:33,769]:----- Signal scaling and IFFT took 2 min 14 sec -----

[2022-04-14 19:24:33,769]:----- Calculating impedance -----

[2022-04-14 19:24:33,792]:Max impedance: 1531.155924348973
[2022-04-14 19:24:36,867]:----- Estimating neuron activity -----
[2022-04-14 19:25:15,613]:0 models were activated
[2022-04-14 19:25:15,616]:0.0% activation (including damaged neurons)

[2022-04-14 19:25:15,622]:----- NEURON calculations took 0 min 38 sec -----

[2022-04-14 19:25:15,622]:----- Simulation run took 9 min 13 sec -----
```

OSS-DBS support

- Do not hesitate to contact us (kbutenko@bwh.harvard.edu)
- The software is rather new, not all features are implemented
- Cluster solution is available upon request