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Anticipation of Brain Shift in Deep Brain Stimulation Automatic Planning

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Introduction

Context:

- Automatic preoperative trajectory planning for Deep Brain Stimulation (DBS)
- Typical approaches perform planning on static images data sets without considering intra-operative changes

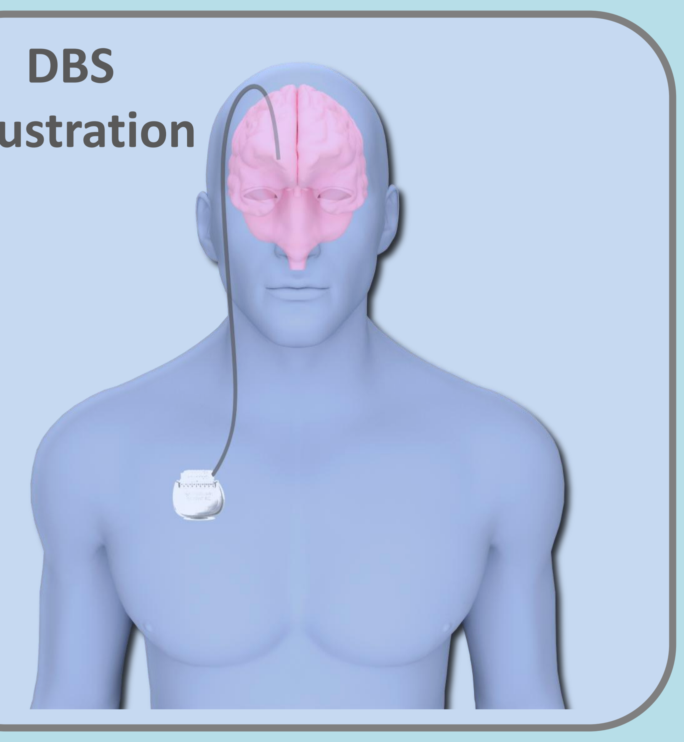
Problem:

Brain tissues may deform during the surgery and alter the preoperative planning "**Brain Shift phenomenon**"

Objective:

Patient-specific automatic preoperative planning for DBS which accounts for the brain shift

DBS illustration



METHODS

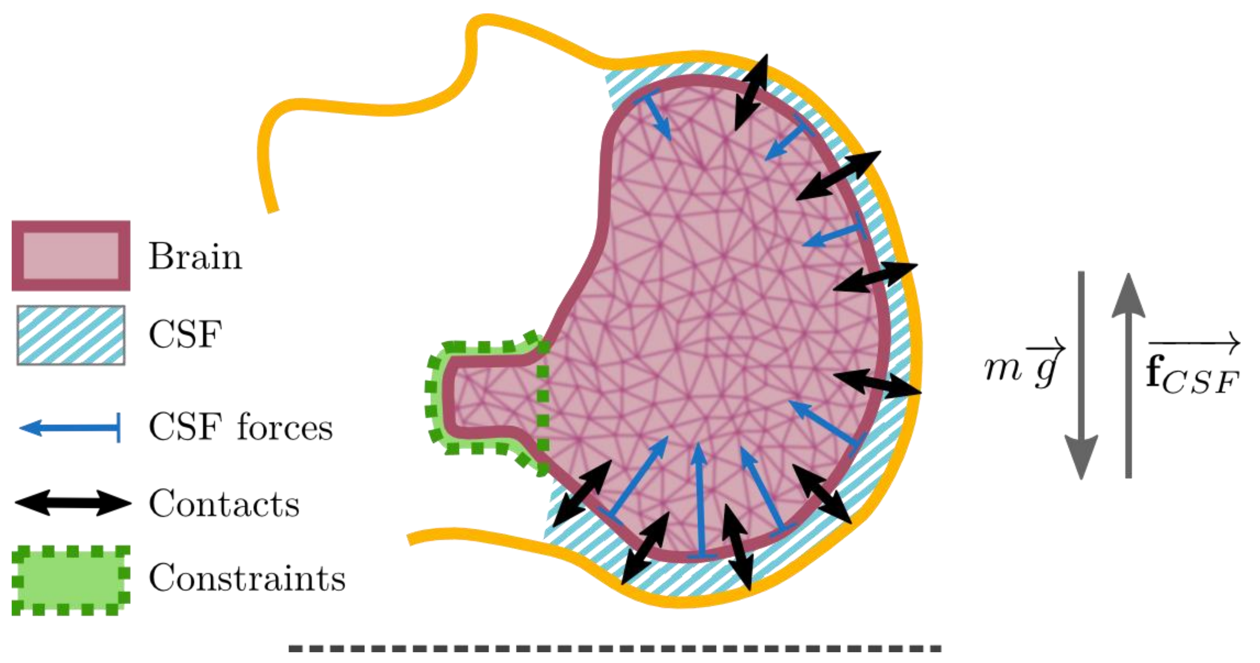
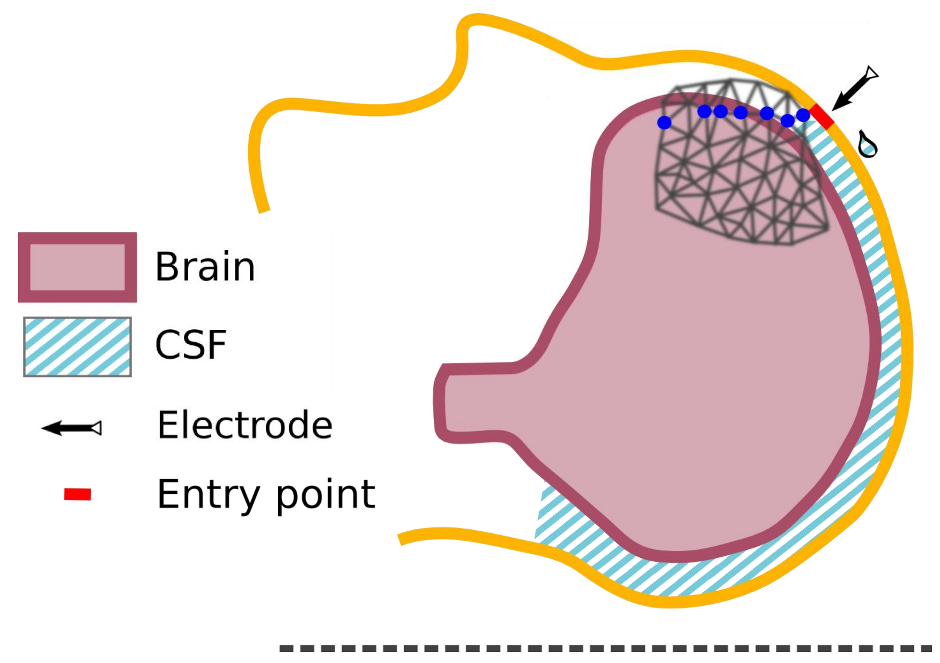


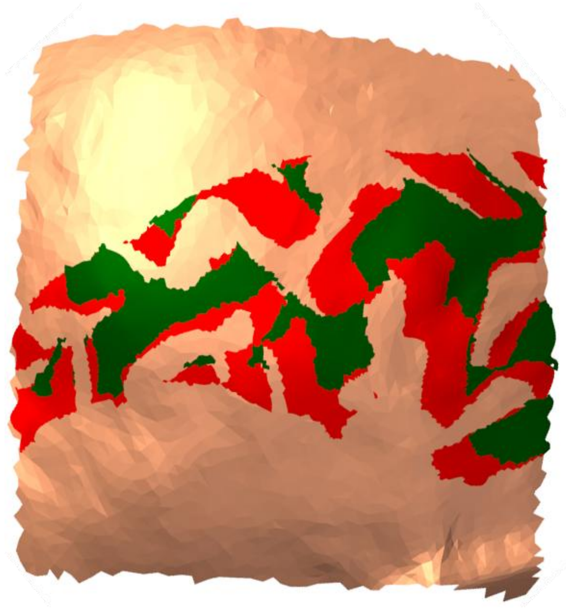
Illustration showing the components of the simulation

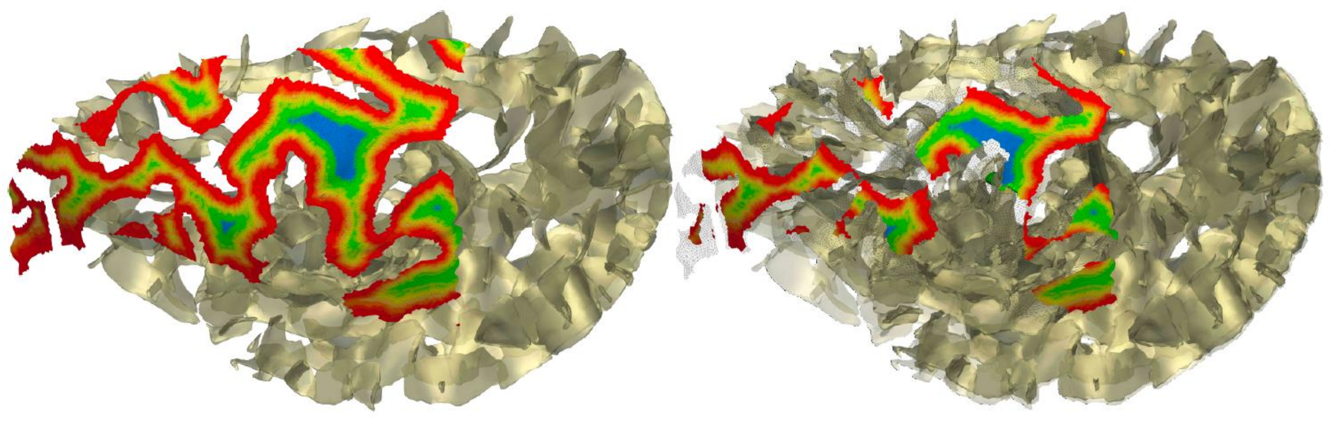
- The brain is modeled using Finite Element Method FEM.
- The main cause of brain shift is a loss of Cerebro-Spinal Fluid (CSF).
- Brain shift occurs in low velocity, we treat the problem as quasi-static.
- We consider the configuration of the brain only at the equilibrium state.
- When the brain deforms and moves, it may collide the endocranium. The detected, contacts are solved using Signorini's law.



Entry points (blue) lying at the same height h and likely to lead to the same possible maximal brain shift

- We build the brain deformed model correspond to a height level h assigned to a every possible entry point.
- We compute the feasible insertion zone Ω_d (maximum brain shift aware feasible zone).
- We compute the optimized trajectory using Nelder-Mead optimization inside Ω_d.





(a) $\mathbf{E_s}$, $\mathbf{M_s}$: ω_s on $\mathbf{\Omega_s}$ (b) $\mathbf{E_d}$, $\mathbf{M_d}$: ω_s on $\mathbf{\Omega_d}$

(a) distance map to the borders of $\mathbf{\Omega_s}$, and (b) the same distance map projected onto $\mathbf{\Omega_d}$. Parts are cut even in the initially safe (blue) zone.

	Ω_0	Ω_s	Ω_d
# Triangles	67920	17408	7868
Comp. time (s)	-	12	36
Ω_0 coverage (%)	100	25.6	11.6

$\mathbf{\Omega_0}$ is the large rectangular patch, $\mathbf{\Omega_s}$ is a subset of $\mathbf{\Omega_0}$ and is the union of red and green shapes, and $\mathbf{\Omega_d}$ is a subset of $\mathbf{\Omega_s}$ and is the green mesh.

Nelder-Mead	$\mathbf{E_s}$	$\mathbf{E_d}$
eval(f) [0, 1]	0.28	0.38
dist. from ventricles (mm)	11.87	7.39
dist. from sulci (mm)	5.13	3.12
# of iterations	31	21
time (s)	0.034	0.258

Tests and Results

- ❑ We have compared both feasible insertion zones Ω_s and Ω_d computed in $\mathbf{E_s}$ and $\mathbf{E_d}$:
- ✓ The feasible insertion zone is reduced by **54.8%** (green to red patch percentage on the skin patch image).
- ❑ We have compared the optimization results in both $\mathbf{E_s}$ and $\mathbf{E_d}$:
- ✓ Nelder-Mead could converge in E_d
- ✓ the resulting trajectory is sufficiently safe.
- ✓ the computation time remains acceptable for clinical practice.
- ❑ Observation :

By comparing (a) and (b): Blue zones (very safe) can be withdrawn from the set of safe trajectories in case of brain shift.

Conclusions

○ A novel approach for DBS automatic preoperative planning coupling physical simulations with geometric optimization.
○ The obtained results illustrate an important variation of size and shape of the safe insertion zones between static and dynamic conditions.

Perspectives

○ Use of intra-operative images to validate the simulations and predictions.
○ Improving brain shift model's accuracy by using more complex deformation and fluid models.
○ Investigating and comparing different optimization techniques.

References

[1] Essert, C., Haegelen, C., Lalys, F., Abadie, A., Jannin, P.: Automatic computation of electrode trajectories for deep brain stimulation: a hybrid symbolic and numerical approach. International journal of computer assisted radiology and surgery 7(4), 517–532 (2012)

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