Introducing Pareto-based MOEA to Neurosurgery Preoperative Path Planning

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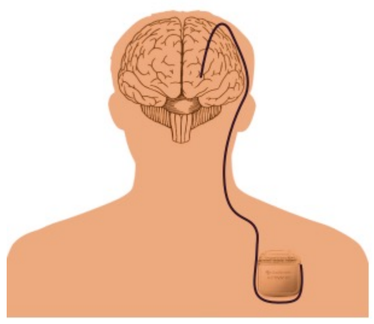
GECCO 2016 Denver, Colorado, USA July 20-24, 2016

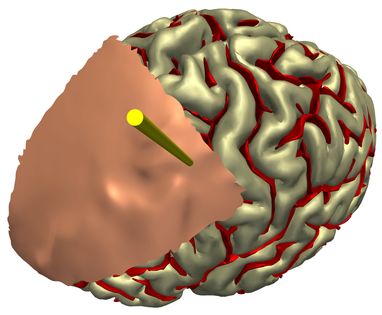
Medical context

- Stimulation of a deep nucleus of the brain
- Electrode inserted from a frame screwed in the skull before intervention
- Time matters !

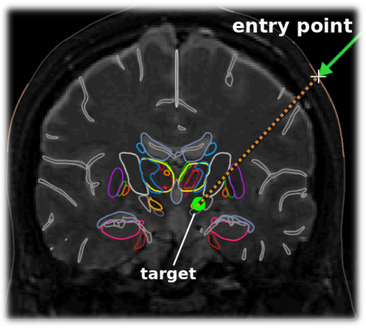
Parkinson's disease



Deep Brain Stimulation



Electrode placement



Path planning

Multi-criteria optimization problem

- Path planning of a safe and efficient trajectory for the electrode [1]
- Find insertion point on the skull:
  - minimizing the distance between the electrode and the vessels
  - minimizing the distance between the electrode and the ventricles
  - proximity to a standard trajectory of 30° anterior and 30° lateral

$$f_{D_{\mathcal{O}}}(\mathbf{T}) = \text{Max}\left[\frac{D_{min\mathcal{O}} - D(\mathbf{T},\mathcal{O})}{D_{min\mathcal{O}}}, 0\right]$$

$$f_{ST}(\mathbf{T}) = \frac{\alpha(\mathbf{T}, ST)}{90}$$

Methods and Results

Method NSGA-II [2]

- Dominance Based Restricted selection (DBX) from 2 parents $p_{1,k}$ and $p_{2,k}$
- BLX-α crossover
  - offspring $c_k = (1-\gamma_i)p_{1,k} + \gamma_i p_{2,k}$, where $\gamma_i = (1+2\alpha)u_i - \alpha$ with u_i random and $\alpha = 0.5$
  - probability of 0.9, crossover distribution index eta_c=10
- polynomial mutation
  - probability of 0.5, mutation distribution index eta_m=5
- initial population size = **2,000** running on **10** generations
- computation time approx. **3 mn**

Illustration of a random initial population

Reference methods

Method 1: weighted sum exploration

- aggregating approach: 3 weights for 3 objectives
- exploring 20,000 combinations of 3 weights
- calculating **20,000** optimal solutions using Nelder-Mead [1]
- average computation time around **20 mn**

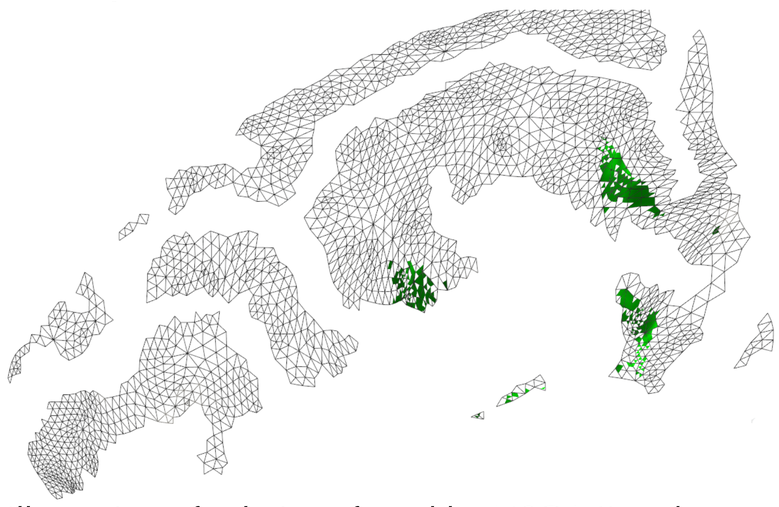


Illustration of solutions found by NSGA-II and not dominated by solutions found by method 1

Method 2: discretization

- discretization approach
- **20,000** points using regular distribution
- calculating a Pareto front
- average computation time around **10 mn**

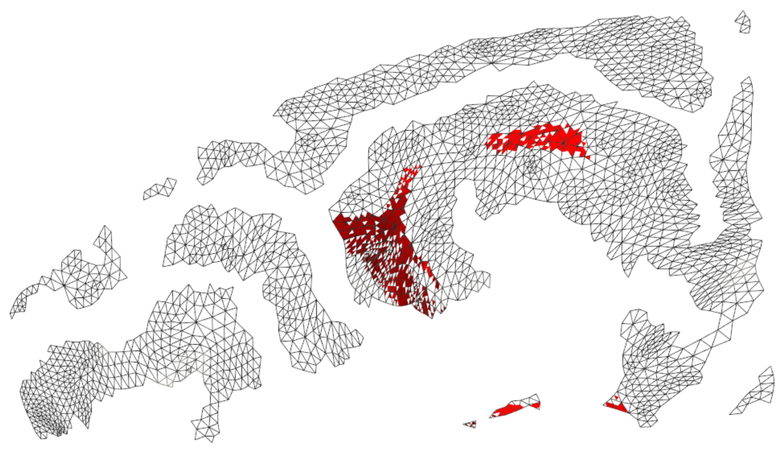


Illustration of solutions found by NSGA-II and not dominated by solutions found by method 2

Experiment on 20 retrospective datasets of preoperative images of Parkinsonian patients from 2 different hospitals

➡ **37%** of the solutions found by NSGA-II could not be found by a weighted sum method

➡ For a semi-exhaustive method to outperform NSGA-II: **650,000** sample points are required, with an average time of **9 hours**

Conclusion

- Pareto-based MOEAs is a promising approach for neurosurgery path planning
- it outperforms the classical methods used in the literature in terms of coverage of the solution space
- computation time is compatible with clinical routine

References

[1] C. Essert, C. Haegelen, F. Lalys, A. Abadie, and P. Jannin. *Automatic computation of electrode trajectories for deep brain stimulation*. Int J Comput Ass Rad, 7(4):517–532, 2012.

[2] K. Deb, A. Pratap, S. Agarwal, and T. Meyarivan. *A fast and elitist multiobjective genetic algorithm: NSGA-II*. IEEE T Evolut Comput, 6(2):182–197, 2002.

Acknowledgements

This research was supported by the French National Research Agency (ANR) through "ACouStiC" grant ANR 2010 BLAN 0209 02.