A Statistical Framework for Visualization of Positional Uncertainty in Deep Brain Stimulation Electrodes
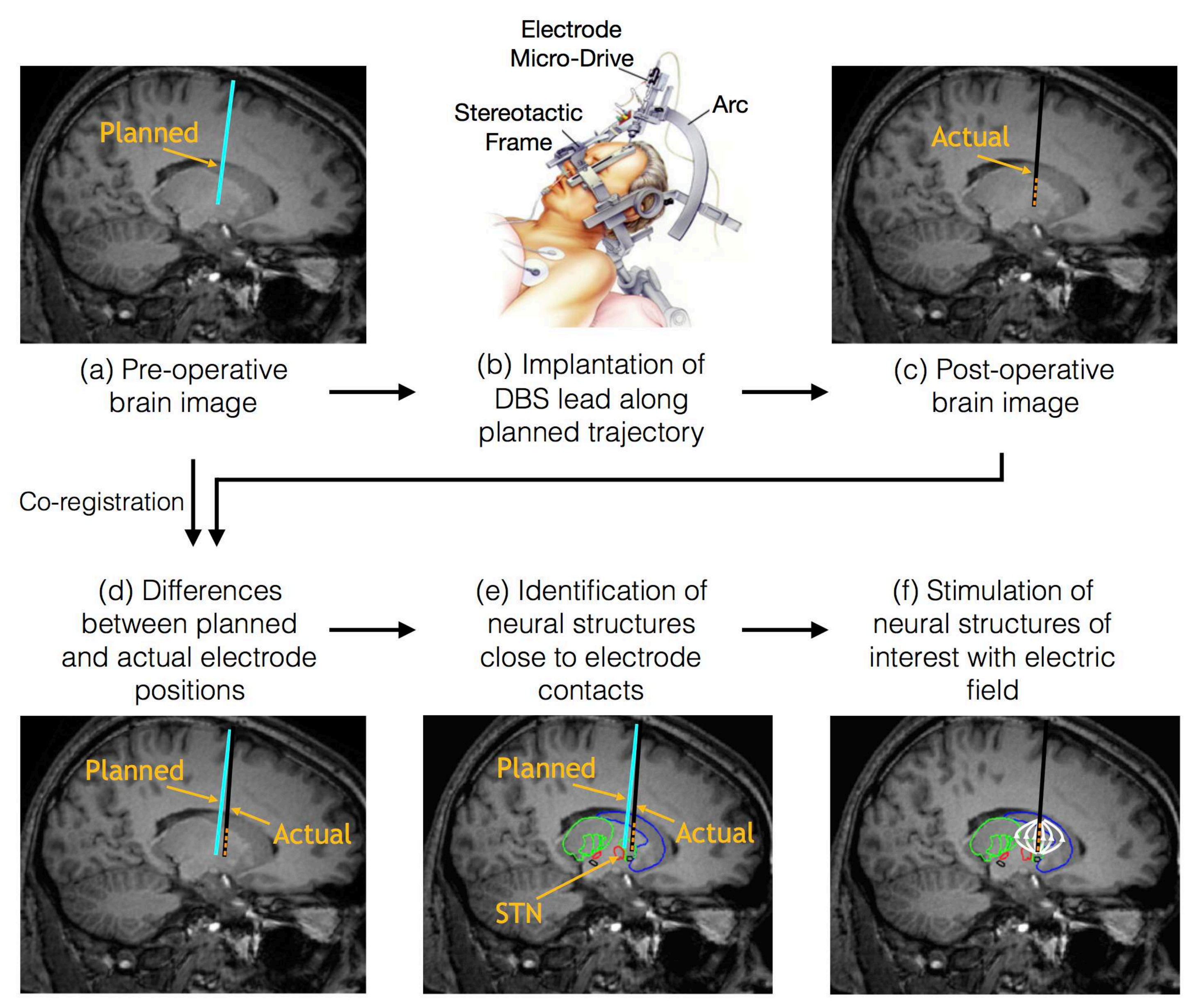
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Deep Brain Stimulation (DBS)

- An FDA-approved neurosurgical procedure for treating patients with movement disorders, e.g., Parkinson's and dystonia.

(a) Pre-operative brain image

(b) Implantation of DBS lead along planned trajectory

(c) Post-operative brain image

Co-registration

(d) Differences between planned and actual electrode positions

(e) Identification of neural structures close to electrode contacts

(f) Stimulation of neural structures of interest with electric field

- The effectiveness of DBS depends upon physician's knowledge regarding precise *DBS electrode positions* in the patient brain.
- The role of post-operative DBS imaging:
  - Understand DBS electrode positions in the patient brain.
  - Mitigate the uncertainty in DBS electrode positions arising from mechanical inaccuracies of stereotactic frames [1] and brain shift [2].
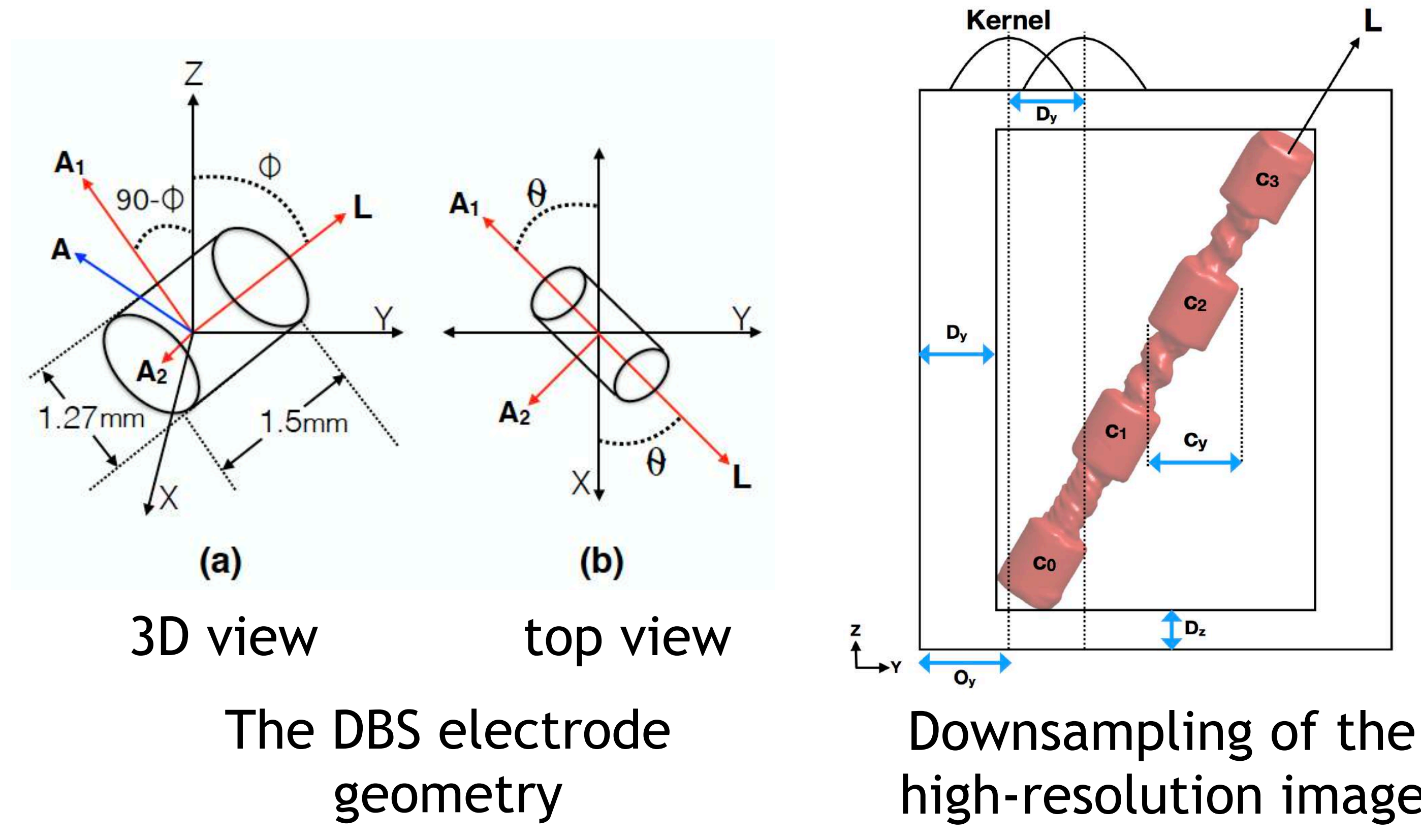
Problem with Post-Operative DBS Imaging

- The finite resolution of post-operative imaging limits our knowledge of exact electrode positions in the patient brain.
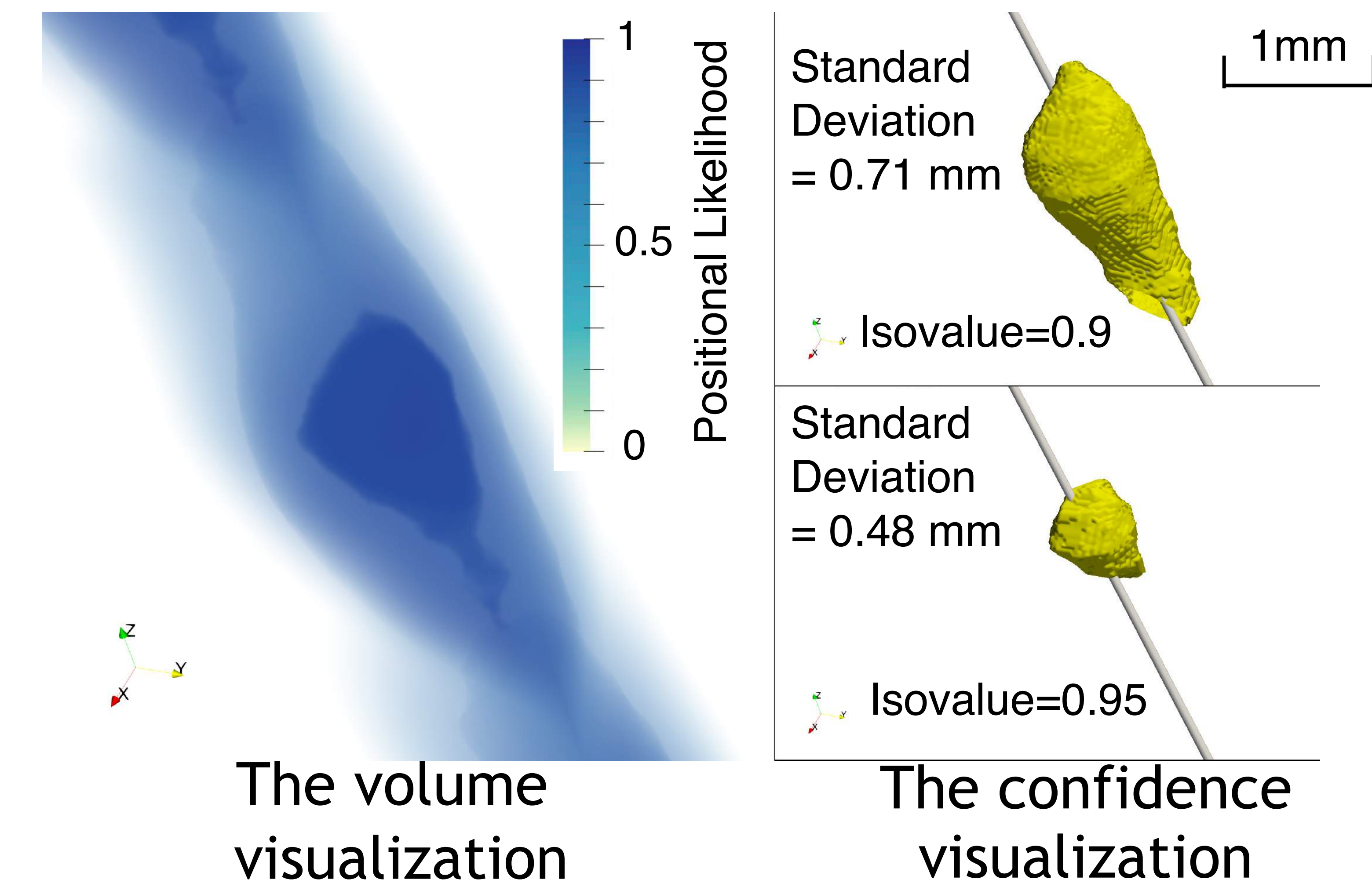
Post-Operative Imaging Uncertainty

DBS lead schematic

Patient image illustration
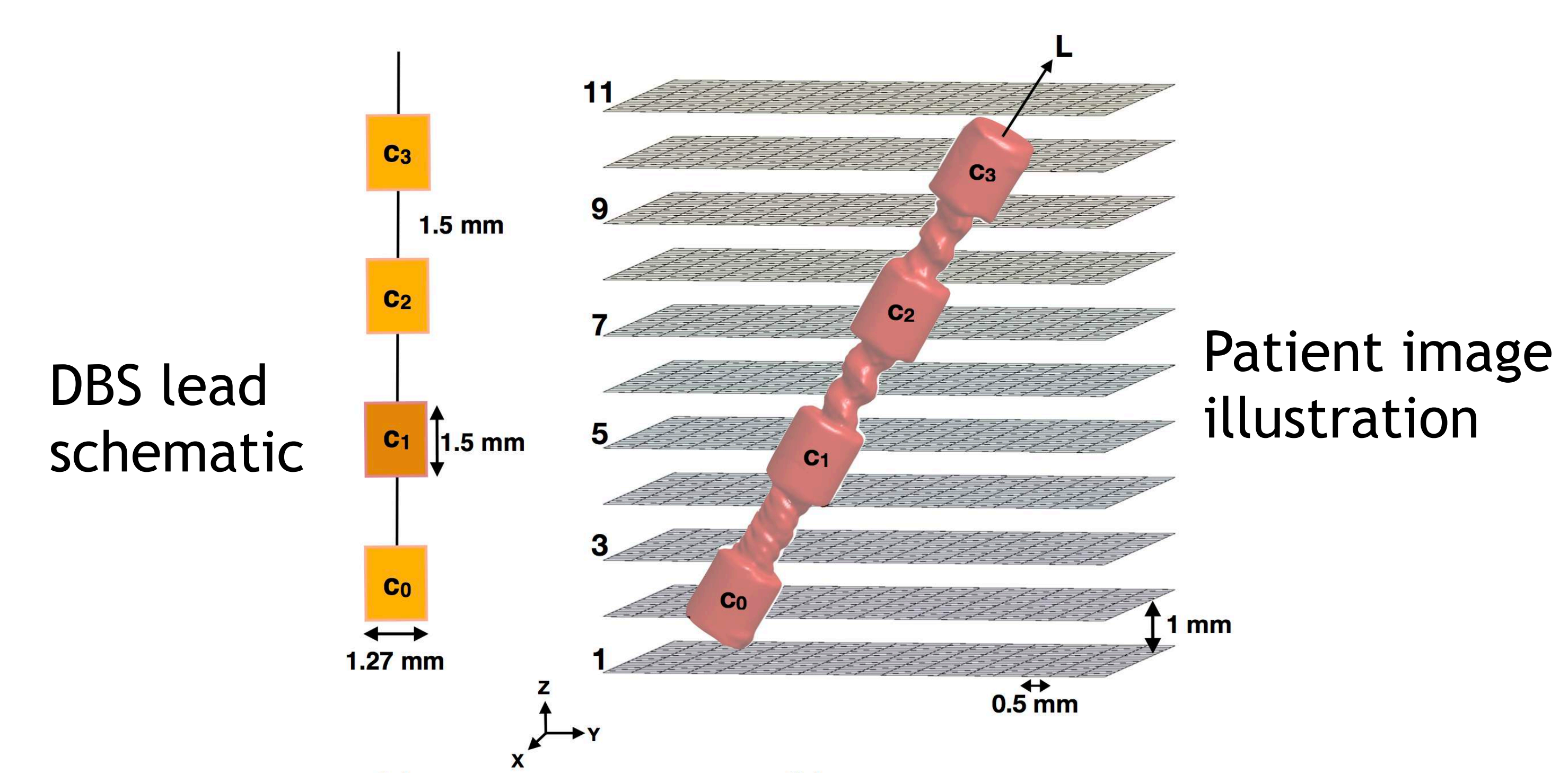
- **Given:** A finite-resolution CT scan of implanted DBS electrodes, e.g., the image above captures data on 11 slices.

- **Goal:** To quantify the spatial uncertainty in DBS electrodes for their finite-resolution imaging and visualize the quantified spatial uncertainty.

- **Approach: (a)** Compute electrode geometry in closed form, **(b)** Map electrode geometry to a high-resolution electrode image (with electrodes out of patient brain), **(c)** Draw low-resolution samples from a high-resolution electrode image, **(d)** Compare low-resolution samples with the patient image [3].

(a) 3D view   (b) top view

The DBS electrode geometry

Downsampling of the high-resolution image

Electrode-Center Spatial Uncertainty Visualizations

Positional Likelihood

Standard Deviation = 0.71 mm

Isovalue=0.9

Standard Deviation = 0.48 mm

Isovalue=0.95

1mm

The volume visualization

The confidence visualization

Conclusion

We show that the uncertainty in DBS electrode positions is significant in post-operative imaging, e.g., 0.49 mm average spatial uncertainty for 0.45x 0.45x1 mm^3 resolution. Further, we integrate DBS computational modeling pipeline with our electrode uncertainty visualizations for accurate prediction of patient response to therapy.

Acknowledgements

References

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[2]: Halpern CH., Danish SF, Baltuch GH, and Jaggi JL. **Brain shift during deep brain stimulation surgery for Parkinson's disease.** *Stereotact Funct Neurosurg, vol. 86, no. 1, pp. 37-43, 2008.*
[3]: Athawale T, Johnson K, Butson CR, and Johnson CR. **A statistical framework for visualization of positional uncertainty in deep brain stimulation electrodes.** *Computer Methods in Biomechanics and Biomedical Engineering: Imaging & Visualization, vol.7, no. 4, pp. 438-449, 2019.*