Image-to-Mesh (I2M) Conversion: Use Cases from Medical and Physical Sciences

Experience from Classical Supercomputers to Quantum Computers

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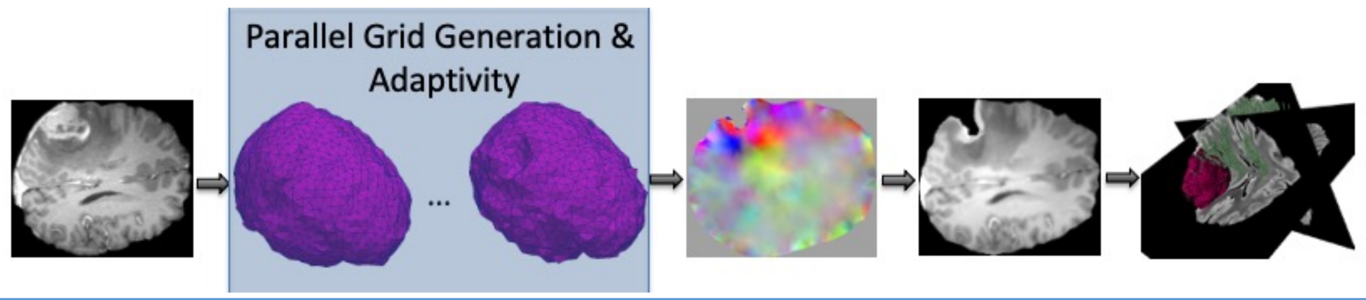
Non-rigid alignment of preoperative MRI, fMRI, DT-MRI, with intra-operative MRI for enchanced visualization and navigation in image-guided neurosurgery

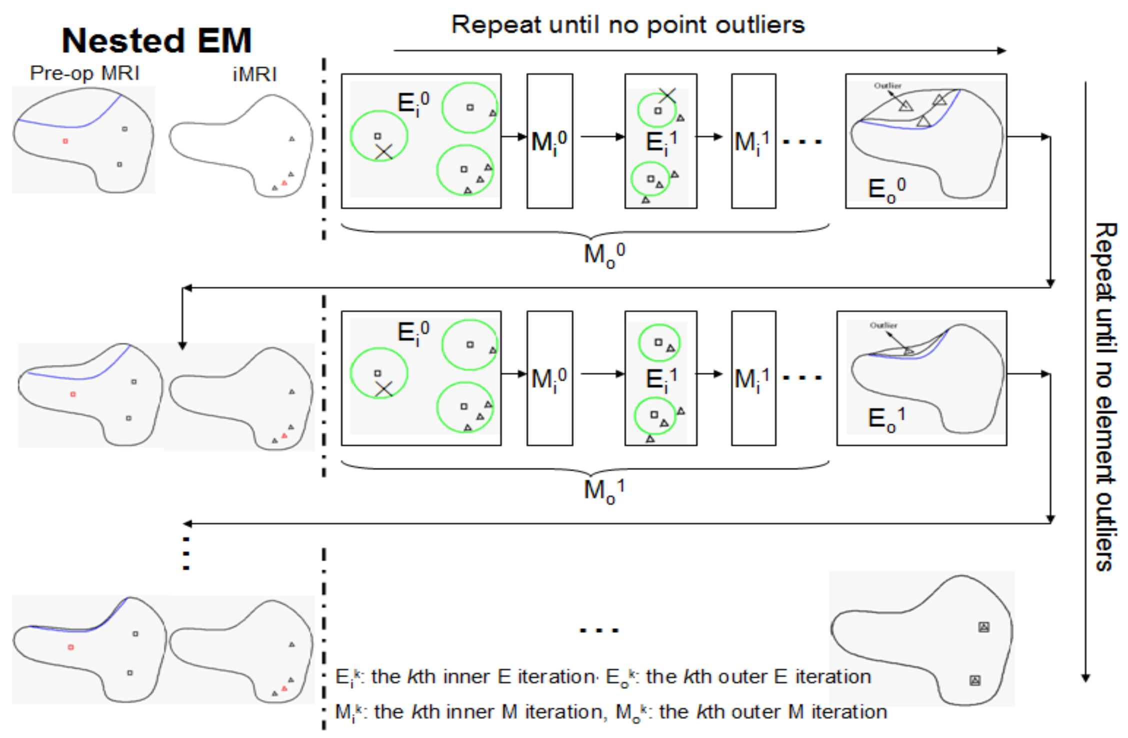
Neuroimage, Volume 35, No. 2, 2007

- *Brain tumor resection* relies on brain visualizations to display seriously compromised brain shift, which inevitably occurs during the course of the operation, significantly degrading the precise alignment between the pre-operative MR data and the intra-operative shape of the brain.
- *Deep Brain Stimulation* (DBS) surgery makes use of stereotactic systems and image guidance to accurately place electrode leads, as well as intra-operative imaging to surveil the location of the lead and guide the surgery.



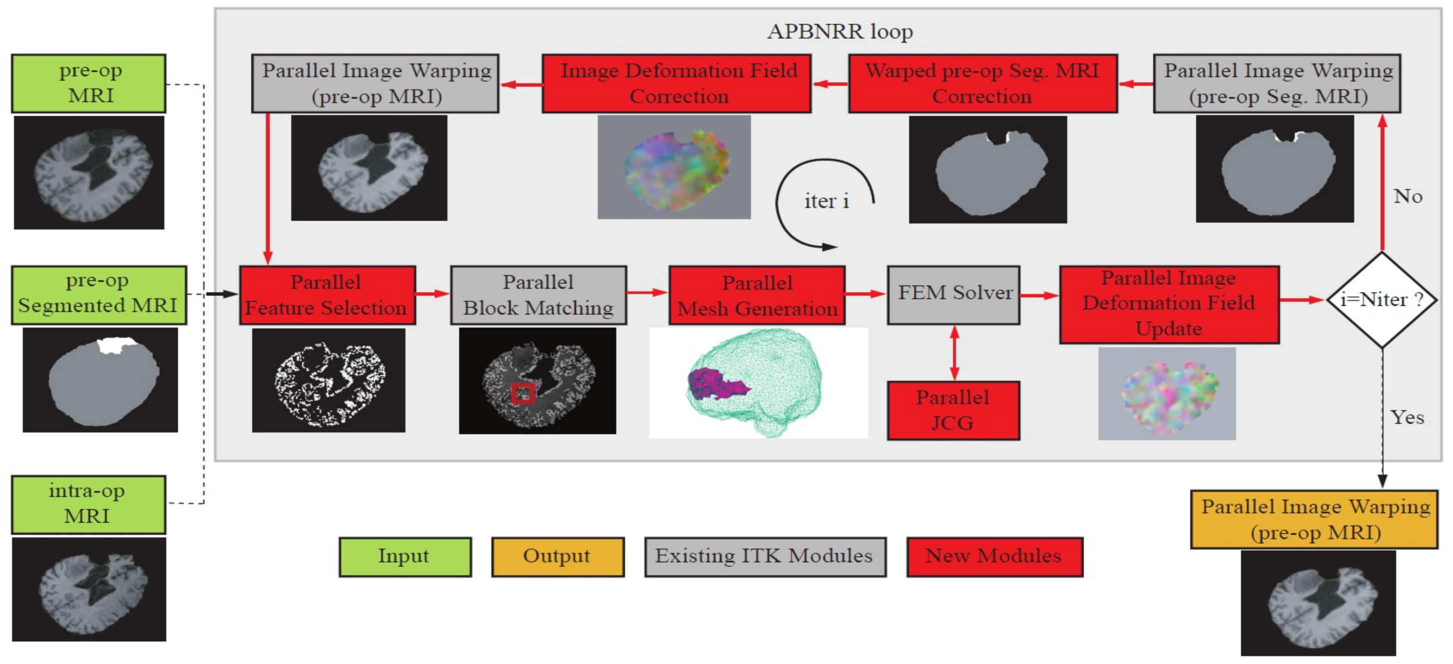
A Non-rigid Registration Method for Correcting Brain Deformation Induced by Tumor Resection

Medical Physics, Volume 41, No. 10, August 2014



Real-time multi-tissue Adaptive Physics-Based Non-Rigid Registration Framework for Brain Tumor Resection

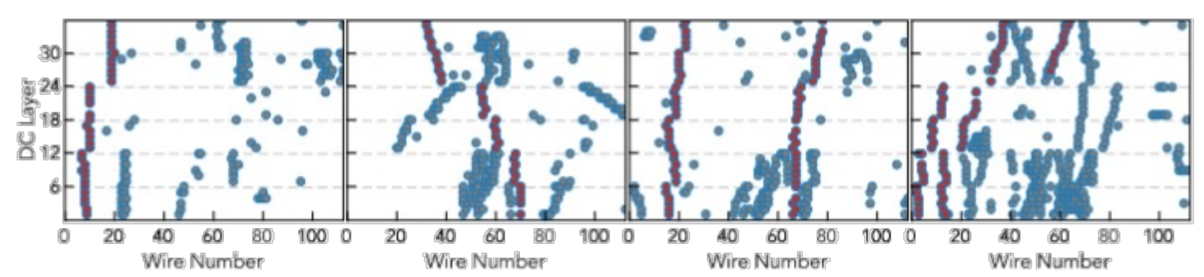
Front. Neuroinform., Volume 8, and Front. Digit. Health, Volume 2, February 2014 and 2021



Using Machine Learning for Particle Track Identification in the CLAS12 Detector

Computer Physics Communications, Volume 276, 108360, 2022

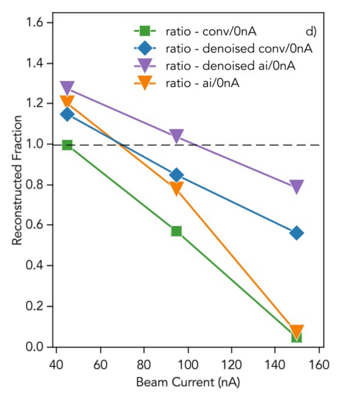
- Tracking takes most of track reconstruction time
  - Computationally intensive (combinatorics)
- Delegate tracking to a machine learning model
  - Classify tracks with machine learning
  - Fit only those with highest probability of being valid
    - 99% accuracy
- Mitigates the cost of track fitting
  - Much fewer candidates to examine
  - 35% speedup
  - $ 5MM/year

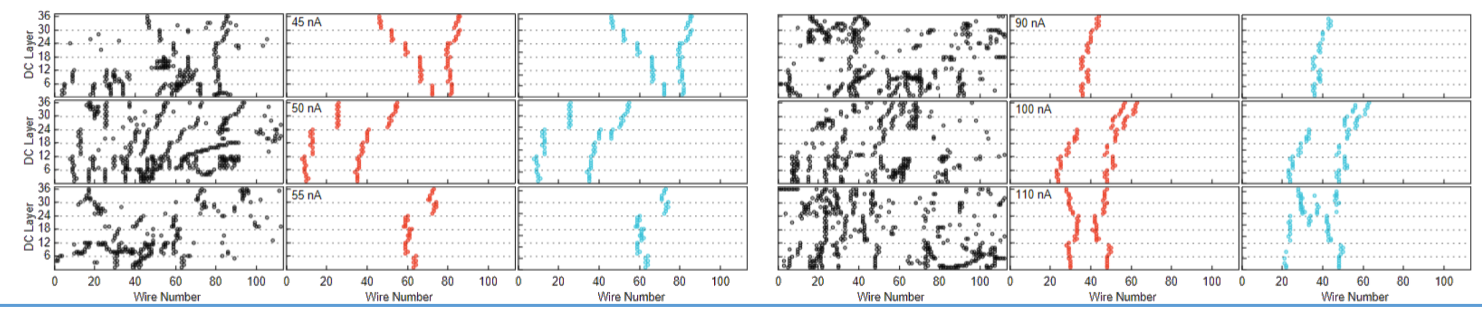


Denoising Drift Chambers in CLAS12 using Convolutional Auto Encoders

Computer Physics Communications, Volume 271, 108201, 2022

- Denoise used Auto Encoder (AE) and then perform tracking with ML
- Denoising with AE maintains samples with higher efficiency
  - ~35% more events in normal operation (45nA)
  - ~80% more events in 100 nA beam currents
- In the current state (45nA) we get 65% to 82% more events
- The higher impact expected in the future
  - Almost double the output when 100nA is possible





Charged Particle Reconstruction in CLAS12 using Machine Learning

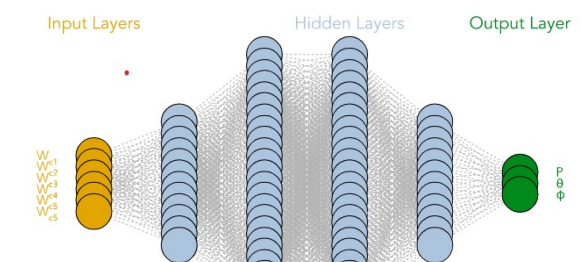
Computer Physics Communications, Volume 287, 108694, 2023

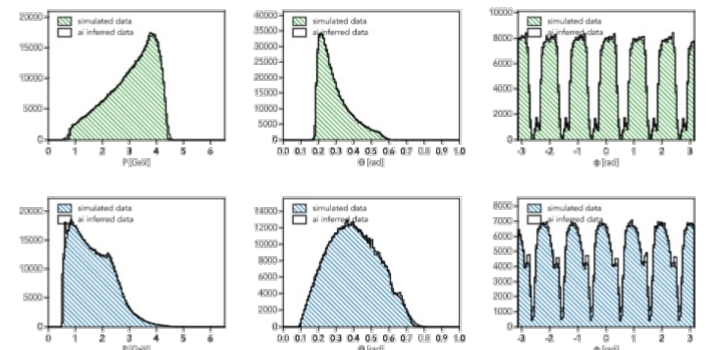
Use machine learning to directly infer physics parameters

- Parameters include momentum, polar and azimuthal angles
- Conventional methods use Hit-Based reconstruction
  - Takes about 380-420 ms per event

Using machine learning takes about 4 ms per event

- ~100 times faster than conventional
- Same accuracy

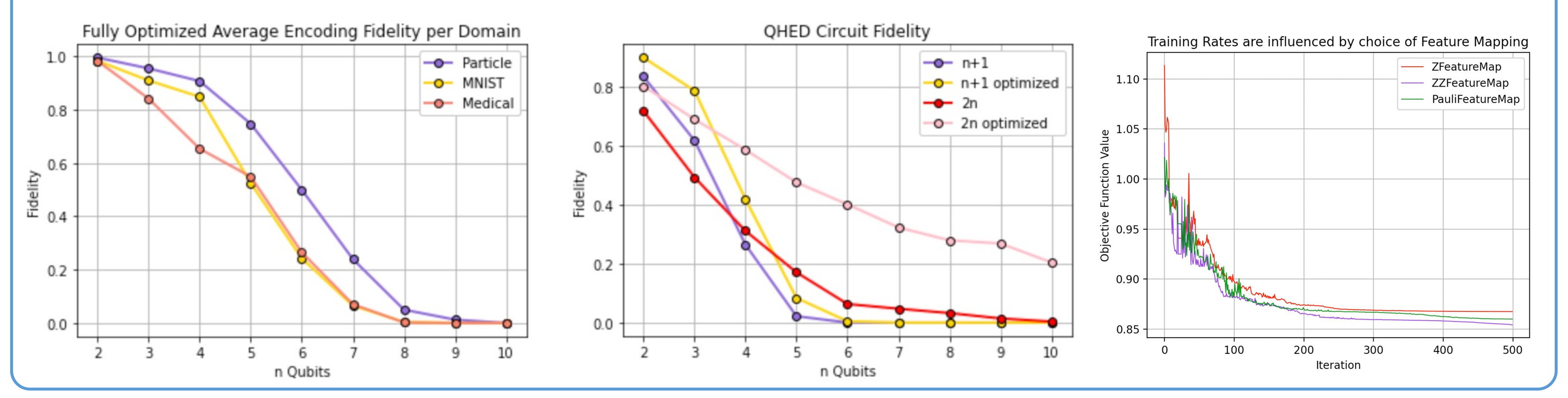




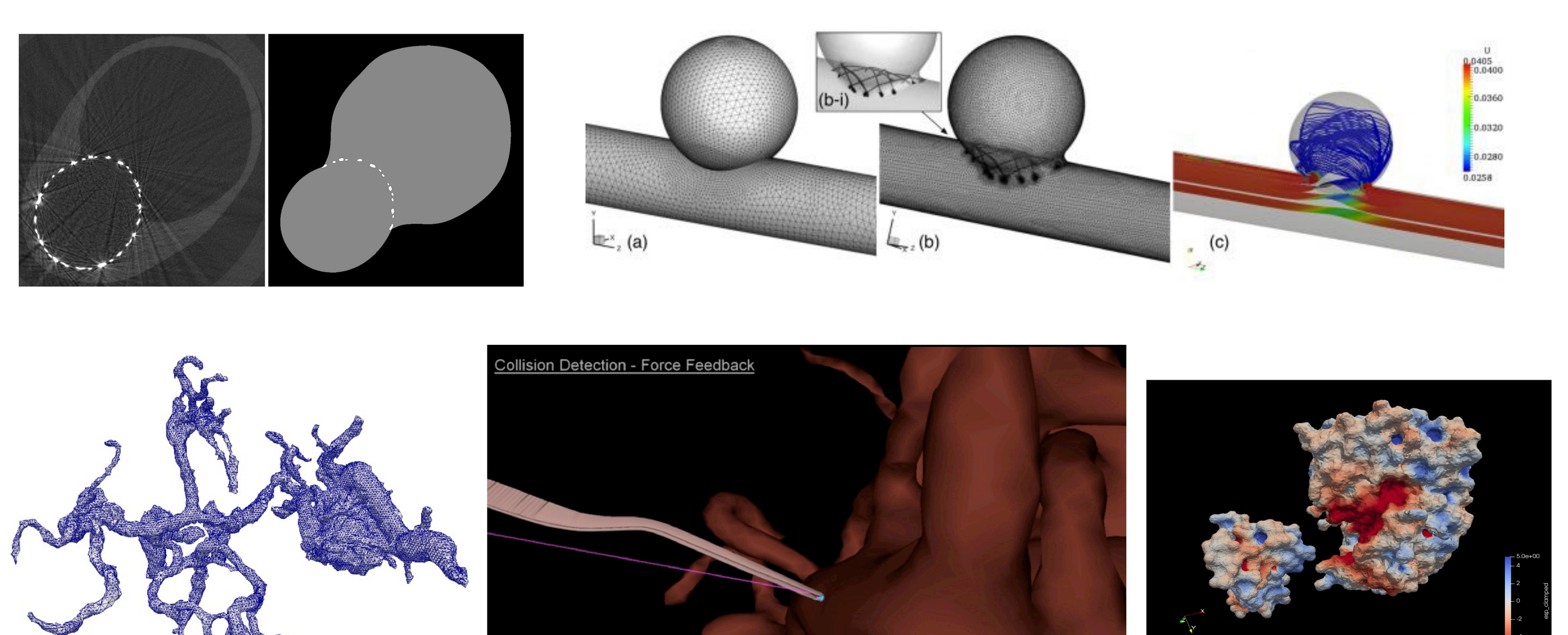
Particle parameters (i.e., momentum, polar and azimuthal angle) distribution for negative (top) and positive (bottom) charge from traditional Hit Based tracking (filled histogram) and ML-inferred tracks (black outline).

Future Work: Quantum Machine Learning For Use Cases from Nuclear Physics and Medical Image Computing

- Image data encoding on NISQ hardware provides limitations in fidelity
  - This can be mitigated with general circuit optimizations and a distributed (D-NISQ) methodology
- Quantum Hadamard Edge Detection relies on an exponential number of CNOT operations (n+1 circuit) which are highly error-prone and thus reduce fidelity
  - The problem can be mitigated with the addition of a linear number of ancillary qubits to create a more efficient decrement unitary (2n circuit), general circuit optimizations, and the D-NISQ methodology

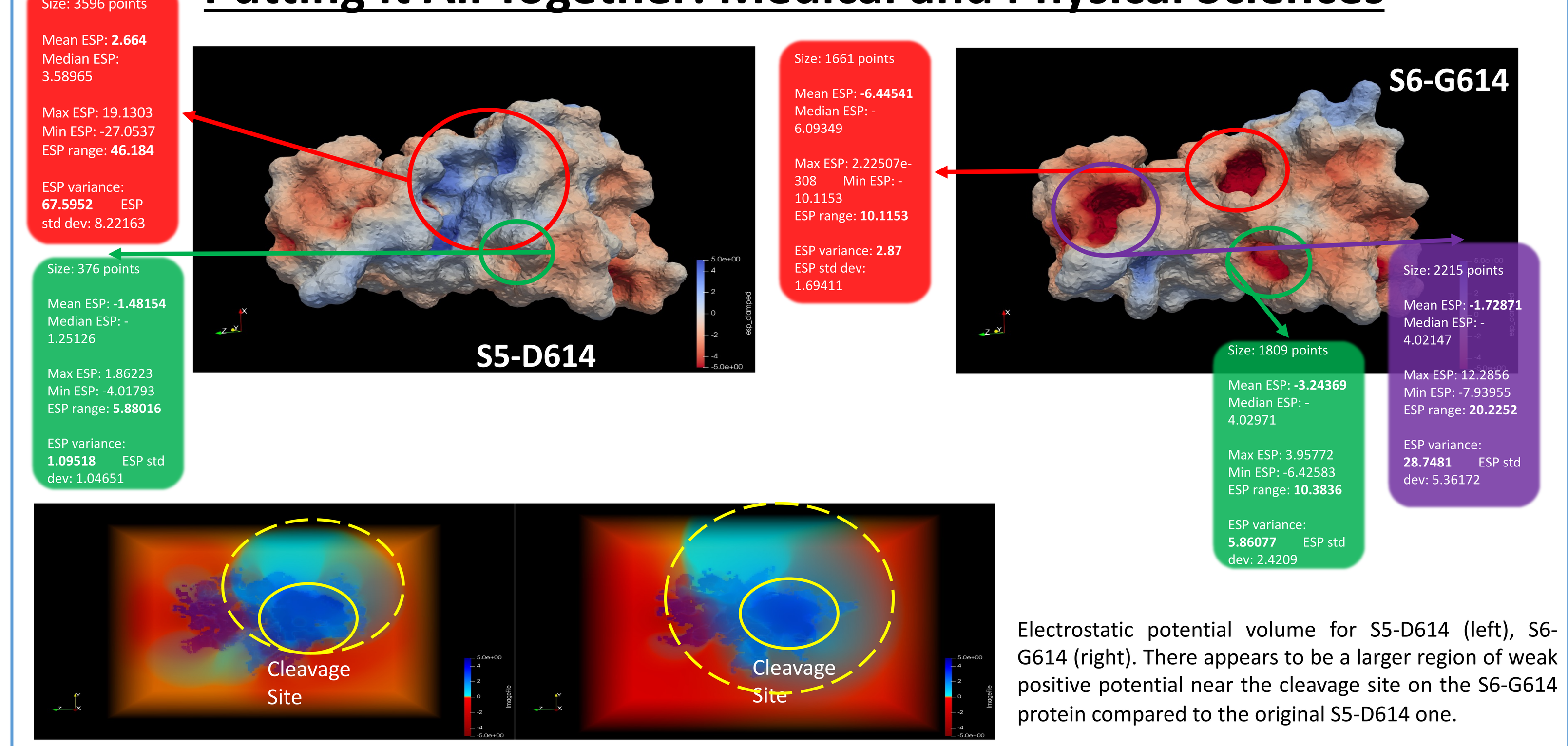


Broader Impact: From Endovascular treatment of cerebral aneurysms to surgical simulation and Drug discovery



Shows S5-D614 with furin (left), and S6-G614 with furin (right).

Putting It All Together: Medical and Physical Sciences



Electrostatic potential volume for S5-D614 (left), S6-G614 (right). There appears to be a larger region of weak positive potential near the cleavage site on the S6-G614 protein compared to the original S5-D614 one.

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