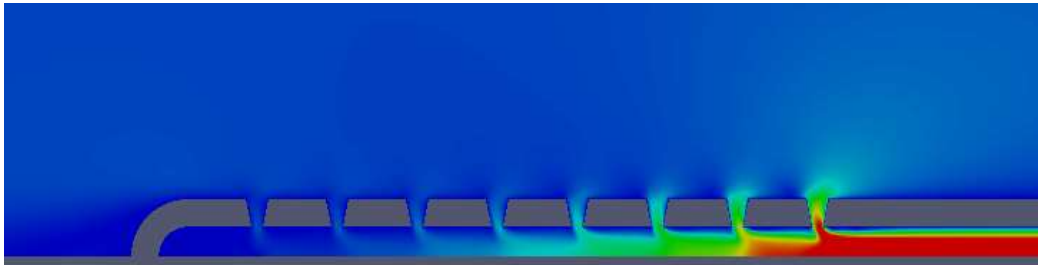
THE UNIVERSITY of TENNESSEE

BIOMEDICAL ENGINEERING

Integrating Engineering and HPC to Solve Multi-physics Challenges



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Key Points

- Multi-disciplinary teams

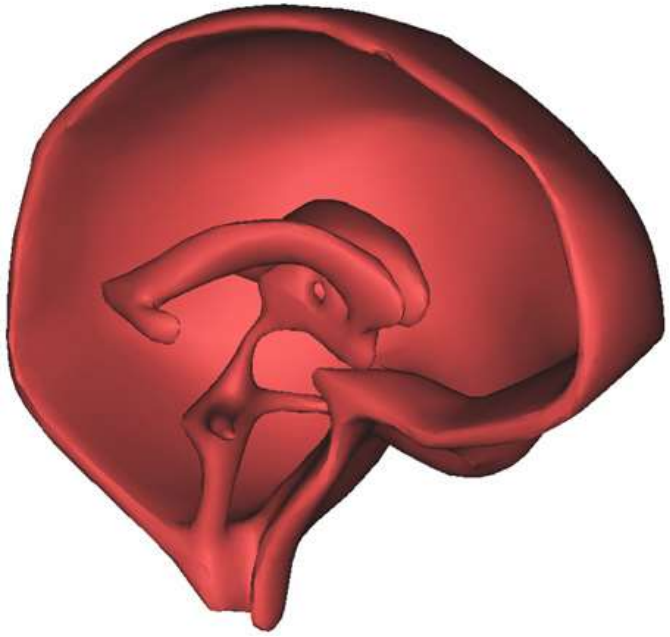
- Big Data interpretation for design optimization

- Validation, validation, and more validation!

Problem Definition

Hydrocephalus: The Invisible Disability

- "Hydro" – water, "Cephalus" – head
- Characterized as excess Cerebrospinal Fluid (CSF) in the ventricles of the brain
- Difficult to diagnose – invasive testing
- No known cure



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Prevalence of Hydrocephalus

- Chronic medical condition that affects over a million people in the US from newborns to the elderly
- Congenital
  - As common as Down's Syndrome
  - Most common reason for brain surgery in children
- Acquired
  - Secondary effect of traumatic brain injury, disease, or blockage
  - Impacts 0.5% of the population over 65 years old
  - Likely an underestimate due to lack of recognition by patients and physicians
  - Misdiagnosed as normal aging or dementia

A newborn has a 1/500 chance of being born with hydrocephalus and facing a lifetime of brain surgeries.

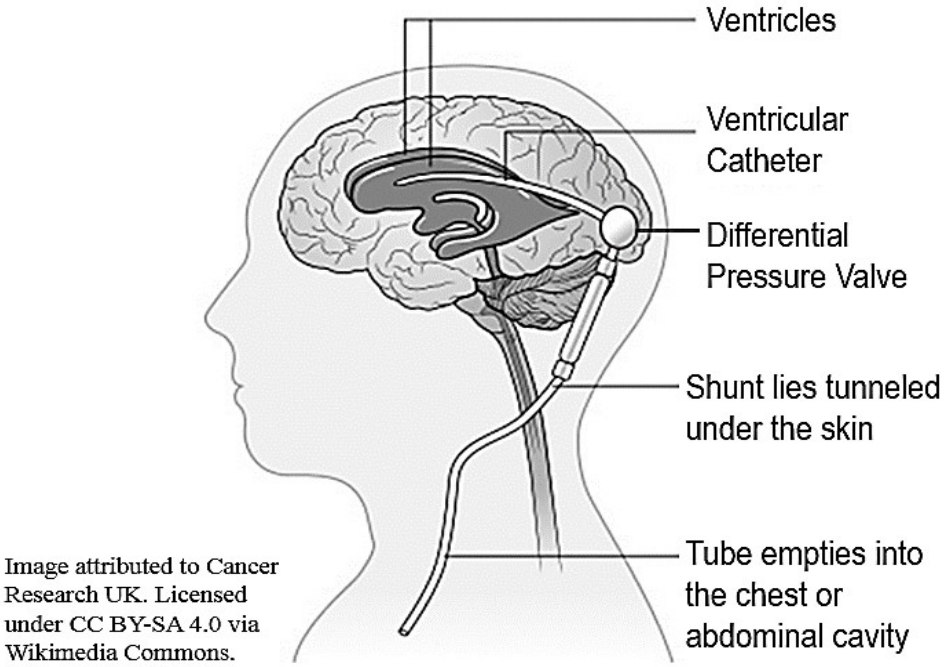
Symptoms

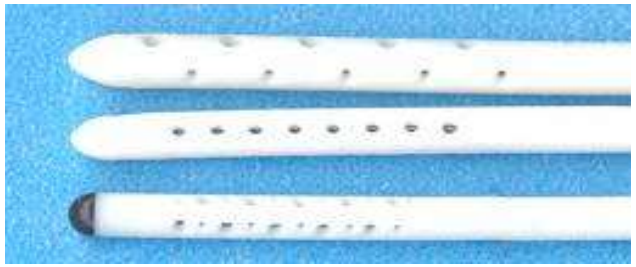
- Result of compression of neural structures due to increased intracranial pressure
- Headaches, nausea, papilledema, seizures, learning disabilities, motor skills impairment
- Symptoms can be debilitating and cause extreme patient suffering.

If left untreated, hydrocephalus can result in death.

Treatment: Ventriculoperitoneal Shunt

Shunts are an effective treatment for brain disorders to prevent brain damage and death.

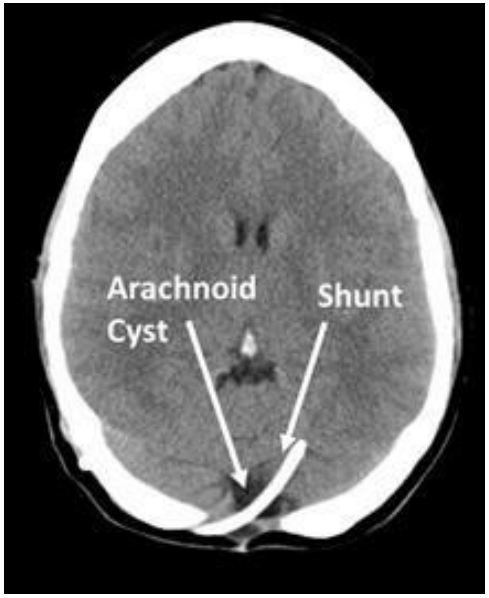




The shunt system was developed 50 YEARS ago.

Failure Rate of Shunts

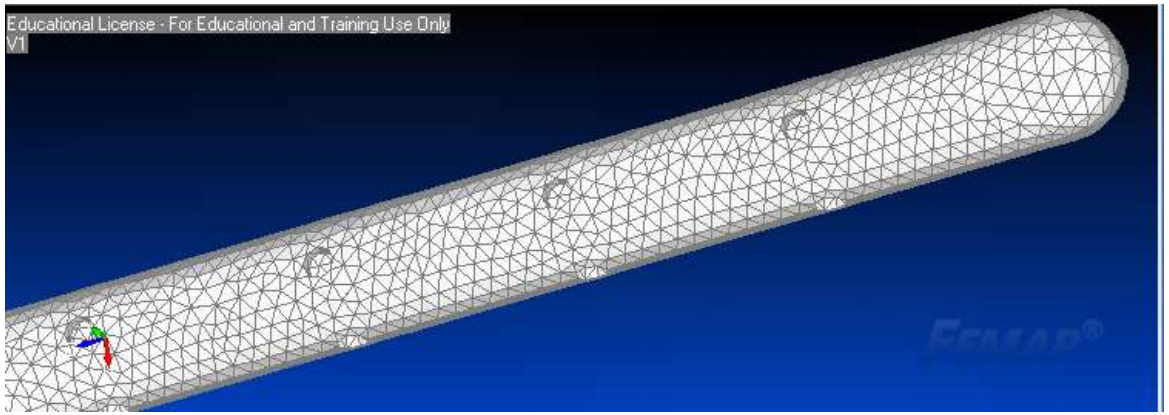
- One surgery every 15 minutes
  - Over ½ are a life or death situation
  - Only 30% are the patient's first surgery
- Over 50% of shunts require revision in the first year and 90% require revision within 10 years.
- Statistically, hydrocephalous patients require between 2 to 4 surgeries for shunt insertion or revision in a 10 year period after their initial diagnosis.

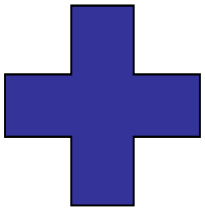


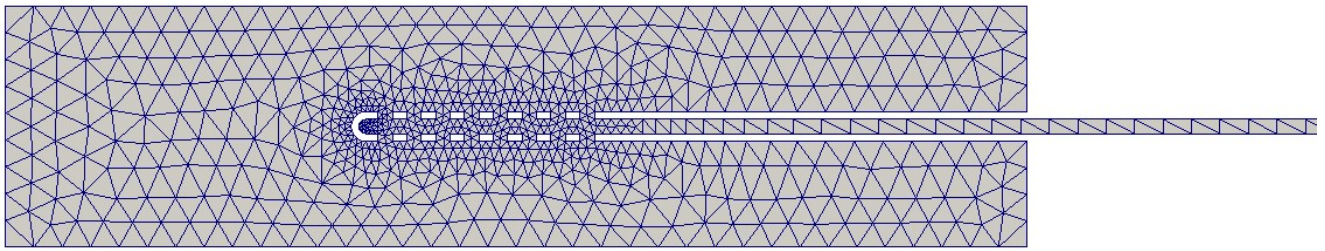
Solutions: Multi-Disciplinary Teams

- Goal is to ***actively*** involve people from disparate fields and areas of expertise
- Including people from diverse backgrounds allows the team to “redefine problems outside of normal boundaries” (*Wikipedia*)
- Team objective is to develop innovative and revolutionary solutions to existing and emerging problems.

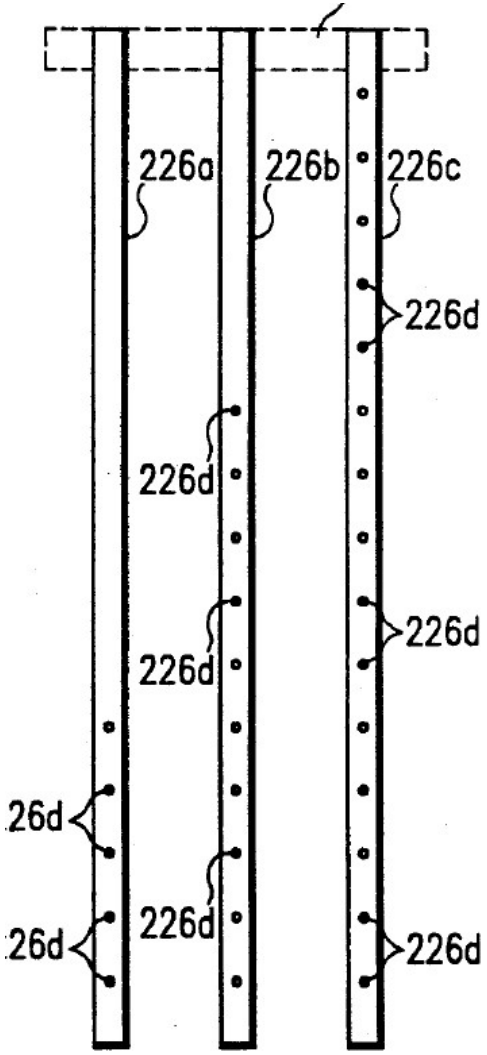
Communication: Fluid Structure Interaction

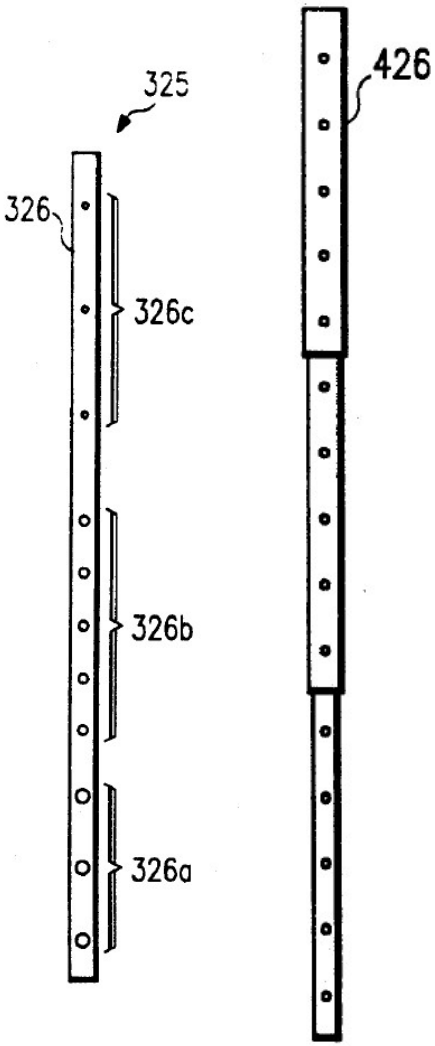


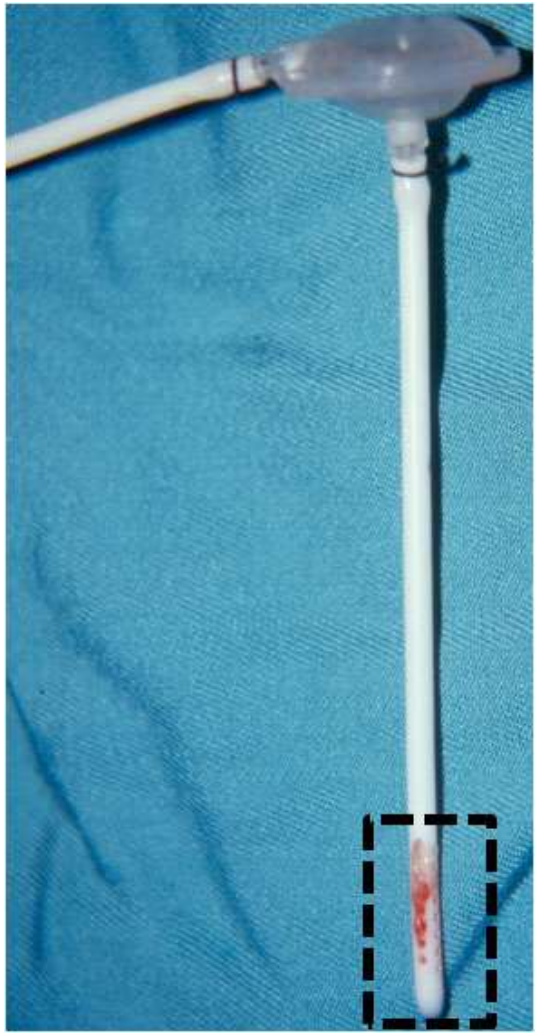




Expertise Translation: Catheter Design







Group Exercise

1. Develop a research approach using HPC to redesigning the ventricular catheter.

2. Staff your multi-disciplinary research and development team.

Problem Solution

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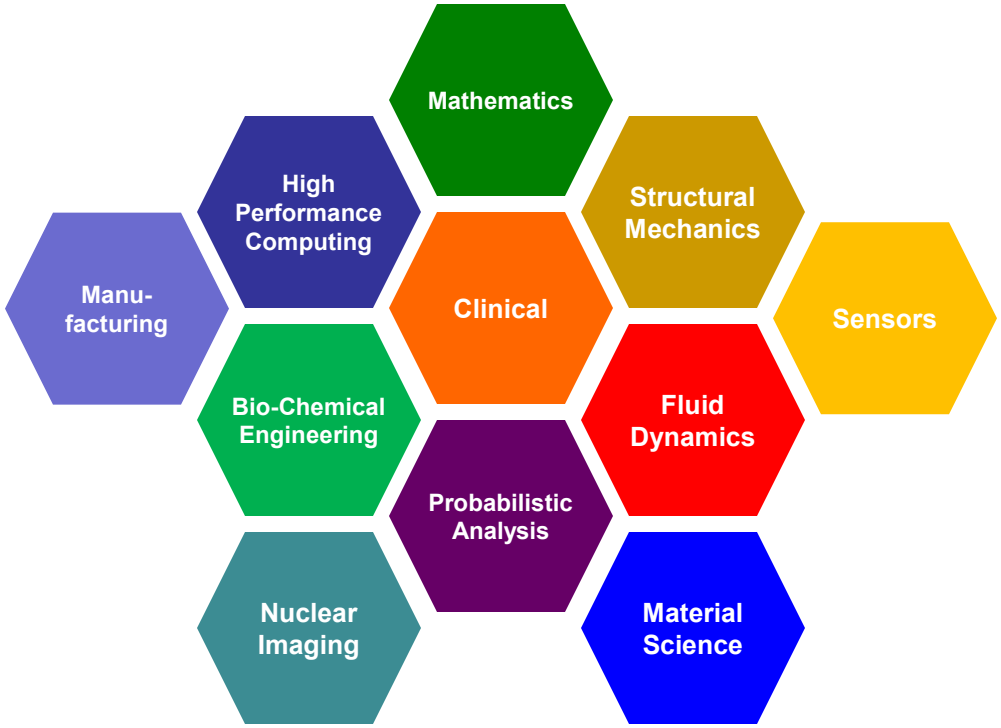
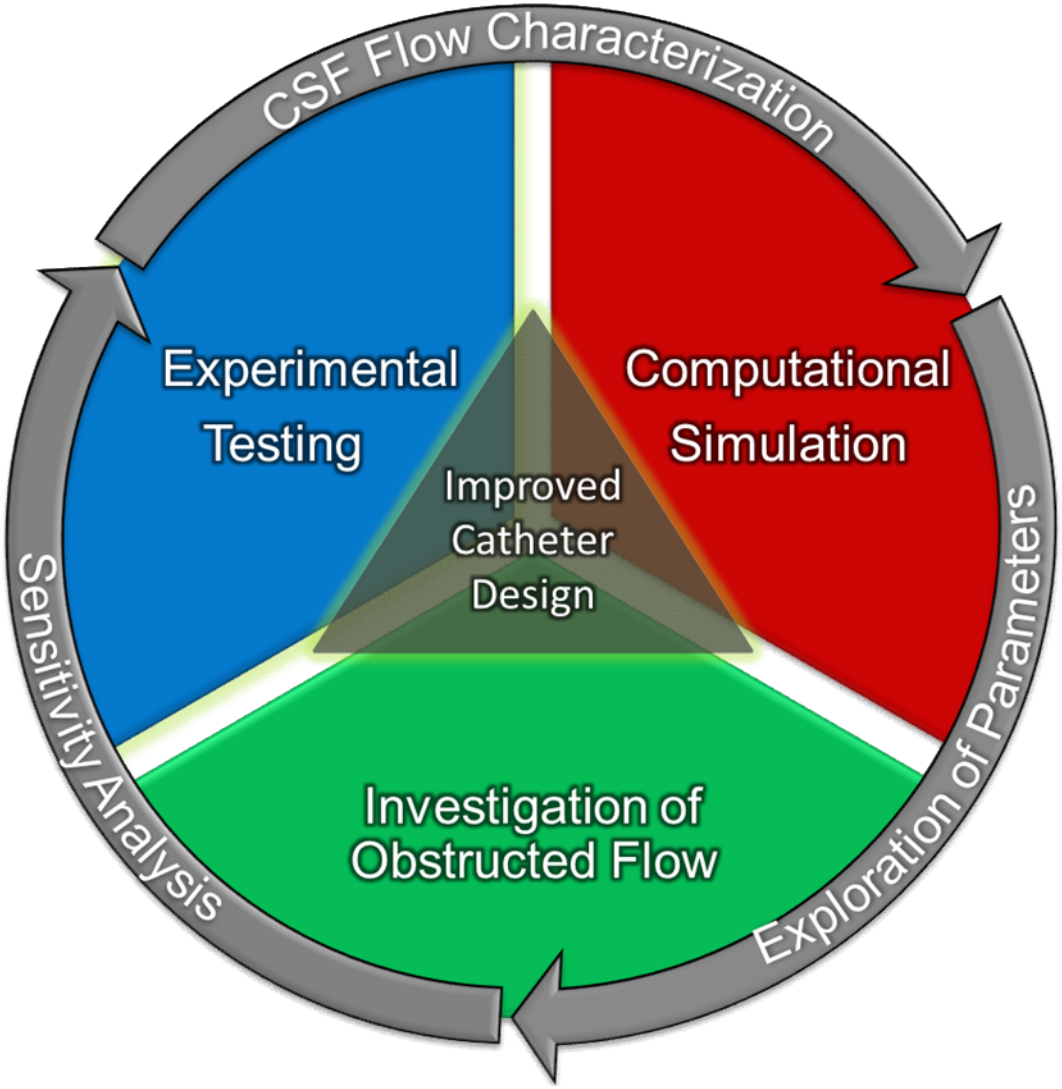
Multi-Disciplinary Collaboration

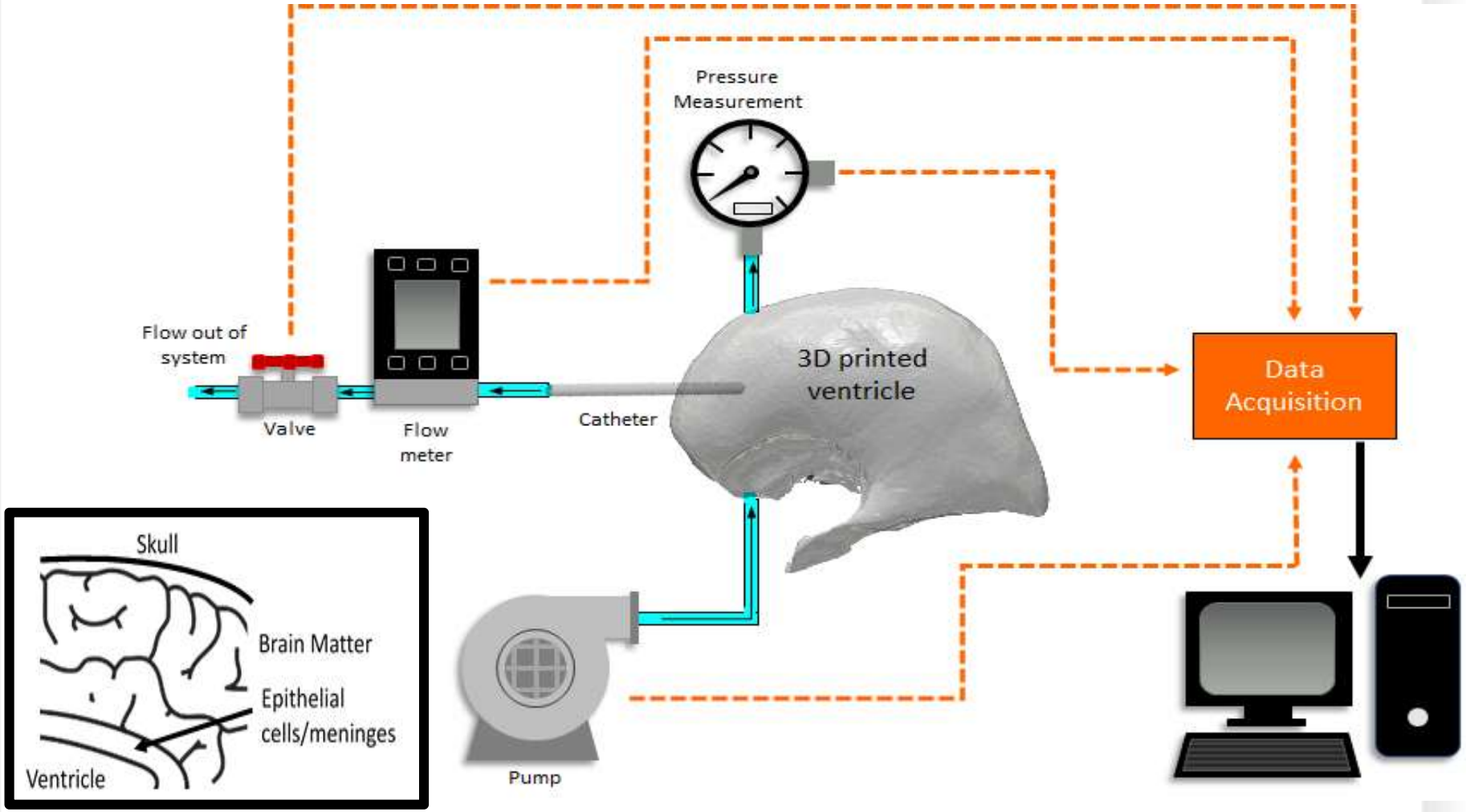


Improved design and optimization of ventricular catheters requires the integration of many diverse fields.

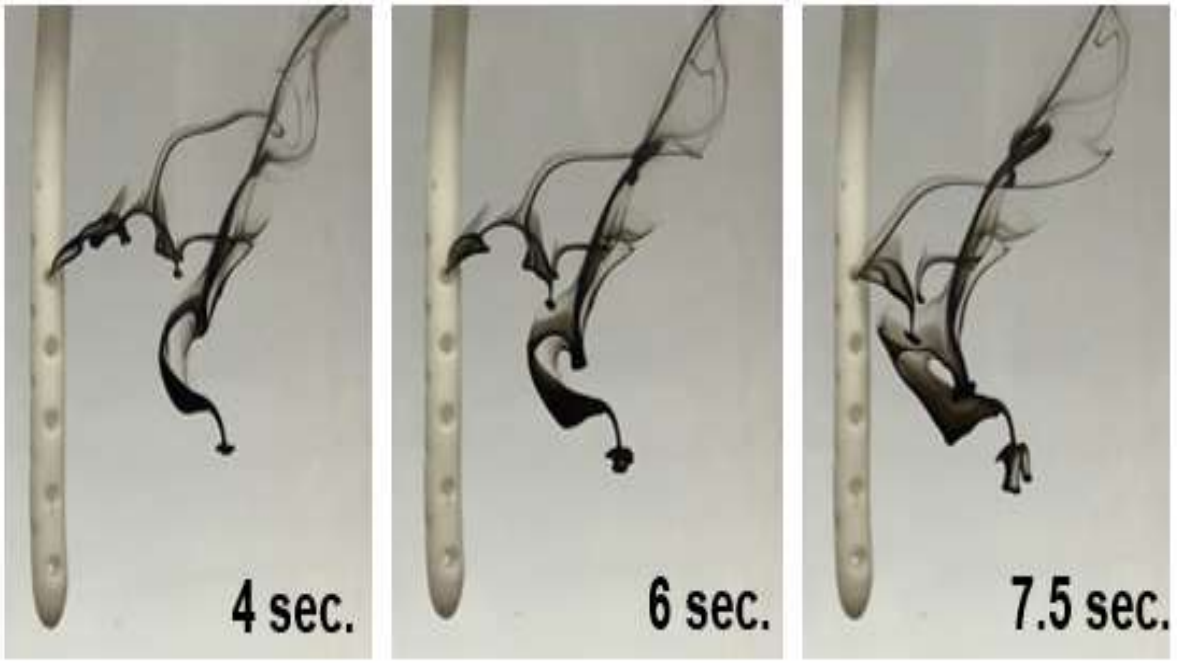
Integrated Approach



Experimental: Characterization and Validation

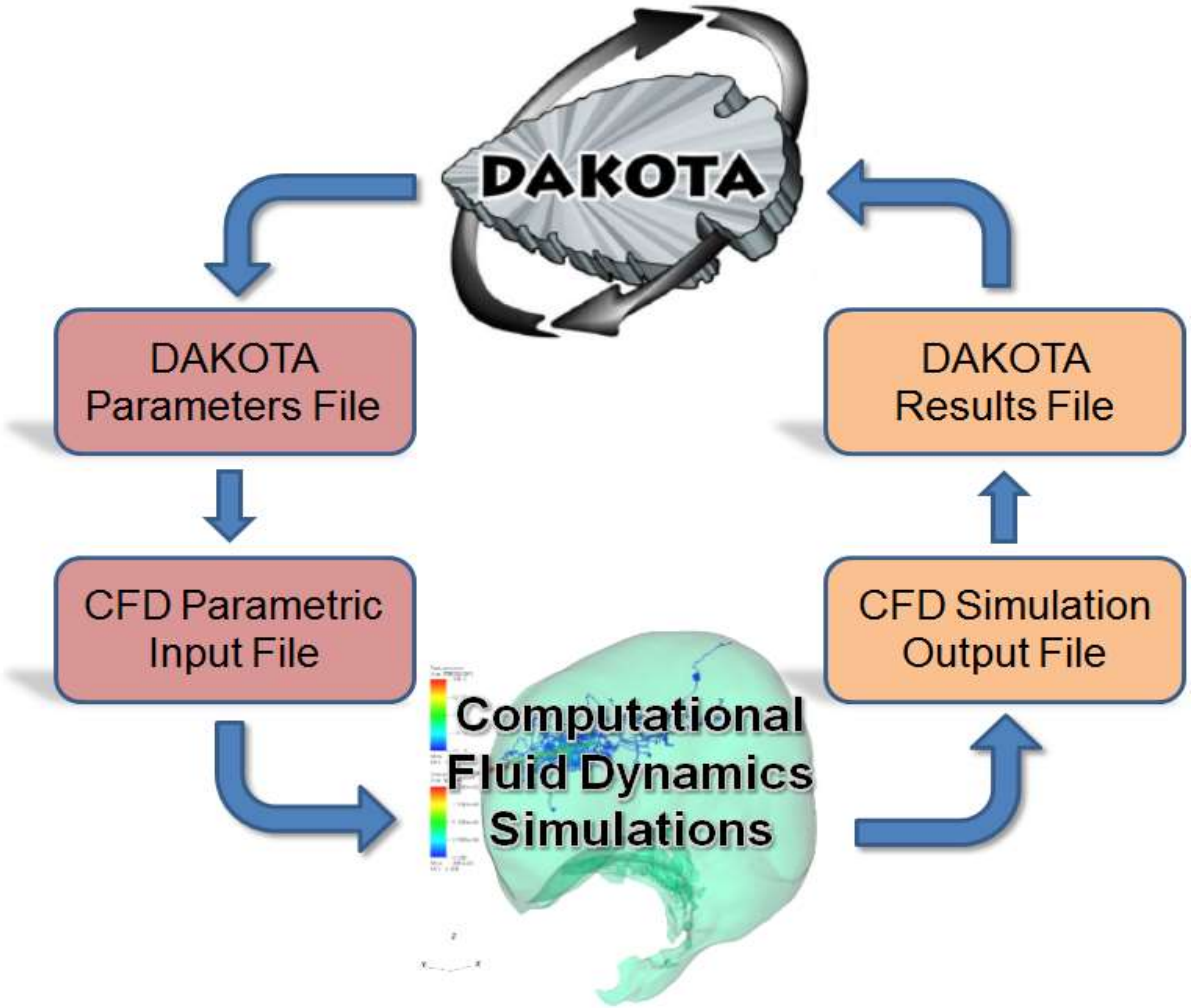


Current Design Flaw

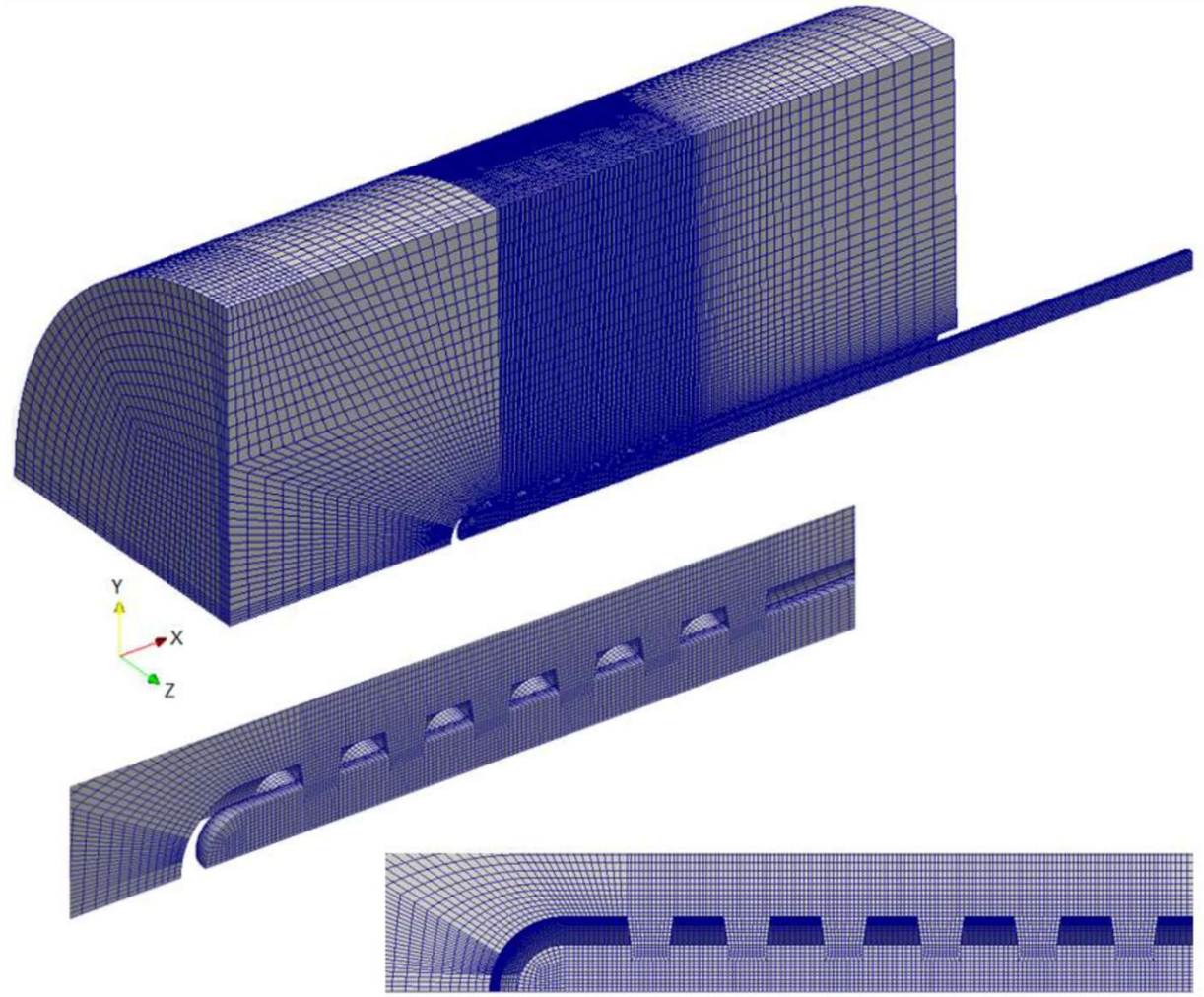


Water and India Ink Experiments: Time-Lapse

Code Coupling on Darter/Beacon



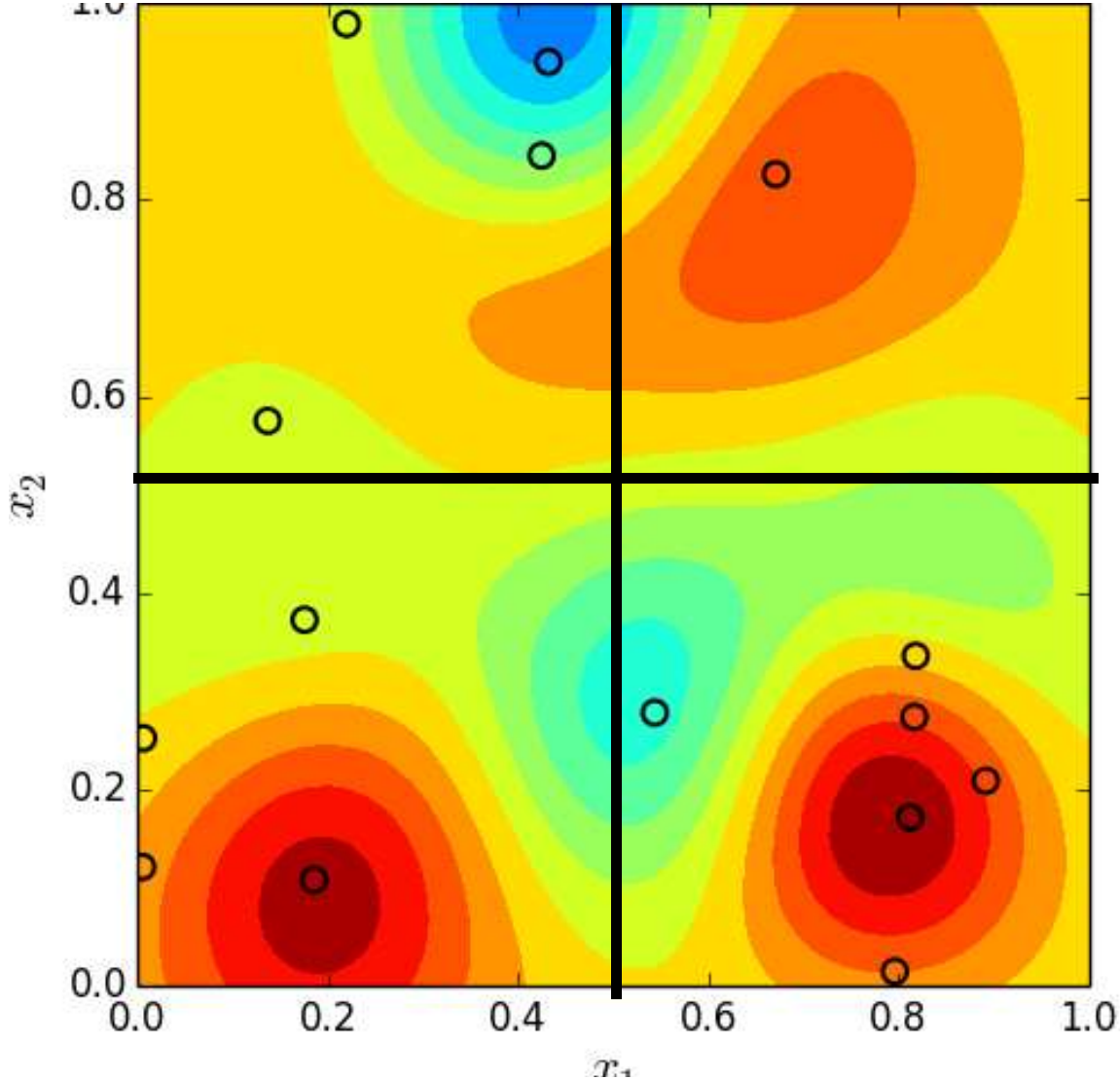
Parametric Input Files



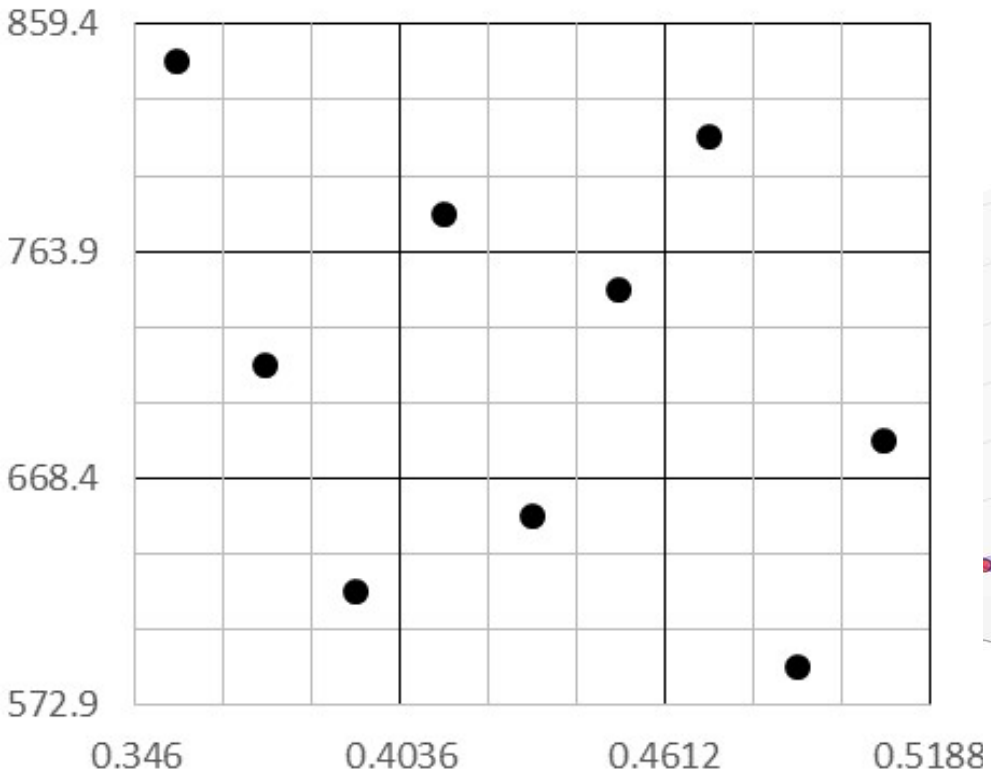
Geometric Parameters Included in Study on an 8 Hole Design

Exploration of limited design space: trillions of combinations

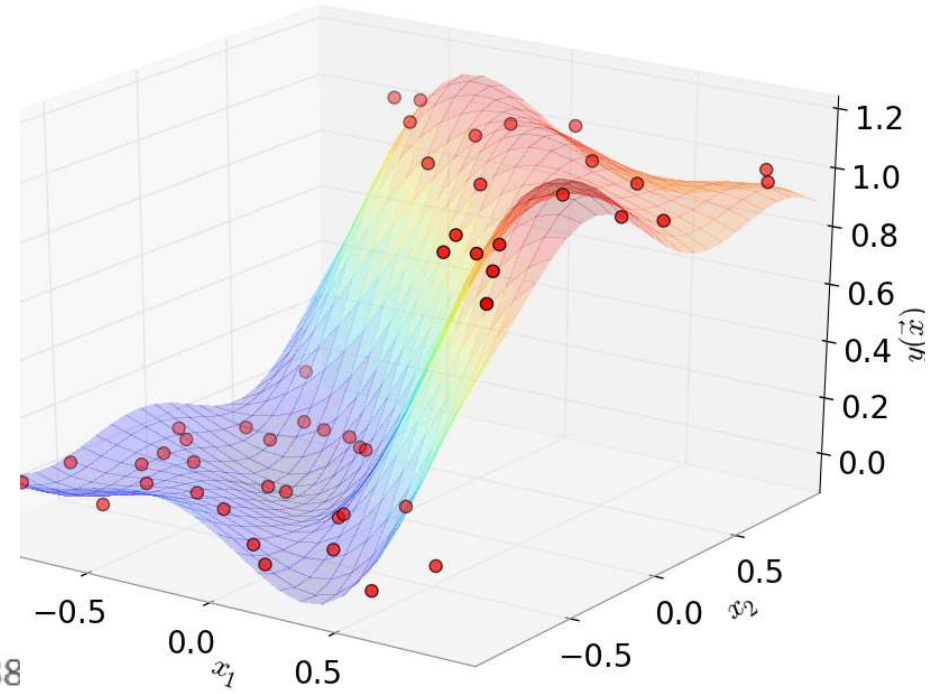
Global Sensitivity Analysis Requirement



Latin Stratified Sampling (Dr. Michael Shields – JHU)

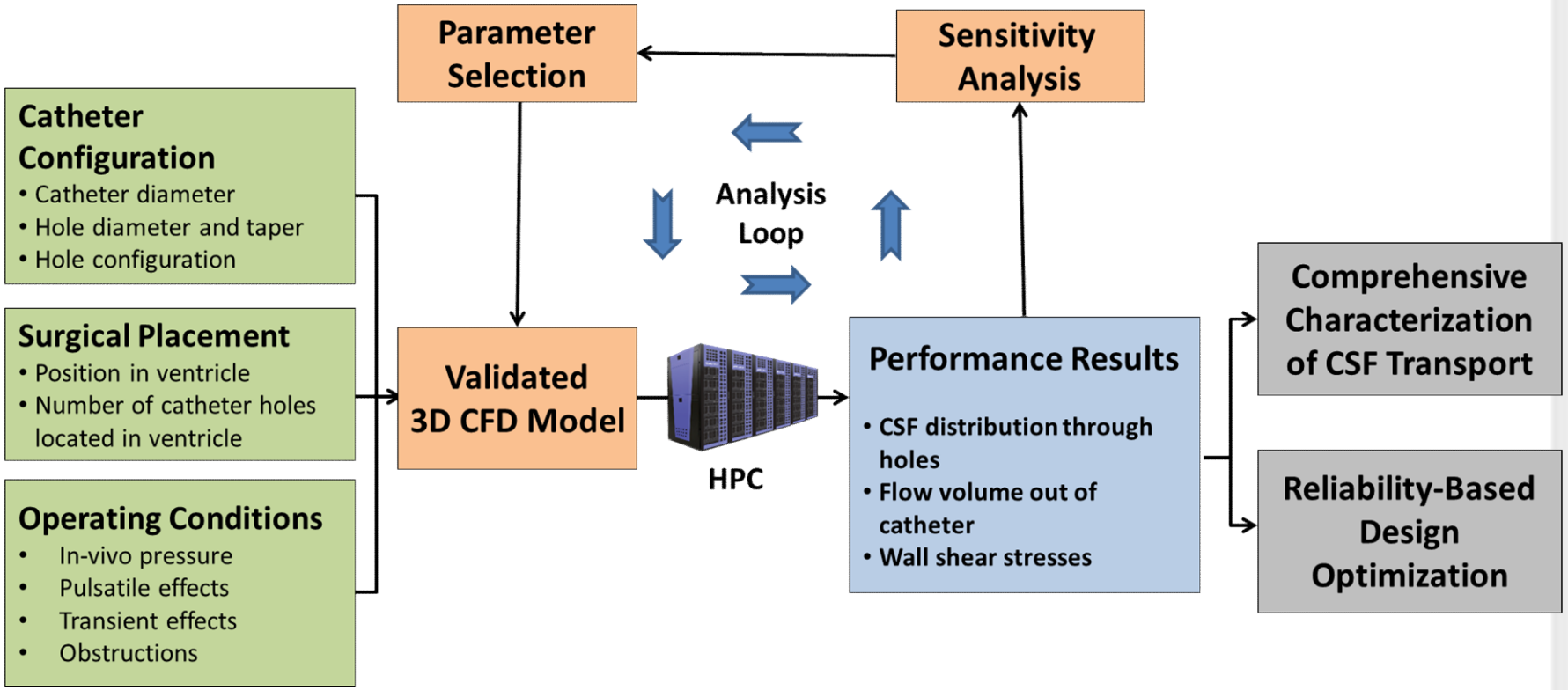


Surrogate Model

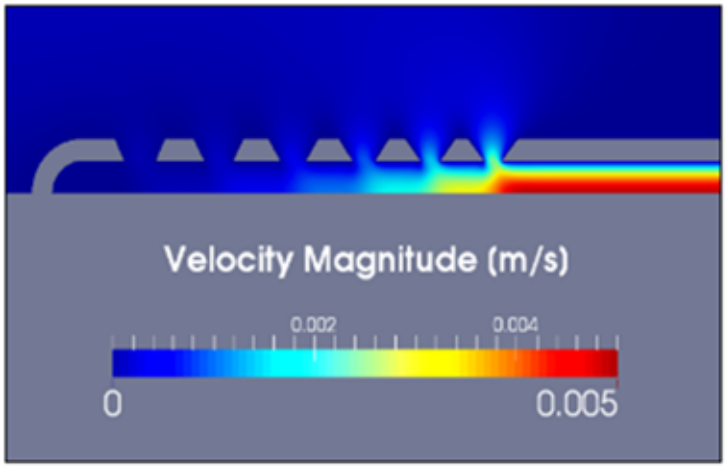


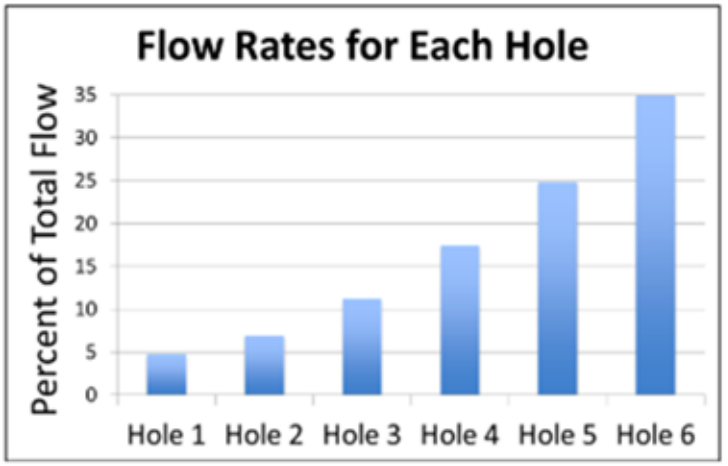
Use computing hours wisely.

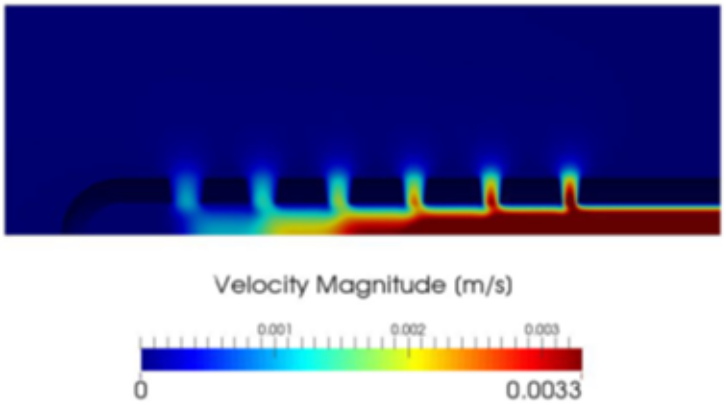
Coupled Sensitivity Analysis and Optimization

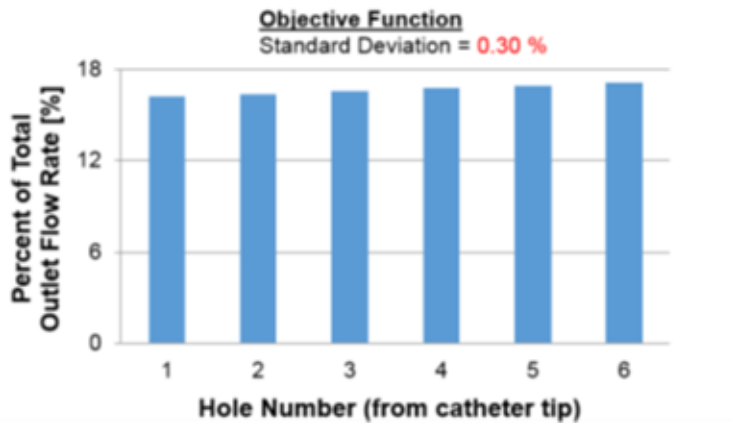


HPC Redesign – 5 hours







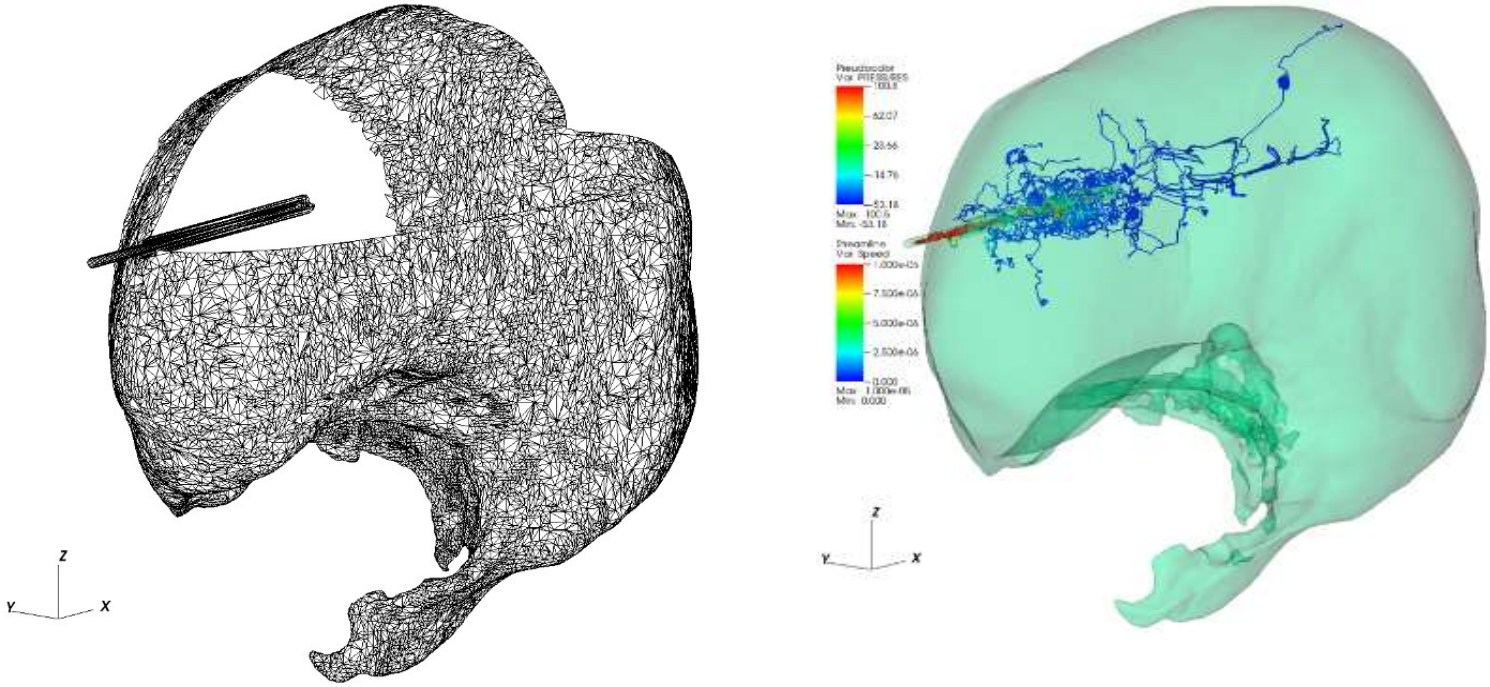


14.27% (baseline), 4.5% (Rivulet), and 0.30% (HPC optimized)

Missing Complexity

- In-vivo operating conditions
  - FSI: CSF interaction with ventricle wall and catheter
  - Transient effects due to valve opening
  - Catheter location
  - Obstructions
- Ventricle modeling
  - Rigid
  - 3-layer model
- Varying catheter configuration/materials

Rigid Ventricle Model



Visualization of flow field 0.124 ms after valve opening. The surfaces of the ventricle and 8-hole catheter are colored by pressure and streamlines are colored by speed.

Disease Crisis News Alert

A new disease has been identified with 100% fatality rate.

Acknowledgment

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