Inverse Design Process: New Methodology to Design Medical Devices with BIG DATA

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Purpose:

Reverse the traditional forward design process, to create a more efficient and effective pipeline for medical device design.

Background:

Millions of dollars are spent on medical devices each year to improve patient health. These devices came to fruition through a linear design process. To reach a final design many ideas are eliminated without complete consideration of the potential impact. This linear process is limited and significantly bounds the design space by discouraging complete exploration of all ideas.

Inverse Design Process:

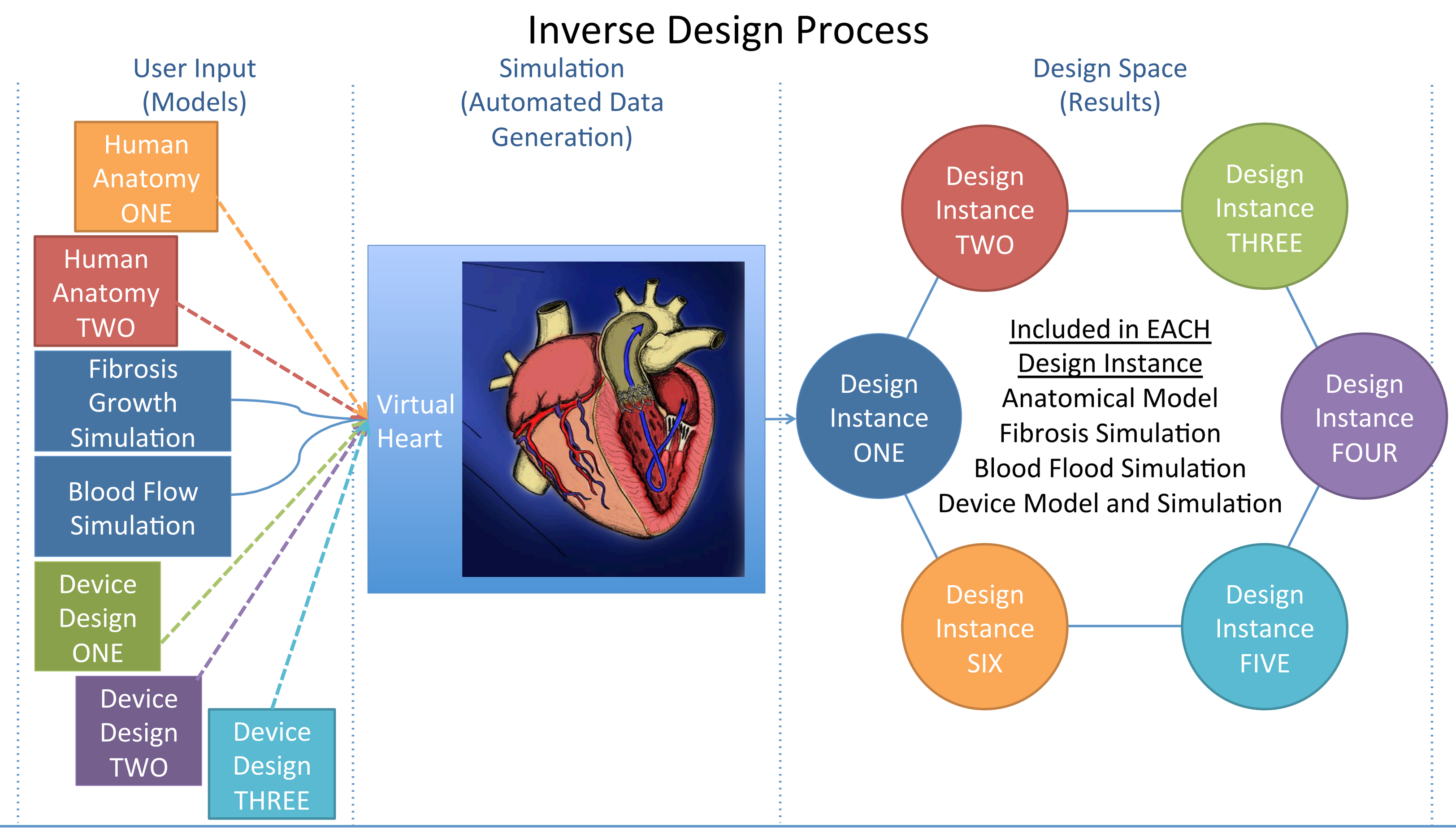
Capitalizes on computational speeds, simulation models and visualization environments to prepare specific output parameters for each design. These designs are visually displayed and presented to the user for inspection and refinement until an optimal design is selected.

Proof-of-Concept Device:

Cardiac leads experience many environmental factors that cause failure, including; anatomical geometric constraints, device shape deformation, blood flow and tissue fibrosis. Tissue fibrosis is the encapsulation of the device by scar tissue and alters the environmental factors experienced by the cardiac lead over the lifespan of the device. The severity of tissue fibrosis is patient specific and increases the complexity of an extraction procedure. The most common complication is rupturing the wall of the heart and requires immediate open-heart surgery to repair the tear. Understanding and modeling the complex environment of the heart would improve the design of the cardiac leads and inform surgeons of patient specific complexities that impact selection of cardiac lead devices.

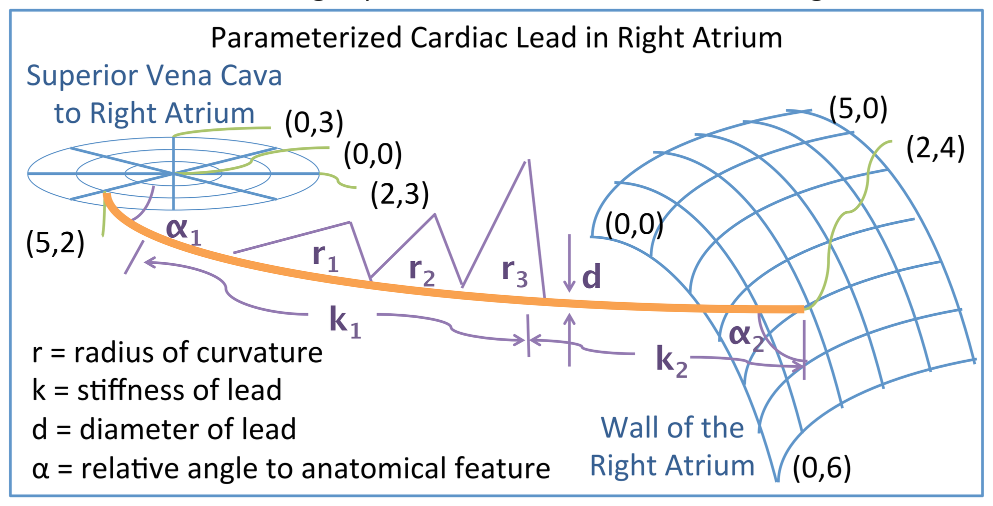
Computer Science:

This research asks the question of how to effectively build a system that utilizes high performance computing architecture to efficiently prepare and query simulation data for remote visualization and interaction. Using GPU compute nodes and rendering nodes, we plan building a visualization engine that iteratively sifts through a dynamically indexed set of simulations. Based on user input, we can hope to quickly find which simulations most closely resemble the desired parameters without moving the data.

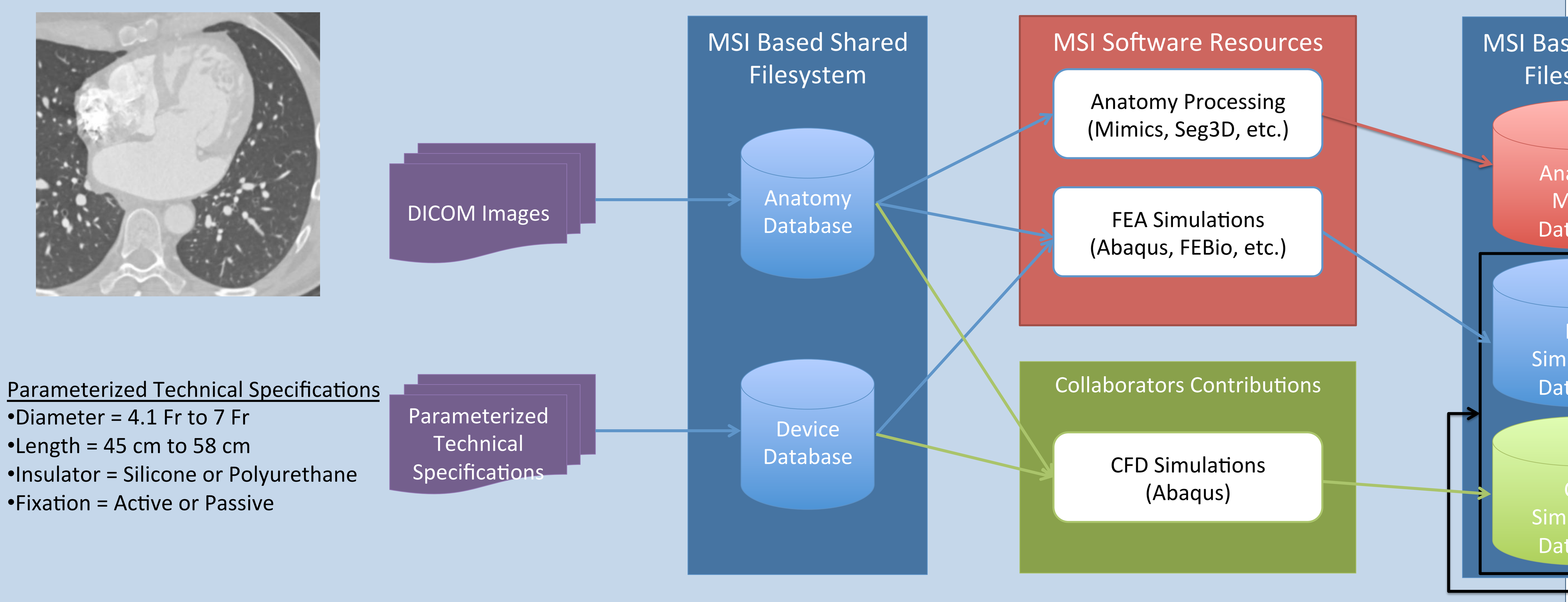


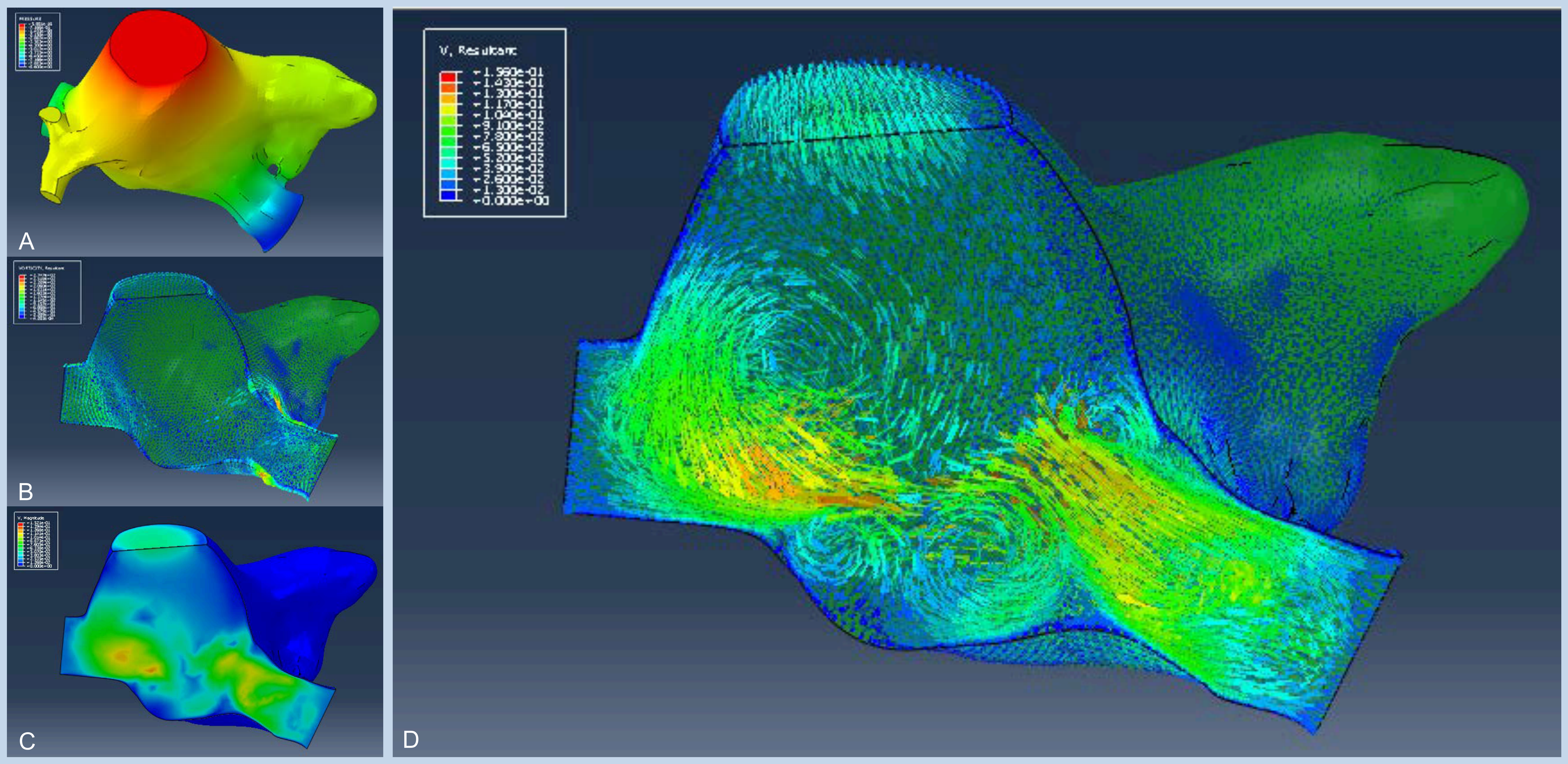
Engineering Science:

The inverse design process starts with a computer-aided design (CAD) model of a device. Each device is parameterized into basic geometric and material variables and the acceptable ranges for each valve. These parameterized values are used to organize the design instances. The parameterized devices are structurally analyzed through finite element analysis (FEA), blood flow is modeled through computational fluid dynamics (CFD) using human specific anatomical models, and tissue fibrosis is simulated to understand the environment surrounding the each model. Each design space will include hundreds of design instances.



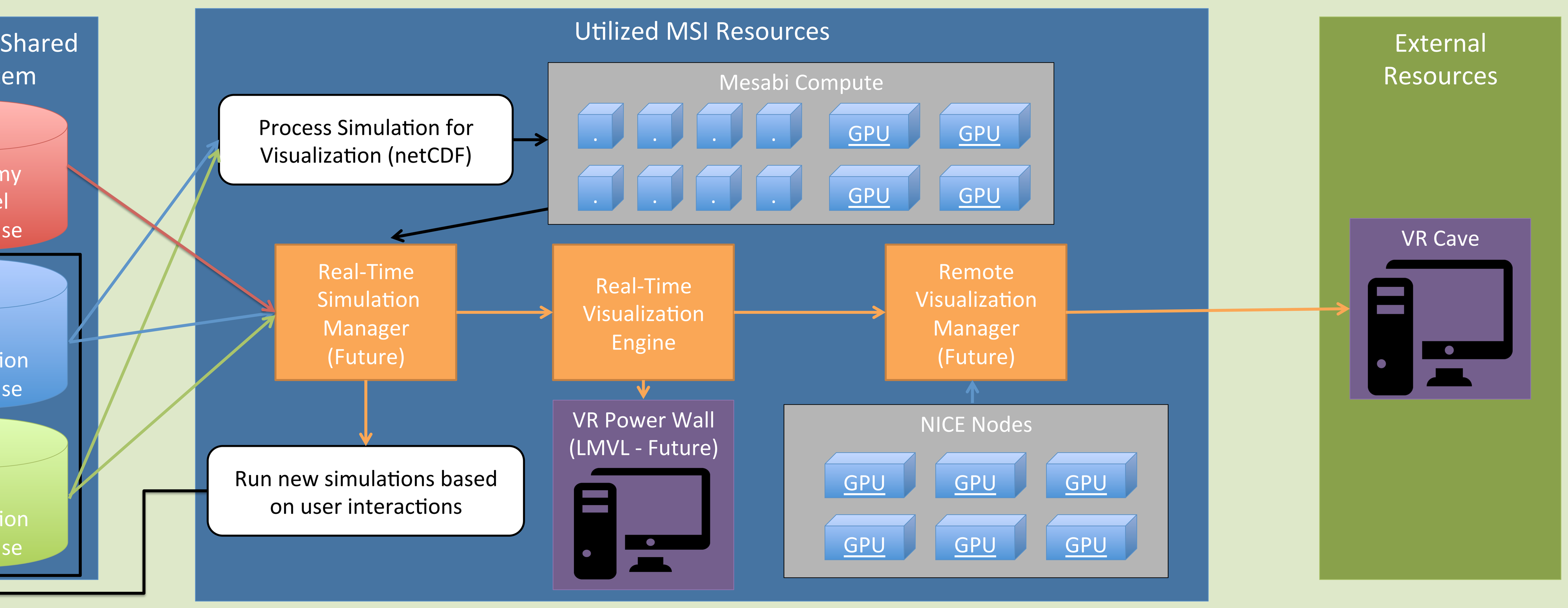
Engineering Science

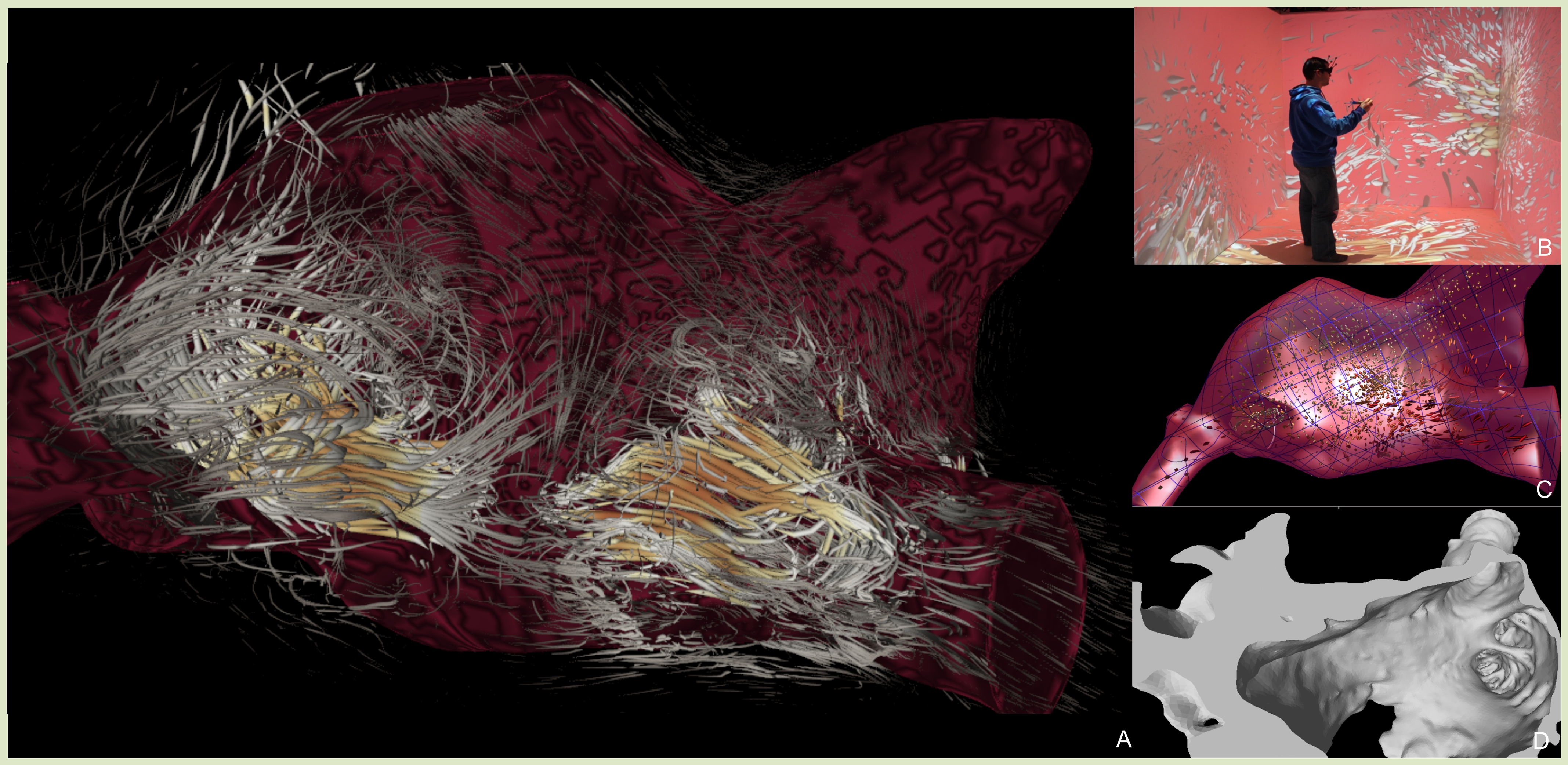




Fluid Flow Simulations from Abaqus: A) Pressure B) Velocity, Resultant: t=0 seconds C) Velocity, Magnitude D) Velocity, Resultant: t=0.3 seconds

Computer Science





Visualizations of Fluid Flow Simulations: A) Fluid visualization B) Interactive fluid flow in CAVE C) Particle visualization D) Anatomical Heart Model

MSI Contribution:

The Minnesota Supercomputing Institute (MSI) provides unique and vital resources necessary to store, process, and visualize the results of this research. In an on-going project, data sets are generated through the use of the specialized software provided by MSI, specifically Mimics for anatomy segmentation and Abaqus for FEA / CFD simulation. MSI storage capabilities create a shared repository that is synchronized with collaborators at the University of Chicago. Models and simulations continue to be added to the repository. Running real-time particle advection using CUDA and high-end graphics cards for rendering, the GPU computer nodes and NICE GPU nodes are ideal for this application. In addition, the LCSE-MSI Visualization Laboratory (LMVL) will be used to interactively design medical devices in virtual reality.

Discussion:

This is an ongoing collaborative interdisciplinary work, which hopes to answer both medical engineering questions related to device design and large data visualization questions in computer science. For engineering science, the focus is largely on segmenting of heart anatomy, developing parameterized simulations of leads within the heart, and developing fluid flow and fibrosis models. This allows for the systematic generation of large amounts of data useful for design. For computer science, the focus is primarily on development of interactive visualization tools for both fluid flow and solid deformation simulation.

Conclusion:

A process and set of tools have been developed to interactively generate and explore coupled CFD and FEA simulations. This information helps understand how to parameterize the engineering problems of medical devices, for example cardiac pacemaker lead design. However, in order to enable the inverse design process described above, much work on how to index the simulations, and appropriate visualization techniques need to be developed. In addition, continuous data generation needs to be aggregated to refine the engineering problem and the design space.

Future Work:

Develop the processes that automatically generate the FEA, CFD and Fibrosis models for new design instances with varying parameters. Currently, all design instances are generated manually. The NICE GPU nodes will be used to build a real-time remote visualization system which has an interactive connection to the Mesabi GPU enabled compute nodes. These GPU nodes, coupled with the remote visualization, can allow real-time processing of the simulation data at scale from any machine. As users interactively explore the available datasets, analytics are gathered which queue more simulations to be run for further analysis.

References:

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Dane Coffey, Chi-Lun Lin, Arthur Erdman, and Daniel Keefe. "Design by Dragging: An Interface for Creative Forward and Inverse Design with Simulation Ensembles." IEEE Transactions on Visualization and Computer Graphics (Proceedings of Scientific Visualization / Information Visualization 2013). 2013.

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The Visible Heart® Laboratory
Lab Focus: Translational Systems Physiology