Comparison of Multiple Large Fluid-Structure Interaction Simulations in Virtual Reality

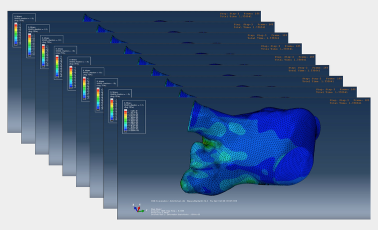
Daniel Orban[1], Seth Johnson[1], Hakizumwami Birali Runesha[2], Lingyu Meng[2], Bethany Juhnke[1], Arthur Erdman[1], Francesca Samsel[3], Daniel F. Keefe[1]

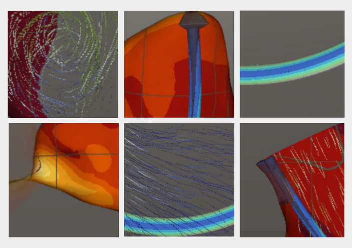
[1]University of Minnesota [2]University of Chicago [3]University of Texas at Austin

Introduction and Motivation

How does the stiffness and length of a cardiac lead affect stress and blood flow in the right atrium of the heart [5]?

1) Run Simulations:
- Vary lead length and stiffness parameters
- 10 Instances > 39 GB
- Fluid-Structure Interaction (FSI)





2) Explore 4D Relationships:
- Compare multiple spatial locations simultaneously.
- Full variable access across space & time for all instances.

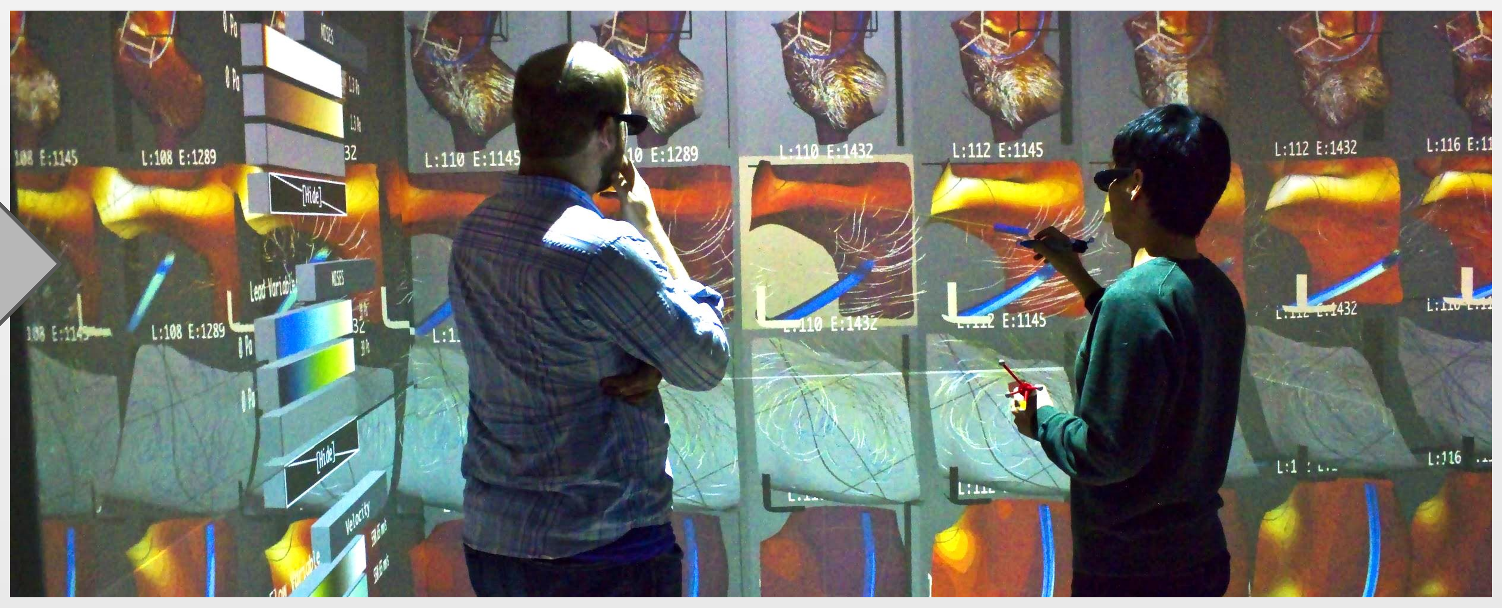
- How can we analyze the **parameter space** [6,7]?
- Visual relationships in **multimodal scenarios** like FSI are rarely explored [2].

- The data is 10 times larger than the GPU memory **(4 GB < 39 GB)**, which requires sophisticated **sampling & rendering** strategies [1].

- **Opportunity for VR** - more than a stereoscopic view [3], and must have **high frame rates**.
- There are only a few tools that **compare multiple large instances in VR** [3,8].

Case Study: FSI comparison in VR for data > GPU memory

Goal: VR Comparative Analysis



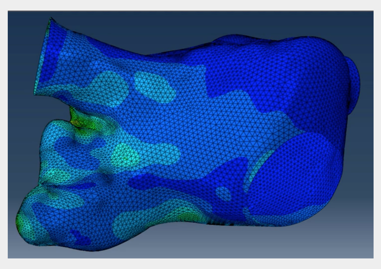
Bento Box: A VR data visualization technique and bimanual 3D interface for exploratory analysis of 4D data ensembles. Comparison is conducted via a grid, with a column per data instance, and a row per view. Views are selected and reframed via 3D gestures, and colormaps can be picked for each view.

Fluid-Structure Interaction Extension to Bento Box

Methods

Solid Domain

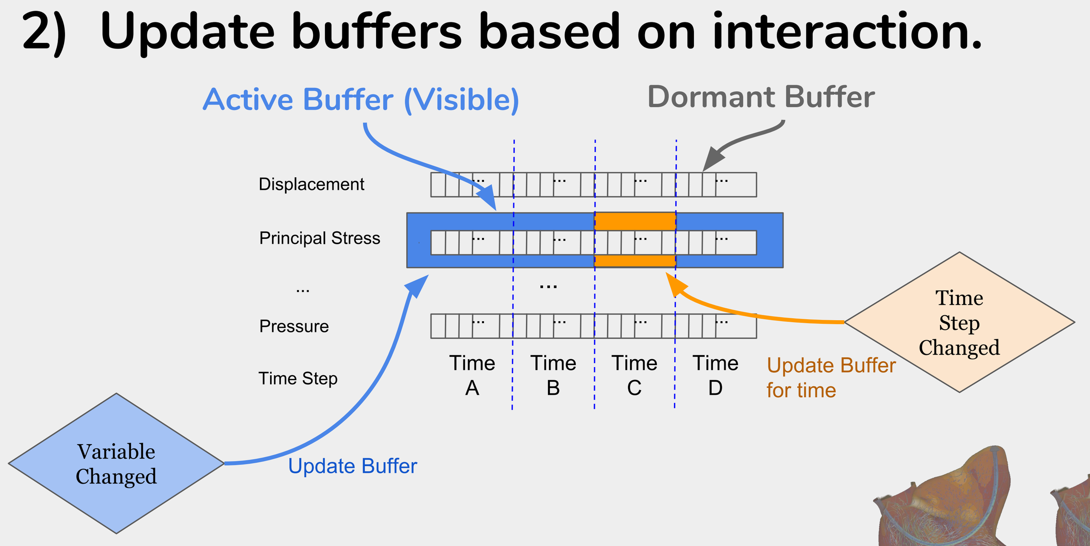
1) Store one triangular mesh with solid-specific variables in GPU buffers.



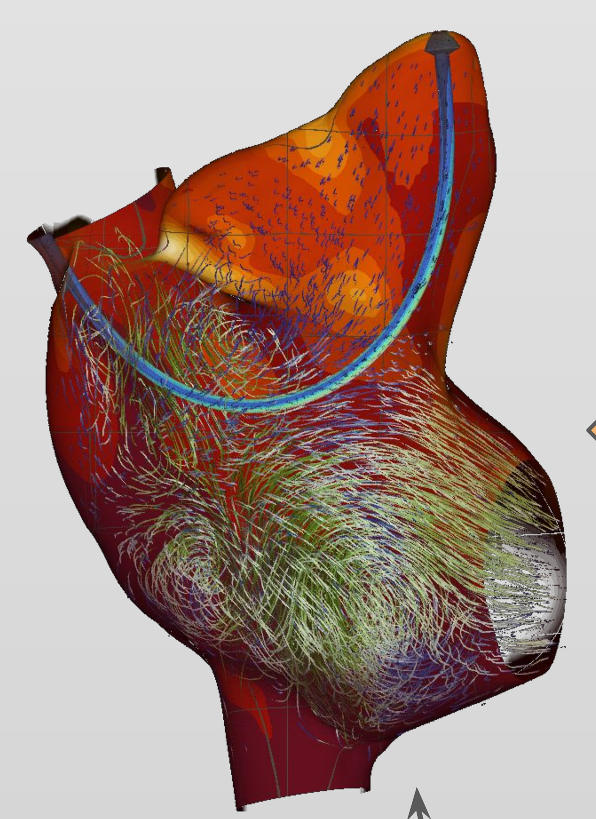
- Displacement
- Principal Stress
- Pressure
- von Mises
- ...
- Stress Tensor

One buffer per variable, where the size is the number of comparable timesteps times the number of vertices. Optimized for static comparison[4].

2) Update buffers based on interaction.



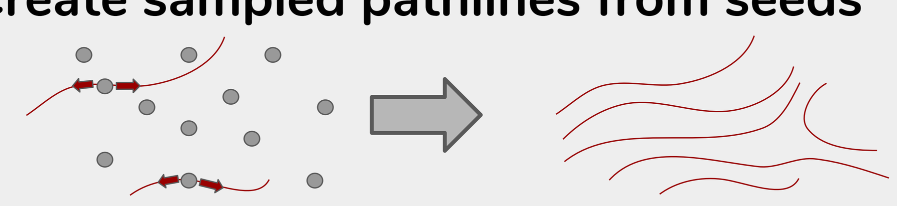
Render Solid



Render Fluid

Fluid Domain

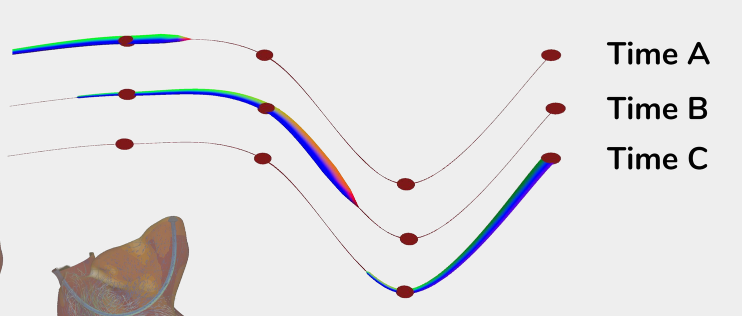
1) Create sampled pathlines from seeds

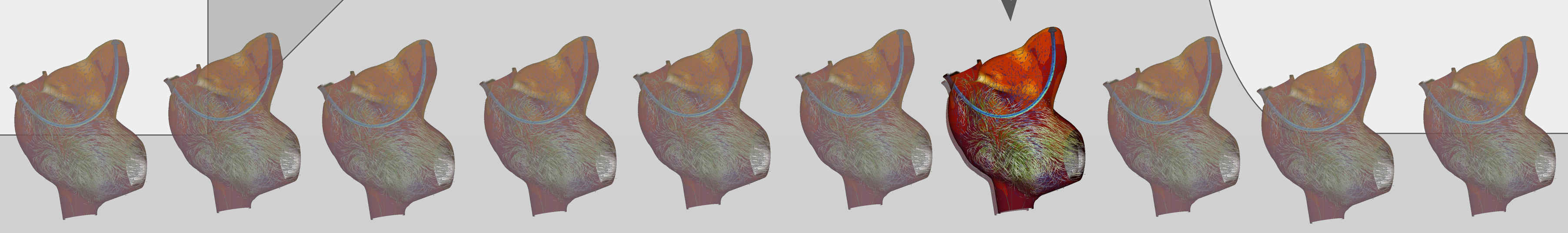


2) Store all pathlines and one particle mesh on the GPU

Path	Positions	Velocities
1	(1,1,1)...(0,0,0)	(1,1,1)...
2	(3,2,1)...(10,1,0)	(2,2,2)...
...	...	...
n	(3,2,1)...(10,1,0)	(5,5,5)...

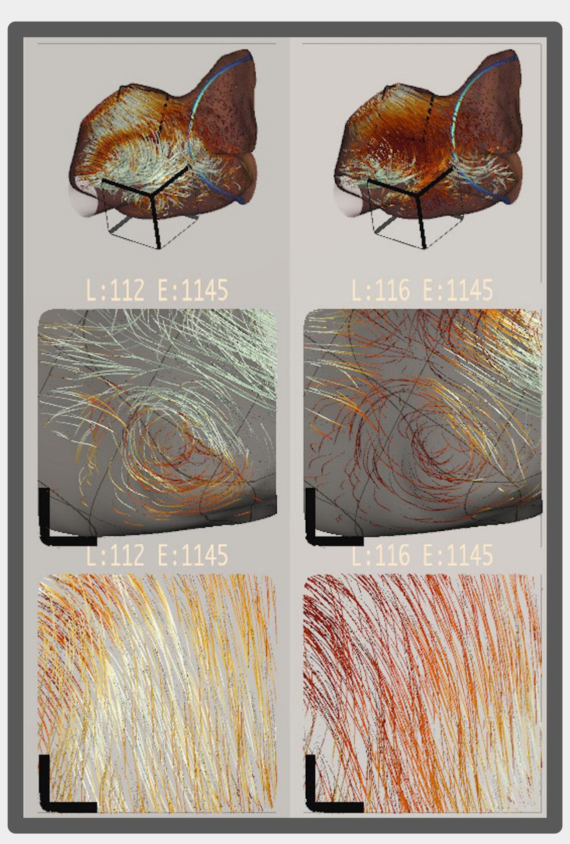
3) Instance render the mesh and morph along path points via a spline





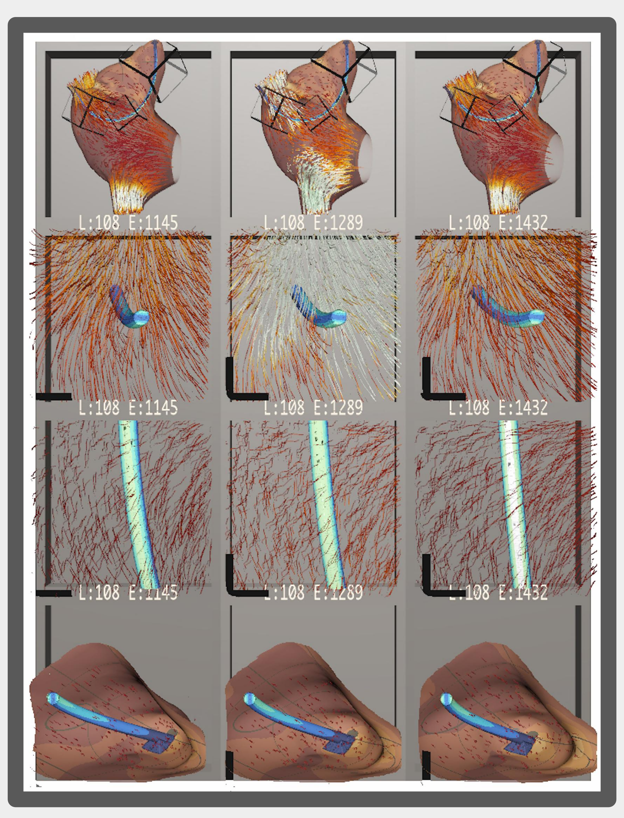
Results

FSI Instance Comparison Using Immersive Virtual Reality Techniques



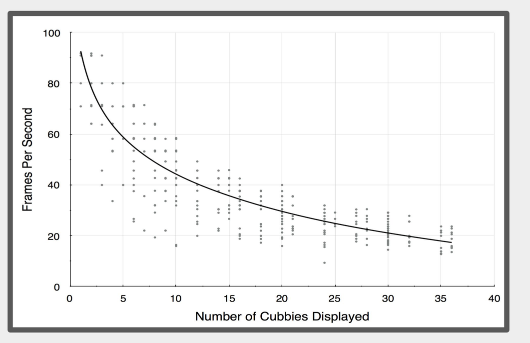
A comparison of the effect of two different lead lengths on the **flow rate** in two regions of the heart. The longer lead length (right) correlates to slower flow on both sides of the heart, indicated by the darker paths.

A comparison of leads of three different **stiffness** at three points along each lead. *(Bento Box shows these views as black boxes in the top row.)* The second row shows a region where the flow rate is greatest near the lead of medium stiffness.



At Interactive Rates

We performed a systematic sampling of Bento Box grid configurations for this 10-instance data ensemble. The trend is above **30 frames-per-second** for Bento Box Configuration of 20 cells or less, and is in the **40-50 frames-per-second** range for smaller arrangements.



Timings were recorded on a 4 core processor Intel(R) CORE(TM) i7-7700HQ CPU @2.80GHz machine with 16 GB of RAM and a NVIDIA GeForce GTX 1070 graphics card. An HTC Vive was used with a 2160 x 1200 resolution.

For Large Data

After processing the **39 GB of raw data**, the amount of memory needed to accurately visualize the solid and fluid domain is over 8 GB, exceeding a 4 GB GPU hardware limit. Our sampling, rendering, and streaming strategies enable a low memory footprint of **1.2 GB on the GPU** at any time.

ID	Raw (MB)	Solid (MB) Processed	Solid (MB) GPU	Fluid (MB) Proc. / GPU	Total (MB) Processed	Total (MB) GPU
108-1145	5,252.6	892.6	7.0	115.2	1,007.8	122.2
108-1289	4,724.4	682.2	7.0	115.2	797.4	122.2
108-1432	4,911.5	682.2	7.0	115.2	797.4	122.2
110-1145	2,933.7	660.9	6.7	115.2	776.2	122.0
110-1289	2,933.7	660.9	6.7	115.2	776.2	122.0
110-1432	2,933.7	660.9	6.7	115.2	776.2	122.0
112-1145	4,926.1	687.5	7.0	115.2	802.7	122.3
112-1289	4,934.6	687.5	7.0	115.2	802.7	122.3
112-1432	4,934.6	687.5	7.0	115.2	802.7	122.3
116-1145	1,588.9	832.4	6.9	115.2	947.6	122.1
	40,073.6	7,134.7	69.1	1,152.3	**8,287.0**	**1,221.4**

There is a 4 GB GPU hardware limit for our 4-wall cave environment, a 2 processor Intel(R) Xeon(R) CPU E5-2640 @2.50GHz machine with two NVIDIA Quadro K5000 cards and 192 GB of RAM

Conclusions

- Our **Bento Box** extension enables comparison of **multiple large FSI simulations** at **interactive rates**.
- The GPU memory required for our approach implies that the number of instances can **scale beyond 10 instances**.
- We hope that this case study can inspire more work in combining **large data visualization techniques with interactive exploration.**

Virtual Poster!
Scan this QR code code with your smartphone to view this poster.

http://ivlab.cs.umn.edu/generated/pub-Orban-2018-Comparison-Poster.php

References

1. Ahrens, et al.. Paraview: An end-user tool for large data visualization. The visualization handbook, 717, 2005.
2. Kehrer and Hauser. Visualization and visual analysis of multifaceted scientific data: A survey. IEEE VIS 2013.
3. Kim, et a.. Comparison techniques utilized in spatial 3d and 4d data visualizations: A survey and future directions. Computers & Graphics, 2017.
4. Robertson, et al. Effectiveness of animation in trend visualization. IEEE Transactions on Visualization and Computer Graphics, 14(6), 2008.
5. Runesha, et al. Fluid–structure interaction simulation of cardiac leads in the heart: Developing a computational model for use in medical device design. Journal of Medical Devices, 10(3):030959, 2016.
6. Schroeder, et al. Trend-centric motion visualization: Designing and applying a new strategy for analyzing scientific motion collections. IEEE transactions on visualization and computer graphics, 20(12):2644–2653, 2014.
7. Sedlmair, et al. Visual parameter space analysis: A conceptual framework. IEEE Transactions on Visualization and Computer Graphics, 20(12):2161–2170, 2014.
8. Vohl, et al. Large-scale comparative visualisation of sets of multidimensional data. PeerJ Computer Science, 2:e88, 2016.

Acknowledgments

This work was supported in part by the NSF(IIS-1251069,IIS-1218058) and NIH(1R01EB018205-01). The authors with to thank the Minnesota Supercomputer Institute for computing resources and support and the University of Minnesota Visible Heart Laboratory for providing feedback and 3D heart surface models.