

Large Scale Data in Virtual Human Atrium Simulations

VizNET Showcase 2007

The Problem

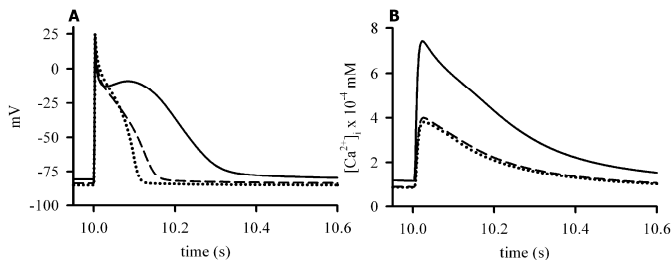
Simulating human atrial malfunction using computational models gives us useful insights into the underlying ionic and intracellular processes and helps in understanding of tissue level electrical behaviour. Analysis of simulation results is usually by computing mathematical measures like ECG, and by accurate visualization of the evolution of membrane potential and other variables (e.g. $[Ca^{2+}]_i$ variable). So far, visualization has been traditionally treated as a post-simulation batch process and is not generally interactive. This is due to High-Performance Computing resources limitations (such as enforced batch processing, or lack of directly-connected display).

A biophysically detailed computer model for human atrial cells was used in the simulations, where a 3D anatomically detailed geometry of human female atria was obtained from the Virtual Human project. Spatial resolution in the 3D anatomical model is $0.33 \text{ mm} \times 0.33 \text{ mm} \times 0.33 \text{ mm}$, producing a dataset of approximately 18 million voxels, each voxel containing two 8-byte double precision floating-point values (voltage and ion strength). With over 1,000 temporal snapshots recorded, this results in over 360GB (0.3TB) to be visualized.

Background: Atrial Fibrillation (AF)

AF is a condition of the upper half of the heart (the atria) when sinus rhythm in the atria is disturbed. This results in the atria being unable to pump blood to the ventricles, leading to hypertrophy and heart failure.

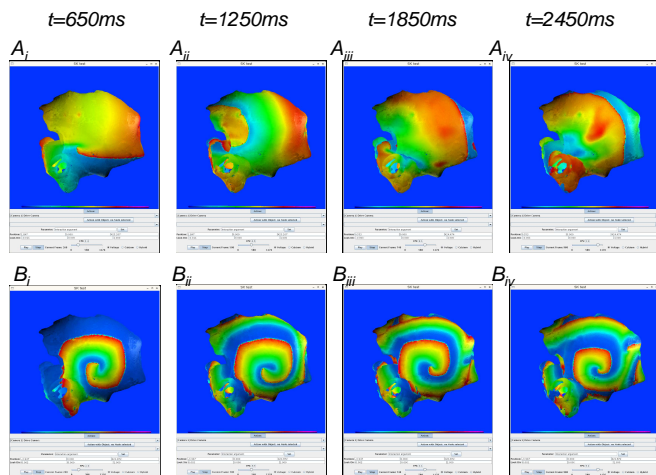
AF, in itself, is not a life-threatening condition. However, it is a precursor to more serious cardiac conditions. Clinically, AF is generally identified by studying the P-waveforms from several ECG leads. An example is shown below, where the changes detected are abbreviation of electrical excitation (action potential duration or APD) and dramatic decrease in



A: Changes in APD. Solid line represents control (normal) data, dashed line represents AF1 data and dotted line AF2 data.

B: $[Ca^{2+}]_i$ transients.

AF is the most common sustained arrhythmia which leads to loss in quality of life and further fatal cardiac complications. AF affects a large section of the aged population and accounts for about 1% of the total National Health Service expenditure in the UK alone, with increasing prevalence. It is characterized by an erratic ECG and re-entrant electrical propagations in the atria. AF induces electrical remodeling (AFER) of membrane ionic channels in atrial cells, and inhomogeneous gap junctional remodeling of atrial tissue.



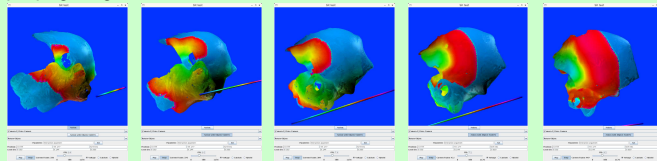
Scroll waves in the 3D model; $A_{i,iv}$ control, $B_{i,iv}$ AF1 dataset

The Solution

The Resource-Aware Visualization Environment (RAVE) was extended to support AF datasets. The datasets were preprocessed, using a combination of shell extraction, indexing, lossy compression and linear interpolation to reduce the size of the datasets to ~190MB. This is then decompressed in real-time to produce a rendered image that appears to the observer as identical to the original 0.3TB dataset. The observer can have full temporal control (akin to a video recorder) whilst being able to freely navigate around the dataset, compared to the original batch-processing approach of rendering a movie from a fixed viewpoint. Several frames are shown above from two AF datasets.

Enablement

The interactive nature of RAVE supports the change of viewpoint for the playback of the results, compared to an off-line rendered movie where the viewpoint can only be changed at creation time. This has enabled the rapid navigation of the dataset and hence speeded up its evaluation. This is especially useful when wishing to follow a scroll wave as it travels around the cardiac geometry, as otherwise a fixed viewpoint movie will hide the wave when it travels around the back of the geometry. This can be seen below, showing several images taken from 87ms to 107ms simulation time. The camera position/orientation has been moved by the modeller to select the best view, revealing the scroll wave entrapment beginning at the superior vena cava (also called the thoracic blood vessel ostium) in the left-hand image. The series of images show the scroll wave propagating around the atrium.



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