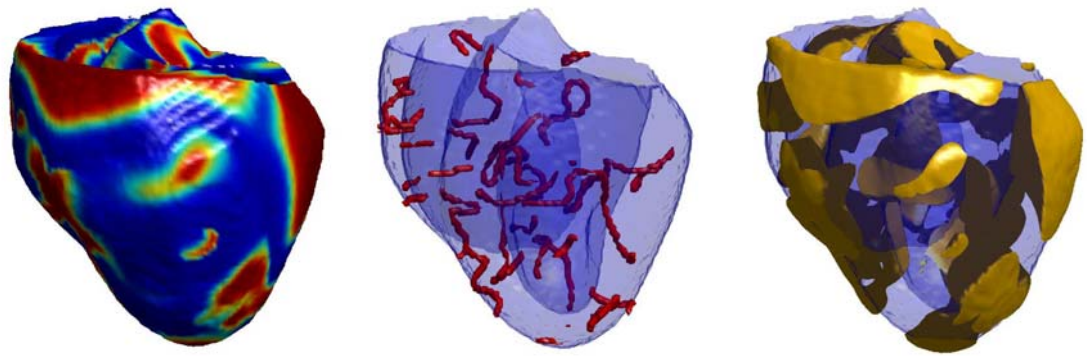
Remote visualization and computational steering of cardiac virtual tissues using gViz



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UNIVERSITY OF LEEDS CENTENARY 1904-2004

Integrative Biology
- exploiting e-science to combat fatal diseases

THE WHITE ROSE GRID
e-Science Centre of Excellence

The University Of Sheffield.

Computational systems biology

From the Wikipedia …

"**Systems biology** is an academic field that seeks to integrate high-throughput biological studies to **understand how biological systems function**."

"**Computational systems biology** is the algorithm and application development arm of systems biology ... with the **goal of modeling dynamic characteristics of a biological system**."

http://en.wikipedia.org/wiki

Computational models of the heart

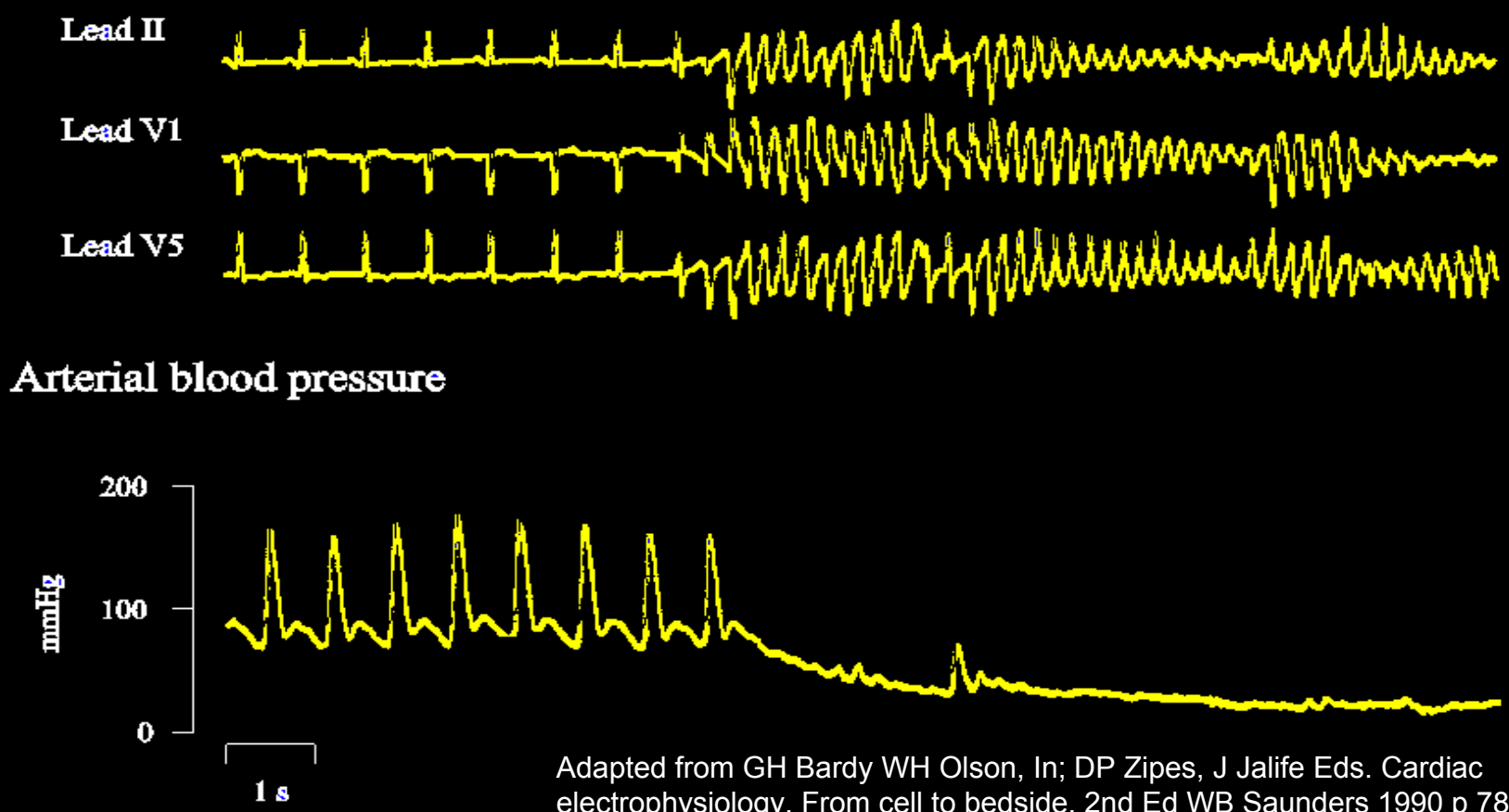
Why model the heart?

- Heart disease is an important health problem.
- Worldwide, cardiovascular disease causes 19 million deaths annually, over 5 million between the ages of 30 and 69 years.
- In the US, cardiovascular disease is the single most common cause of death.
- Spectrum of acquired and congenital heart disease, multiple disease mechanisms.
- All disease mechanisms are difficult to study experimentally.
- Heart is simpler (structurally and functionally) than other organs.

The killer

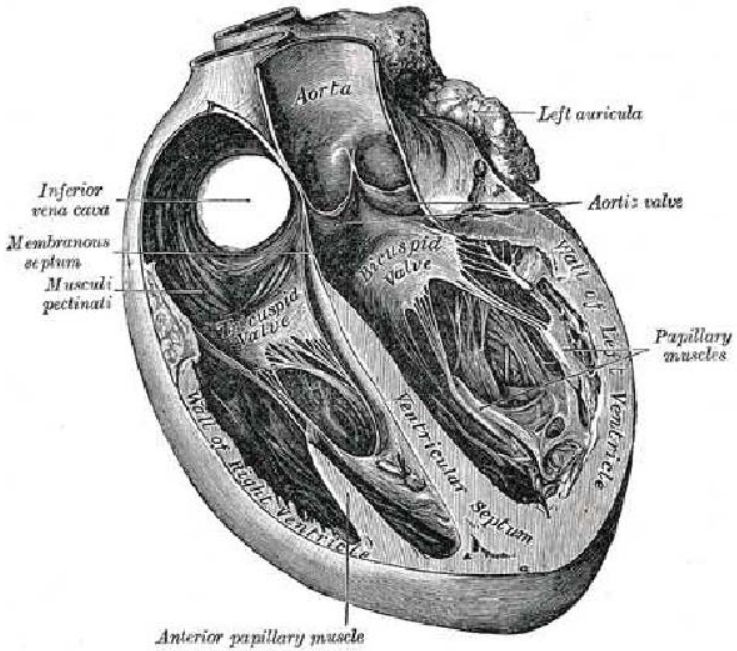
Normal rhythm Ventricular fibrillation

How does it start? How can we stop it?



Adapted from GH Bardy WH Olson, In; DP Zipes, J Jalife Eds. Cardiac electrophysiology. From cell to bedside. 2nd Ed WB Saunders 1990 p 783

Modelling the heart



- The heart is an electromechanical pump; electrical activation of heart cells (the action potential) initiates contraction.
- Activation and recovery.
- Electrical activity propagates rapidly (~0.6 ms^{-1}) within tissue.
- Cardiac arrhythmias are associated with abnormal propagation.
- Electrical properties of cells are well characterised experimentally.

Model cardiac tissue as a continuous excitable medium.

$$\frac{\partial V_m}{\partial t} = \nabla \cdot (\tilde{D} \nabla V_m) - \frac{I_{ion}}{C_m}$$

Numerical approach

Model cardiac tissue as a continuous excitable medium.

$$\frac{\partial V_m}{\partial t} = \nabla \cdot (\tilde{D} \nabla V_m) - \frac{I_{ion}}{C_m}$$

Solve using finite difference grid. At each timestep

- Compute dV due to diffusion.
- Compute dV due to dynamic response of cell membrane
- Update membrane voltage at each grid point

Each stage can be parallelised with reasonable efficiency for SMP using OpenMP directives.

Scaling on HPCx

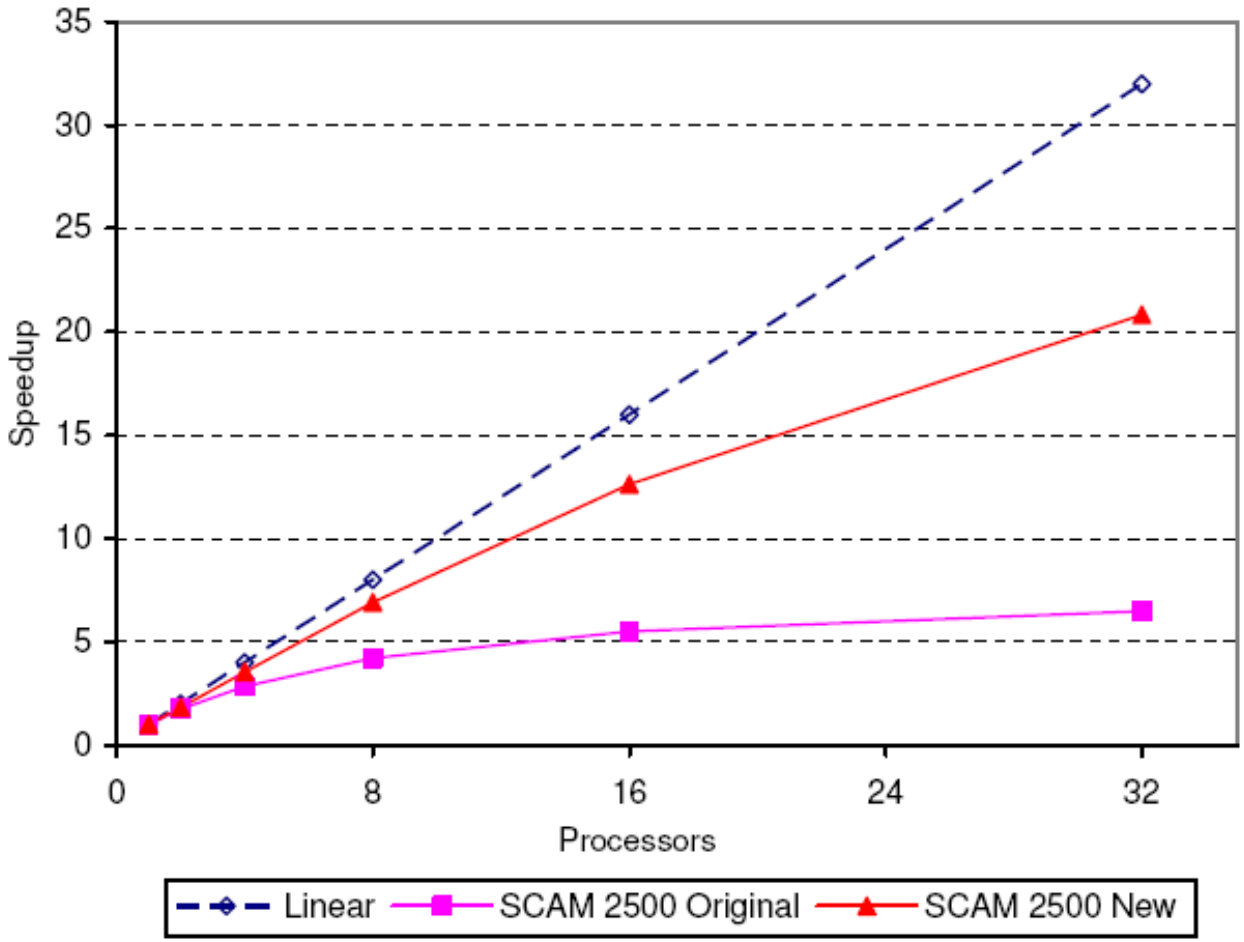
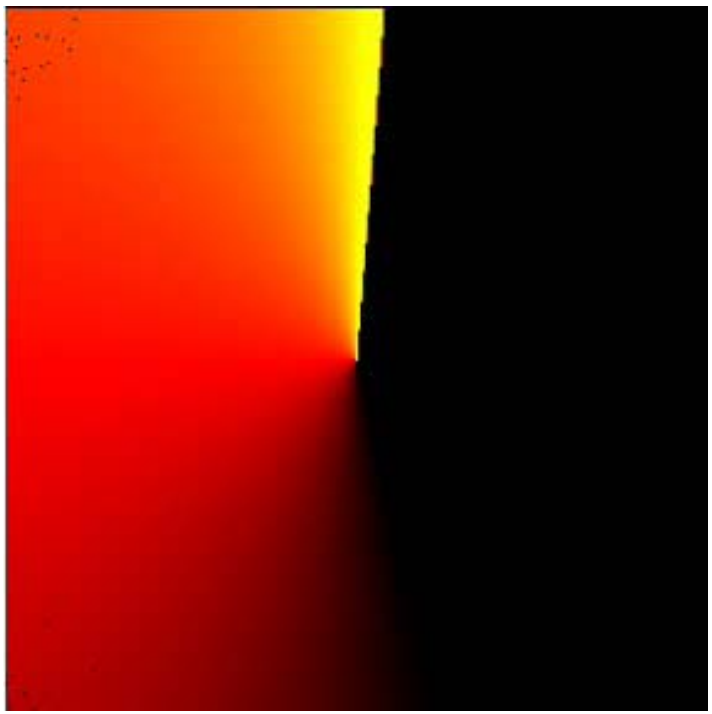


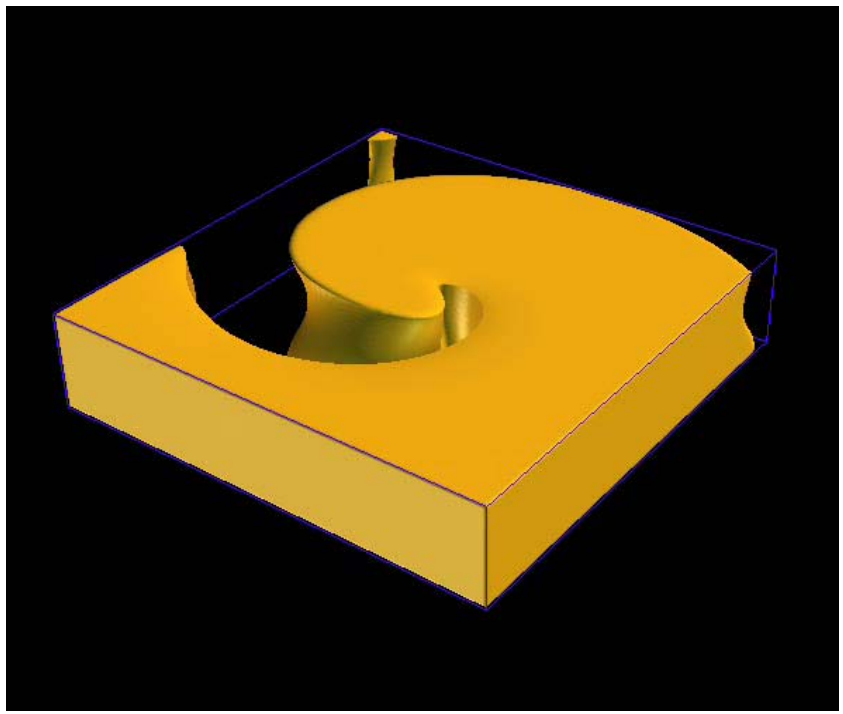
Figure 4-1: SCAM optimised Parallel Speedup

Thanks to Michael Holden at epcc

Re-entry

Excitable media support rotating waves that form a spiral in 2D and a scroll wave in 3D





Visualising simulations

- **Post processing** - store output, and visualise later.
  - Conventional route
  - Can be done at leisure
  - Used to produce movies already shown
- **Tracking** - visualise model as the simulation runs.
  - Remote visualisation of simulations running on HPC resources
  - Eliminate worthless simulations
  - gViz library developed for this purpose
- **Steer** - visualise model, and use this information to interact with the simulation.
  - Extension to gViz
  - Human in the loop

gViz Computational Steering

Threaded library compiled into clients and simulations using simple ‘hooks’,e.g.:

Simulation

```
init(…)
registerStartupToService(…)
setParamDbl(…)
getParamDbl(…)
updateData(…)
```

Client

```
connectChild(…)
startDataCommsSync(…)
startViewParamsSync(…)
```

Control and termination of re-entry

- Defibrillation - global “reboot”.
  - Used in clinical practice
  - Defibrillators can be implanted
  - Requires high energy - ~10 J for internal defib, ~100 J for external.
- Low energy approaches
  - Apply point stimuli to “push” re-entrant waves beyond boundaries.
  - Computational model provides ideal environment to test ideas.
  - Computational steering.

Demonstration

- 2D spiral wave, aim to control by applying point stimuli.
- Adds value of stimulus to membrane voltage in designated area.
- Stimulus may be positive or negative (excitation or inhibition).
- No attempt (at this stage) to model details of current injection into tissue.
- Simulation running on machine in Leeds, visualised and controlled from the podium.

Conclusions

- This approach is easy to implement and enables rapid exploration of parameter space
- More efficient use of computational resources, especially for more complex models
- Potential for application to patient specific models