Neurosurgery with Lightpaths

Patient-specific whole cerebral blood flow simulation - A future role in surgical treatment for neurovascular pathologies

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Overview

• Why lightpaths?
• What is patient-specific medical simulation?
• Clinical computing
• The project: Treating neurovascular pathologies
• Achieving real-time simulation with lightpaths in the operating theatre
• Making patient-specific medical computing a reality

What are we trying to achieve with these lightpaths?

• Setup a dedicated Gb network which spans the UK and US to be used as a problem solving environment for neurovascular surgery
• What are we actually using it for?
  – Shifting datasets from the NHNN to UK/US - 0.5GB - 4GB in size
  – Real time visualisation, 1000 pixels @ 30 FPS
  – Real time computational steering
  – Cross-site MPI runs (e.g. between NGS2 Manchester and NGS2 Oxford)
• Why?
  – Clinical computing, importance is in the timeliness
  – Use various facets of computing to achieve timeliness:
    • Grid middleware - application hosting environment
    • Advance reservations and urgent computing
    • Cross-site runs and distributed computing
    • Lightpaths
    • Real time in situ visualisation and computational steering

Patient-specific medicine

• 'Personalised medicine' - use the patient’s genetic profile to better manage disease or a predisposition towards a disease
• Tailoring of medical treatments based on the characteristics of an individual patient

Why use patient-specific approaches?

• Treatments can be assessed for their effectiveness with respect to the patient before being administered, saving the potential expense of ineffective treatments while also increasing their efficacy

Patient-specific medical-simulation

• Use of genotypic and or phenotypic simulation to customise treatments for each particular patient, where computational simulation can be used to predict the outcome of courses of treatment and/or surgery

What is grid computing?

“Distributed computing performed transparently across multiple administrative domains”

Any production grid should be:
• Stable
• Persistent
• Usable

It must provide easy access to many different types of resources from which to pick and choose those required.

It is debatable whether many grids in operation today fit this definition but we're getting there

What is clinical (grid) computing?

• Computational experiments integrated seamlessly into current clinical practice
• Clinical decisions influenced by patient specific computations: turnaround time for data acquisition, simulation, post-processing, visualisation, final results and reporting.
• Fitting the computational time scale to the clinical time scale:
  – Capture the clinical workflow
  – Get results which will influence clinical decisions: 1 day? 1 week?
  – This project - 15 to 30 minutes
• Development of procedures and software in consultation with clinicians
• On-demand availability of storage, networking and computational resources
Grid Enabled Neurosurgical Imaging Using Simulation

The GENIUS project aims to model large scale patient specific cerebral blood flow in clinically relevant time frames.

Objectives:
- To study cerebral blood flow using patient-specific image-based models.
- To provide insights into the cerebral blood flow & anomalies.
- To develop tools and policies by means of which users can better exploit the ability to reserve and co-reserve HPC resources.
- To develop interfaces which permit users to easily deploy and monitor simulations across multiple computational resources.
- To visualize and steer the results of distributed simulations in real time.

Yield patient-specific information which helps plan embolisation of arterio-venous malformations, aneurysms, etc.

Arterio-venous malformations (AVM)

- Working with neuroradiologists at the NHNN to provide this type of simulation support from within the operating theatre, making part of the clinical workflow in the treatment of AVMs.
- Surgeons would like to predict what might happen in terms of pressure changes, stresses etc. in the vasculature if they take a particular course of treatment.
- Need access to resources from within the operating theatre which can run the simulations.
- Lightpaths - dedicated national and international links to high-performance grid resources, all links are 1 Gb/s.

Modelling vascular blood flow - HemeLB

Efficient fluid solver for modelling brain bloodflow called HemeLB:
- Uses the lattice-Boltzmann method.
- Efficient fluid solver for sparse geometries, like a vascular tree.
- Machine-topology aware graph growing partitioning technique, to help minimise the issue of cross-site latencies.
- Optimized inter- and intra-machine communications.
- Full checkpoint capabilities.

Modelling and visualisation

- Convert DICOM slice data to 3D model, MRI or CT scan where the vasculature is of high contrast, 200 - 200 μm resolution, 1000^3 voxels.
- Each voxel is a solid (vascular wall), fluid, fluid next to a wall, a fluid inlet or a fluid outlet.
- Our current simulation has 3 inlets and ~50 outlets.
- We apply an oscillating pressure at the inlet and an oscillating or constant one at the outlets.
- Real-time in-situ visualisation of the data using streamlines, iso-surfacing or volume rendering.

Modelling and visualisation

- A ray tracer has been incorporated into HemeLB core to efficiently monitor simulation results in real time.
- Sub-frames are rendered on each MPI processor/rank and composited before being sent over the network to a (lightweight) viewing client.
- Data transmission and pre/post processing are avoided.
- Only updated image is sent to the client.
Cross-site runs

MPIg is the next version of MPICH-G2

• Some problems won’t fit on a single machine, and require the RAM/processors of multiple machines on the grid.
• MPIg allows for jobs to be turned around faster by using small numbers of processors on several machines - essential for clinician
• MPIg uses a true threaded model for overlapping communication and computation, so with appropriate programming, latencies between sites can be effectively hidden.

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The clinical work flow (clinical view)

Clinician’s view of how things should work in the software environment

Clinician’s shouldn’t have to be concerned with where the job is running... or how.

All the details such as advance reservations, file transfers, job launching, machine availability, etc. are hidden.

The clinical work flow (detailed view)

1. A dataset derived from a patient’s scan is anonymised locally in the hospital and uploaded from the medical imaging workstation to a DICOM server which is dual-homed on both the UCL production and lightpath network. To adhere to NHNN network security policies, the two networks are physically separate in order to prevent direct traffic between them.
2. The client software connects to the DICOM server, giving the clinician the ability to browse and download a patient’s dataset.
3. The data is segmented into the 3D neurovasculature, boundary conditions are applied here by a clinician or workstation operator.
4. This data is staged to remote computational resource using the AHE. The job can be executed within a pre-reserved slot which was booked using HARC or GUR, as a cross-site or single-site run.
5. As the job commences running, the client connects to the back end node which is used for steering and visualization purposes.

Hurdles

• Dropping a lightpath connection right into the middle of the NHS network at the National Hospital
  – Completely separate to the NHS network
  – We have to use two separate networks, even though both machines are in the same room
• Private link shares UCL and NHS network resources
  – Dedicated links pass through multiple administrative domains
• There has to be a joining point, in this case a dual-homed machine which sits on both the UCL production network and the lightpath network
• Sending personal medical data over the grid
  – Development of data anonymisation protocols with the NHNN
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Concluding remarks

- Clinical relevance of patient specific medicine
  - Both correctness and timeliness are important, fitting into current clinical practice
  - Batch-job submission won’t work here - real-time interactive simulation and real-time visualisation
- Current emergency computing scenarios are far and few between (hurricane, earthquake simulations)
  - Successful patient-specific simulation techniques will likely have 1000’s of cases. The level of compute time required will dwarf current resources.
- Economics of computational treatments
  - Using current available HPC resources, it would be impossible to conduct this day to day. Policies, who gets access? Do hospitals have in-house systems? Do supercomputers become public infrastructure? Much like utilities such as electricity?
- For widespread use, there are many moral, ethical and policy questions which need to be addressed
  - Resource availability
  - Data privacy, moving medical data around the grid, data anonymisation, data security, moving data to and from (often secure) hospital networks

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