Computer Visualisation of Medical Data - Improving Healthcare Provision for You

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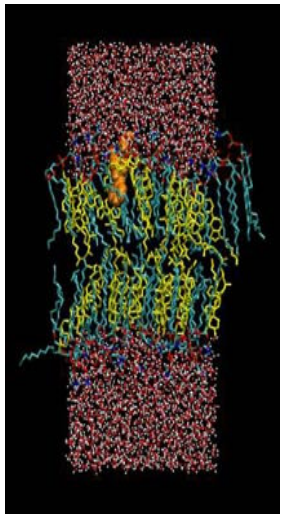
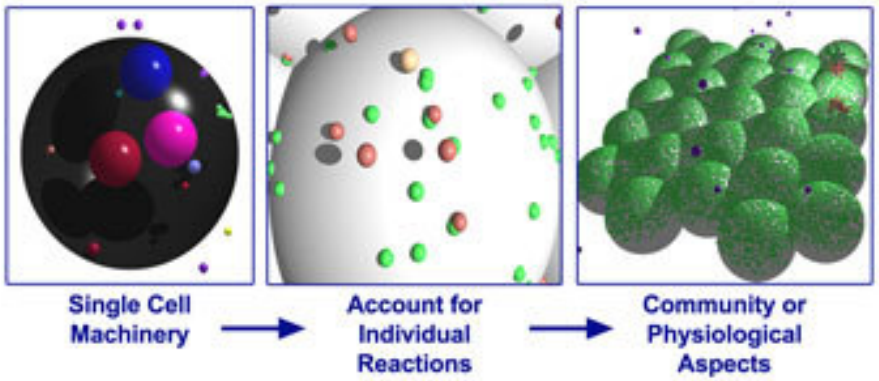
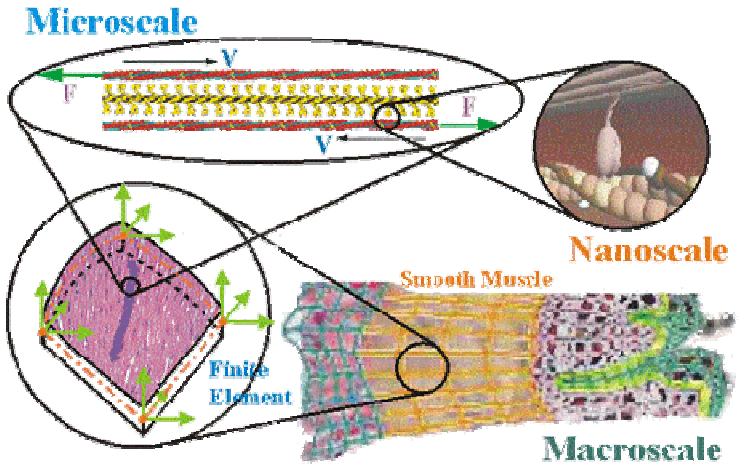
The Physiome

- the physiome is the quantitative and integrated description of the functional behaviour of the physiological state of an individual or species
  - *the physiome describes the physiological dynamics of the normal intact organism*
  - *the term comes from "physio-" (life) and "-ome" (as a whole)*
  - *broadly, it should define relationships:*
    - from genome to organism and
    - from functional behaviour to gene regulation
- it includes:
  - *integrated models of components of organisms, such as particular organs or cell systems, biochemical, or endocrine systems*

Life is Multiscale







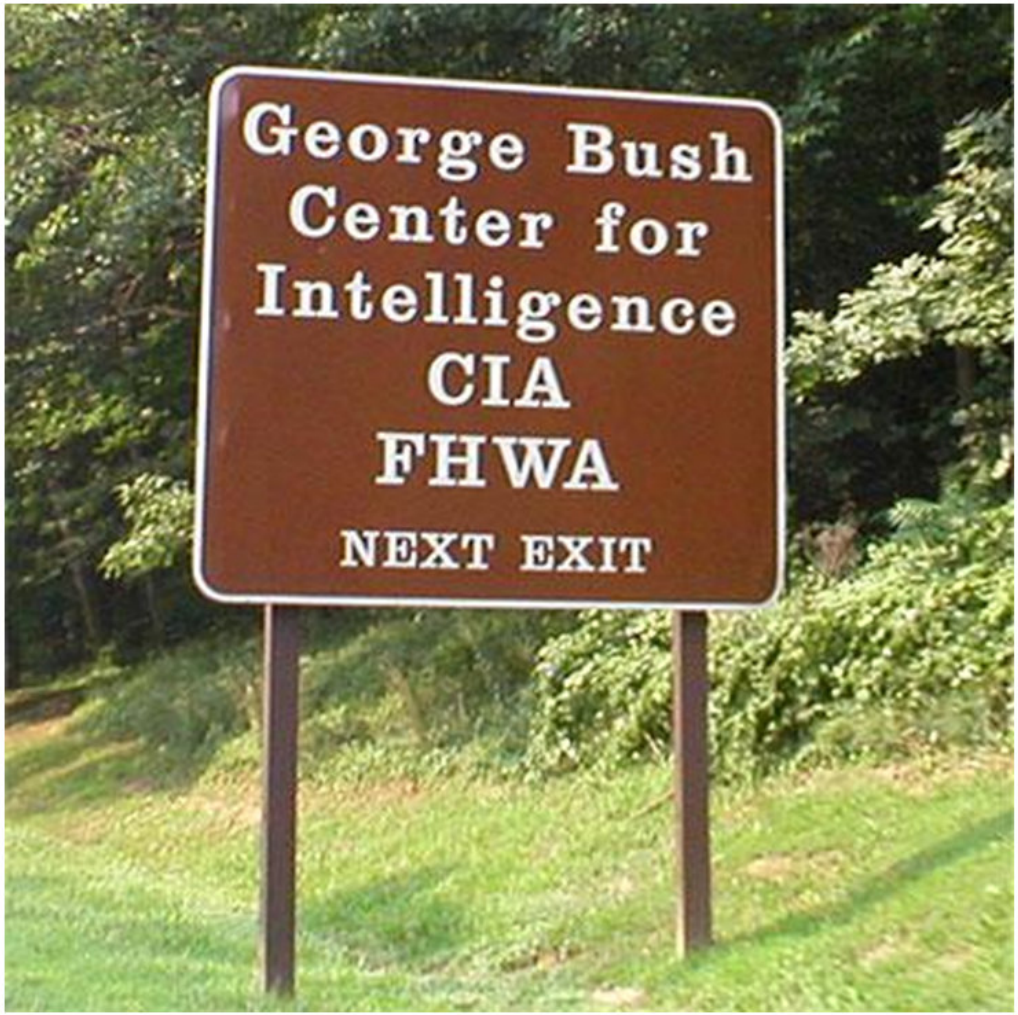
Modelling the Human Physiome

- the human physiome is extremely complex
- activities in the body are taking place at different spatial scales
  - *from the body to the organ to the cell and beyond …*
- and at different temporal scales:
  - *from a lifetime down to nanoseconds*

Simplification

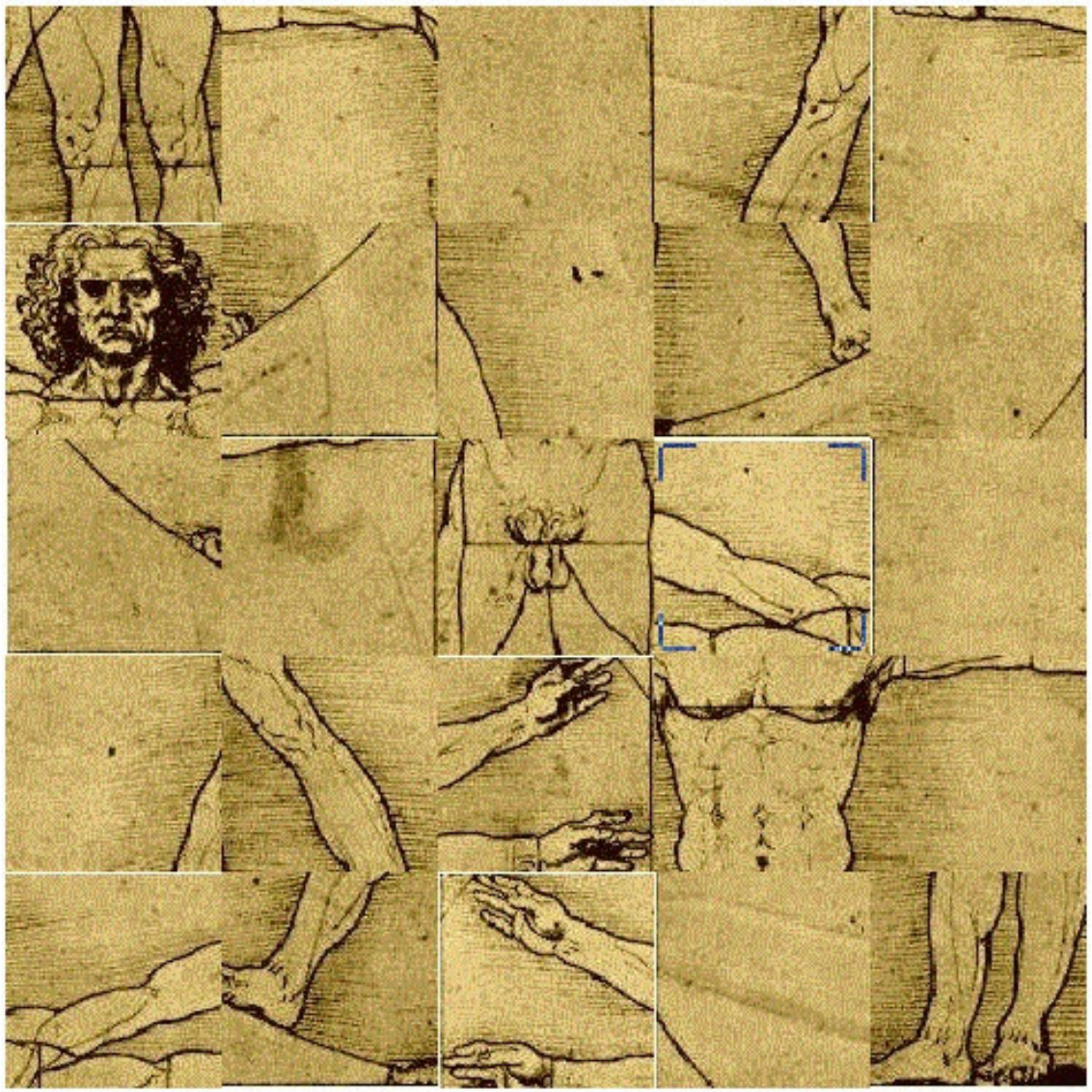
- we can try using a simplified human model

- and it may produce some successes …..



- **however, …..**

The Human Puzzle



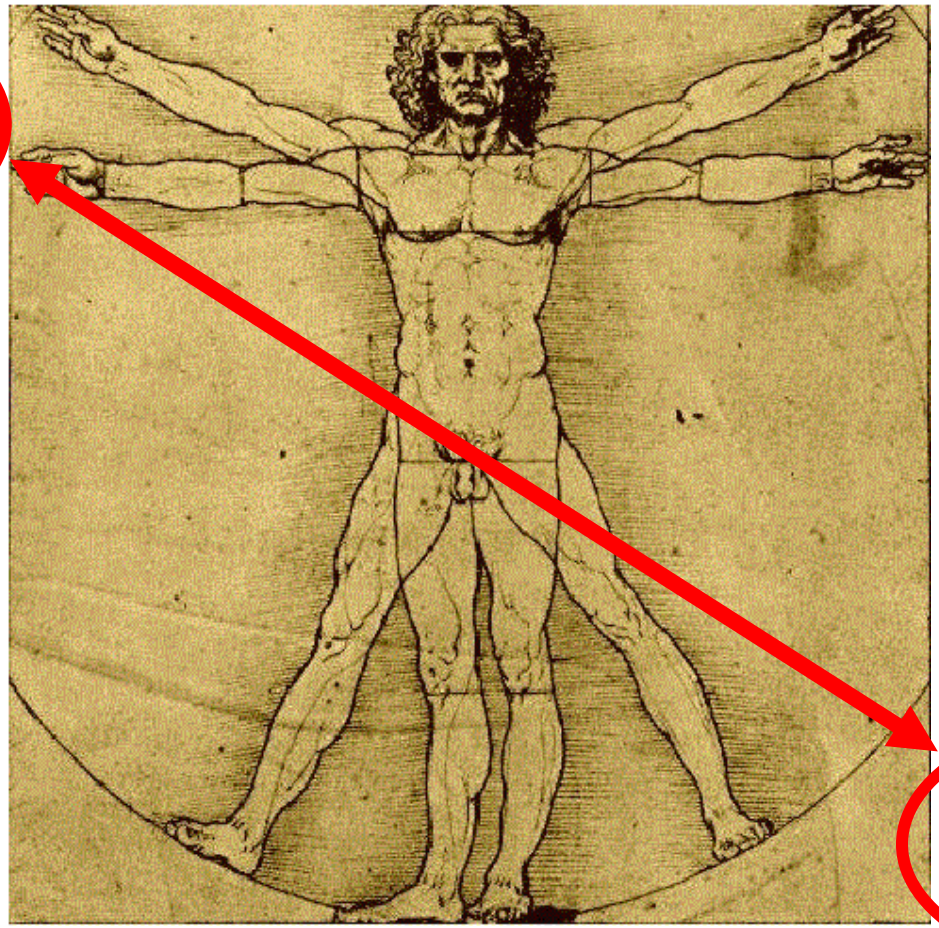
The Human Puzzle

- currently the human body is investigated as if it is a jigsaw puzzle made of a trillion pieces
- we are trying to understand the whole picture by looking at a single piece, or at a few closely interconnected pieces

- we need a framework within which we can start to put the pieces together and the glue to join them
- the framework is not the whole picture, but it is the only way we might, one day, hope to see it

Paradigmatic Shift in Biomedical Research

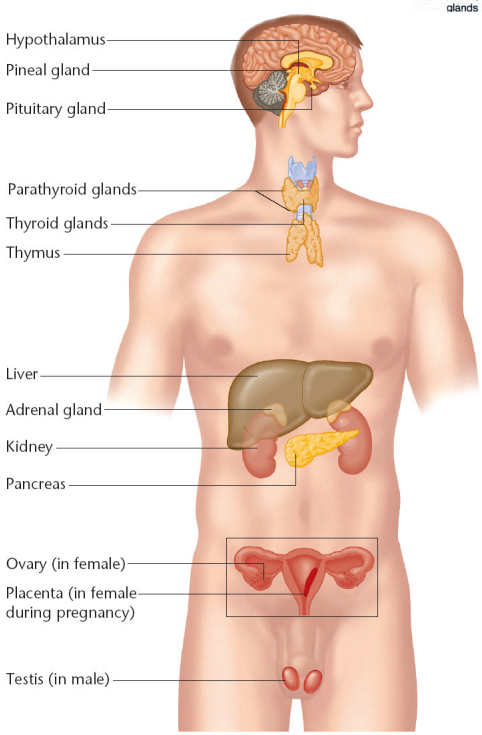
Complement Reductionism

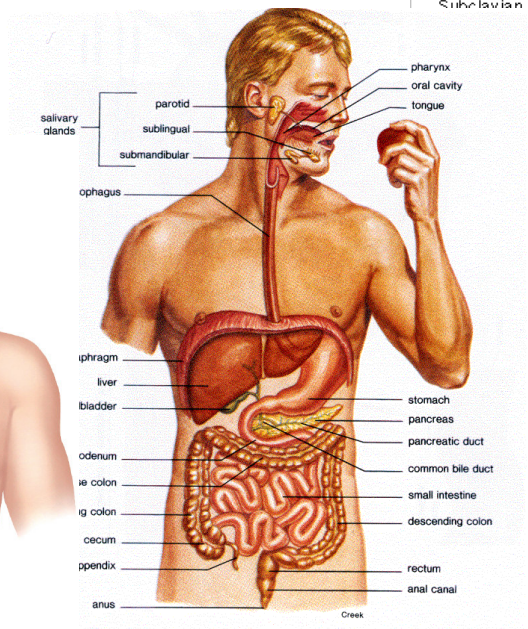


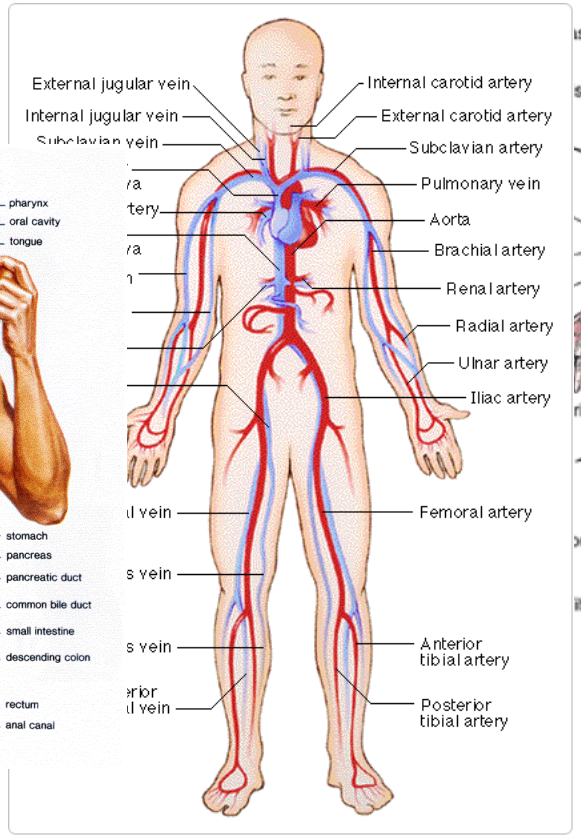
with Integrationism

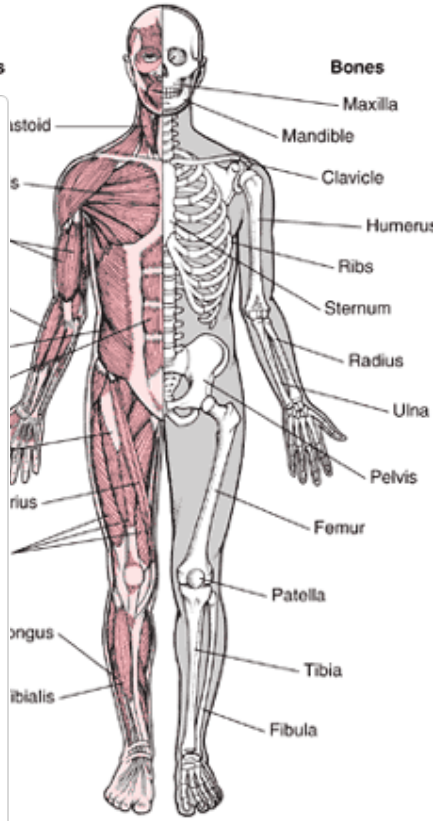
Integration across ….

sub-systems

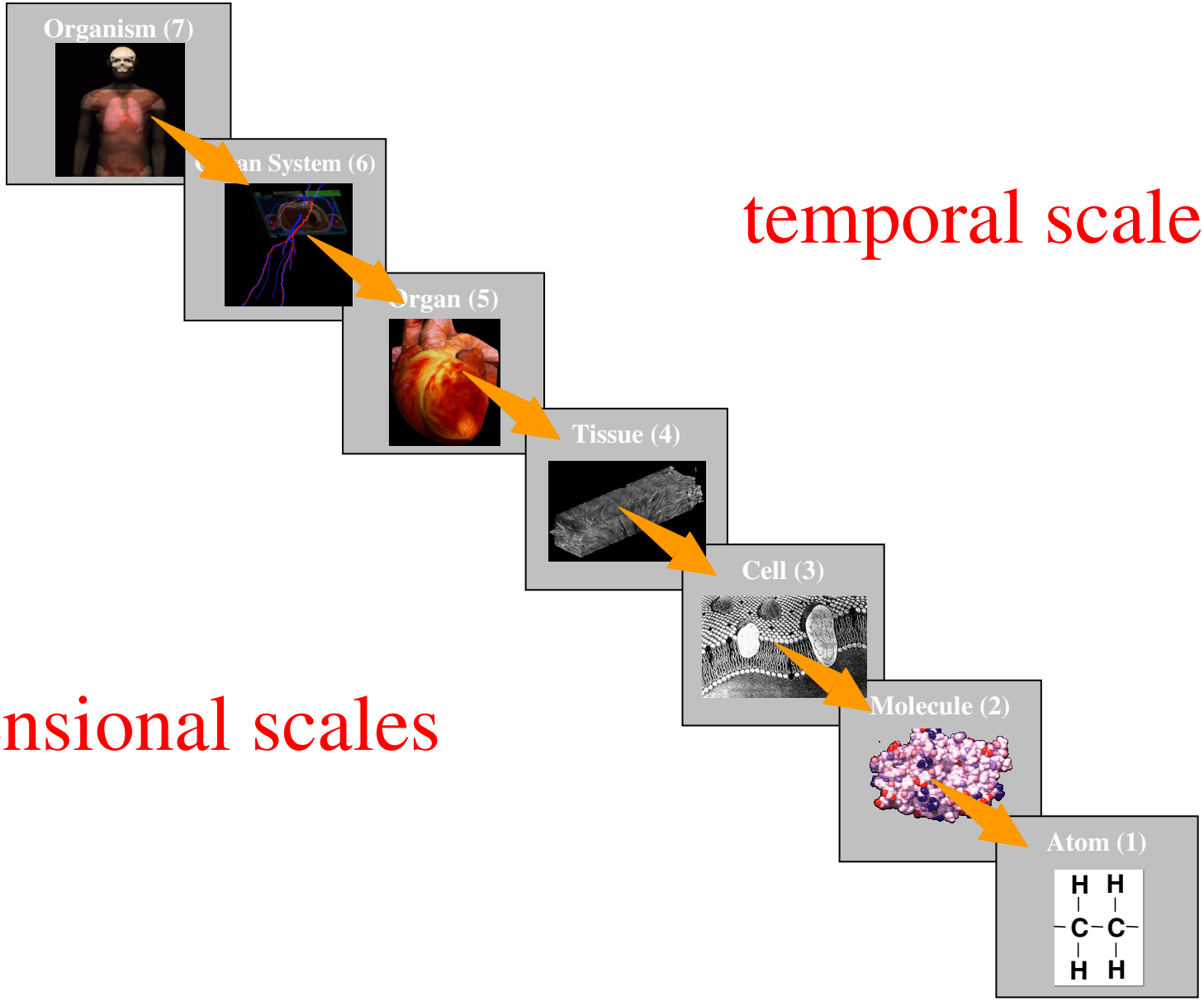








Integration across ....

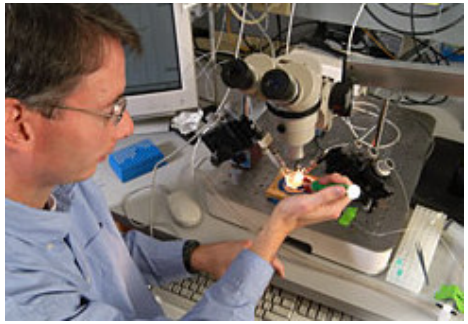


temporal scales

dimensional scales

Integration across ….

disciplines



Medicine

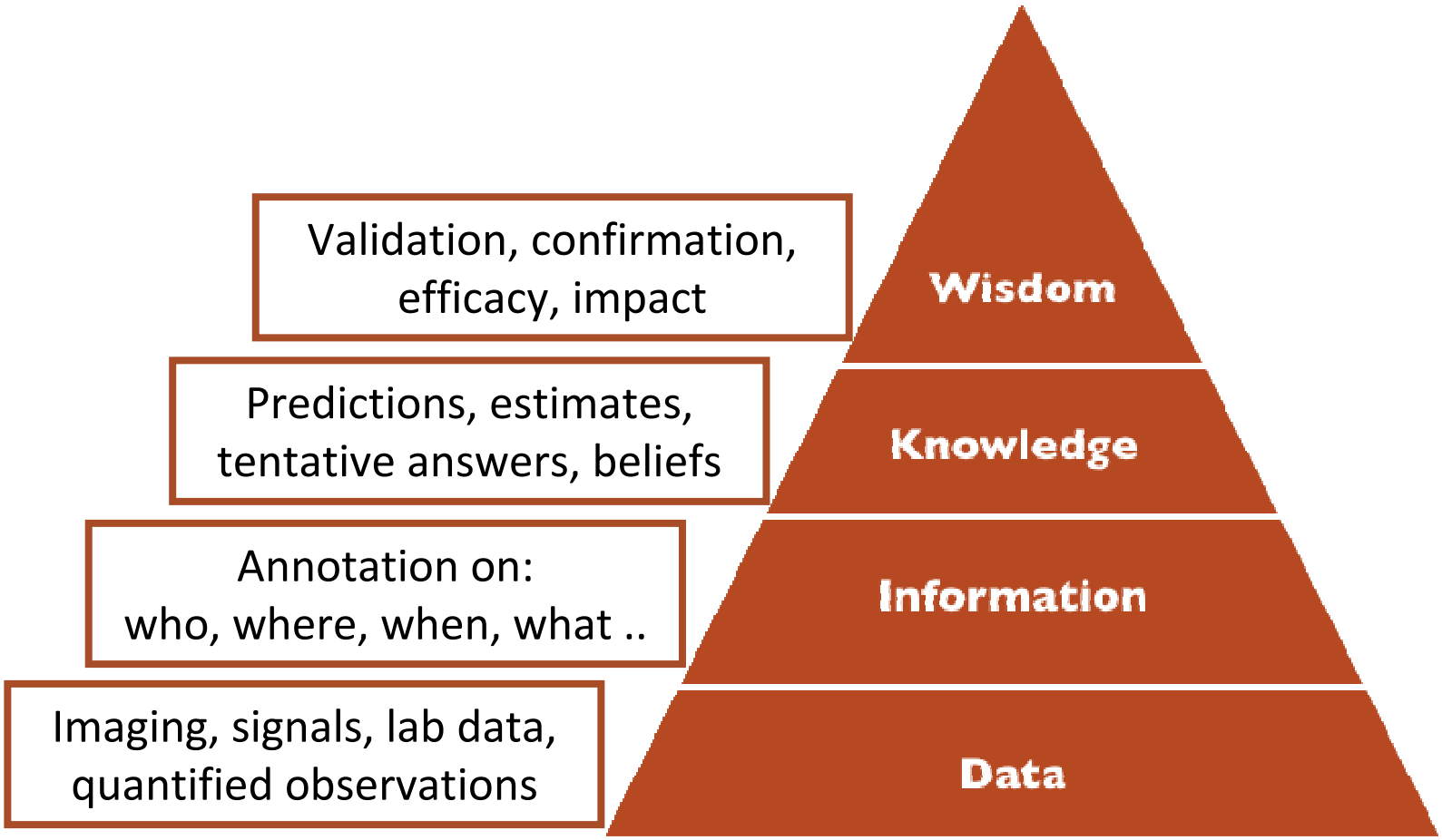
Biology

BioEngineering

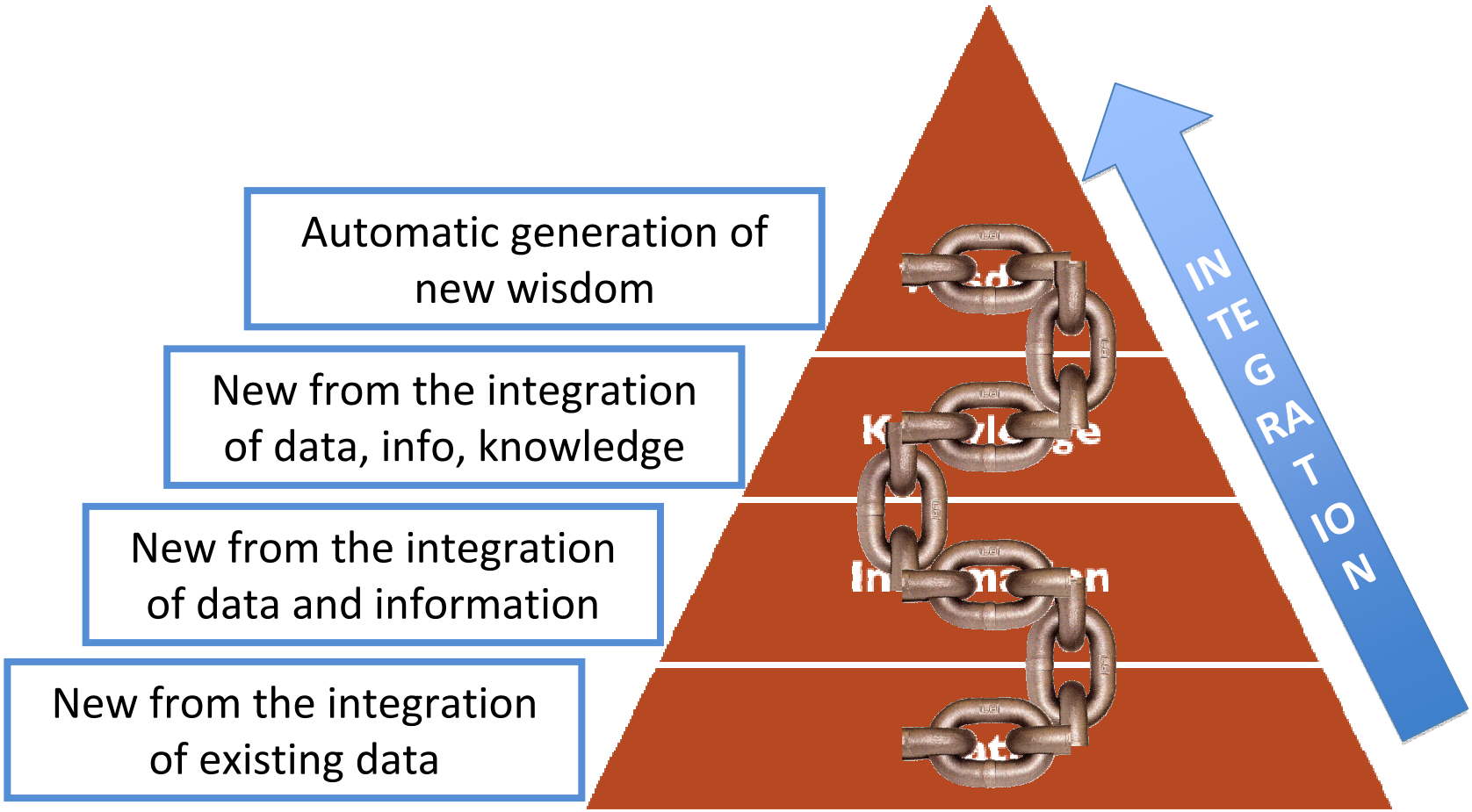
Virtual Physiological Human (VPH)

- Integrative Research requires a radical transformation in the way biomedical research is conducted
- it is necessary to create a framework made of technology and methods
  - *we call this framework the Virtual Physiological Human*
- VPH is a methodological and technological framework that, once established, will support the investigation of the human body as a single complex system
- this framework should be:
  - *descriptive*
  - *integrative*
  - *predictive*
- the last point is critical for clinical application

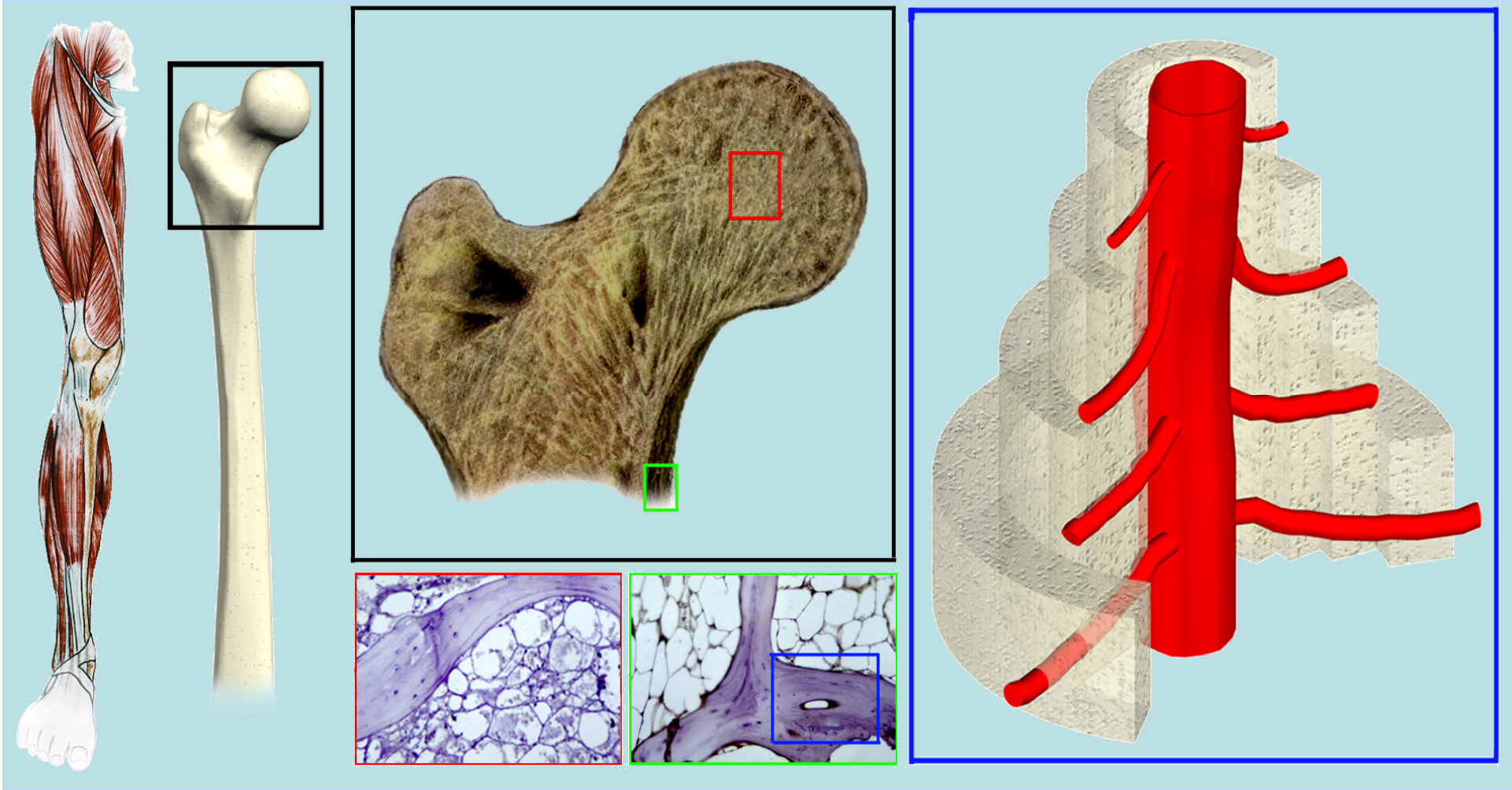
DIKW Pyramid



VPH Infostructure



The Physiome Concept - Musculoskeletal



Implications

Data Explosion

- the resolution of data capture devices is increasing rapidly
  - *data sets are becoming larger*
- multiscale problems require the use of multiple data sets
  - *overall data demands escalating*
  - *data compatibility across scales is important*
  - *registration issues*
- data often captured at different sites
  - *compatibility of computational resources for processing the data*
- boundary conditions for simulations across multiple scales must be compatible

Computers and Infrastructure

- distributed resources:
  - *data, software, computers*
- this implies an architecture to support user access:
  - *allocation of computer time on HPC resources*
    - access may require planning in advance & bureaucratic complexity
  - *suitable search capability (semantic search)*
    - the more data that is available, the more difficult it ecomes to find what you want
    - quality evaluation and control
  - *appropriate previews*
    - to ensure that you ARE getting what you expected
  - *inter-operable and flexibly combined software*
    - combine "atomic" functions into a well-define workflow
- different scales may require different degrees of computational power
  - *molecular simulations may take several days even using HPC*
- problems with security, firewalls, etc

Impact on Healthcare

Patient-Specific Medicine

- availability of multiscale data
  - *this must be combined to aid the clinician to interpret it*
- acquiring data:
  - *some data can be collected only by highly invasive techniques*
  - *data from cadaver studies can be scaled to the patient using generic atlases*
- genetic data may be relevant in some conditions
- population data can supplement data collected from the individual patient
- use of simulations to try out "what if" scenarios
  - *particularly useful for therapy using combinations of treatment (e.g. multiple drugs)*
- clinical trials are critical for rapid deployment
  - *recent legislation designed to help is actually making these more difficult and more expensive*

CCGV activities in VPH

CCGV – 5 Main Areas of Focus

- mainstream graphics, visualisation, modelling, systems
  - *Gordon Clapworthy*
- GPU and GPGPU
  - *Dr. Baoquan Liu*
- web services
  - *Dr. Enjie Liu*
- image-based approaches
  - *Prof. Feng Dong*
- computer games
  - *Prof. Edmond Prakash*
- VPH spans most of these

CCGV – Current EC Projects

- **VPHOP & VPHOP-EEU** (osteoporosis)
- **VPH2** (heart failure)
- **ContraCancrum** (brain & lung cancer)
- **RT3S** (stent placement)
- **NMS Physiome** (neuromusculoskeletal)
- **MSV** (multiscale visualisation)
- **GAMVolVis** (use of GPUs)
- **VPH-FET** (developing "blue skies" research for VPH)
  - *similar to the previous successful STEP project*

General Description of Work

- supply tools to suit the requirements of the project
  - *work closely with users*
  - *tools may involve visualisation, modelling, image analysis, etc.*
- supply web services to support access to distributed resources and to simplify orchestration within workflows
- re-engineer existing software to take advantage of GPU technology
- use games technology to increase speed where appropriate to the problem

Medical Visualisation

- data normally comes from medical imaging
  - *CT, MRI, PET, etc*
  - *CT is good for bone, MRI helps to distinguish better between different forms of soft tissue*
- data is provided in 2D slices that can be stacked to make a 3D volume
  - *like a set of playing cards*
- the readings can be interpreted as grey values
  - *each tissue type has a characteristic grey value*
- two forms of visualisation
  - *surface visualisation:*
    - the surface of an object lies at the boundary between two grey values – this is called an **isosurface**
  - *volume visualisation:*
    - a **transfer function** makes a correspondence between the grey value and visual properties of the corresponding tissue (colour, transparency, surface characteristics, etc.) for display of the whole volume

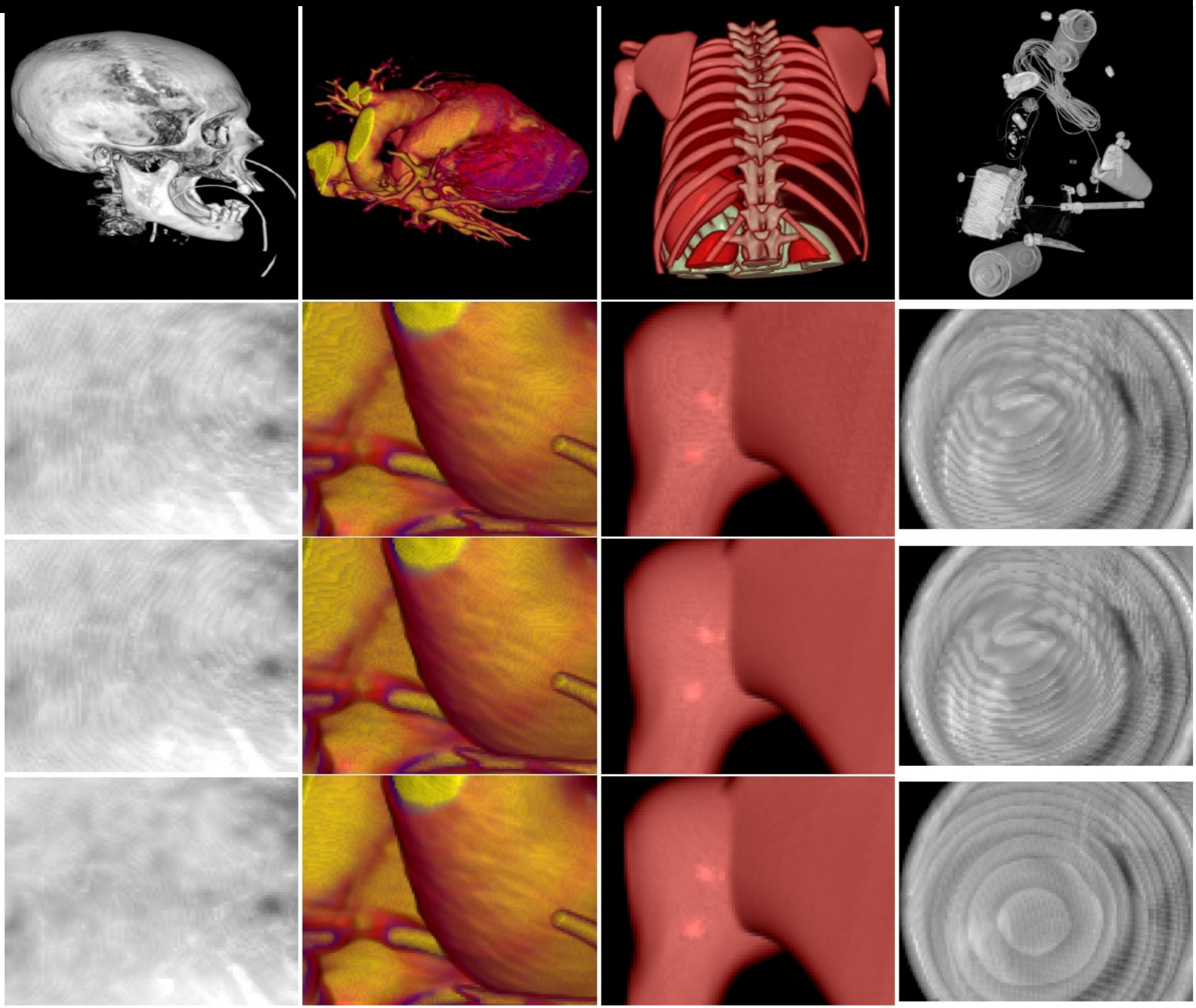
Characteristics of Medical Visualisation

- visualisation is computationally demanding
  - *often methods use shortcuts such as precomputation to reduce demands in interactive applications*
- changing the viewpoint retains the shape and visual characteristics of the individual objects
- changing the isosurface or the transfer function changes the nature of the display and how the objects are viewed
- GPU technology has greatly reduced the computational time associated with visualisation
  - *however, the GPU architecture often imposes bottlenecks that have to be carefully avoided for efficient GPU usage*

Our Approach

- use ray casting
  - *ensure all ray fragments are of equal length*
- ignore empty voxels
- use proxy geometry
  - *voxels represented by spheres, which simplifies some of the computation*
- use view-dependent sorting for occlusion
- more accurate ray-cell intersection for improved quality
- multiple transparent isosurfaces at no additional cost
- use of empty-space skipping

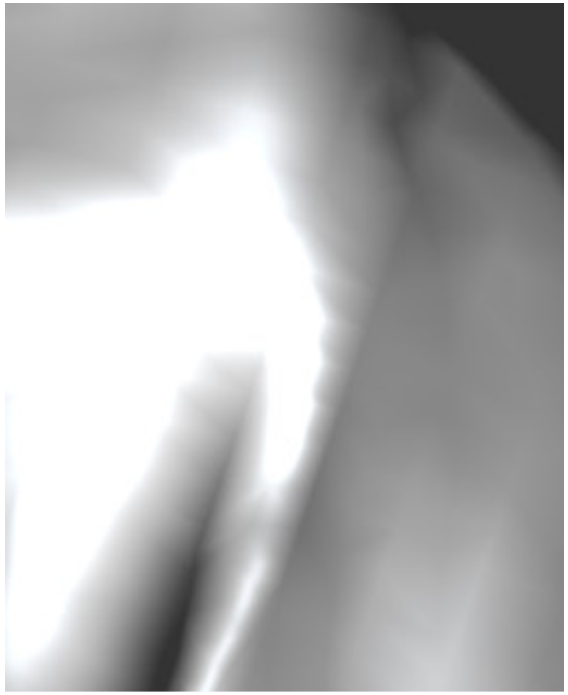
Quality Comparison

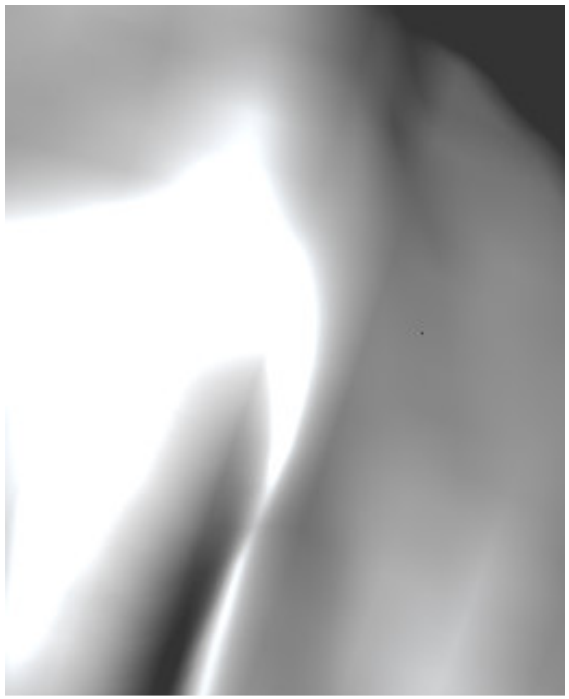


Quality Comparison

Marching Cubes

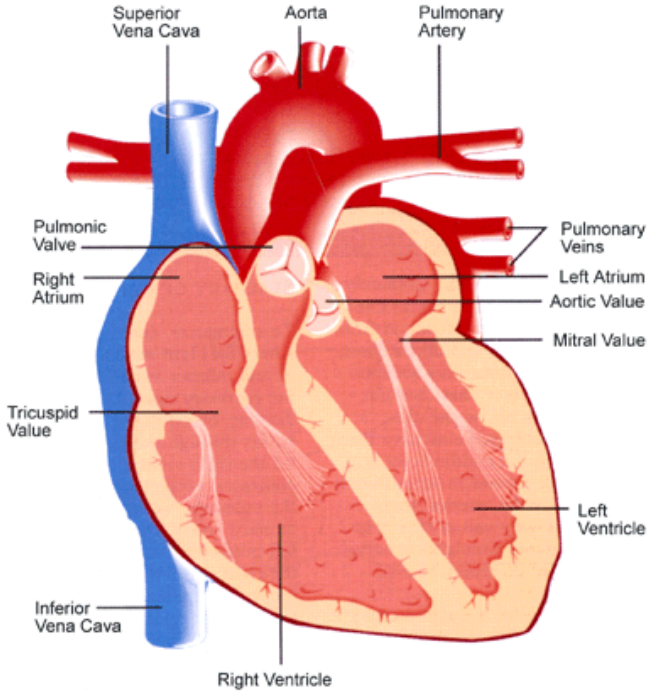
Our method





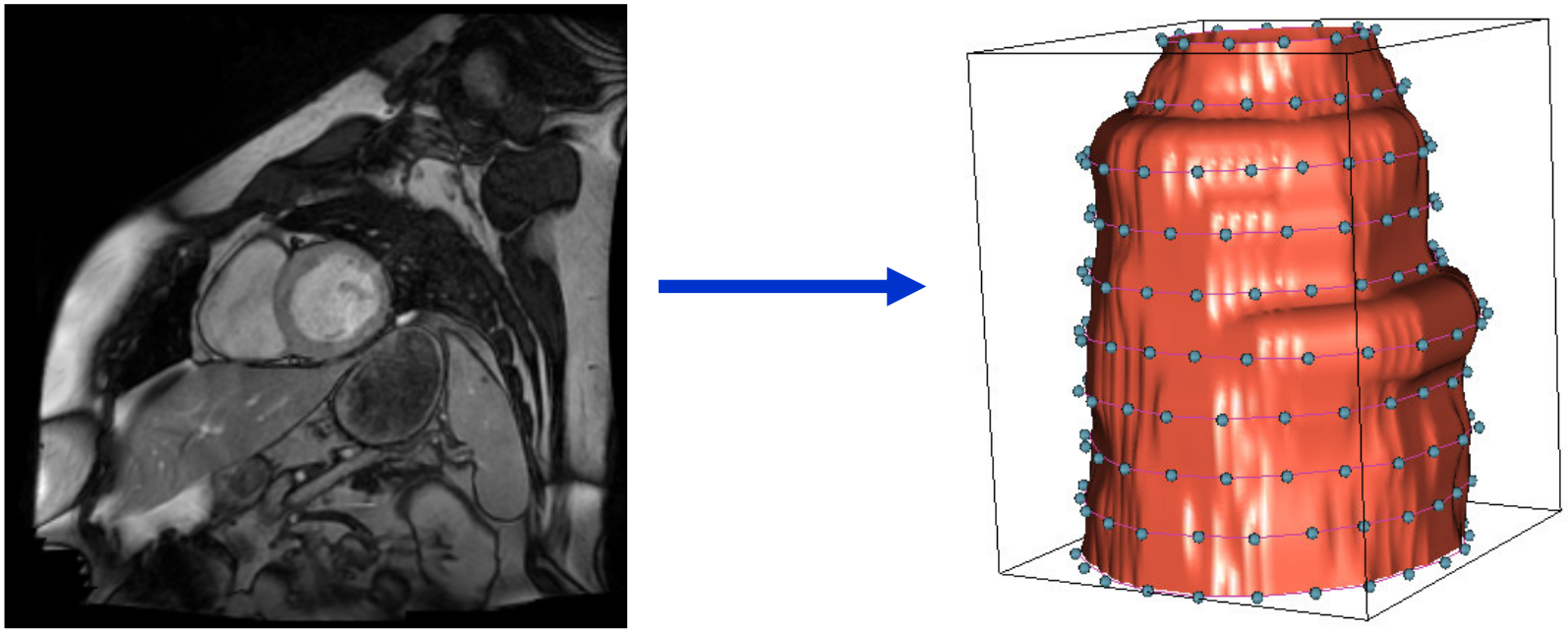
VPH2 – Heart Failure

- left ventricular dysfunction is a major cause of death
- the left ventricle is responsible for pumping oxygenated blood to the body
- blockage of blood vessels within the heart wall can cause part of the heart to die
- in heart failure, the heart often enlarges:
  - *difficult for the heart to beat*
  - *regurgitation through the valves*
- the cardiologist and cardiac surgeon have to decide on the optimal treatment



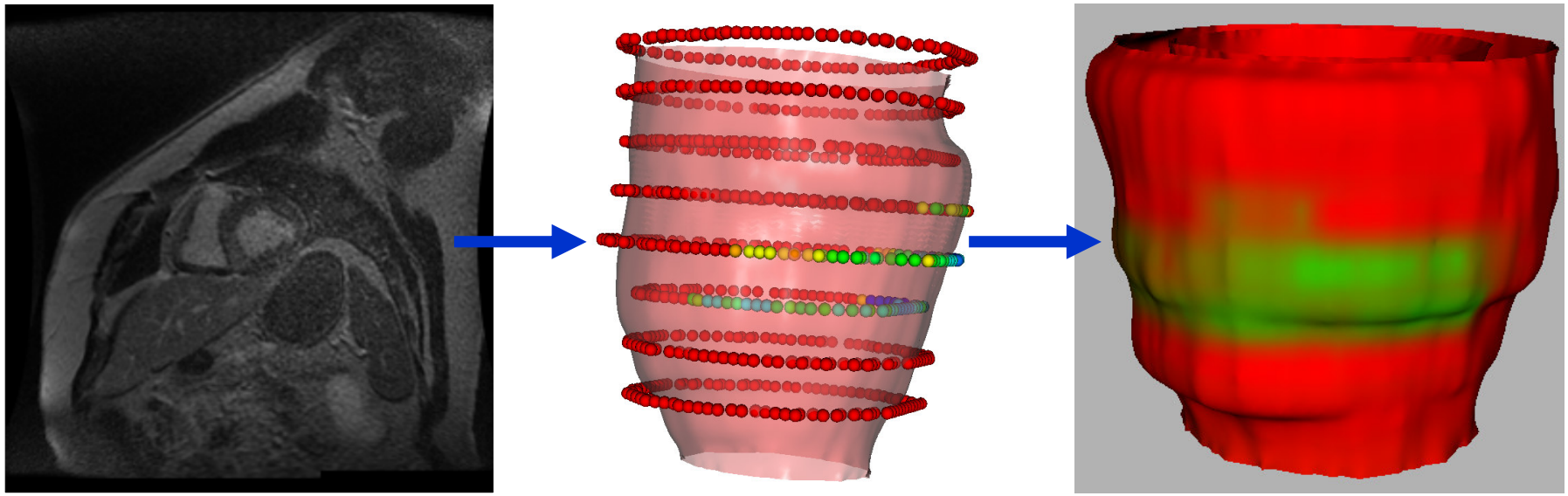
CCGV Tasks in VPH2

- create a model of the left ventricle:
  - *data is of low resolution (8mm slices)*
  - *data capture not instantaneous*
  - *standard techniques of surface reconstruction could not cope*



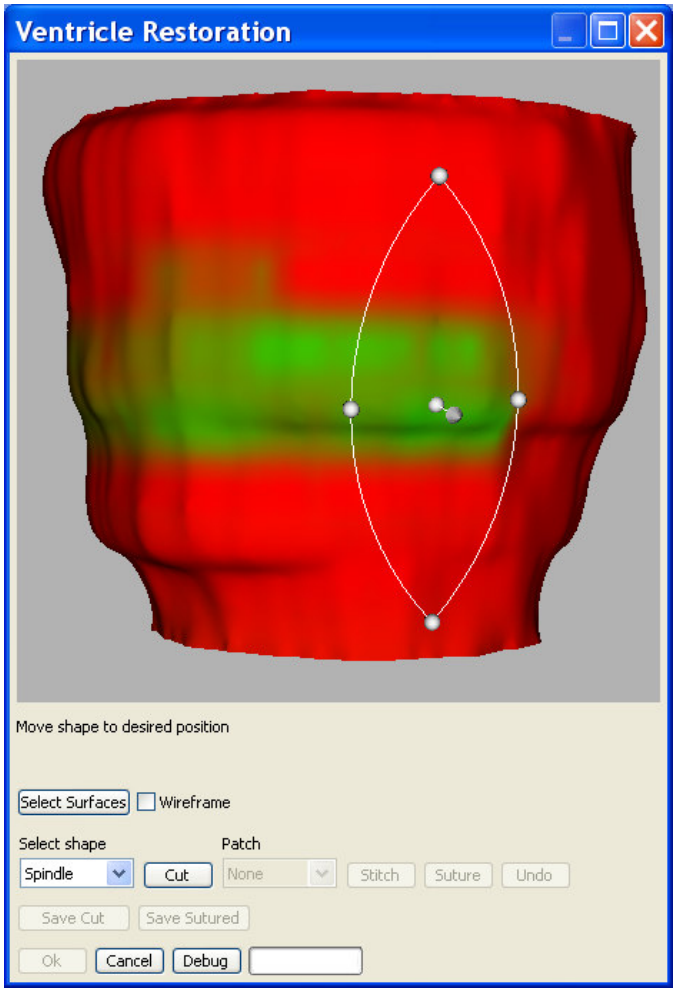
VPH2

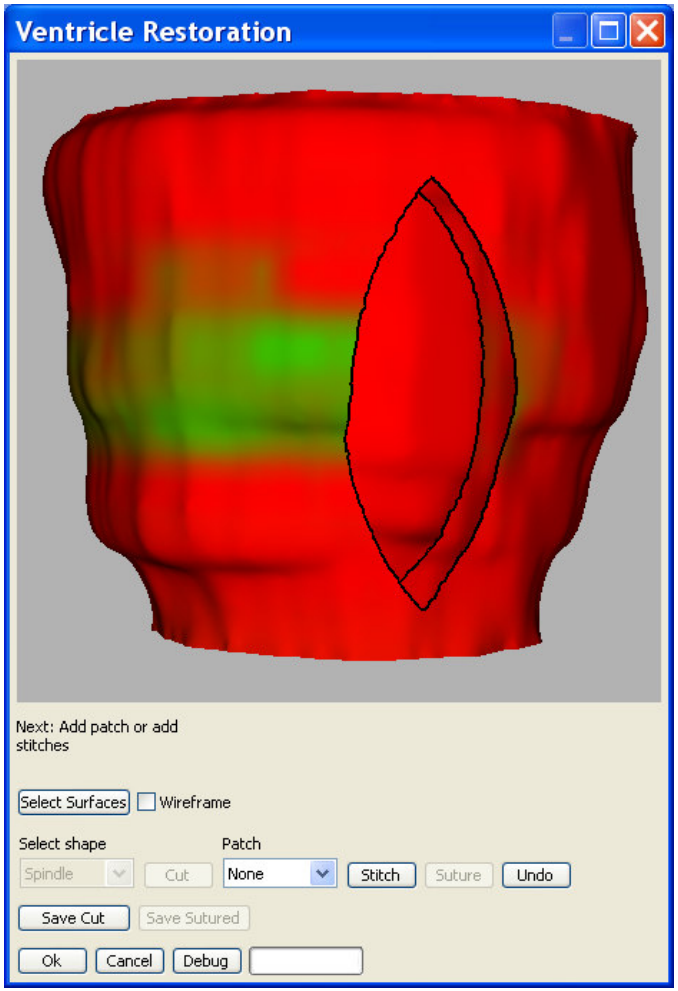
- register data from gadolinium scan with model
  - *indicates areas of necrotic tissue*



VPH2 – create incision

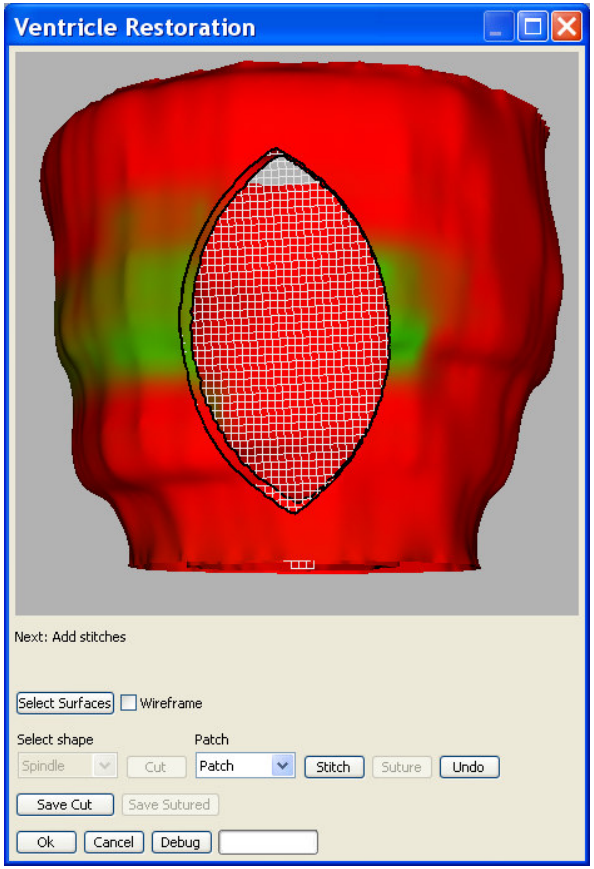
- produce incisions of various surgeon-defined shapes

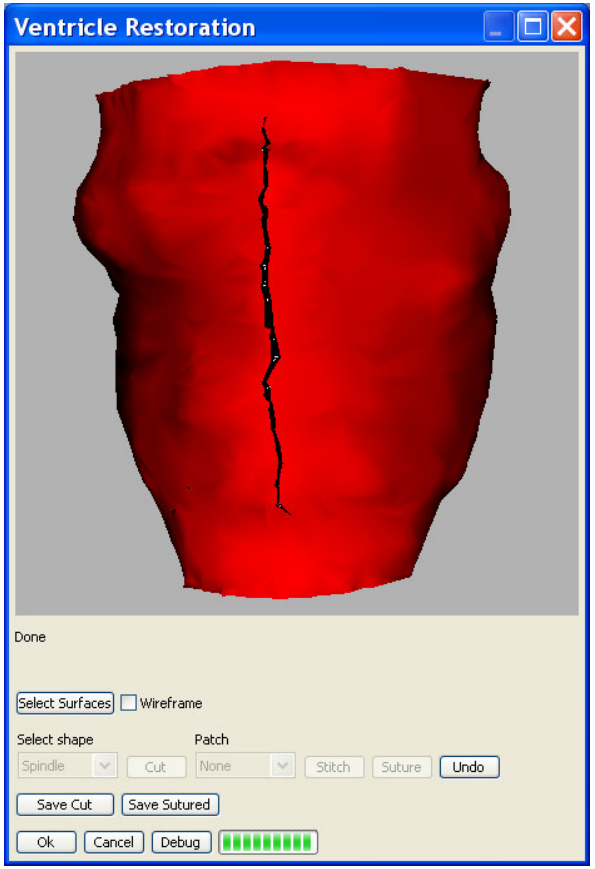




VPH2 - repair

- decide on stitching pattern and possible use of a patch
- apply suture to close incision (need a physically based model)





VPH2 – still to do

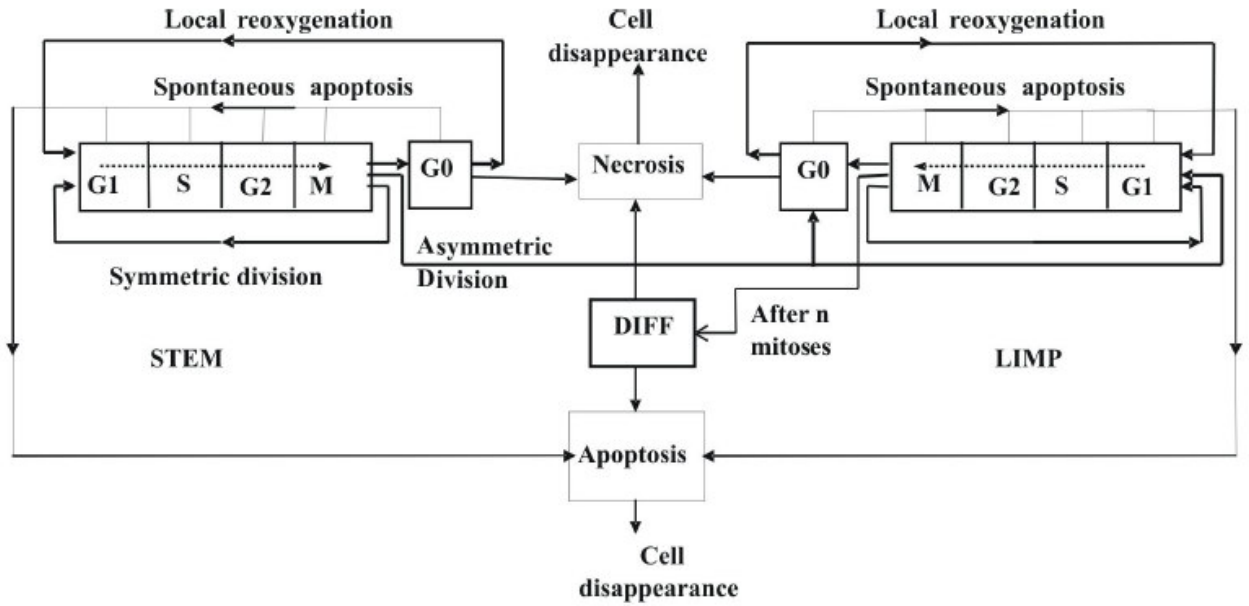
- register shape with heart vasculature
  - *see if revascularisation is appropriate*
- predict post-operative situation:
  - *new shape, volume, etc., of ventricle*

ContraCancrum

- **ContraCancrum will develop an advanced multiscale simulation platform of tumour growth and response to treatment, driven by real clinical needs**
- **CCGV tasks involve modelling, visualisation, web services and GPUs**
  - ***we concentrate here on the GPU work***

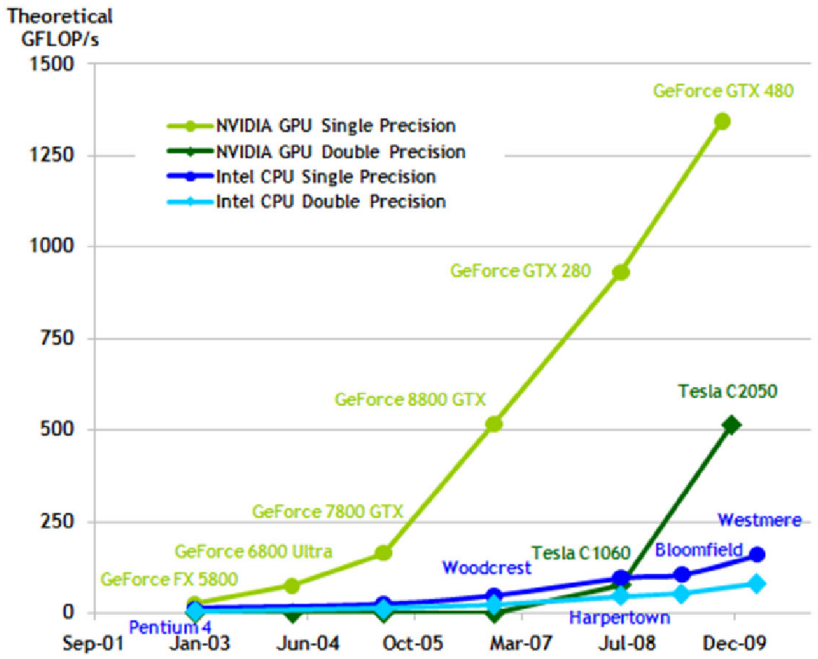
Tumour Growth Simulation

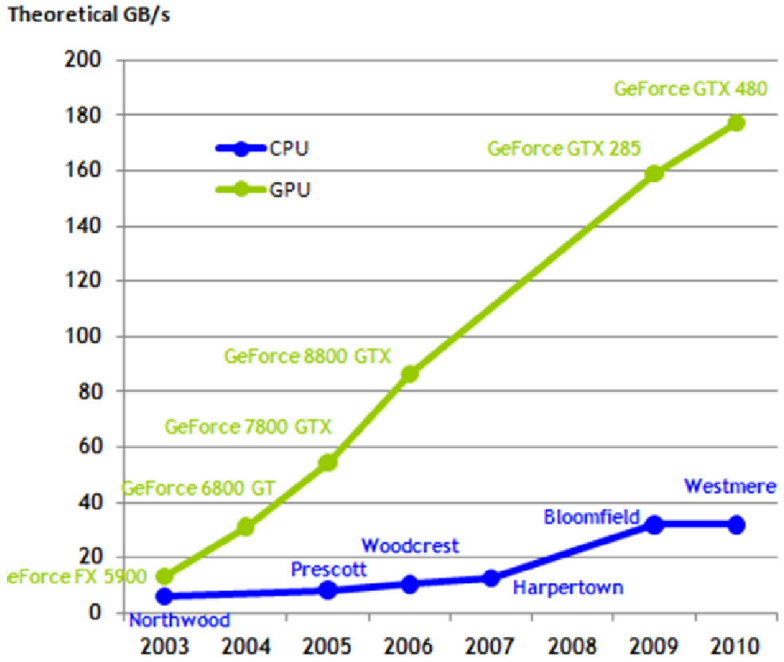
- statistical approaches to tumour growth simulation using Monte Carlo method
- volume divided into geometric cells (GCs)
- all cells in all GCs follow the generic cytokinetic diagram shown below
  - *this can be adjusted to any particular clinical case through assigning appropriate values to its parameters.*



GPUs

- are not only powerful graphics engines but also highly parallel programmable processors
- they feature peak arithmetic and memory bandwidth that substantially outpaces the CPU
- nowadays they can be used for general-purpose programming (GPGPU)



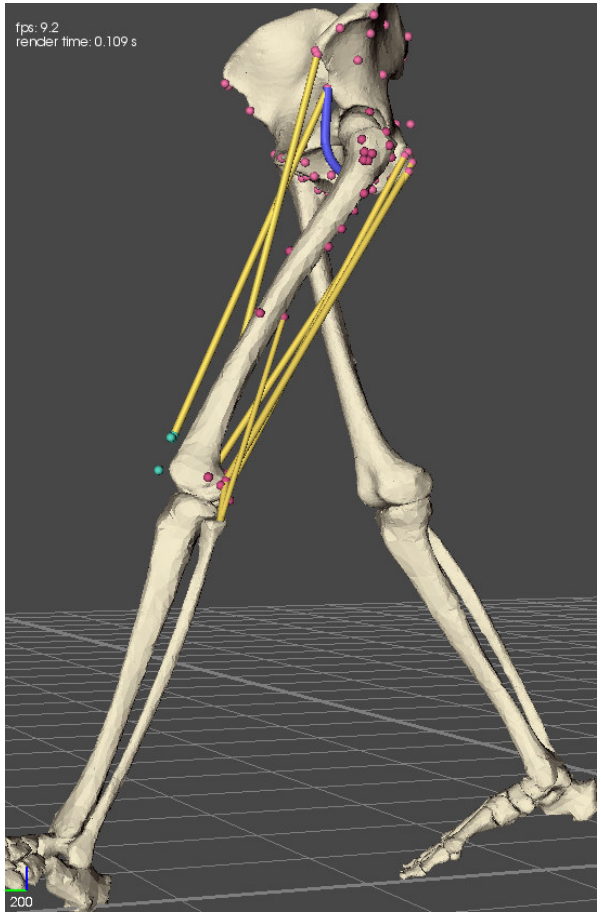


Performance Improvement

- each run of the simulation previously took 20 minutes on a desktop computer
- hundreds or even thousands of runs are necessary to create a statistical picture of likely tumour development
- the more complex the problem (higher resolution, more time steps), the greater was the benefit of using the GPU
- use of the GPU reduced the time to 8 seconds:
  - *a speed-up factor of ~150*
- use of a Tesla S1050 (an off-the-shelf GPU cluster) reduced the time to 2 seconds:
  - *a speed-up factor of over 500*

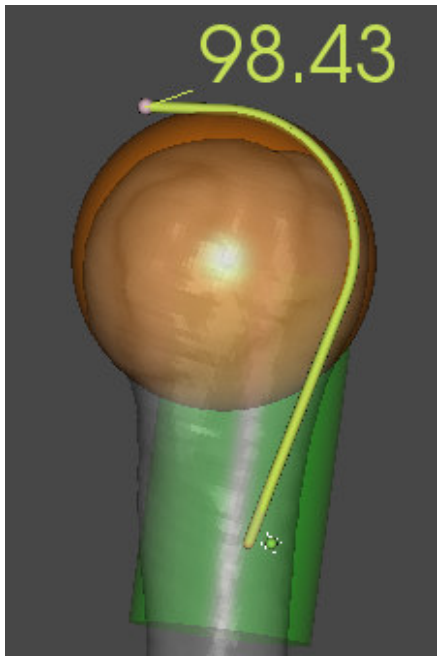
VPHOP - Muscle Wrapping

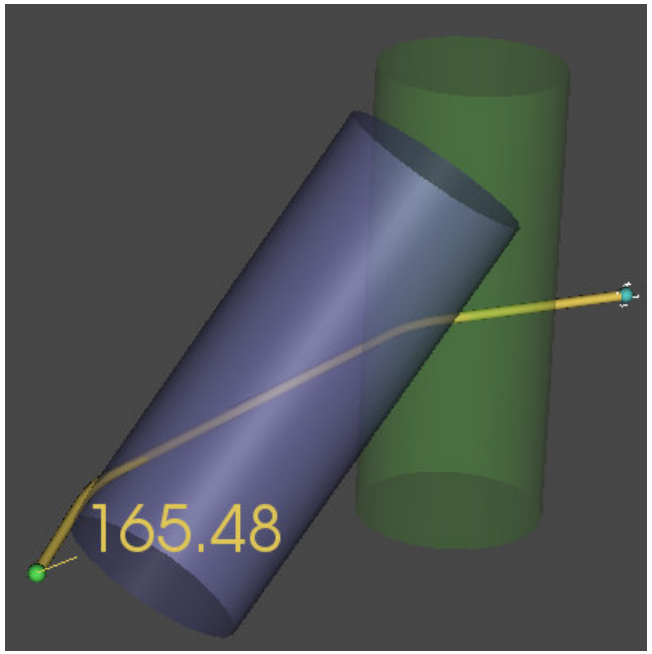
- muscles are attached to the bones by tendons
- the normal way for muscle action to be modelled in biomechanics is by a simple action line
  - *in most cases this is a straight line joining the attachment points of the muscle to the skeleton*
- sometimes a muscle wraps around bones or other muscles
  - *the line of action is now more complex but generally still formed from piecewise straight lines*



Wrapping the Line of Action

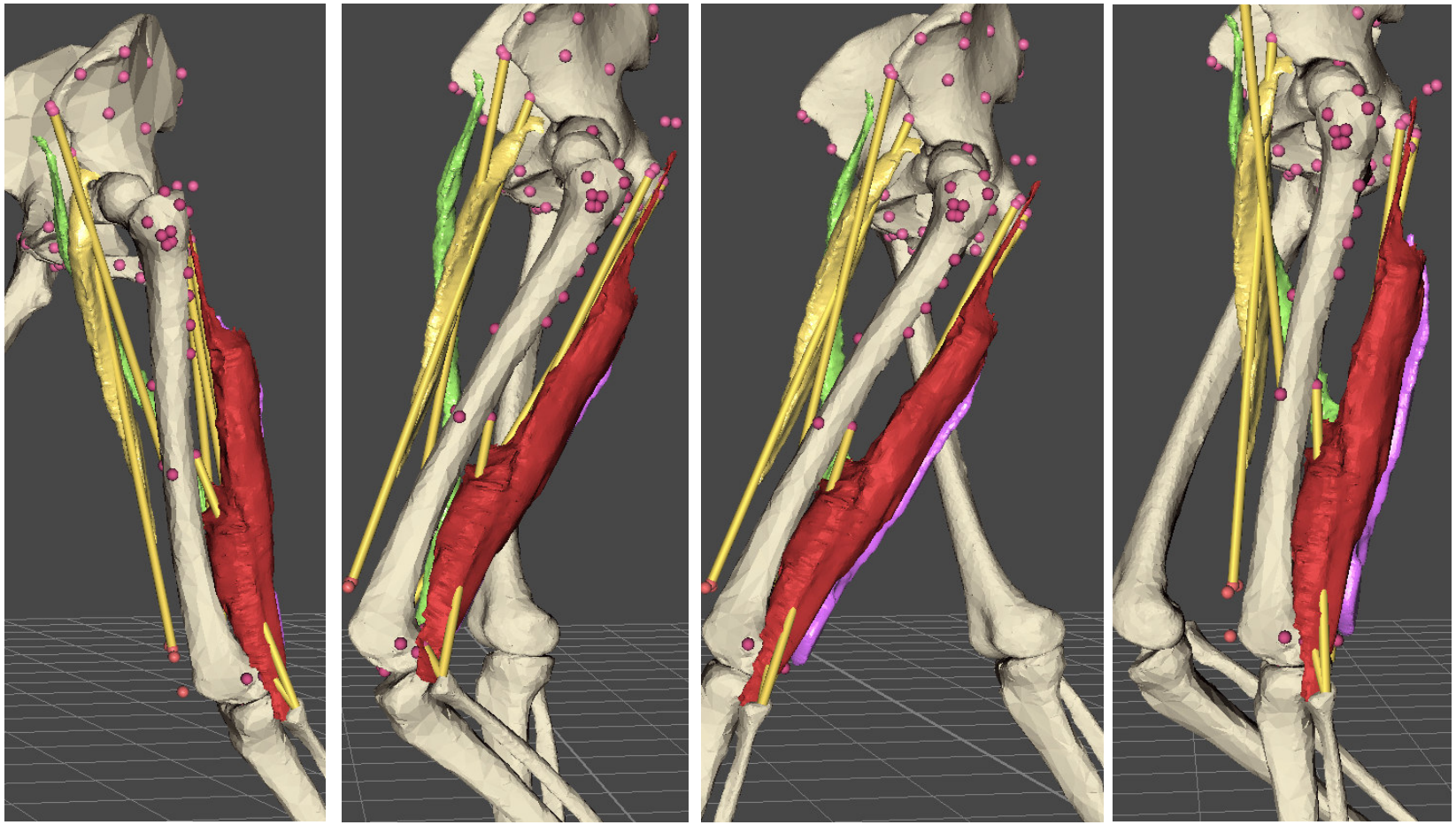
- CCGV has developed a new algorithm to model wrapping of the action line
- obstacles are simplified by geometric primitives
  - *spheres, cylinders, etc.*





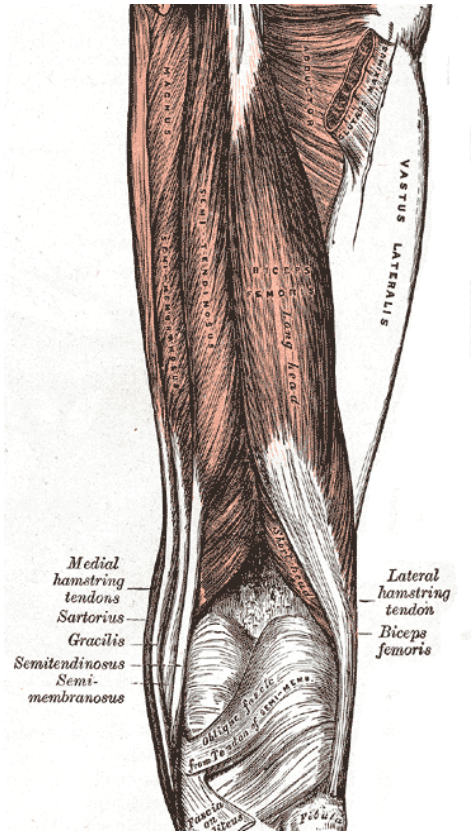
Creating the Muscle Volume

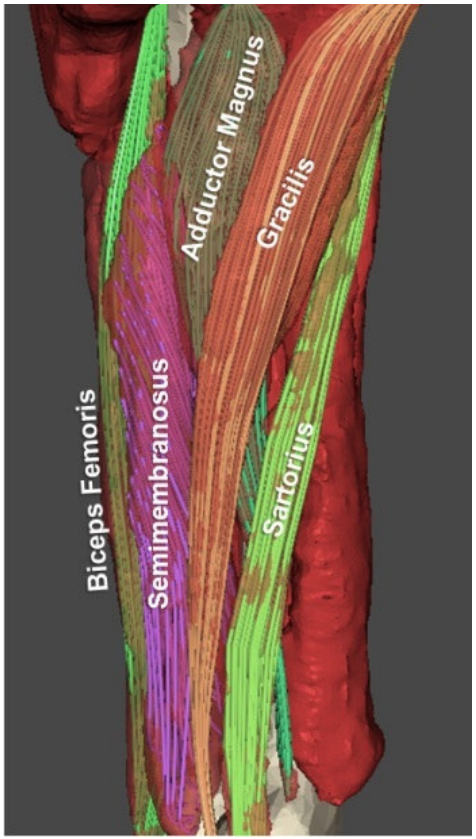
- an entirely method is currently being developed to model the deformable muscle volume, based on the action line, together with the muscle fibre pattern



Fibre Orientation

- adding fibre orientation can add significantly to the accuracy of muscle force calculations





Large Volume Data

- medical datasets are becoming increasingly large
- multiscale modelling will make the situation worse
  - *multiple sets of data held in memory simultaneously*
- some sets may exceed addressable memory
  - *the computer cannot hold all of the data, it must choose which parts are required at any particular moment and ensure access to them*
- use a variety of approaches
  - *out-of-core techniques*
  - *preprocess the data to create a suitable structure*
  - *shift it in and out of memory as required*

Conclusion

- is the Virtual Human virtually here?
  - *not yet, expect significant progress in the next 10 years*
- substantial multiscale models for the human physiology will be available in under 10 years
- change of thinking and considerable collaboration required to cross dimensional scales
- in use in clinical practice in 15-20 years
  - *highly dependent upon industrial uptake*
  - *some specialised companies already created in the USA, particularly in pharmaceutical industry*
- results will permeate non-medical applications