Leveraging Open Source for Geographically Dispersed Workflows

Release 1.01

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Abstract

Personalized simulations can help assess and predict the clinical status of patients and are a key tenet of the Virtual Physiological Human (VPH) framework. This paper shows how the turnkey access of GIMIAS, an open source software platform built on open source toolkits (VTK, MITK,ITK), thanks to his inclusion in VPH-Share, an infrastructure European project with open-source components, was key to progressing the deployment effectiveness for MySpine, a VPH European project, among his geographically dispersed community.

Contents

Virtual Physiological Human (VPH) [1] is a methodological and technological framework whose approach to projects is to perform personalized simulations that, in turn, enable the acquisition of clinical insights on a patient status. One of the most valuable applications of this methodology is to use the simulations to predict possible outcomes and, eventually, help clinicians in improving the selection among available treatment options. Achieving these results, typically involves going through several steps to be performed by users with different sets of competencies and often geographically dispersed. Hereby an application of VPH-Share [2], an infrastructure European project with open-source components, is presented. It will show

how this infrastructure, through the access to a customized version of the open-source GIMIAS [3, 4] software platform for the European project MySpine [5], can be used to enable visual interaction and workflow progression and monitoring in scenarios where users are not co-located.

1 The projects: VPH-Share and MySpine

The VPH-Share integrated project aims at building a collaborative VPH environment for workflow developers and users. In particular, the project is creating a unified space where, through an easy-to-use web interface as well as a back-end API, the functions needed by workflow developers are made available, including workflow design and execution, data-access and storage, high-speed computations, and results presentations. In order to achieve its goals the project has a multi-layer architecture, shown in Figure 1, where the Master Interface layer (made of web-accessible Resources and Functionalities) operates through and orchestrate a set of extensible capabilities that are accessed securely as back-end services.

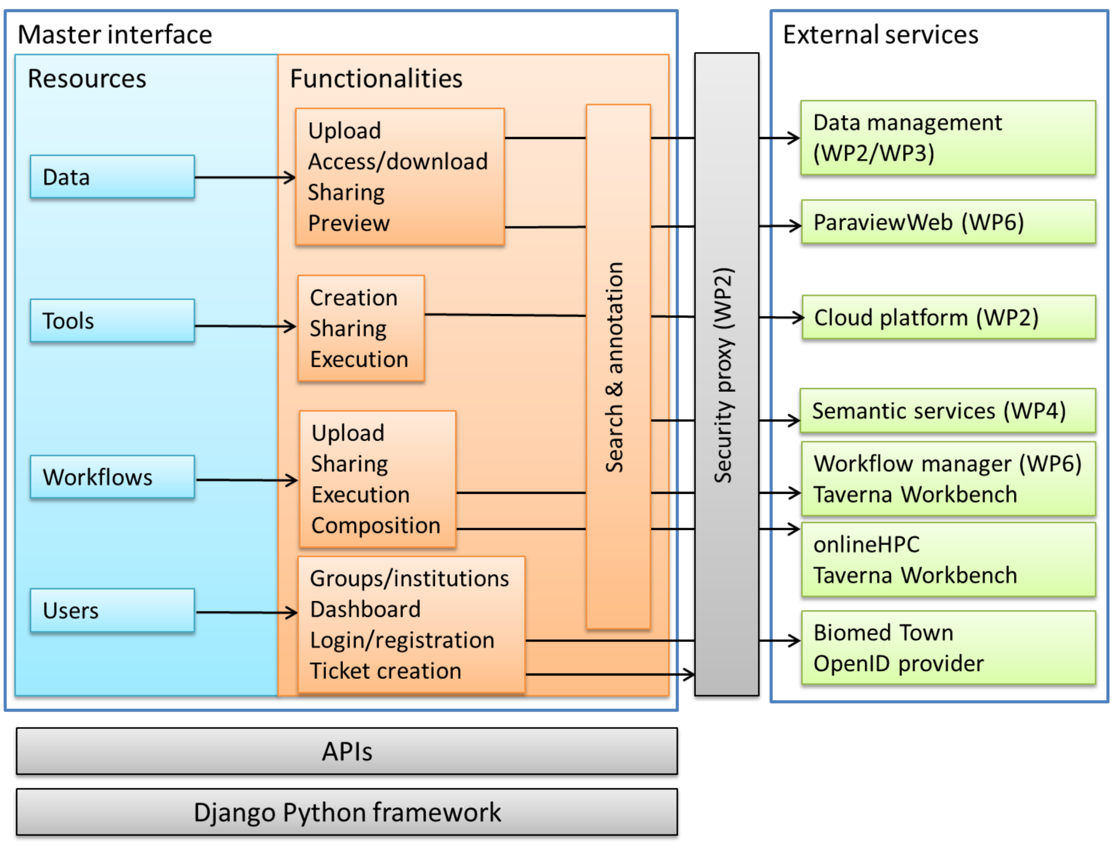

Figure 1: The VPH-Share Architecture Components

From the workflow developer point of view, the VPH-Share project offers a streamlined way of organizing the computational steps as well as sharing access to original data and to results. It is important to highlight that each workflow item is actually a web-service (SOAP or REST interface) and that, thanks to a cloud-

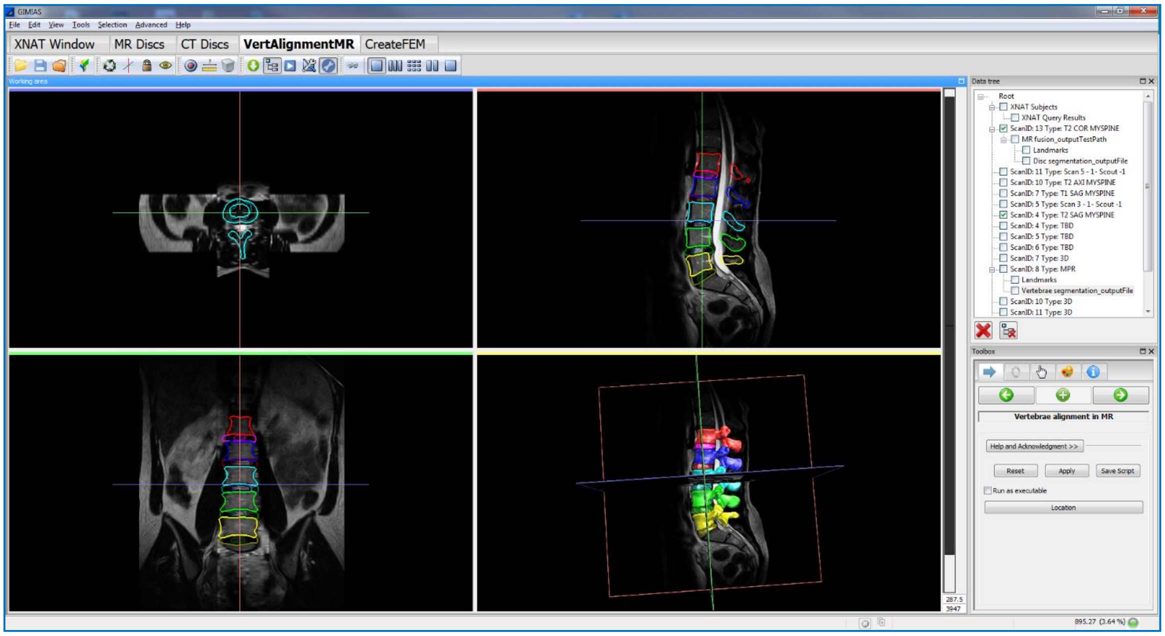

Figure 2: GIMIAS with MySpine extensions

based approach, these services can span a whole range of complexities from very simple commands, similar to Unix filters, to interactive applications with 3D graphics via remote visualization. It is in this context that the integration of MySpine, a STREP European project, took place.

MySpine aims to create a clinical predictive tool to provide the clinicians with patient-specific biomechanical and mechano-biological analysis. This tool will help on determining the best patient-specific treatment for low back pain. The project focuses on disc degeneration pathology, because of its prevalence, although the developed prototype system will be able to analyze other spinal pathologies as well. To achieve these project goals a patient-centric procedural workflow was devised to go from the initial imaging data to the simulation results: (a) generation of a personalized Finite Element Model (FEM), (b) simulation of patient-specific evolutions, and (c) comparison with follow-up scans (pre- and/or post- treatment when available). The FEM personalization is comprised of several sub-steps: (a.1) the patient data are selected and, in order to improve the global 3D resolution because of the large distance between acquisition planes (spacing between slices between 4 and 4.4 mm), the coronal and sagittal MRI acquisitions are fused automatically, (a.2) then the vertebral discs are segmented on the fused MRI scan using the location of their centers as manually marked by the users, (a.3) subsequently the vertebrae are segmented on the CT scan using the disc centers now located manually on the same CT scan, and (a.4) the surfaces of discs and vertebrae are merged together according to their appearance in the fused MR scan; finally, (a.5) the template volumetric mesh is warped to match the segmented spinal surfaces while preserving key quality parameters to avoid inaccuracies and convergence problems in the simulation stage. A version of the open-source software GIMIAS with customized plug-in extensions was developed and validated to support the steps leading to the FEM generation with an assisted workflow.

2 Geographically Dispersed Communities

The progress of the project was excellent, but the distant location of consortium partners was making it difficult to provide an adequate support for local installation to remote partners. The inclusion of MySpine as a use-case of VPH-Share was extremely beneficial. By turning the customized GIMIAS into a virtual appliance (a complete virtual machine, whose instantiation occurs on-demand) it was possible for any registered user with granted permissions to request the execution of the virtual appliance and get access to the running instance through remote visualization. Provided the internet connection has reasonable large bandwidth and low latency, the advantages typically associated with web-based applications hold true for virtual appliances, too, including no installation required, transparent updates, simpler support options, mobility (connection from different locations), and they are especially important when dealing with collaborators with limited IT support and, as stated before, distant locations.

Additionally, by configuring the HPC simulation execution request as an application hosting environment submission, it would be possible to turn the procedural workflow into a computational environment with a complete control on the creation and destruction of the virtual appliance instances, and their associated costs.

3 Assisted workflows in a paraclinical setting

The MySpine project is actually representative of a large number of applicative areas, certainly not limited to the VPH group, where state-of-the-art computational methods are executed on bespoke models that provide boundary conditions that are unique to each case under analysis. Typically the process of tailoring the bespoke model has a number of interactive steps that occur in a paraclinical setting. In those cases scientists' primary expertise is the medical field – they are surely computer literates, but it can be expected that only a limited amount of training will be viable. In these contexts assisted workflows play a key role in minimizing training as to guide users step by step. Figure 3 shows the steps of the assisted workflows that were specifically implemented for MySpine as detailed in Section 1.

The open source software platform GIMIAS streamlines the creation, configuration and use of assisted workflows. Its flexibility comes from being built around several open source libraries: VTK [6] and MITK [7] for visualization, ITK [8] for image processing, boost for general computational capabilities, DCMTK [9] for DICOM [10] file access, etc. In the context of MySpine, the customized data access GUI combined with the advanced visualization capabilities provided by the underlying libraries was key to the streamlining of the complex operations. Besides the already mentioned landmark positioning activities (on both MR and CT scans), the QA process benefit particularly from the visualization power: assessing the segmentation quality required zooming in and switching across the different 2D views to check the exact boundary locations while using the 3D view as a global navigational support; and also the assessment of the merging of the vertebrae with the disc required the orchestration of the 4 views, as shown in Figure 2, to make sure that there were no overlaps among the different surfaces or the evaluation of the FEM quality index, again, the 4 views were instrumental to its quick assessment. Currently under development are the visualization modes required to assist in comparing the imaging data of the follow-up scans with the model generated from the simulation results.

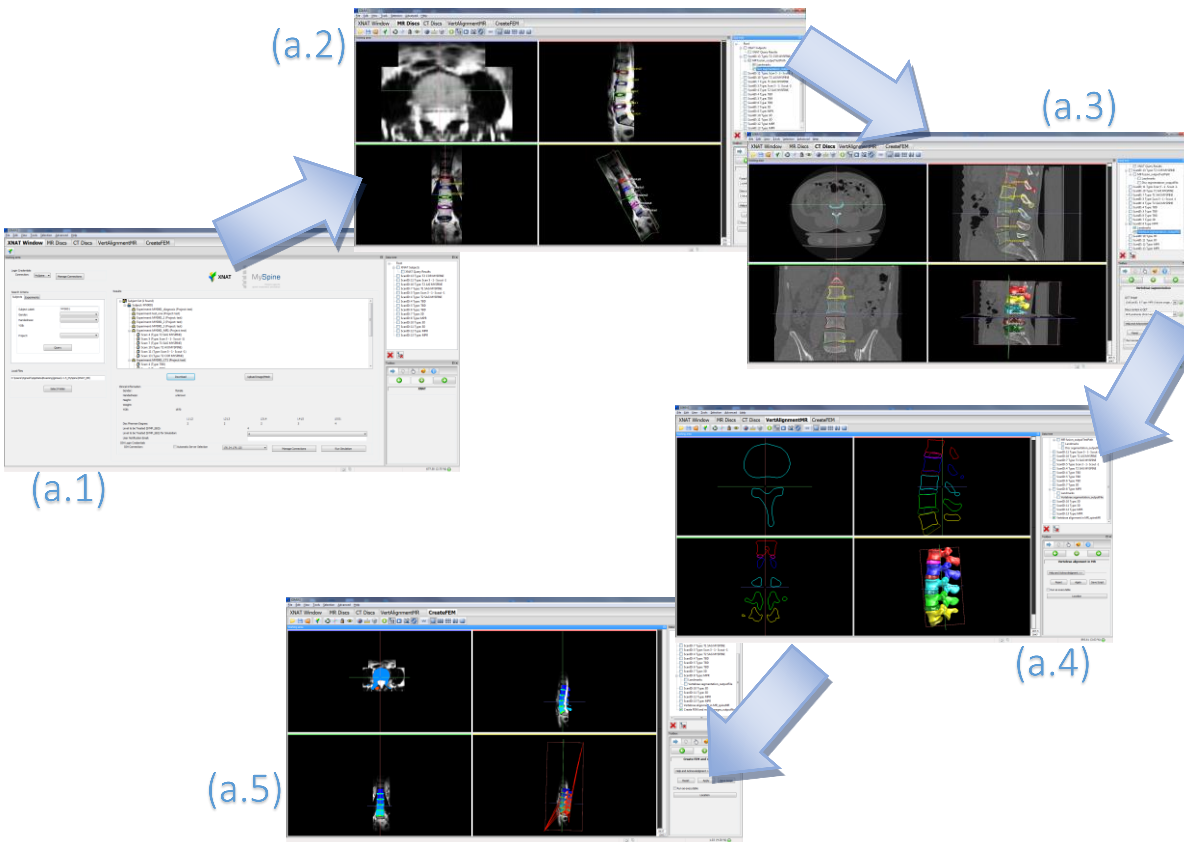

Figure 3: The steps of MySpine assisted workflow

In addition to the possible visualization through the GIMIAS virtual appliance, graphical files located in the VPH-Share persistent storage (LOBCDER) can be viewed within the browser itself (with no additional wait time nor costs) thanks to the seamless integration of ParaviewWeb in the directory browser page of VPH-Share Master Interface, see Figure 4.

4 Conclusions

VPH-like projects require the generation and simulation of bespoke models and their generation requires activities by experts whose primary domain is not IT and who may be geographically dislocated. By leveraging open source solutions we have shown how to overcome these hurdles, promote remote cooperation, and keep projects successful. Looking to the future, this is a model that could also be applied to clinical practices where decision support systems could be located in the cloud as soon as all the issues and concerns related to the management of sensible information are fully addressed.

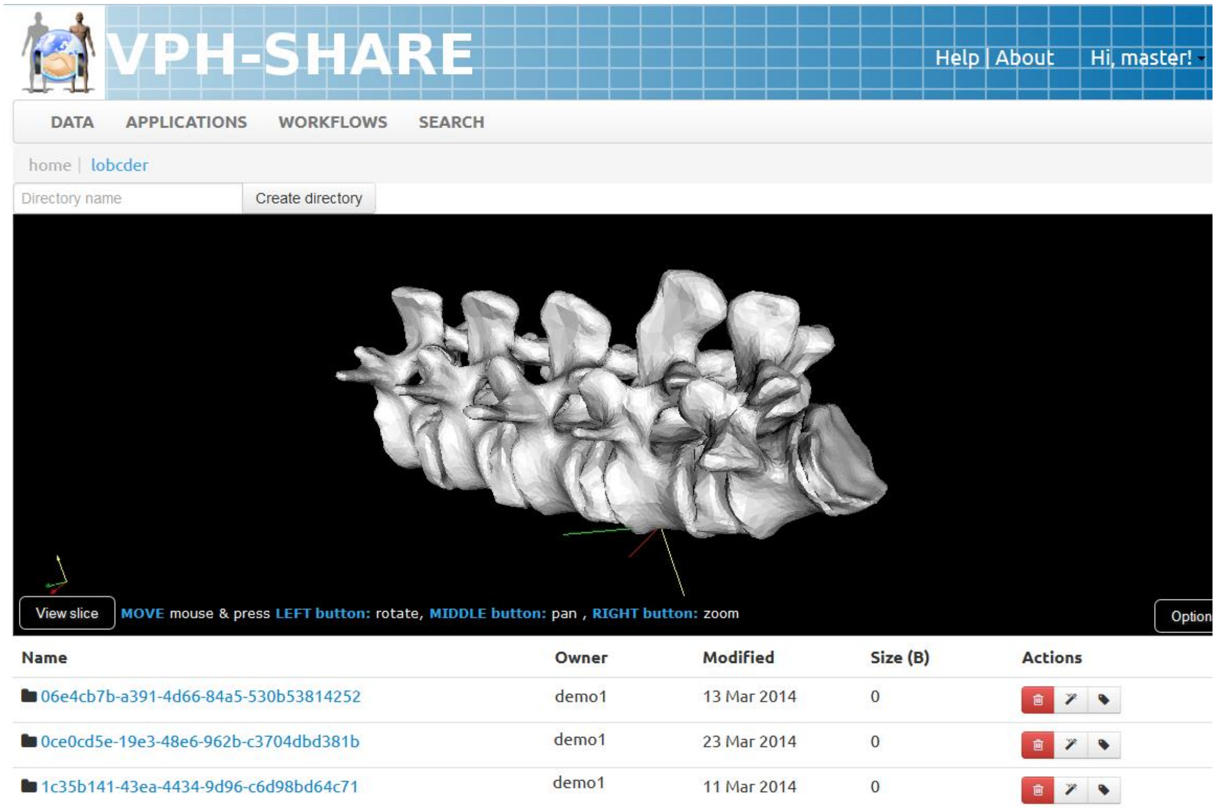

Figure 4: In-browser visualization using ParaviewWeb in LOBCDER

A Appendix: Workflow Definitions

By definition a workflow consists of *a sequence of connected steps where each step follows without delay or gap and ends just before the subsequent step may begin*[1]. In the different scenarios where the research platform might be used, many diverse workflows may take place; instead of trying to find new unique words for each usage type, we are standardizing on a (mandatory) compound use of the word *workflow* as follows:

- *procedural workflow* – the description of sequence of steps to accomplish a task;
- *assisted workflow* – a guided sequence of steps to be performed with minimal training and within a single software environment to carry out, from start to end, the predefined procedure to accomplish an applicative-domain goal;
- *computational workflow* – a directed graph, typically acyclic, where nodes represent processing sub-tasks and arcs describe the data flow (this kind of workflows is also known as scientific workflows to differentiate them from business workflows).

[1] ISO 12052:2006, http://en.wikipedia.org/wiki/Workflow, http://dictionary.cambridge.org/dictionary/business-english/workflow

References

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[10] NEMA (National Electrical Manufacturers Association), "The DICOM Standard," 10 08 2011. [Online]. Available: http://medical.nema.org/standard.html. [Accessed 31 03 2014].

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09 June 2014

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The VPH Approach

- Estimate future outcomes by simulating personalized physiological models
- Personalization mostly comes from imaging, but demographics and lifestyle are considered, too

- Typically, in a study:
  - the same *procedural* workflow needs to be repeated for all the subjects
  - the workflow is carried out by researcher that are either more technically minded or with a more marked clinical-background
  - specialized clinicians oversee the final quality of the results

A Common Denominator

- A common characteristic of the projects to be presented is that

each of them assembles

open-source or open-source-derived components

to deliver innovative services

The sum is bigger than its components

the orchestration of the three projects
exemplifies
a template of a new way to provide
access to advanced solutions

MySpine

GIMIAS

VPH-Share

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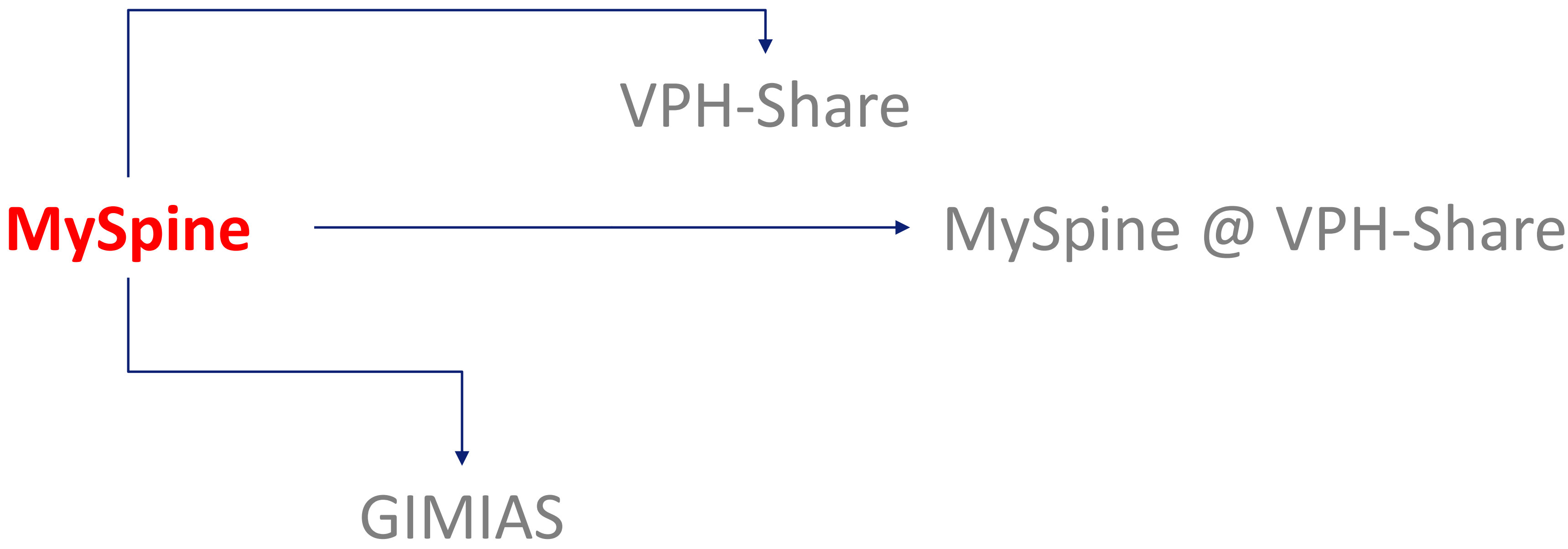


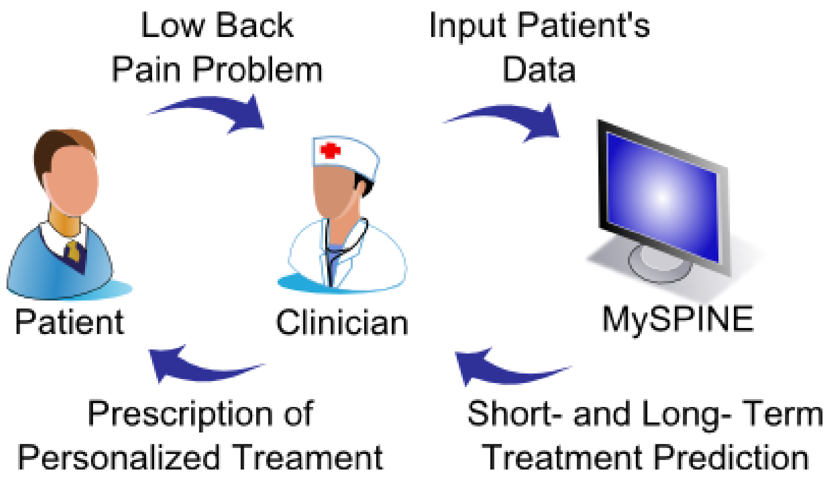
MySpine Motivation

- Low back pain is a well-known and widely spread illness.
- Prevalence estimates for chronic low back pain between 6 and 11% (and annual direct cost of low back pain of 7.000 € per person)
- Billions of Euro are spent each year in Europe on treating this disorder.

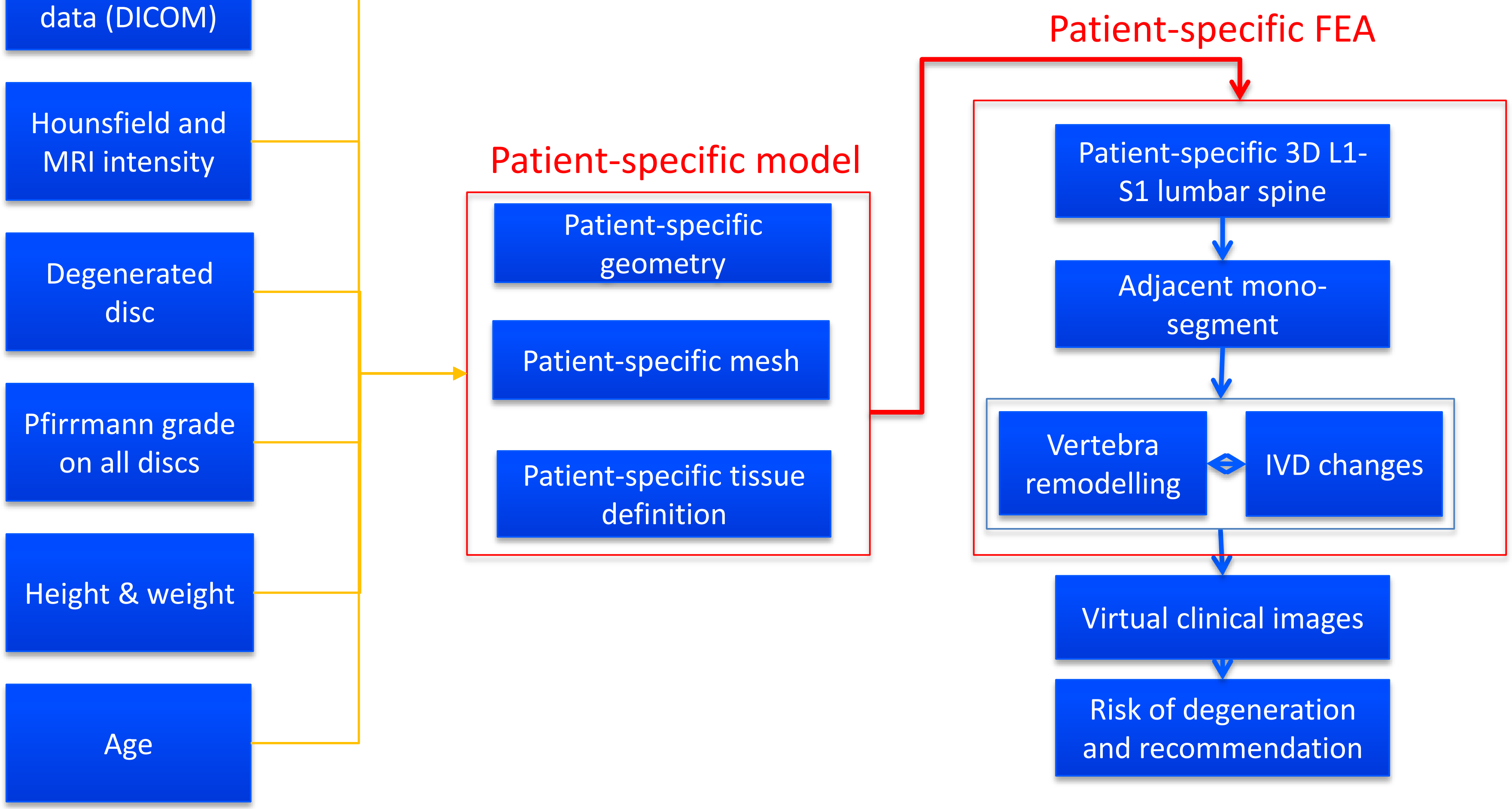
(Juniper et al. 2009)

MySpine Goals

- Aims to create a clinical predictive tool to provide clinicians with patient-specific biomechanical and mechanobiological analysis.
- This tool will help to determine the best patient specific treatment for low back pain.
- The project will focus on disc degeneration pathology although the developed prototype system may be able to analyze other spinal pathologies as well.



MySpine Data Flow



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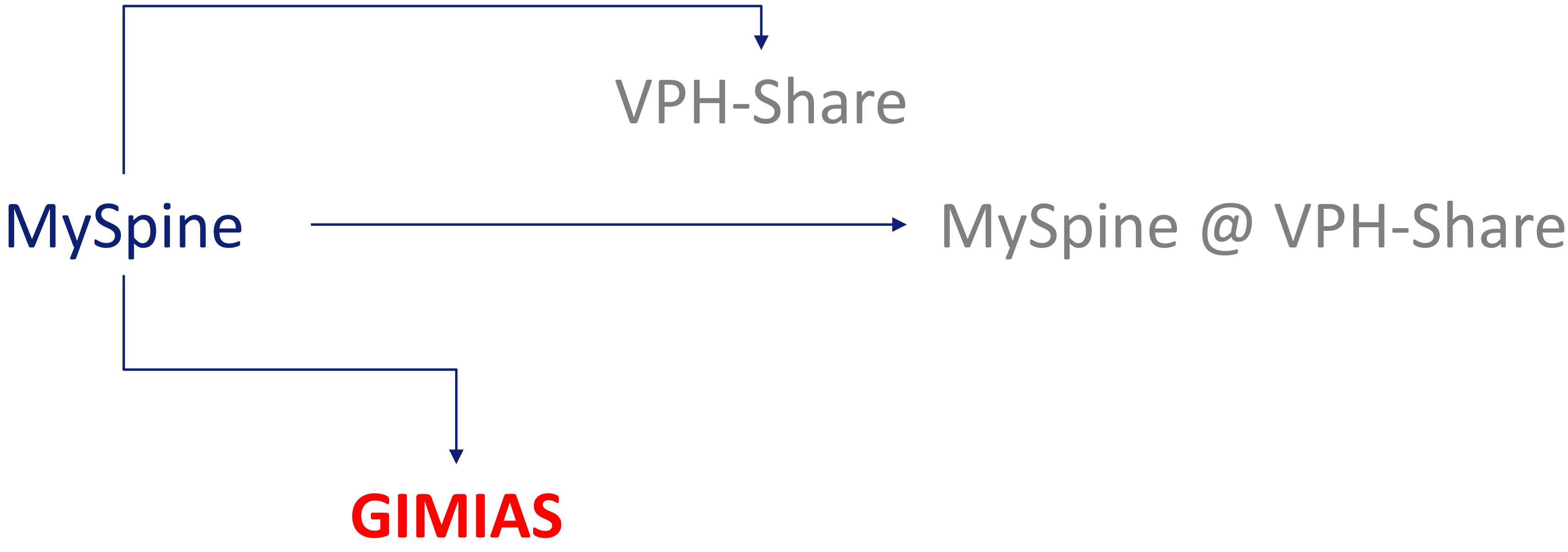
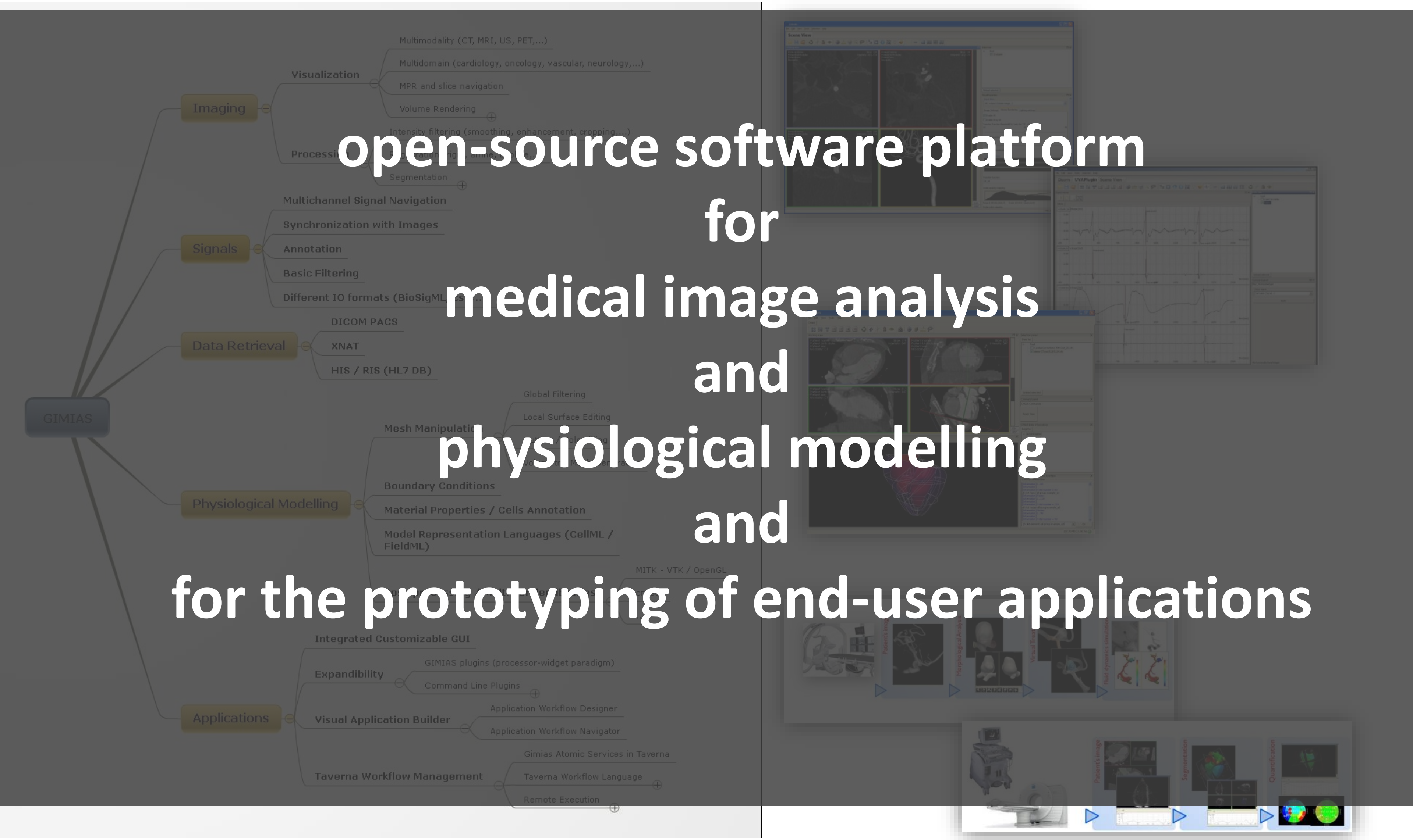
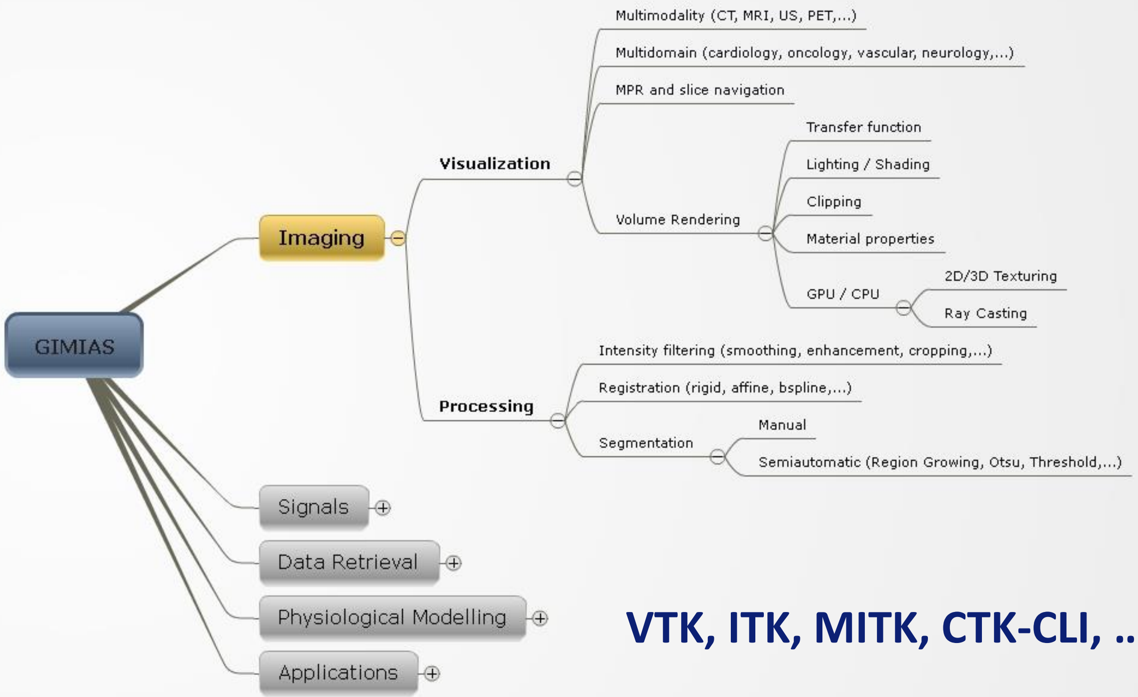


GIMIAS



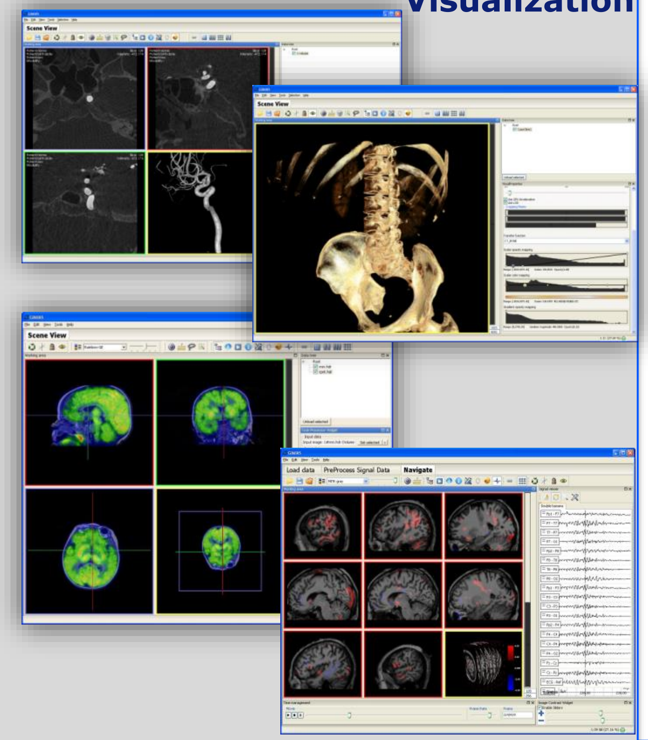
open-source software platform
for
medical image analysis
and
physiological modelling
and
for the prototyping of end-user applications

GIMIAS – Imaging

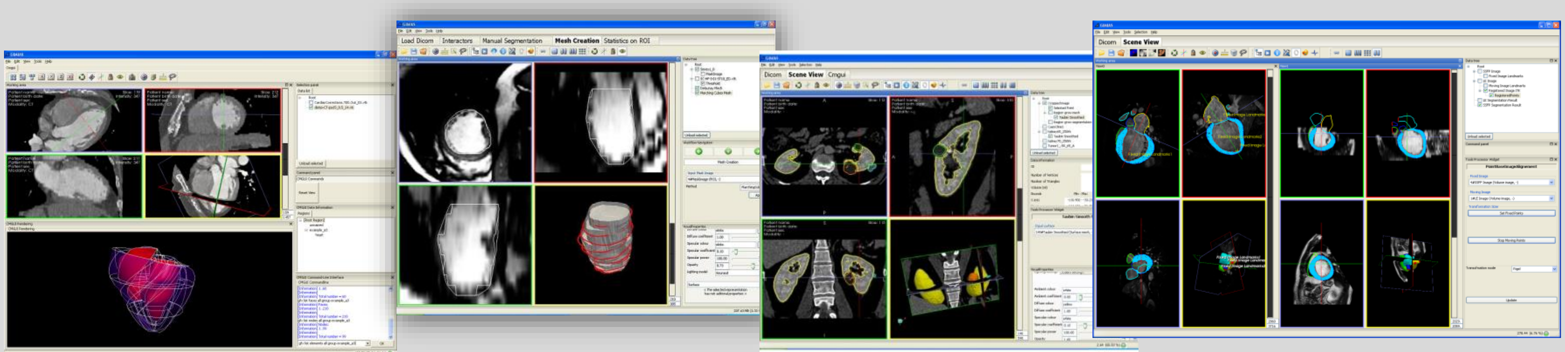


VTK, ITK, MITK, CTK-CLI, …

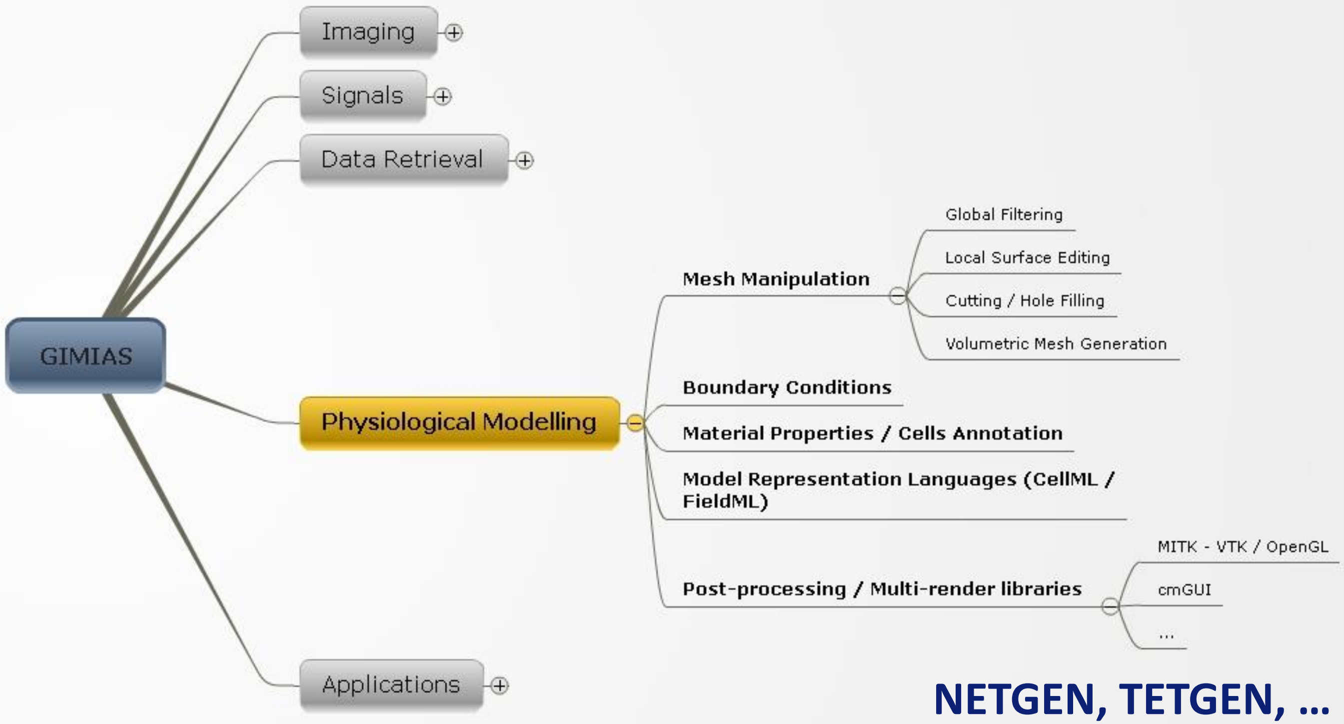
Visualization



Processing

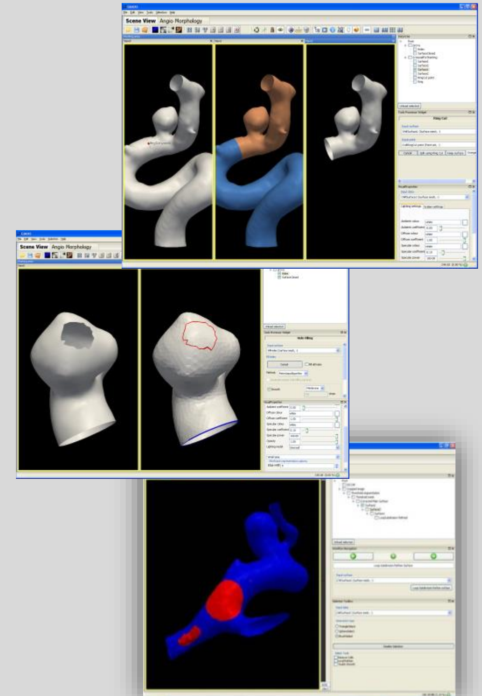


GIMIAS – Physiological Modelling

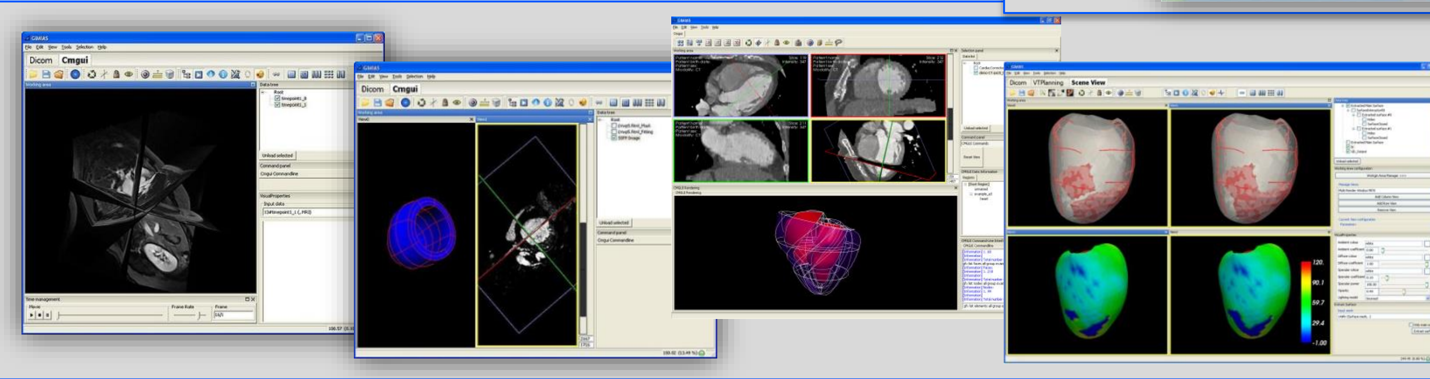


NETGEN, TETGEN, …

Mesh Manipulation

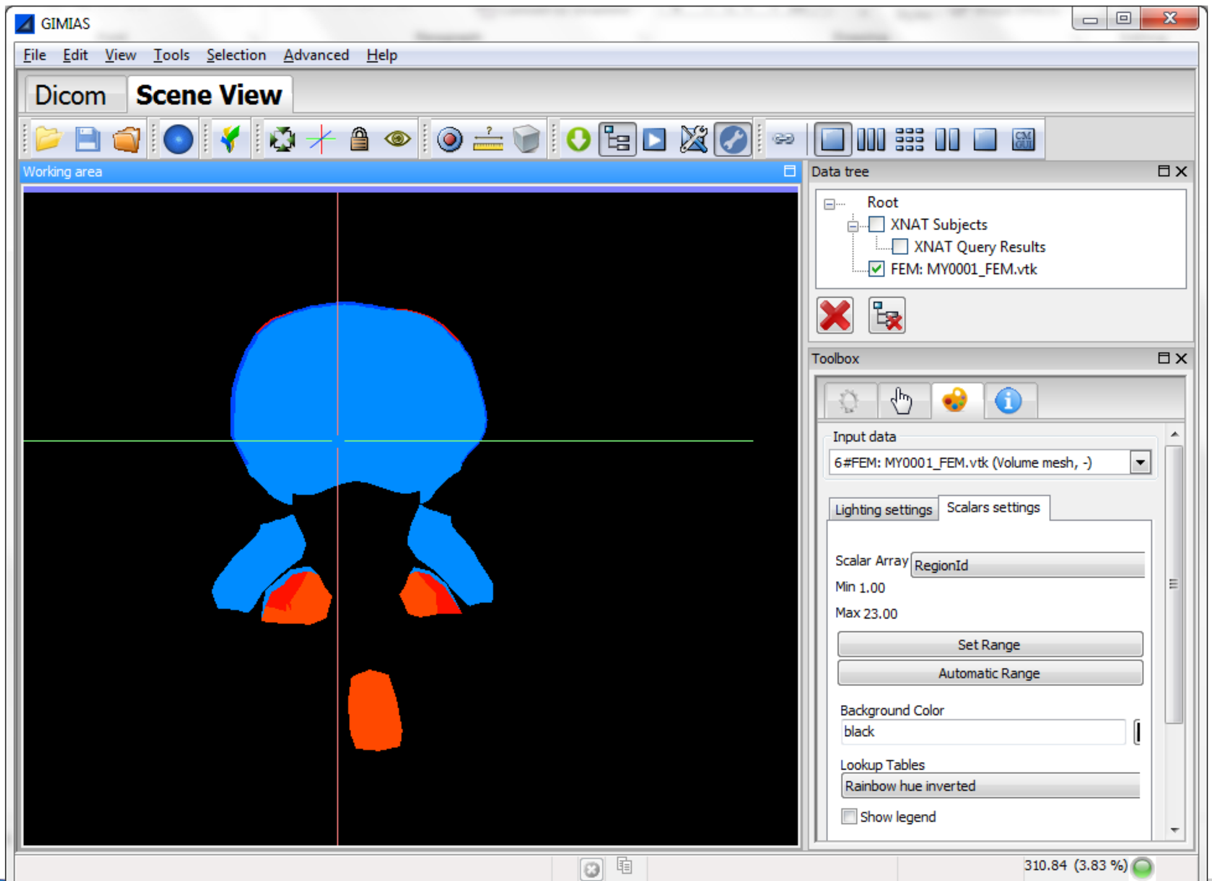


Post-processing
Multi-render libraries



GIMIAS 4 MySpine

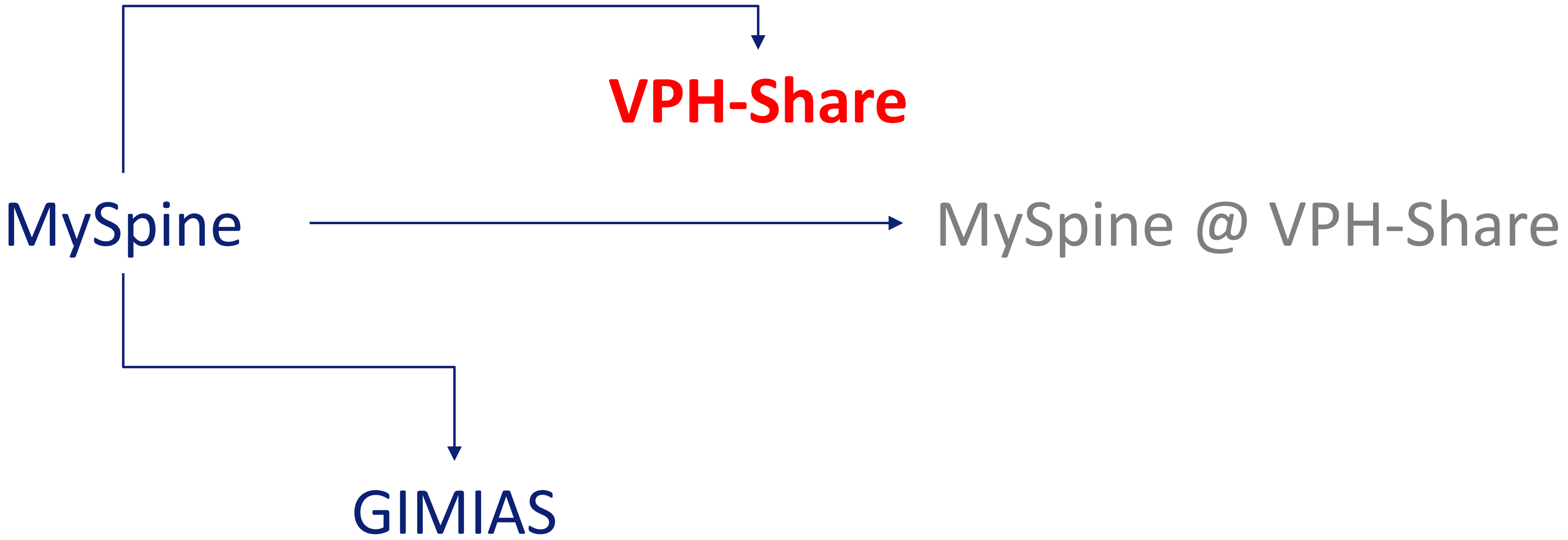
- Proper handling of unstructured grids
- Enhanced **XNAT** connectivity



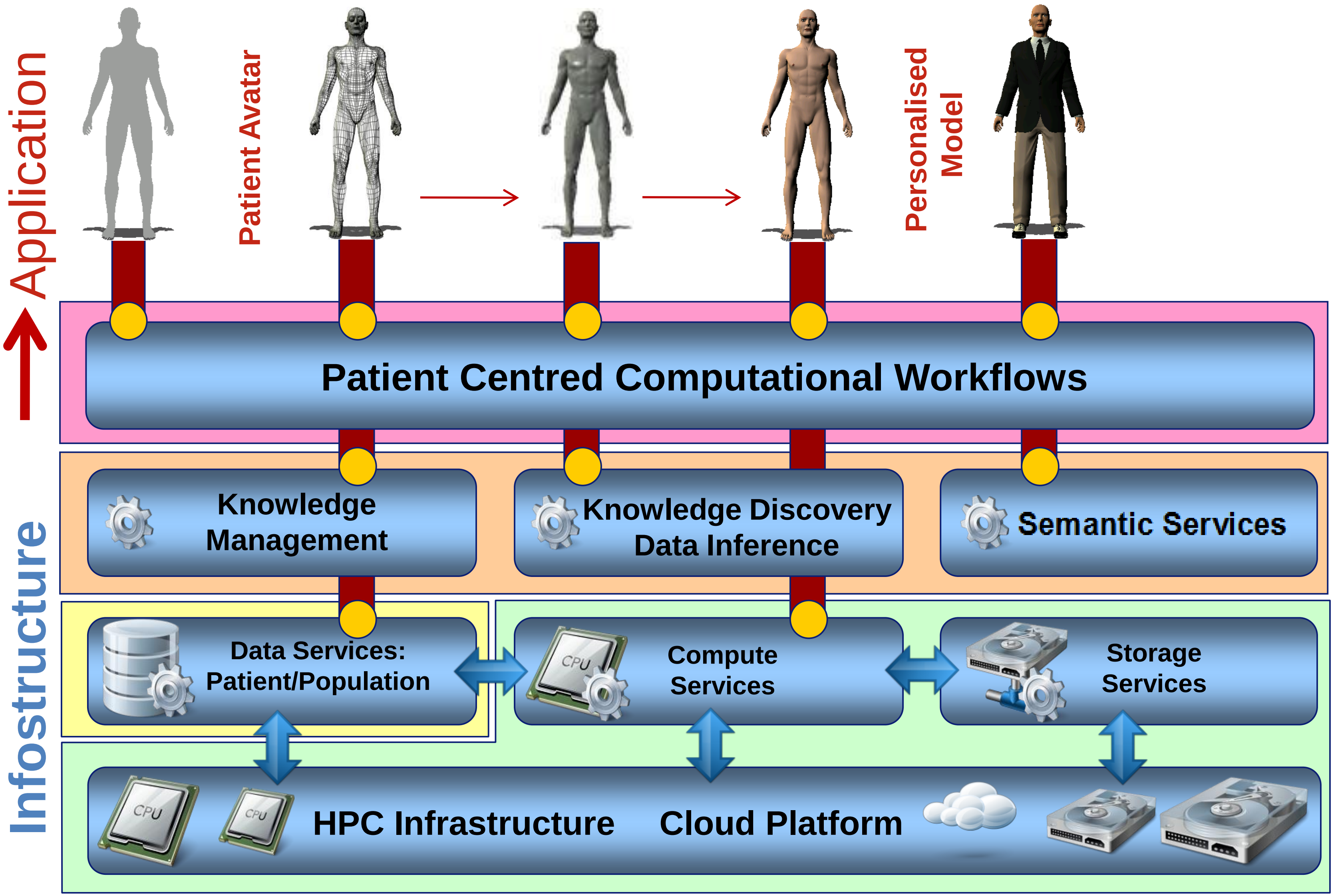
MySpine goals & needs

- Run 250 lumbar spine reconstructions in 3 weeks involving 6 Partners, 4 HPC facilities and 2 Medical centres.
- Provide a clinical prototype for validation by the medical centres and the project advisory board.
- Facilitate continuous deployment of upgrades and fixes to the users

Route Information

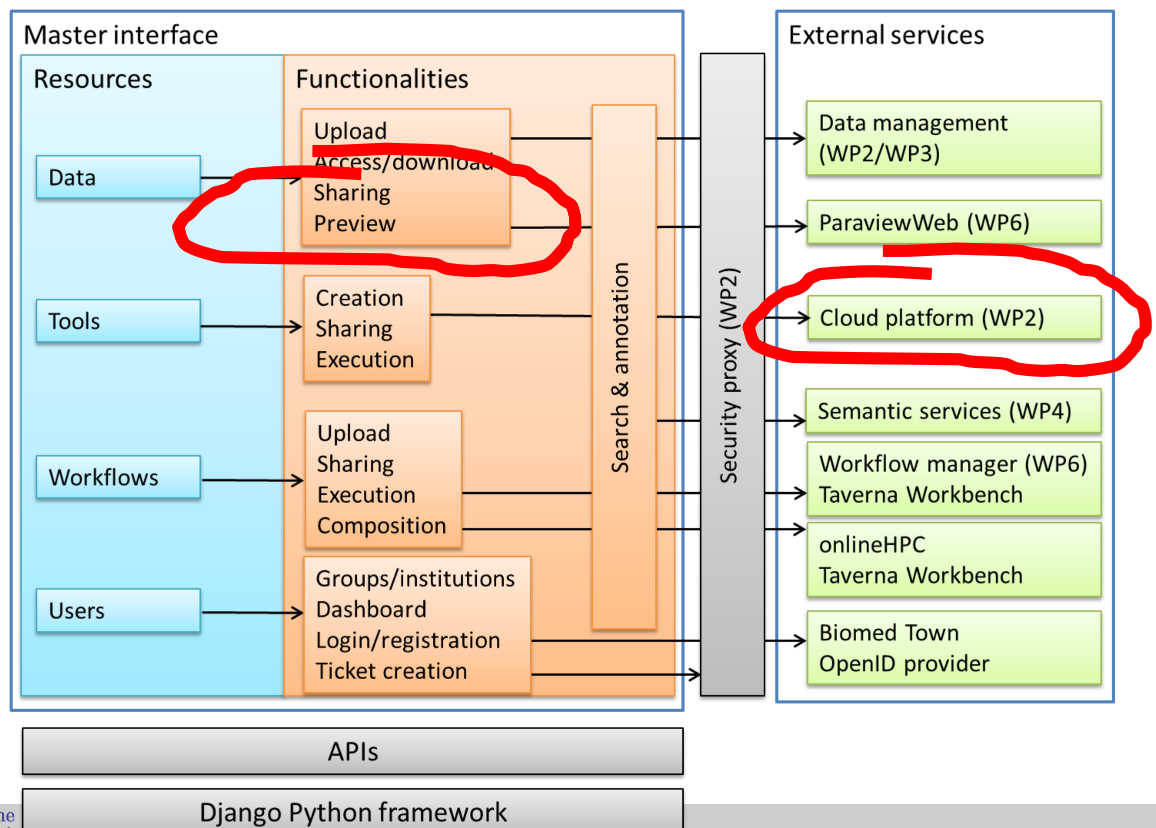


VPH-Share Overview

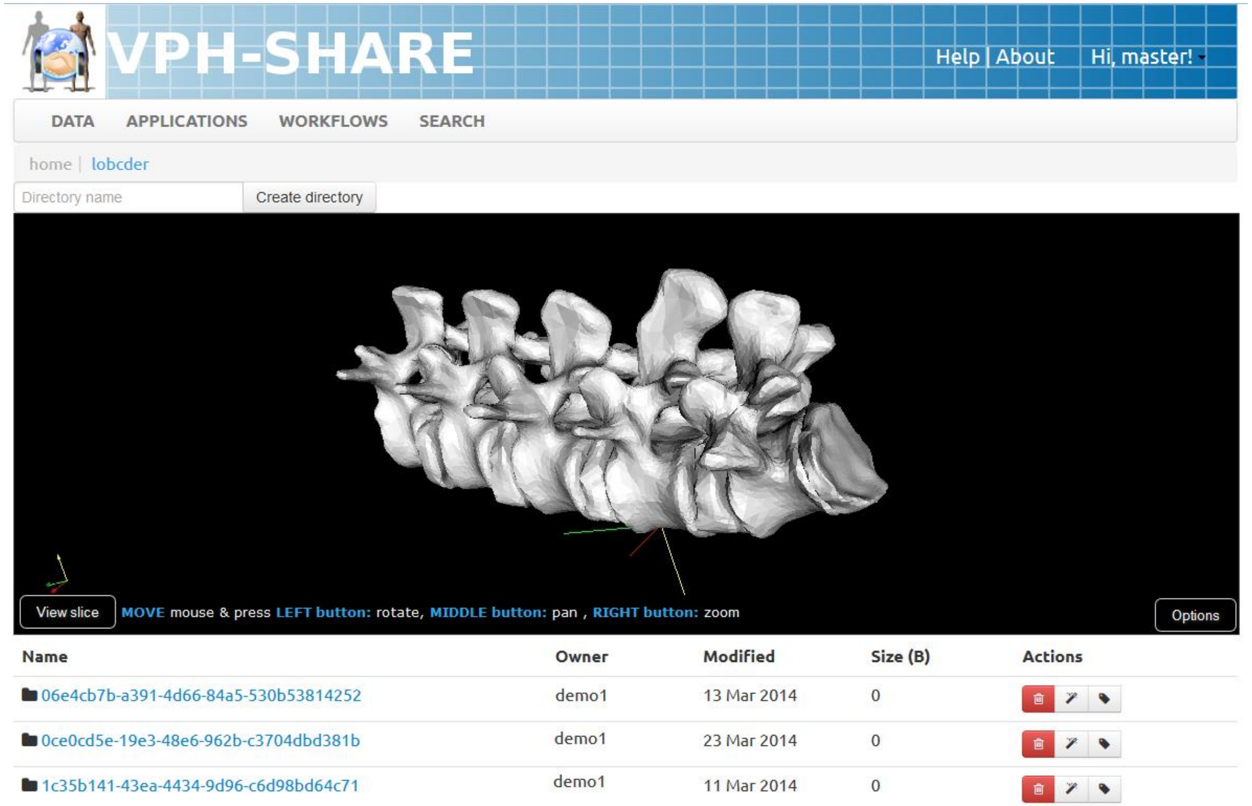


VPH-Share Infostructure

- VPH-Share flexibility comes from a rich support layer (the infostructure) where services are made accessible to user through the web-based Master Interface

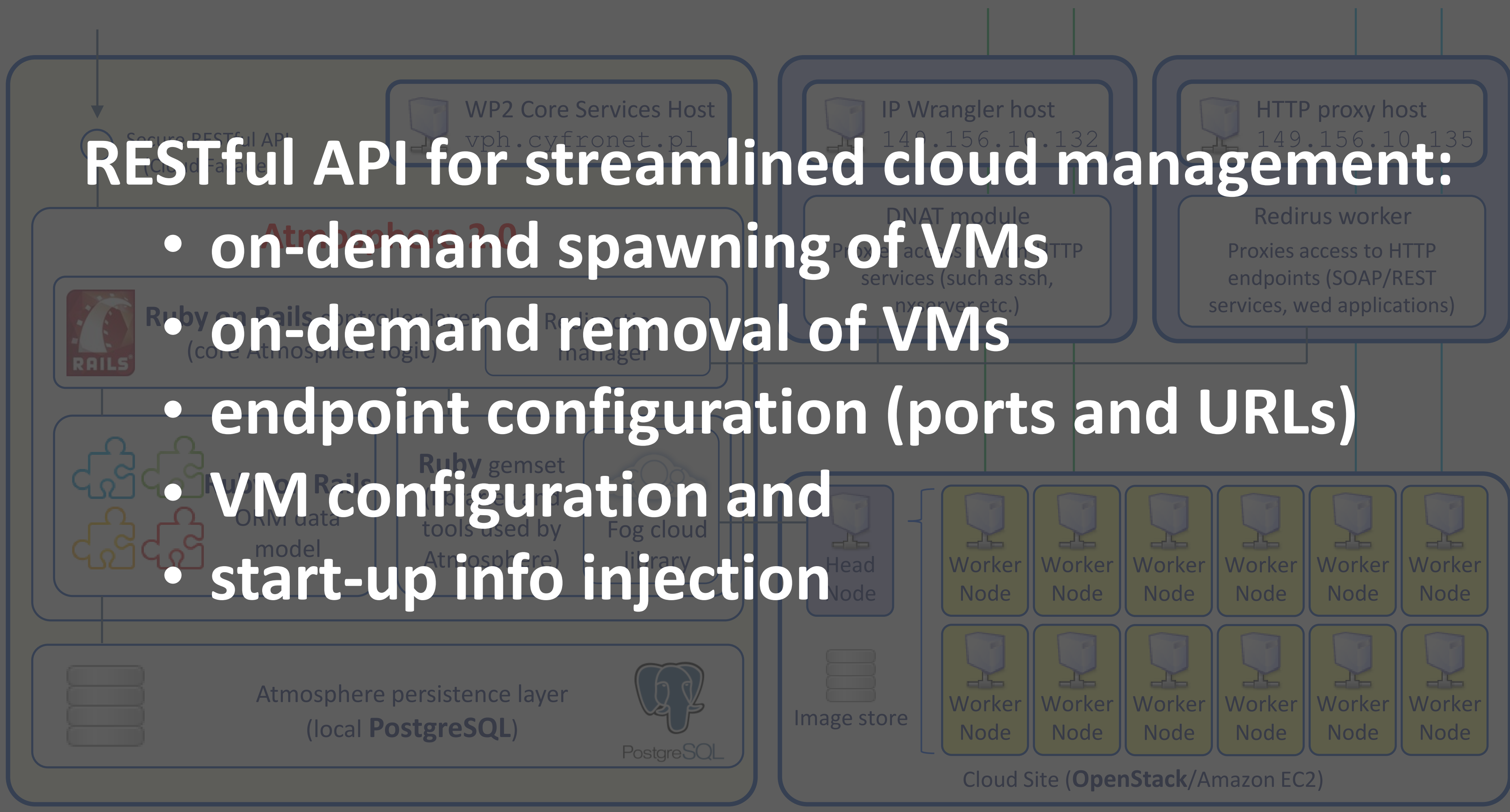


VTK File Preview in LOBCDER



ParaView Web

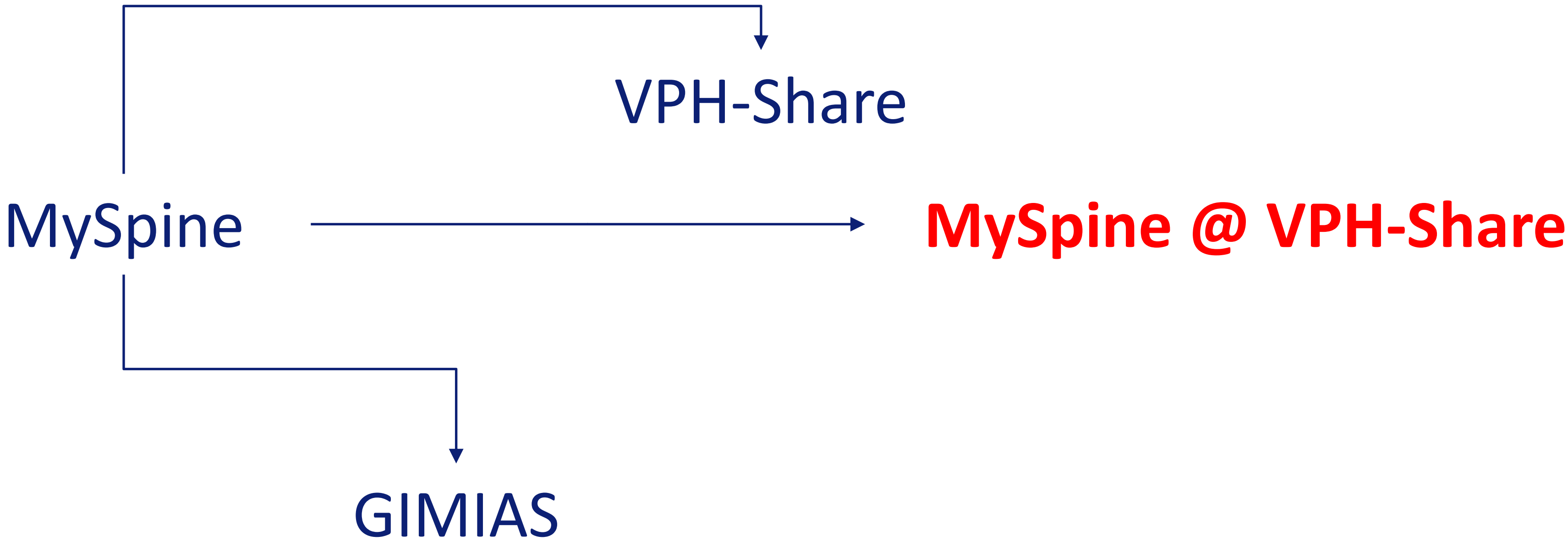
VPH-Share Cloud Services



RESTful API for streamlined cloud management:

- on-demand spawning of VMs
- on-demand removal of VMs
- endpoint configuration (ports and URLs)
- VM configuration and
- start-up info injection

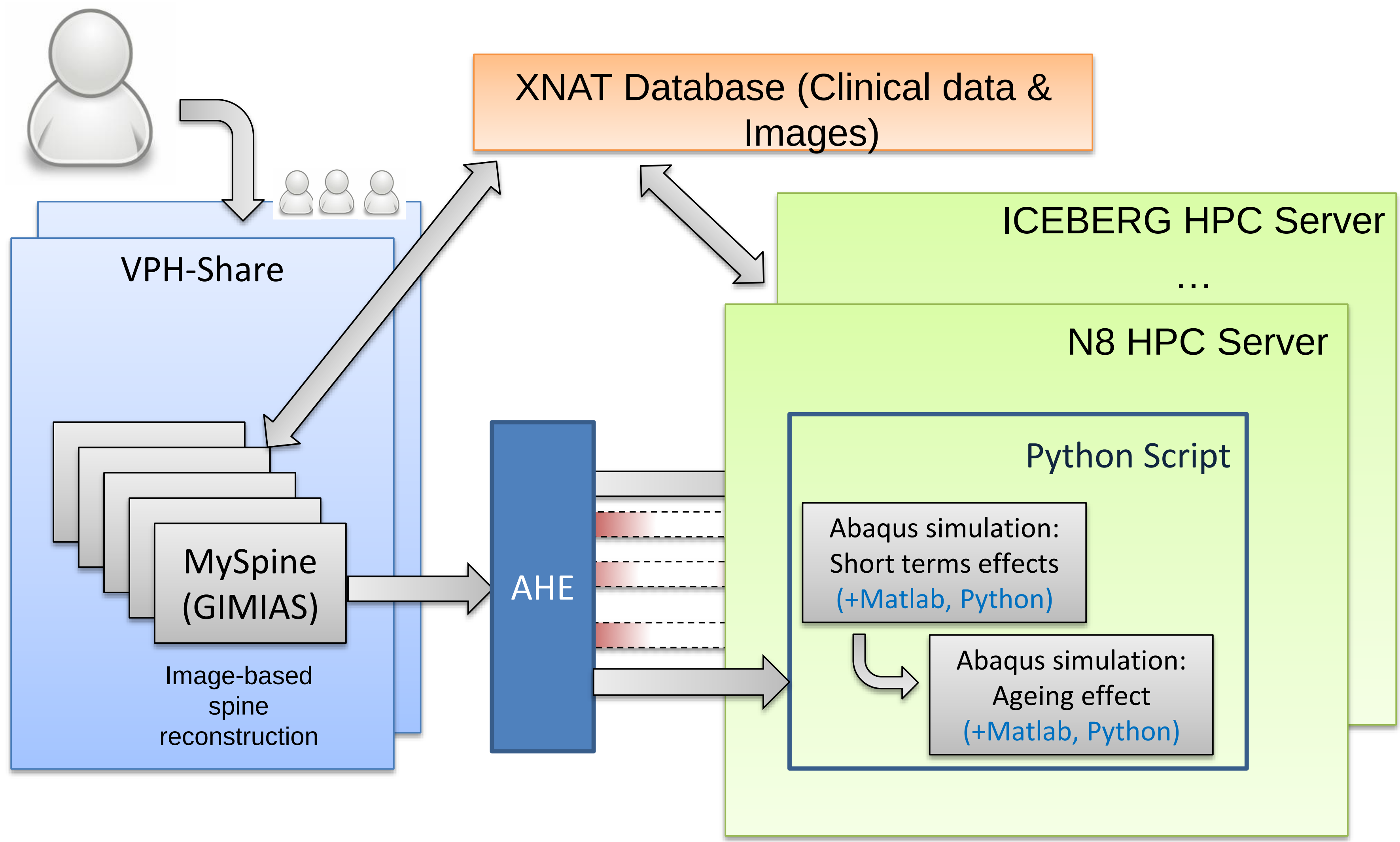
Route Information



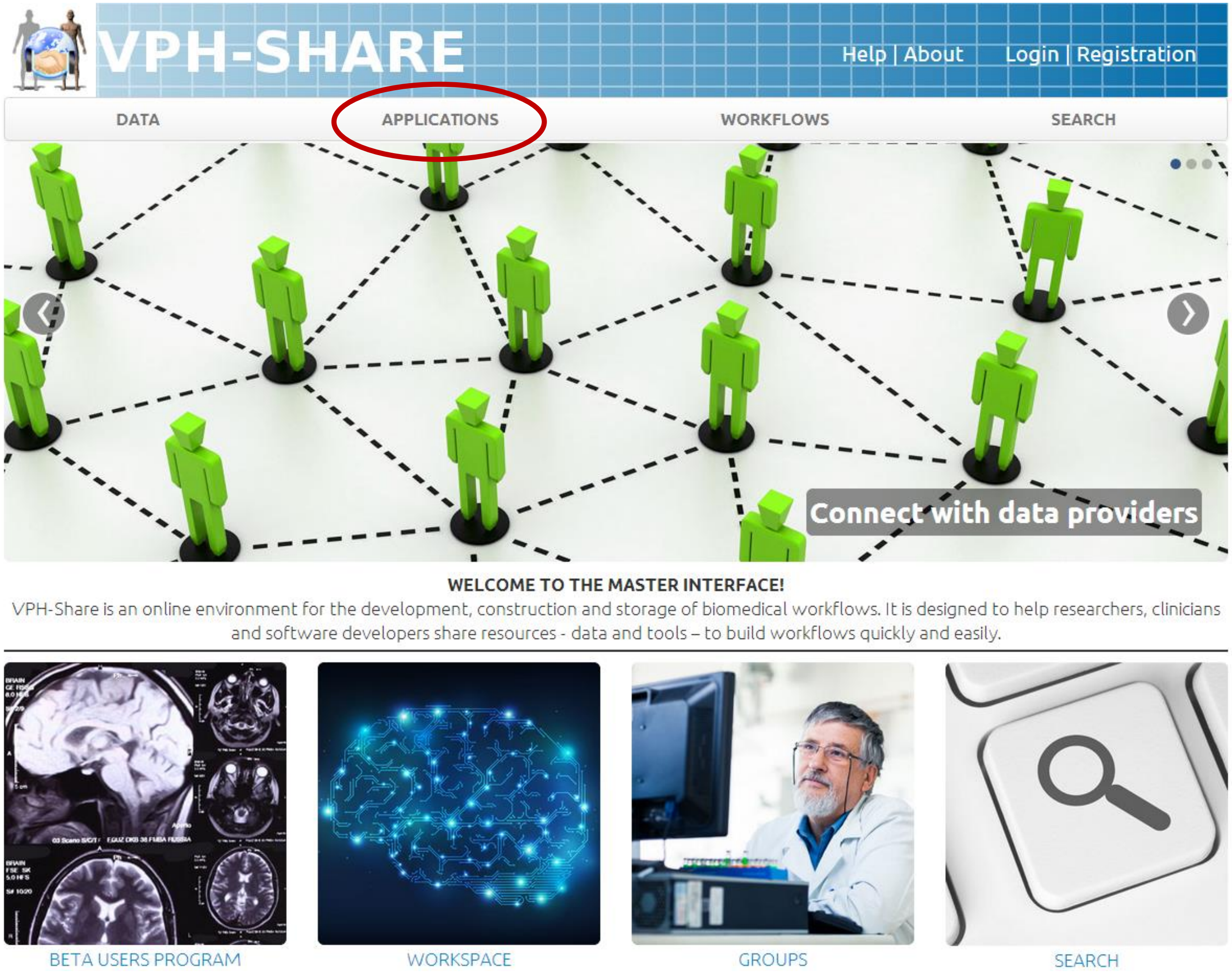
Expected Outcomes of MySpine in VPH-Share

- MySpine workflow made available at anytime, in anyplace to all partners
- Deployment of software upgrades automatically accessible to all partners
- Facilitate connectivity between MySpine software platform and HPC facilities

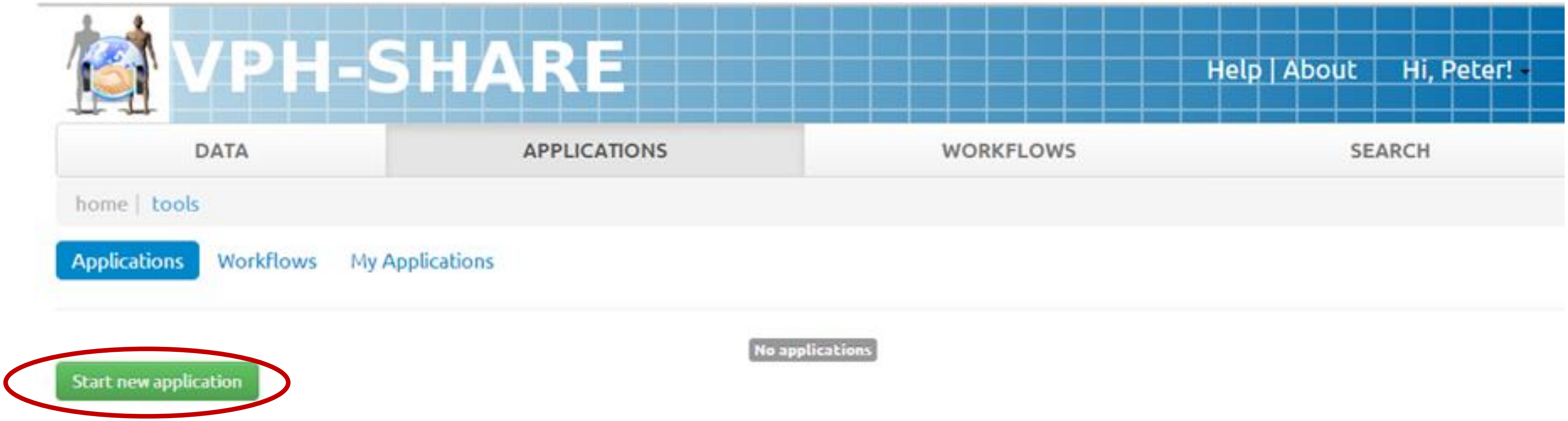
MySpine@VPH-Share Main Components



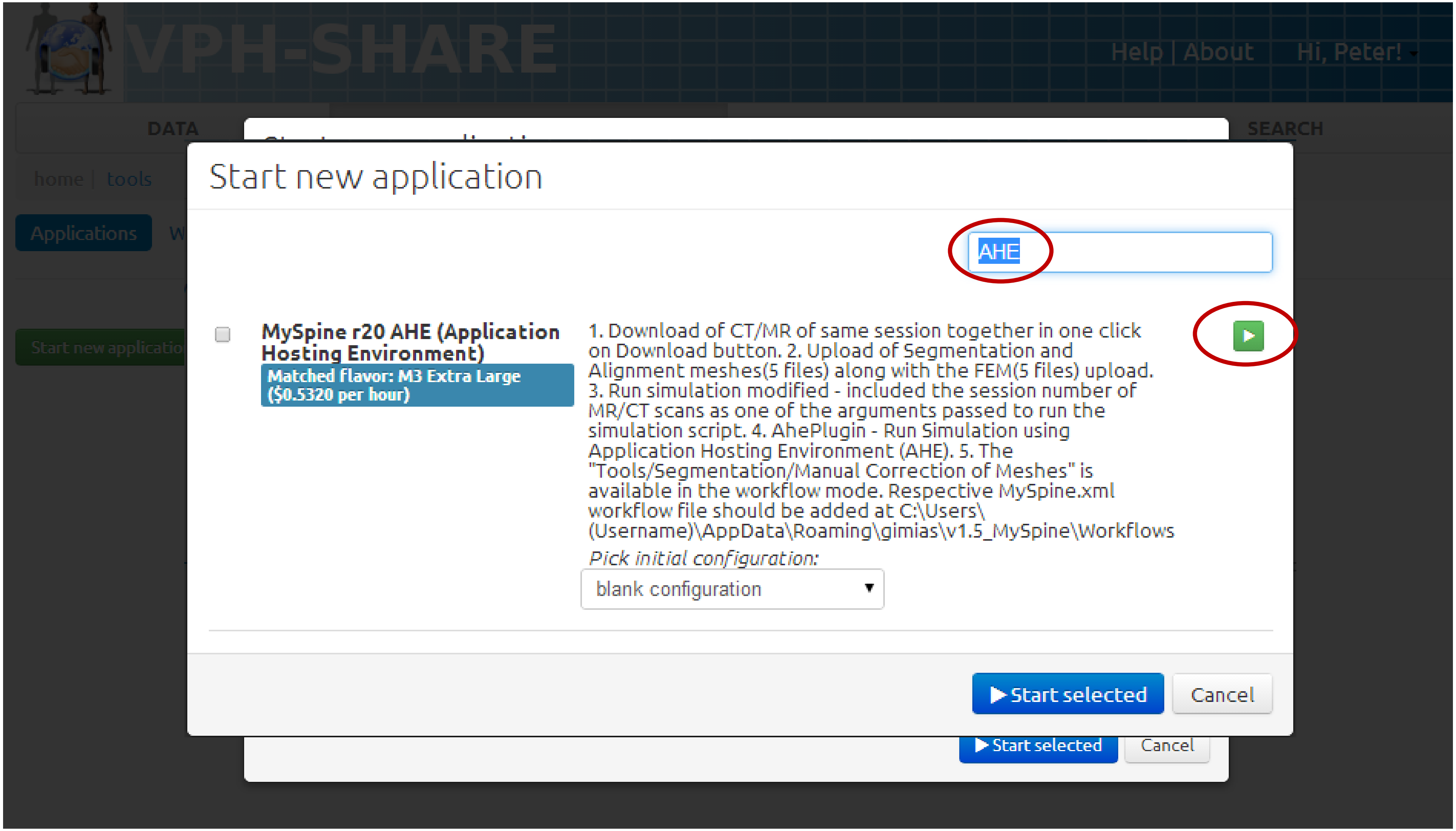
Starting MySpine@VPH-Share: application selection (1/3)



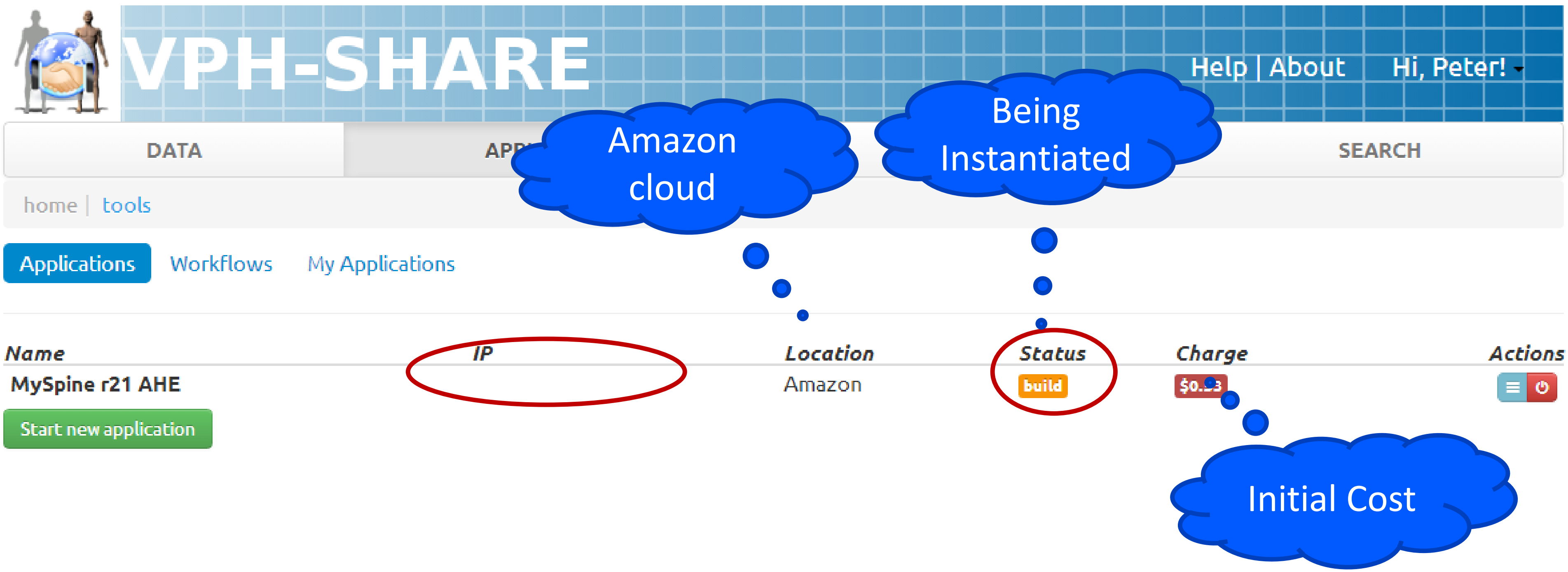
Starting MySpine@VPH-Share: application selection (2/3)



Starting MySpine@VPH-Share: application selection (3/3)

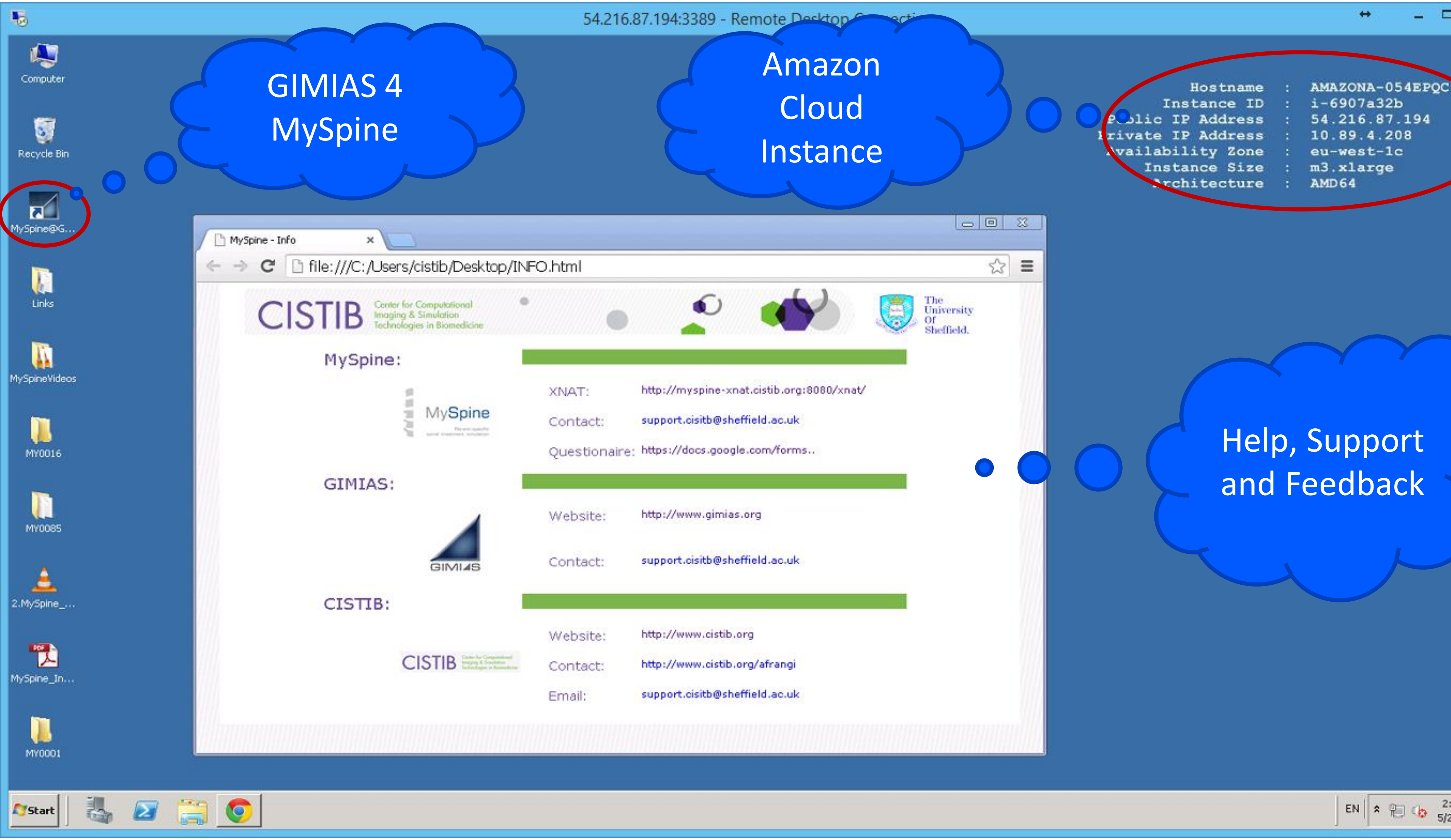


Starting MySpine@VPH-Share: cloud instantiation (1/2)



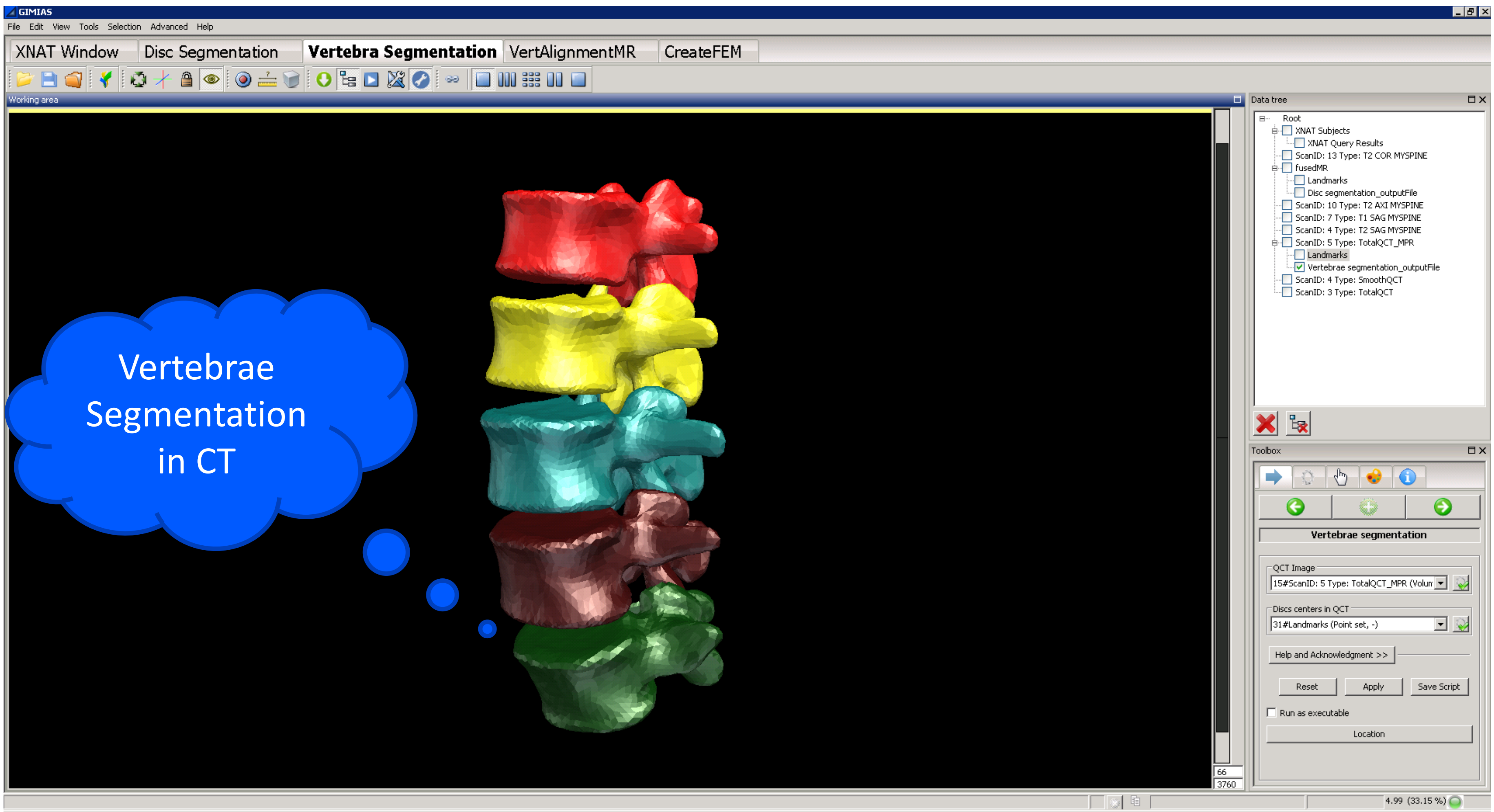
Starting MySpine@VPH-Share: cloud instantiation (1/2)

Connecting to MySpine@VPH-Share

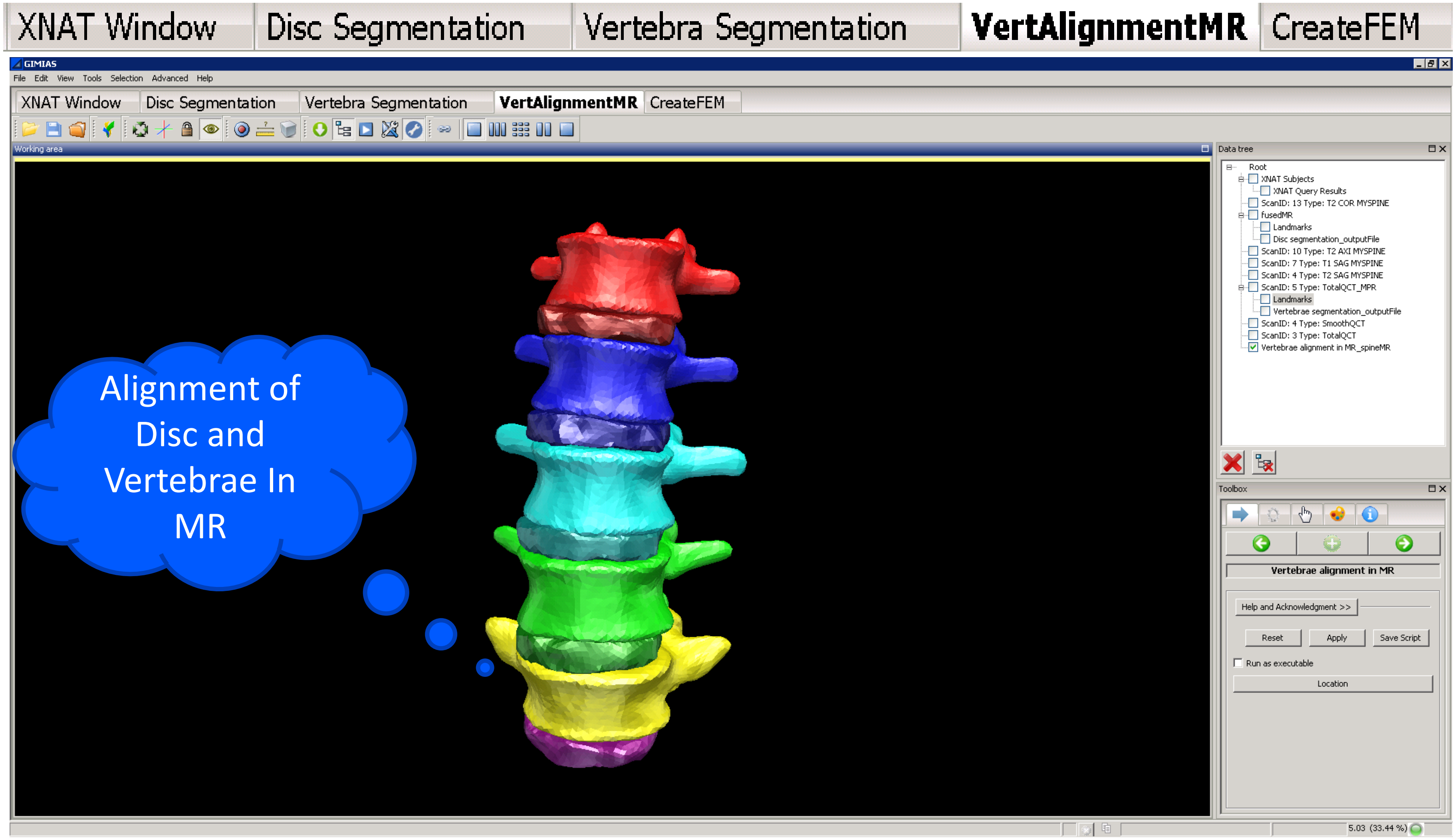


MySpine VM: Vertebra Segmentation

XNAT Window | Disc Segmentation | **Vertebra Segmentation** | VertAlignmentMR | CreateFEM

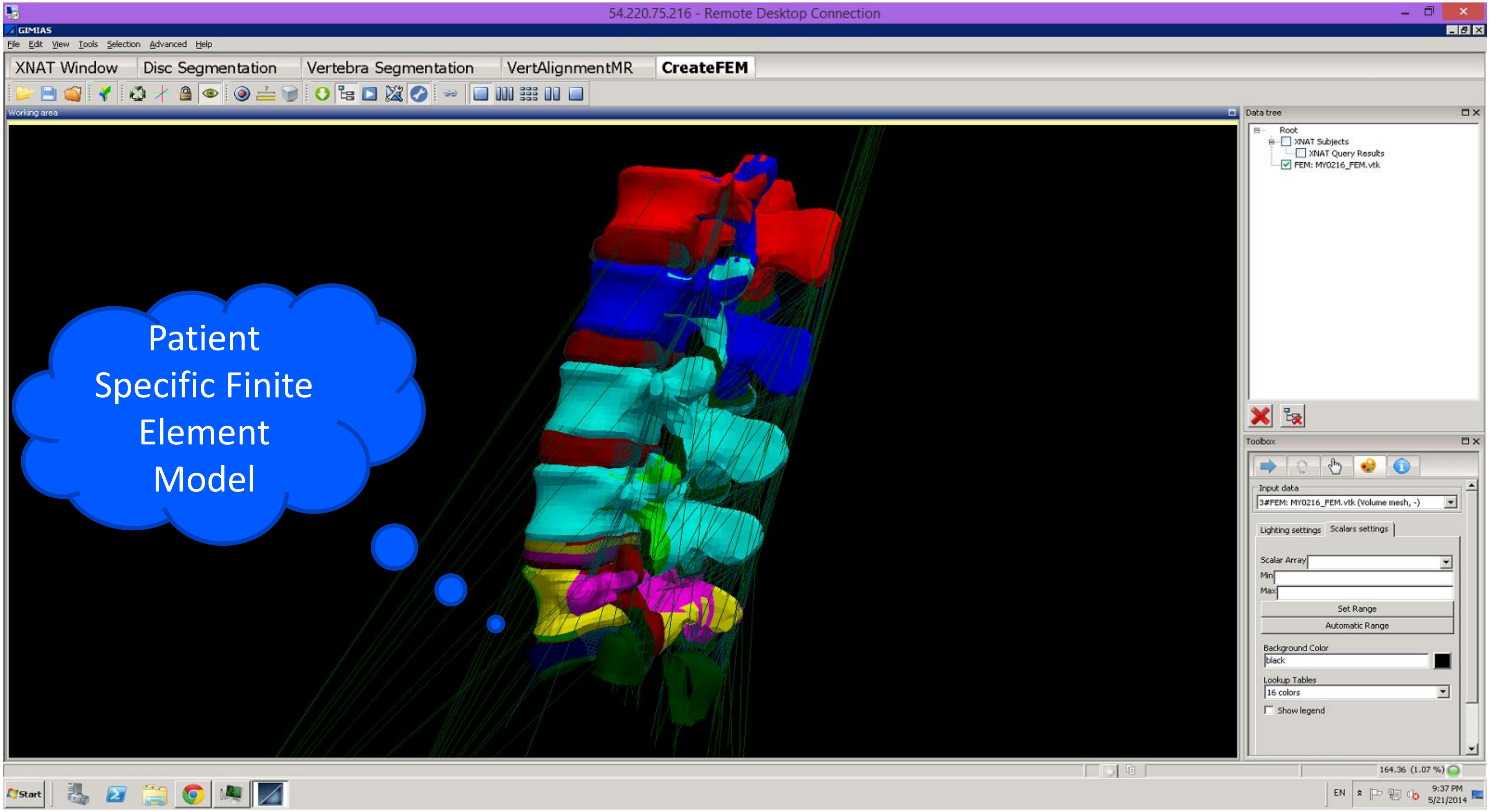


MySpine VM: MR/CT Alignment



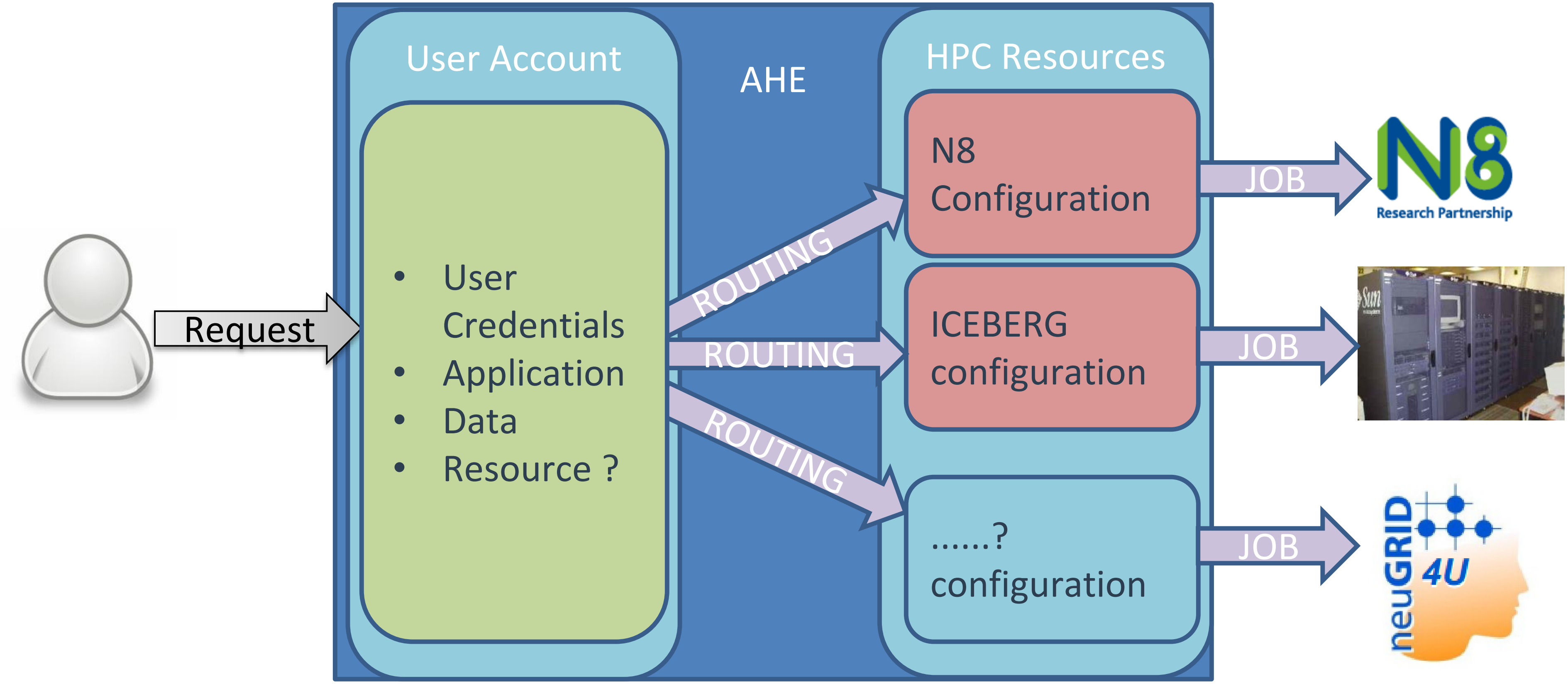
MySpine VM: FEM Generation

XNAT Window | Disc Segmentation | Vertebra Segmentation | VertAlignmentMR | **CreateFEM**

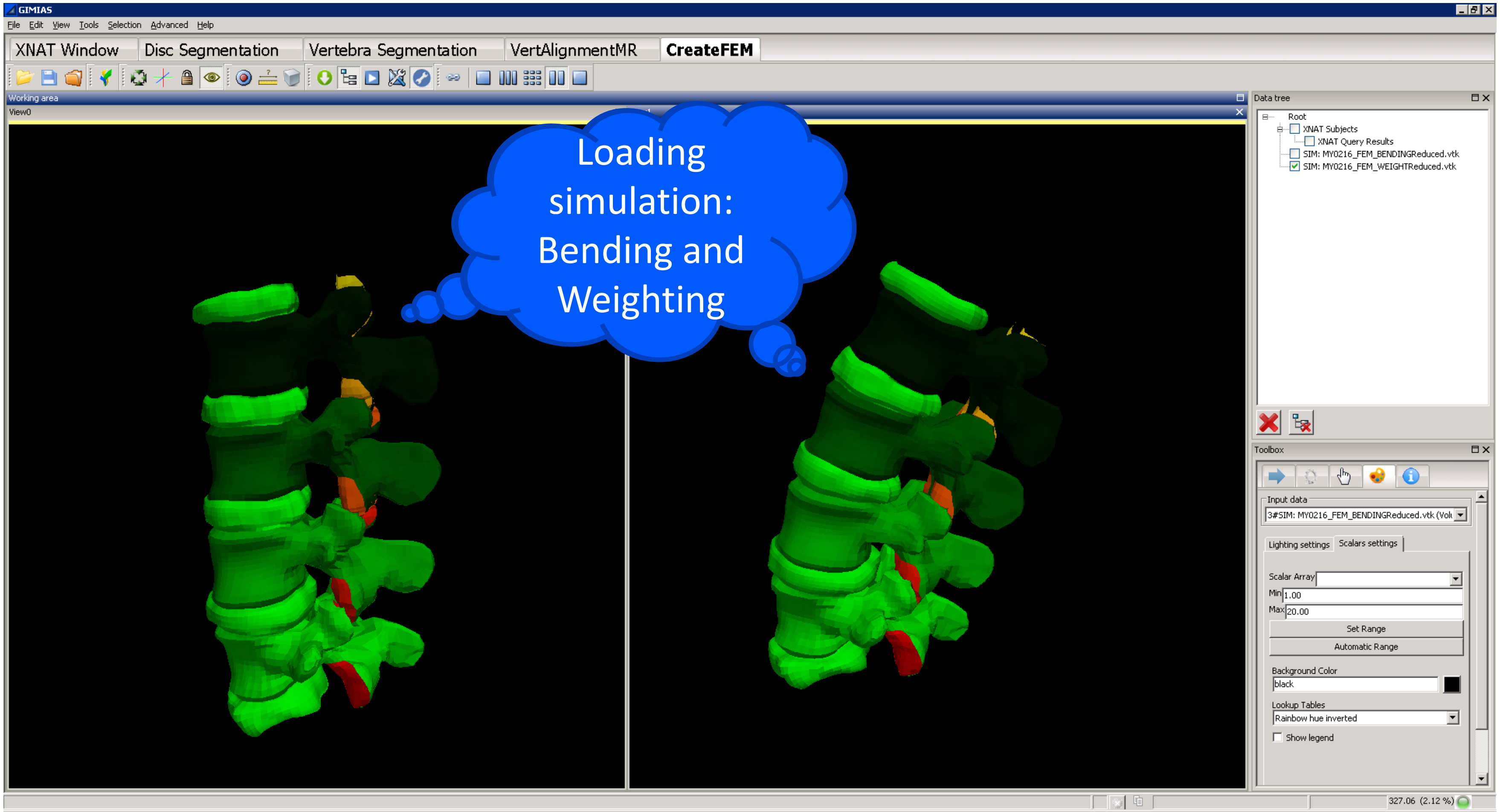


MySpine Workflow: Simulation on HPC

- Application Hosting Environment (AHE)



MySpine VM:
Visual Assessment of Simulation Outcomes



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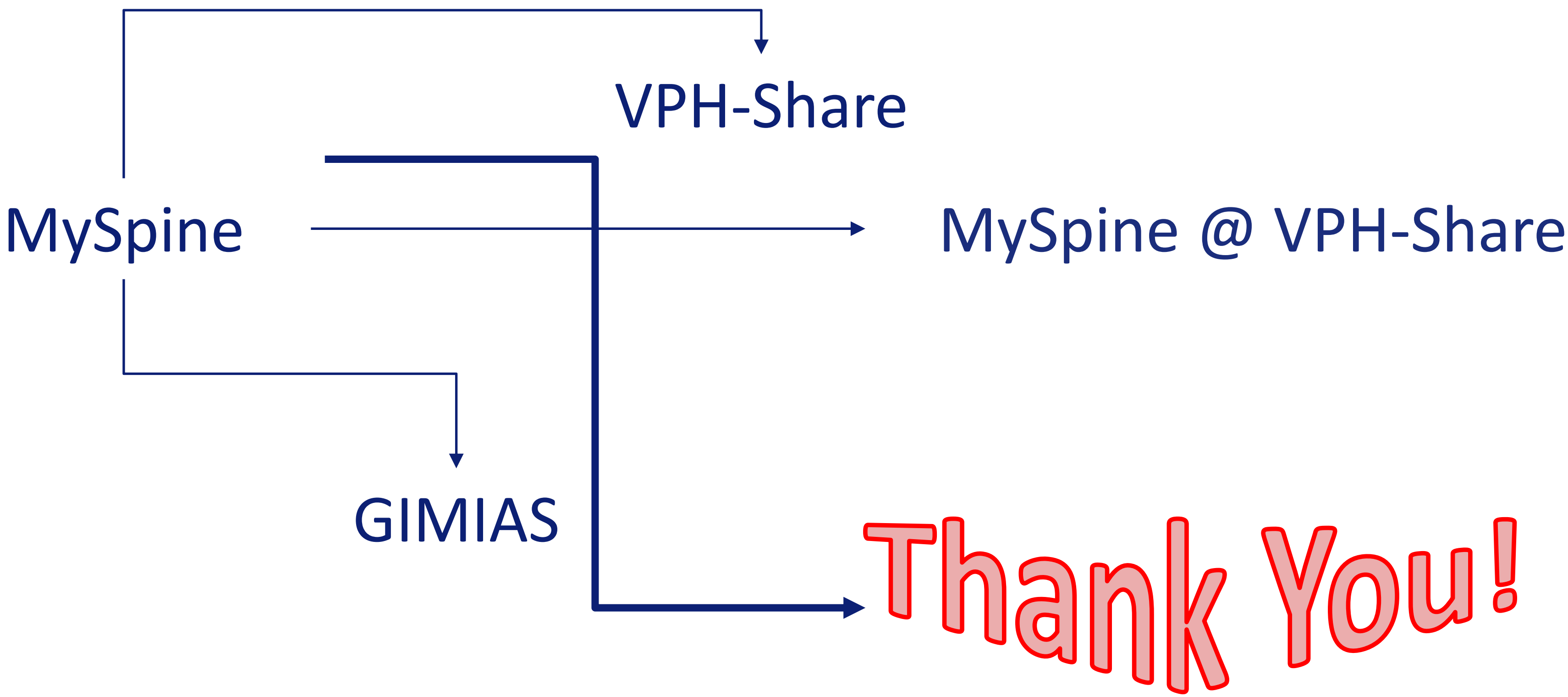

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