Accelerated Medical Computing Toolkit and GPU Accelerated Importance-Driven Volume Visualization

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Abstract

The aim of our Accelerated Medical Computing Toolkit is to significantly reduce the effort required to construct medical and surgical applications, such as visualization, image-based diagnosis, data processing and sharing, surgical planning, simulation, image-guided surgery and robot-assisted surgery. The toolkit is developed and organized as components which are appropriate cohesive units of functionality. Its component-based architecture allows developers to facilitate the design and assembly of applications from a mix of newly and previously developed components. Each component utilizes multicore CPU and GPU to accelerate the process. We demonstrate the use of the toolkit in the development of several medical applications including an innovative GPU accelerated importance-drive volume visualization method.

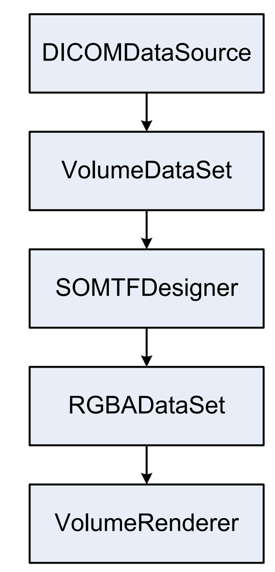
GPU Accelerated Importance-Driven Volume Visualization

Volume visualization aims to identify and visualize meaningful structures in a volumetric dataset. Typical volume visualization methods follow a bottom-up approach in which users would have no idea of *what is to be explored* and *what remains to be explored* in the volume.

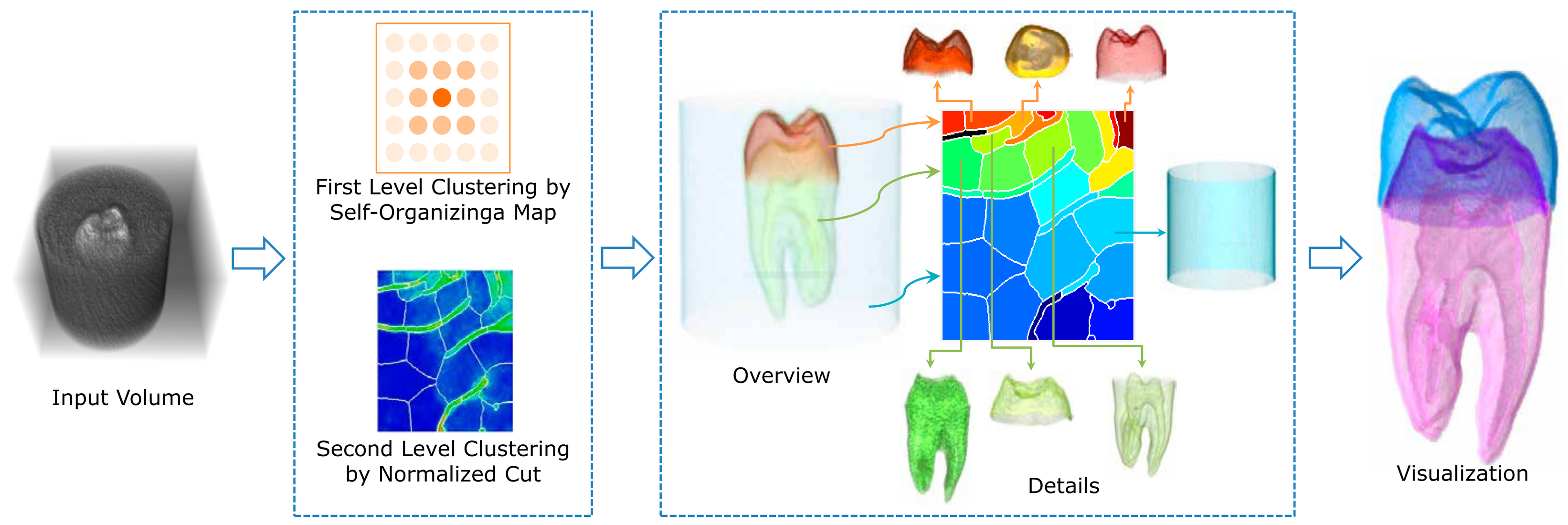
We propose an "overview first, details-on-demand" approach:

- The entire volume: a collection of volume items.
- Overview: the visualization of all volume items.
- Details-on-demand: the selection of volume items that correspond to interesting or important volumetric objects.

Our GPU-based implementation shows that the method improves the effectiveness and efficiency of volume visualization in medicine.

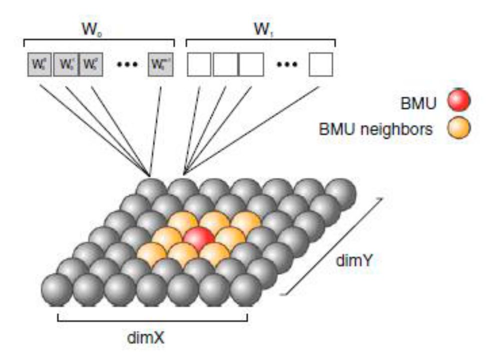


Component Diagram

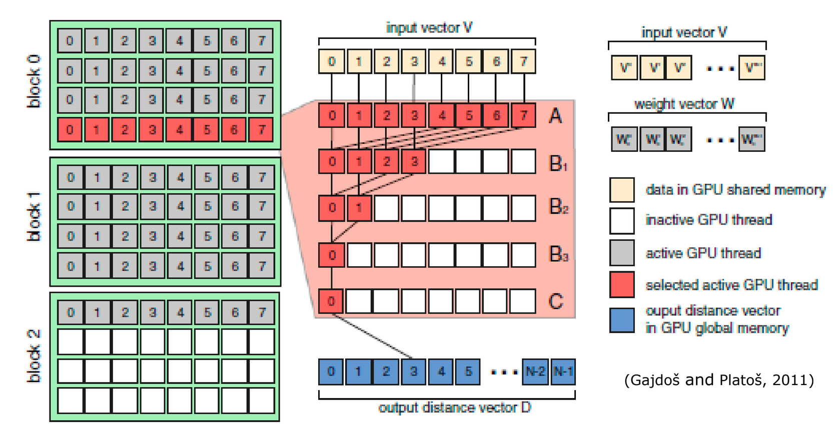


Volume Items Generation — "Overview first, details-on-demand" Volume Exploration

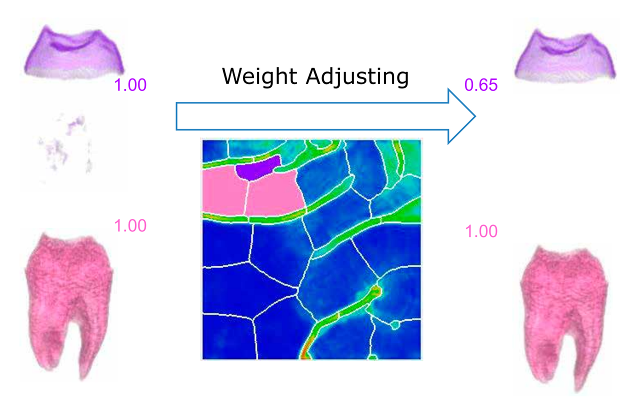
Generation of Volume Items



Example of the SOM

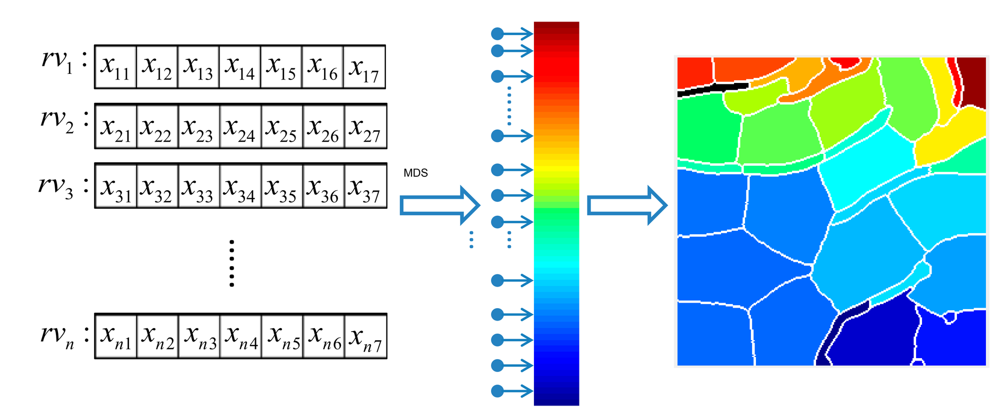


Processing of a single input vector by parallel GPU threads (Speed-up: ~20 times)

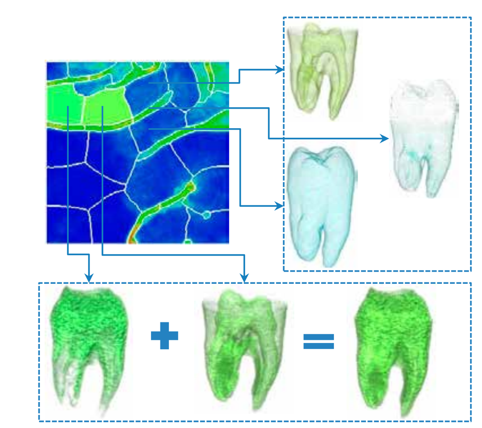


- Use self-organizing map (SOM) to project high-dimensional feature vectors to a 2-D topology-preserved embedding.
- Use Normalized cut to segment the 2-D SOM map into semantically related sub-regions.
- Modify *volume items* by weight adjusting.

Volume Exploration



Color assignment for overview generation



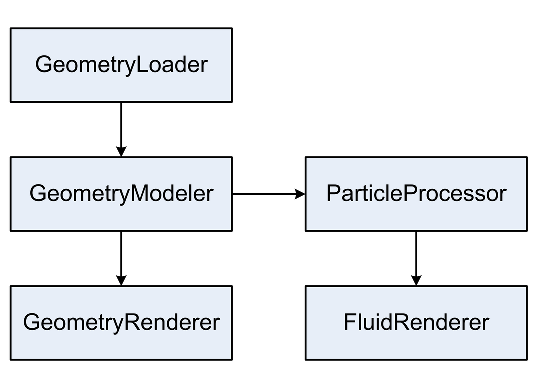
Exploration guidelines for details inspection

- Use multi-dimensional scaling (MDS) to convert representative vectors to 1-D points on the rainbow color scale.
- Use intensity and gradient to automatically assign opacities.
- Allow users to adjust optical properties.
- Guidelines for details inspection:
  - Valley items represent more meaningful structures than ridge items.
  - Similarly colored volume items represent similar structures and can be combined to form a complete structure.

Snapshot of Software Components

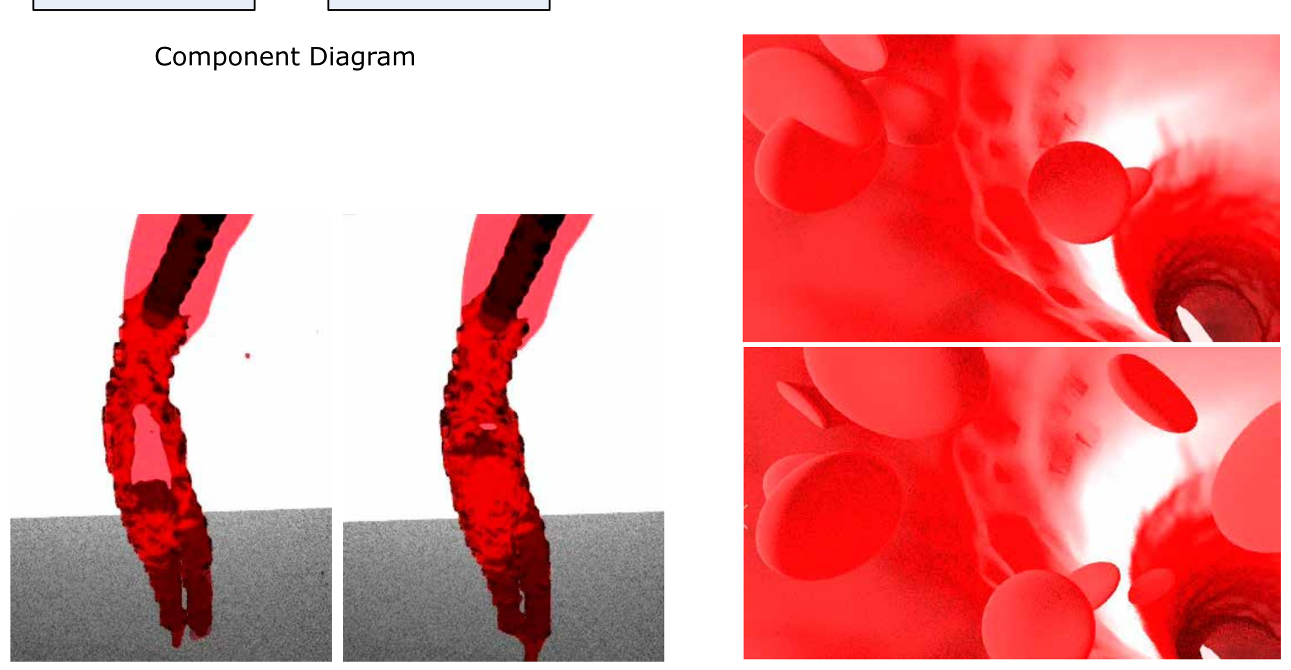
- Data Access: DICOMDataSource, RAWDataSource, VolumeDataSet, RGBADataSet
- Data Manipulation: SliceManipulator
- Segmentation: StdVolSegmenter, LSVolSegmenter, MLVolSegmenter
- Transfer Function Design: StdTFDesigner, VisDisDesigner, SOMTFDesigner
- Reconstruction: GeometryModeler, GeometryExporter, GeometryLoader
- Visualization: VolumeRenderer, GeometryRenderer, ParticleProcessor, FluidRenderer
- Tracking and Registration: ImageAcquirer, PointCloudProcessor, ObjectTracker, ImageProcessor, MedRegister, ARGenerator, InteractionProcessor
- Others: ClientServerCom

Simulation of Vascular Drug Delivery

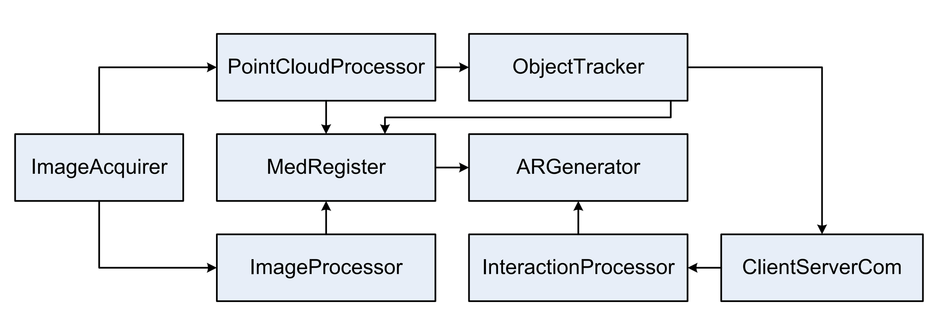


Component Diagram

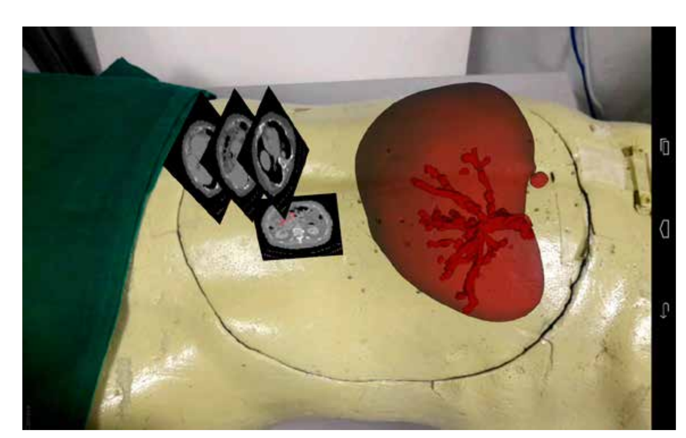
- A meshless flow simulation method based on an improved finite particle method.
- Task parallelization is performed to optimize the intensive computation of particle system using GPU.



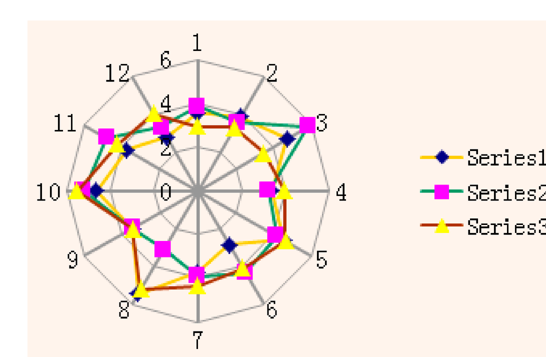
Augmented Reality-based Image-guided Surgery

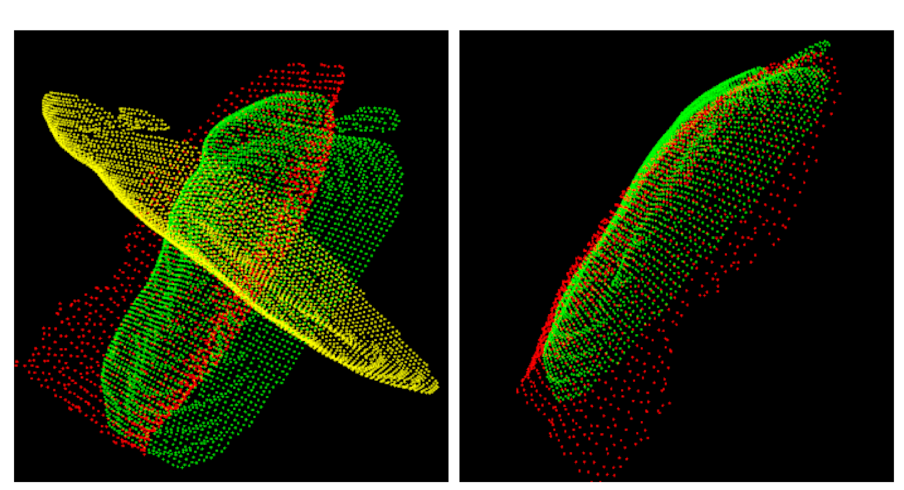


Component Diagram

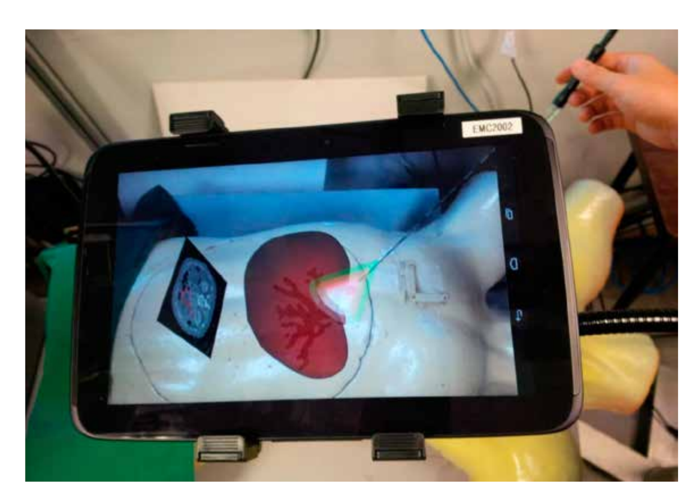


AR display of multimodal medical data





GPU-accelerated registration between point cloud and 3D model



Interactive surgical guidance using tablet-based AR

- GPU-accelerated computation is used for real-time augmented reality interaction between surgical tools and the organ models.
- AR visual guidance enables surgeons to manipulate radiofrequency needle to reach the target points from different directions.
- The colored cone volumes represent the safety working spaces and depth differences for surgical guidance.

Conclusion

We proposed and developed a GPU-accelerated component-based computing toolkit for medicine. The capability of the toolkit was demonstrated with applications including physics-based simulation of vascular blood flow, an augmented reality-based image guided surgical system and an innovative "overview first, details-on-demand" approach to importance-driven volume rendering of medical images. The latter GPU solution improves the effectiveness and efficiency of volume visualization in medicine.

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