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Software for the Use of Multi-Modality images in External Radiotherapy

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1. Introduction

This document contains the updated requirements list for SUMMER – WP4 Adaptive Visualization. It includes notes for changed or deleted requirements that, during development, were reconsidered.

1.1 Purpose of This Document

This document is intended to guide development of VrVis SUMMER – WP4 Adaptive Visualization.

1.2 How to Use This Document

The understanding of this document relies on the technical background of the reader. We expect that this document will be used by people with different skill sets, since the SUMMER Project brings together people from different professional and scientific backgrounds.
Medical doctors, project managers, software engineers and physicists are some of these with different backgrounds.

This document is organized in the following manner: the first chapter introduces the topic of this document and gives indications of its background and lists use-cases that moulded the requirements list. The second section describes the general requirements for the integration with other work packages and gives overview of the visualization framework. Section three gives details about the updated list of requirements for the visualization framework.

1.3 Scope of the Prototype

The software developed by VrVis for the SUMMER project is use-case based. Interviews, discussions, data and challenges from each medical partner (AKH, ICR, UKF and FSL) moulded the requirements listed in this document. The contributions to the project are driven by the specific needs of each use-case developed together with medical partners.

All software implementations must be integrated into MITK.

1.4 Medical Use Cases for the Prototype

The development of different features and MITK plugins will result in solving current challenges faced by medical staff in using their current software tools. Each partner has different data and requests, therefore a single, all comprehensive tool will not answer all needs. For each (use-) case, one or more plugins with specific UI, options and visualization modes have to be developed. Following, a list of use-cases and respective data and descriptions give the starting point for the discussion of the list of requirements.

1.4.1 4D PET/CT, 4DGTV, ITV, OAR, Dose Distribution

Radiation therapy proved to be a promising treatment in patients with lung cancer. Due to irradiation of the tumor with high dose and tempted sparing of the surrounding tissue and organs, precise delineations are necessary. One tool to realize higher precision is 4D imaging. During the whole treatment quality assurance (QA) is one crucial step. However, current treatment planning systems offer only QA steps based on 3D imaging. The QA capabilities (contour rating and plan evaluation) will be extended with a newly developed 4D visualization, which may better define the full physiologic extent of moving tumors and improve radiation treatment. For quality assurance purposes and follow up studies, adding dose volumes to the visualization will help to answer questions about how much dose was in a defined margin.

The data available for the development of the system is:

- 4D-PET/CT
- CT
- Binary volumes representing delineations of target volumes and OARs
- Dose distribution volumes

Use-Cases:

- Assessment and QA of defined structures such as GTV, ITV, and OARs.
- QA by better understanding the spatial configuration
- Visualization of the specific breathing motion of target volumes and OARs by including 4D images to better understand the full physiologic extent of moving tumors and therefore improve treatment
- Assessment of the planned dose for QA or to choose between alternative plans

1.4.2 Deformable Registration Visualization

Modeling of respiratory motion has become increasingly important in various applications of medical imaging (e.g., radiation therapy of lung cancer). Current modeling approaches are usually confined to intra-patient registration of 3D image data representing the individual patient's anatomy at different breathing phases. Uncertainties in image registration may be a significant source of errors in anatomy mapping as well as dose accumulation in radiotherapy. It is, therefore, essential to validate the accuracy of image registration, before applying contour deformation and dose summation. Including this information in tumor delineation and dose planning has the potential to improve treatment planning in radiotherapy.

The data available for the development of the system is:

- 4D-CT
- CT
- CBCT

Use-cases:

- Visual inspection a deformable registration results of 4D-CT for motion modelling
- Automatic detection and visualization of registration mismatches
- Visualization and detection of DVF irregularities
- Image and contour warping for live image fusion and 4D contour propagation
- Dose warping and visualization of DVHs and fusion 3D dose distribution data-fusion

1.4.3 MRSI visualization, segmentation and analysis

MR Spectroscopy data is highly complex by gathering many values per pixel. These values represent concentrations of chemical components in the brain. For tumour patients, certain ratios of these components are well known to be strong indicators of radio-resistant tumour cells. Furthermore, patients with GBM relapse after RT treatment and survival rate is null. Medical partner wishes to have faster methods to select/segment interesting ranges of values, as well as appropriate ways of looking at data and interact with it [STAR2014].

The data available for the development of the system is:

- MR: CE-T1, FLAIR
- MR Spectroscopy metabolite maps and ratios
- Segmentations

To realize this, a set of use-cases were design to support our development. Our solution is an IVA system combining MITK and ComVis. ComVis, a CMV system, is used to support an alternative approach to data visualization. It brings many different statistical views that are connected between them. ComVis is flexible enough to allow the creation of new views to mitigate specific requirements.

Use-cases:

- Analysis and BTV computation – Faster analysis and delineation of BTV
- Tumour Signature – Take measurements of different tissues for each patient, in a very short period of time and be able to compare it to other patients' data values.
- Personalised Analysis – Allow analysis of different tissues types to determine which ranges of values can be considered healthy or anomalous, for each patient.
- Tissue classification – Probability analysis over spectral ranges of MRSI, for comparison with relapsed volumes.
- Longitudinal Studies – analyse the evolution of ratios and other MR values throughout exams per patients. Medical partner wants to understand how these values change and possibly find common indicators across relapsing patients.

1.4.4 fMRI visualization and analysis

Medical partner wishes to visualise and analyse fMRI data together with accompanying MR datasets. Connectivity matrices are extracted from raw data, as well as network measurements. It is required to visualize longitudinal changes in patients' connectivity values to understand how RT impacts local and general brain functioning. In addition, doctors would like to know if it is possible to assess the direction tumour evolves in the brain.

The data provided by our medical partner is:

- MR: CE-T1, FLAIR
- functional MRI: connectivity matrices, brain network measurements by nodes
- DTI tracts
- Segmentations
- MNI Standard Brain

The same IVA system from 1.4.3 is used to provide support for the designed use-cases.

Use-cases:

- Tractography– Visualise disruptions in main white matter tracts filtered by ROIs.
- Connectivity measures together with tracts – Visualising connectivity matrix as a heatmap and fast interaction with connectome by selecting and thresholding matrix nodes' values. DTI tracts can be filtered according to user selection.
- Longitudinal comparisons – Comparison of two connectivity matrices of different time points. It is wished to map these matrices back to the brain as a network graph and then analyse the differences between the two time points. Analysing changes in connectivity values between time points: if they get stronger or weaker, or if there are new connections or loss of connections. It is also desired to see the evolution of tracts between exams.
- Inter-Patient analysis – Since datasets are registered to the same standard brain, medical partner would like to see if it is possible to find patterns in data across patients and brain areas.

2. General Description

The SUMMER project agreed to use MITK as the common framework for development and integration of the different parts of the project. VrVis' contribution to this framework will help to solve visualization and analysis challenges for multi-modal radiotherapy data. The software is targeted to be used by physicians, medical researchers and clinical staff.

2.1 Prototype Functions

Main functionalities of the plugins will include:

- 2D, 3D and 4D (3D+time) visualization of multi-modal radiotherapy data
- Multi-modal data fusion
- Extraction of features for visualizing properties of the underlying data
- Interaction with data
- Including visual analytics tools complementary to volume visualization, such as CMV (ComVis)

2.2 MITK

The Medical Imaging ToolKit is the common framework used as an integration platform and used by the different partners to exchange data and results. MITK offers already a range of plugins for medical imaging processing, interaction and visualization. It also offers the possibility to be extended by adding new plugins. The MITK Workbench (Fig. 2) is composed by 3 main sections: Data Manager (1), the standard display for Axial, Sagittal, Coronal and 3D views (2), and the plugin area (3) where several plugins can run at the same time in a tabbed sequence.

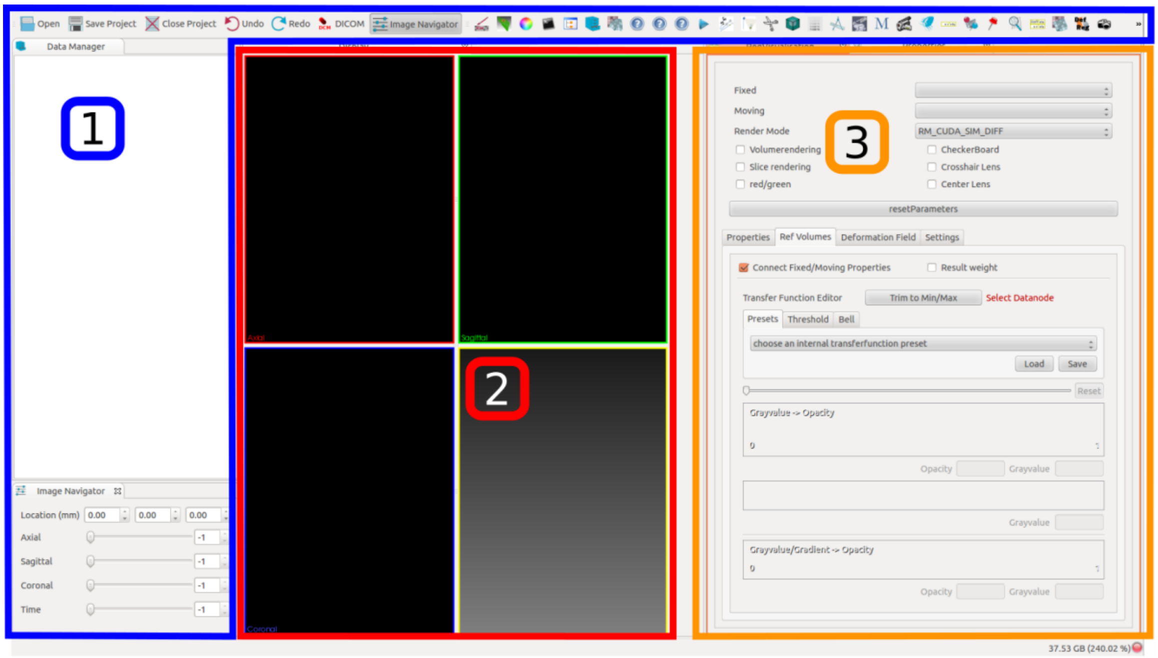

Figure 1: MITK Workbench

Plugins will be developed to answer specific requirements obtained from the use-cases discussed with medical partners. These plugins are responsible for user interaction, loading and feeding data to our internal implementations, such as the rendering core, image processing algorithms and connected software.

2.3 Integration

Rendering Engine

In order to answer the need of a 3D multi-modal volume renderer for multiple datasets, a separated rendering engine has to be developed and later integrated into MITK.
Since MITK uses VTK as its core visualization pipeline, VTK was chosen to be used as basis for the integration of the rendering engine. To make full use of GPU capabilities, the development of rendering algorithms will be performed in NVIDIA's CUDA language and OpenGL.
The integration process of our rendering mechanisms can be seen in fig. 2. A VTK Mapper interface is responsible to maintain communication and information transfer between data held in the MITK data manager and the GPU data storage and our rendering algorithms.

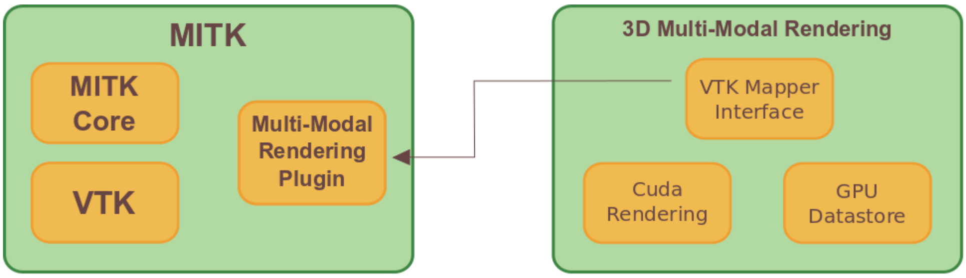

Figure 2: MITK Integration

Coordinated Multiple Views

Another part of the system's workflow is depicted in Fig. 3. Data is loaded into MITK, which will then connect to ComVis and send the necessary data. Interaction in ComVis' views results in the automatic creation and update of segmentations in MITK. ComVis allows the creation of new data through its data fusion plugin [MRS_2014].

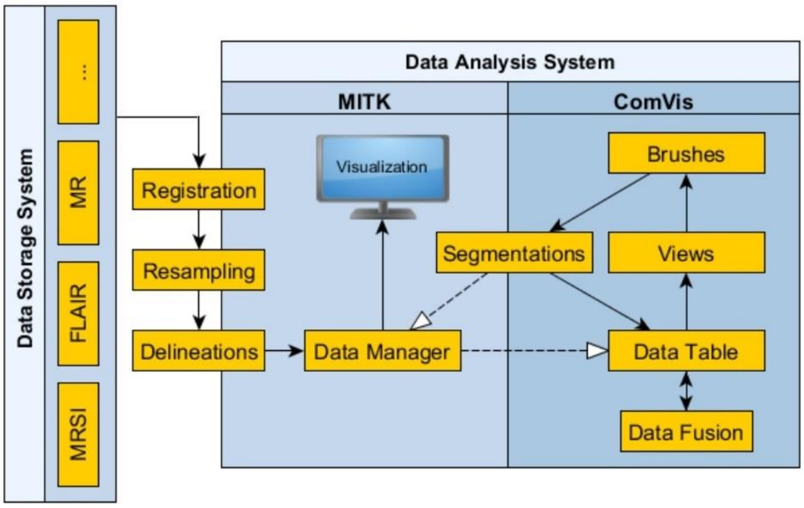

Figure 3: MITK-ComVis System Workflow

Communication between ComVis and MITK is done via TCP/IP. Messages containing data information and 3D positions of voxels are transmitted whenever the user modifies data or when there is interaction. This keeps the system updated allowing instant visual validation of what data is selected and what it represents in the reference anatomical images.

2.4 Core

The core rendering system is depicted in Fig 4. It consists of three main parts: a GPU data store, a compute module and a rendering module. It integrates in MITK via a VTK interface and is configurable via the UI. For different use cases different plugins are implemented and used to configure the use-case specific visualizations. The compute and rendering modules make use of a template library for defining the use-case specific computations and rendering modes in a modular extendible way. Data exchange between the CPU and GPU is bidirectional.

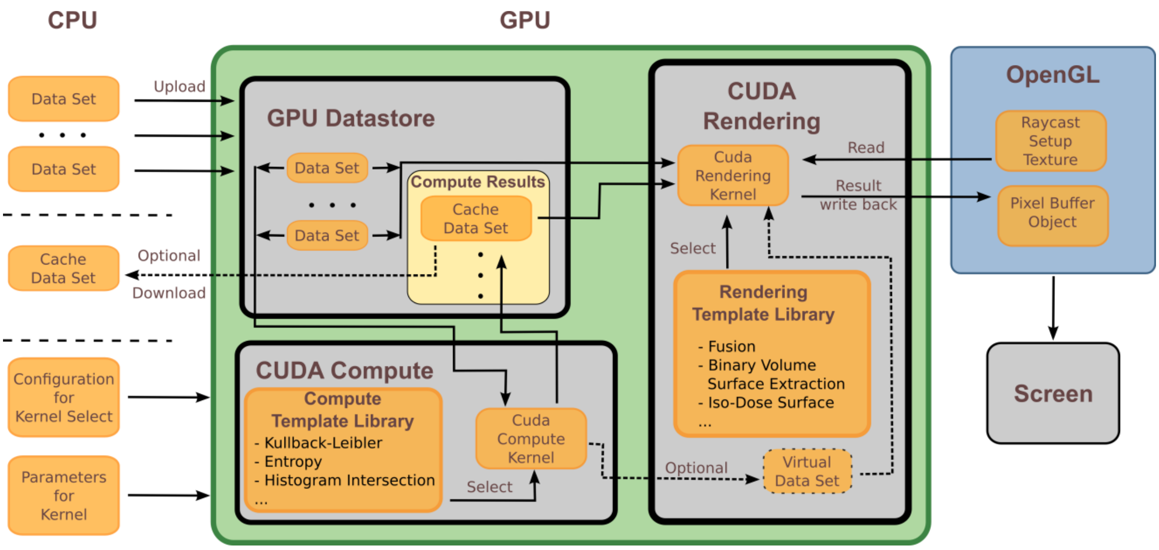

Figure 4: Rendering Framework Core

2.5 User Characteristics

This software is thought to be used by physicians and researchers from the radiotherapy area. Users from other research areas, such as neuro-degenerative diseases, could include their data in our system and find similar benefits from our visualization and analysis implementations.
Users should be experienced in interpreting medical imaging data.

Users might initially find the use of CMV as an initial obstacle, for the reason that this kind of approach is not typically found in medical research centres.

2.6 General Constraints

The development of specific visualizations is constrained by the data delivered by medical partners and existing combinations of multi-modal data.

MITK plugins run both in Linux, MacOS and Windows, however, ComVis is only distributed for Windows. ComVis can be connected to MITK via TCP/IP, which allows users to use MITK in a Linux, MacOS or Windows machine and use a second Windows machine to run ComVis.

2.7 Assumptions and Dependencies

The CUDA rendering engine is delivered as linkable libraries. ComVis is delivered as executable and DLLs for Windows 7 64bits.

Hardware requirements as agreed by the SUMMER consortium are:

- NVIDIA graphics card supporting CUDA compute capability 3.0 or higher with a minimum of 2GB memory
- 16GB RAM

3. Specific Requirements

This section of the document lists specific requirements for WP4 Adaptive Visualization. Requirements are divided into the following sections:

1. Medical Use Case Requirements. These are requirements coming directly from the discussions with the medical partners.

2. Application Level Requirements. These are detailed specifications describing the functions the plugins must be capable of doing.
3. Core Level Requirements. These are detailed specifications describing the functions the visualization core must be capable of doing.
4. Interface requirements. These are requirements about the user interface, which may be expressed as a list, as a narrative, or as images of screen mock-ups.

Both priorities and innovation level columns list values with the following correspondence: 1-High, 2-Medium, 3-Low. “MITK responsibility” stands for a certain functionality is already provided by the internal sub-system of MITK. “Changed to plugin responsibility.” Stands for functionality available in MITK but needs to be implemented in specific plugins and not in the core library.

3.1 Medical Use-Case Level

Type	Comment	Requirement	Priority	Innovation Level	Changes?
Data Analysis	-	The prototype shall support visualizing medical data in coordinated multiple views (ComVis)	1	3	no change
Data Analysis	-	Brushing data in ComVis shall be represented in MITK as binary masks	1	2	no change
Data Analysis	-	Brushes in ComVis shall be enhanced to support uncertainty visualization	1	2	no change
Data Analysis	-	ComVis shall allow gathering/clustering of points with similar characteristics	1	1	no change
Data Analysis	-	ComVis shall support creation of new datasets (columns) on the fly	1	3	no change
Data Analysis	-	ComVis shall allow exporting brushed values into a CSV file	1	3	no change
Data Analysis	-	ComVis shall support new views to assist in fMRI and DTI analysis and visualization	1	2	no change
Rendering	-	The library shall support surface rendering of binary volumes	1	3	no change
Rendering	-	The library shall support using binary volumes for masking	1	3	no change
Rendering	Requirement6	The library shall support picking of binary volumes and return surface point	1	3	no change
Rendering	-	The library shall support iso-dose surface visualization of dose volumes	1	3	no change
Visualization	-	MITK plugin shall support dose volume histogram computation and visualization	1	3	no change
Data Processing	-	The library shall support computing DVF properties	1	2	no change
Data Processing	-	The library shall support computing image similarity measures of two volumes (fixed/moving)	1	2	no change
Rendering	-	The library shall support visualization of image similarities	1	1	no change
Rendering	-	The library shall support visualization of DVF properties	1	2	no change

3.2 Application Level

Type	Comment	Requirement	Priority	Innovation Level	Changes?
Data Initialization	Requirement-1	~~The library shall support adding time-dependent datasets to the visualization pipeline.~~	1	1	MITK is responsible for sending the correct time step. Represented as a set of scalar volumes.
Data Processing	-	The library shall support updating the parameters of the fusion algorithm during run time.	1	1	See Requirement-2
Rendering	Requirement-2	The library shall support setting the rendering technique and respective parameters per view.	1	3	No change
Rendering	Only restricted by GPU memory.	The library shall support rendering an arbitrary number of objects in the same view.	1	2	No change
Rendering	-	~~The library shall support rendering to a file, void or off-screen.~~	3	3	No request from medical partner
Rendering	-	The library shall support changing the projection mode.	1	3	No change
Rendering	-	~~The library shall support defining an arbitrary number of clipping planes per object in arbitrary positions in space.~~	3	3	No request from medical partner
Rendering	Requirement-5	The library shall support defining an ~~arbitrary number of~~ clipping planes per view ~~in arbitrary positions in space~~.	3	3	Up to now only axes aligned clipping planes. No request from medical doctors for arbitrary clipping planes.
Rendering	-	~~The library shall support setting the current time step.~~	2	3	see REQUIREMENT-1
Rendering	not different to general fusion of data.	~~The library shall support fusion of time steps for one time-dependent dataset.~~	3	3	see REQUIREMENT-1
Rendering	not different to general fusion of data.	~~The library shall support fusion of registered time-dependent datasets for the corresponding time steps.~~	3	1	see REQUIREMENT-1
Rendering	-	~~The library shall support setting up animations of time-dependent datasets.~~	3	1	done by MITK
Rendering management	-	~~The library shall support creating new views.~~	1	3	MITK responsibility.
Rendering management	-	~~The library shall support closing existing views.~~	1	3	MITK responsibility.
Rendering management	-	The library shall support synchronization between views.	1	3	Changed to plugin responsibility.
Picking	-	~~The library shall support returning a list of 3D points along a ray which have a predefined value or threshold.~~	3	3	No request from medical partners for general case. For specific case see

					REQUIREMENT-3
2D	-	~~The library shall support setting the crosshair position in each of the orthogonal views.~~	2	3	MITK responsibility.
2D	-	~~The library shall support panning per view.~~	1	3	MITK responsibility.
Visualization	-	~~The library shall support setting a background colour.~~	3	3	MITK responsibility
Visualization	-	~~The library shall support setting a background image.~~	3	3	MITK responsibility
ROI	-	The library shall support defining ROIs by means of a binary mask.	2	3	No change
ROI	-	The library shall support defining ROIs by means of a cube.	2	3	Can be realized by axis aligned clipping planes. See requirement-5
ROI	-	~~The library shall support defining ROIs by means of a sphere.~~	3	2	No request from medical partners
ROI	-	~~The library shall support defining ROIs by geometrical objects.~~	3	2	No request from medical partners
ROI	-	~~The library shall support modifying ROIs: changing parameters, deleting, transformations.~~	2	3	No request from medical partners
ROI	-	~~The library shall support creating a copy of ROI into a new object.~~	3	3	No request from medical partners

3.3 Core level

Type	Comment	Requirement	Priority	Innovation Level	Changes?
Data Initialization	-	The library shall support adding multiple geometry datasets to the visualization pipeline.	1	3	No change
Data Initialization	-	The library shall support adding and managing multiple scalar volume datasets to the visualization pipeline.	1	1	no change
Data Initialization	-	The library shall support adding multiple higher order (vector, tensor) volume datasets to the visualization pipeline.	1	1	Only MR spectroscopy and vector fields requested
Data Initialization	-	~~The library shall support augmenting objects with metadata (i.e. adding properties to objects).~~	1	2	No request from medical partners
Data Processing	-	The library shall support creating new objects by means of applying a filter (process objects) to an arbitrary number of input objects.	1	3	No change
Data Processing	-	~~The library shall support modifying input objects.~~ Changed to: Modifying geometric Objects or binary masks representing segmentations.	1	3	Reformulation of requirement

Data Processing	local features are calculated for registration. Toulouse use case: Metabolic maps.	The library shall support calculating metadata from objects.	2	2	No change
Data Processing	-	The library shall support setting up parameters for the fusion of datasets.	1	1	No change
Data Processing	-	The library shall support setting the fusion algorithm.	2	1	No change
Data Processing	-	The library shall support calculating uncertainty related information.	2	1	No change
Rendering	-	The library shall support defining transformations per object.	2	3	no change
Rendering	-	The library shall support setting the rendering technique and respective parameters per view.	1	3	No change
Rendering	only restricted by GPU memory.	The library shall support rendering an arbitrary number of objects in the same view.	1	2	No change
Rendering	-	~~The library shall support rendering to a file, void or off-screen.~~	3	3	No request from medical partners
Rendering	-	The library shall support changing the projection mode.	1	3	No change
Rendering	-	~~The library shall support defining an arbitrary number of clipping planes per object in arbitrary positions in space~~.	3	3	No request from medical partners
Rendering	-	The library shall support defining ~~an arbitrary number of~~ clipping planes per view in arbitrary positions in space	3	3	Up to now only axes aligned clipping planes. No request from medical doctors for arbitrary clipping planes. See requirement-5 .
Rendering	-	The library shall support visualizing uncertainty related information.	2	1	No change
Rendering management	-	~~The library shall support setting camera parameters per view.~~	1	3	MITK responsibility
Rendering management	-	~~The library shall support setting lighting parameters per view.~~	3	3	MITK responsibility
Rendering management	-	The library shall support setting shading parameters per view.	3	3	No change
Picking	Requirement-3	The library shall support picking datasets through ray casting.	3	3	See Requirement-6
Picking	-	~~The library shall support picking datasets through lasso.~~	3	3	no request
Picking	Geometry is represented as Binary volumes which	The library shall support displaying the outline of selected geometry.	3	3	No change

	are rendered as Isosurfaces in 3D and in 2D as contours.				
2D	-	~~The library shall support browsing a stack of slices (slice by slice).~~	1	3	MITK responsibility
Visualization	Visualized currently only for reference frame	The library shall support displaying a bounding box per dataset.	1	3	No change
Visualization	-	The library shall support displaying an orientation indicator per view.	1	3	Changed to plugin responsibility.
Visualization	-	~~The library shall support displaying a scale bar in real world units per view.~~	1	3	No request from medical partners
ROI	pet-ct plugin uses this in combination with binary volumes	The library shall support using ROIs for clipping: render only inside or outside.	2	3	No change
Non-scalar	Eg: glyphs for DTI Datasets See requirement-4	~~The library shall support mapping non-scalar volumes to renderable objects.~~	3	3	No request from medical partner MITK functionality
Non-scalar	Requirement-4	~~2nd order tensors to glyphs or ellipses.~~	3	3	No request from medical partner MITK functionality
Non-scalar	-	The library shall support visualizing properties of deformation vector fields	3	2	no change

3.4 Interface Requirements

The design of the UI is not part of WP4 – Adaptive Visualization. The only requirement for the UI in relation to the visualization framework is to provide the necessary interface to change parameters and rendering modes for the specific medical use-cases.

4. Glossary

In this section, it is presented a list of terms used throughout this document and its' respective meaning.

Term	**Meaning**
Transformations	Scaling, rotating and translating
Dataset/entity	An independent object
Object	Can be any geometrical set, mesh, binary mask, volumetric texture
View	A single render window containing a single context, which can display 2D, 3D or 3D+time datasets.
Metadata	Annotations and labels related to objects
MITK	Medical Imaging Toolkit (www.mitk.org)
VTK	Visual Toolkit (www.vtk.org)
ITK	Insight Segmentation and Registration Toolkit (www.itk.org)
CUDA	Compute Unified Device Architecture (http://www.nvidia.com/)
CMV	Coordinated Multiple Views
IVA	Interactive Visual Analysis
CE	Contrast Enhanced
MR T1	Magnetic Resonance spin–lattice relaxation time

FLAIR	Fluid-Attenuated Inversion Recovery
MRSI	Magnetic Resonance Spectroscopy Imaging
CBCT	Cone Beam CT
MRI	Magnetic Resonance Imaging
fMRI	functional MRI
CT	Computed Tomography
PET	Positron emission tomography
OAR	Organs at Risk
ROI	Region of Interest
RT	Radiotherapy
GBM	Glioblastoma Multiforme
CTV	Clinical Target volume
PTV	Planning Target Volume
GTV	Gross Tumour Volume
ITV	Internal Target Volume
BTV	Biologic Target Volume

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