Interoperable communication of quantitative image analysis results using DICOM standard

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Introduction

As quantitative imaging (QI) is gaining momentum in research and commercial platforms, it becomes important to support its usage scenarios:

- **Clinical workflows**: storage of the analysis results on PACS alongside the imaging data; longitudinal followup of the patient with quantitative imaging across workstations.
- **Research workflows**: validation of imaging biomarker analysis tools; community repositories of the analysis results; secondary analysis of data.

Various types of derived data important in quantitative imaging research include image annotations (points, distance measurements, contours, labeling of image voxels), parametric maps and numeric results of the quantitative measurements.

Image segmentation is a key preprocessing task concerned with defining a region of interest for subsequent analysis and quantitation. It is therefore of critical importance to support interchange of the segmentation results.

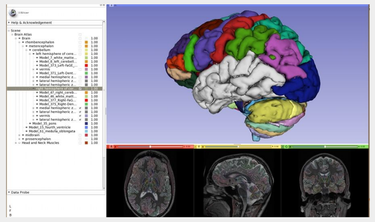
Digital Imaging and Communication in Medicine (**DICOM**) is the standard used ubiquitously for communicating image data. Although DICOM provides the means to also describe *derived* image-related information, thus far it has found very limited acceptance in the quantitative imaging community.

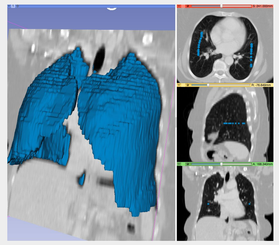
As a step towards improving QI analysis results interoperability, we investigate the use of DICOM Segmentation Storage SOP Class (DICOM SEG) for communicating image segmentation results.

Image Segmentation and Quantitative Imaging

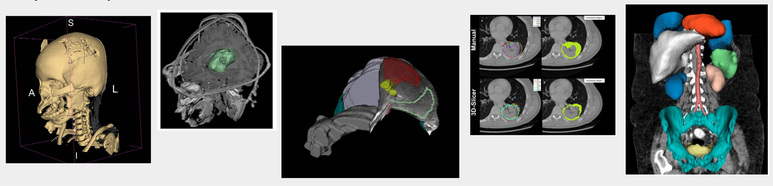
Image segmentation is concerned with labeling areas of the image into distinctive regions. These regions can correspond to pathology areas, organs, or identify regions of general interest, to support for example

- volumetric assessment of tumor burden
- quantification of the metabolic of functional activity within the ROI
- quantification of the image properties by means of the radiomics features





Segmentation tools vary in complexity, typically need to be customized to the specific problem, and can be manual, semi-automatic or automatic.



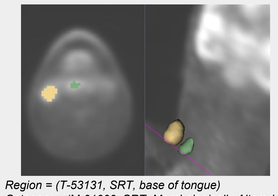
DICOM for Image Segmentation Storage

DICOM SEG is the preferred way of communicating segmentations represented as labeled voxels. Some of the important features supported include:

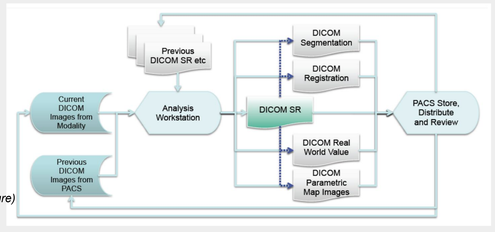
- size efficiency with multi-frame storage and bit encoding
- structured terminology for encoding semantics
- binary and fractional segmentation (e.g., probability maps)
- encoding of the presentation (color)
- multiple voxel occupancy

Being part of the DICOM object "family", integrates with other types of data:

- patient and study composite contexts, frame of reference maintained
- references source image data
- can be referenced from the measurement documents (DICOM SR)



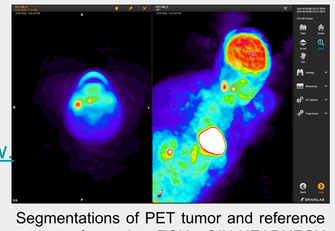
Region = (T-53131, SRT, base of tongue)
Category = (M-01000, SRT, Morphologically Altered Structure)
Type = (M-80003, SRT, Neoplasm, Primary)



Workstation Support of DICOM SEG

Workstations evaluated (commercial products are in italics):

- 3D Slicer X, http://slicer.org
- ePAD v1.7, http://epad.stanford.edu
- AIM on ClearCanvas v4.0.6.4, http://www.ict.mahidol.ac.th/research/Imaging-Informatics
- *Brainlab PDM 2.2*
- *Siemens syngo.via VA30A_HF06*



Segmentations of PET tumor and reference regions from the TCIA QIN-HEADNECK collection created using 3D Slicer tools as visualized in the Brainlab workstation.

See the up-to-date version of the evaluation spreadsheet at https://goo.gl/nPm3aU or scan the QR code.

Below: summary of the DICOM SEG ingestion and display test: import and display segmentation produced by the "source" workstation as image overlay in the the "sink" workstation. In the table below green color means "sink" can import and visualize objects from the source workstation, red means source objects cannot be displayed.

Source \ Sink	3D Slicer	ePAD	Brainlab	ClearCanvas AIM	Siemens syngo.via
3D Slicer					
ePAD					
Brainlab					
ClearCanvas AIM					
Siemens syngo.via					

Disclaimer: the workstations evaluated do not necessarily represent the complete list of workstations that support DICOM SEG, although we attempted to contact a number of major vendors.

- Know of a workstation/toolkit supporting DICOM SEG but not listed?
- Want to learn more or get help adopting DICOM SEG?
- Have sample DICOM SEG datasets you would like to contribute?

We would LOVE to hear from you!

Please email andrey.fedorov@gmail.com

Support in Developer Toolkits

DCMTK - DICOM Toolkit (C++, free open source)

http://dcmtk.org

DICOM@OFFIS

- high-level abstractions for initializing and interacting with SEG (functional groups, image frames)
- attribute-level validation
- helper APIs, propagation of the relevant attributes from the image dataset
- query and retrieval of SEGs with DICOM networking
- used by 3D Slicer

PixelMed Toolkit (Java, free open source)

http://www.dclunie.com/pixelmed/software/

- classes providing abstractions to support interaction with SEG
- used by ePAD

dicom3tools (C++, free open source)

- *dciodvfy* tool for validating DICOM SEG IOD compliance

Sample Datasets and Community Adoption

- Sample datasets used in this evaluation are publicly available
- DICOM SEG is the recommended format for communicating segmentation results generated by the teams participating in the NCI Quantitative Imaging Network (QIN).
- Several collections of the NCI Cancer Imaging Archive (TCIA, http://thecancerimagingarchive.net) contain various segmentation results stored as DICOM SEG objects:
  - QIN-HEADNECK: longitudinal PET/CT, head&neck cancer, tumor and lymph node segmentations
  - LIDC-IDRI: CT, lung cancer, tumor segmentations obtained using various tools
  - NSCLC Radiogenomics: CT, lung cancer, tumor segmentations
  - QIN Lung CT: CT, lung cancer, tumor segmentations obtained with different tools
  - QIBA CT-1C: CT phantom segmentatins
  - RIDER Lung CT (QIBA CT-1B Round 2)

See the up-to-date version of the evaluation datasets at https://goo.gl/IDgDhi or scan the QR code

Acknowledgments

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quantitative image informatics QIICR for cancer research