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The Roadmap for DICOM Support of the Clinical Brain Mapping Workflow

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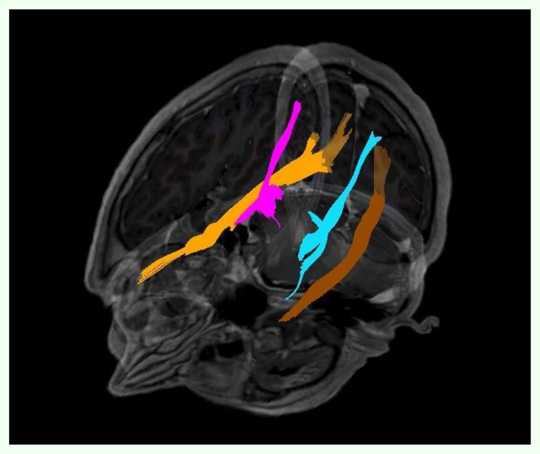
Abstract

We provide an update on DICOM development initiatives directed to improving the ability of the DICOM standard to capture brain mapping workflow, particularly diffusion tractography (commonly DTI) and functional MRI (fMRI).

Considerable progress has been made in multiple supplements to the standard; work remains, however, particularly in fostering industry adoption of new methods.

Tractography Representation

Supplement 181 to the DICOM standard, Tractography Results Storage (TRS), defines sets of tracks, each a linearly ordered collection of points [1]. Optional parametric Real World Value (RWV) data is associated with points. Statistics of RWV parameters may also be stored by track or track set. Visualization is supported with point-wise and track-wise color coding. The standard supports current and future acquisition methods (e.g. DTI, HARDI, diffusion spectrum imaging (DSI) and diffusion kurtosis imaging (DKI), etc.) and documentation of algorithms, software packages, and their provenance.



Use cases supported include basic visualization of tracks in space, such as surgical navigation and radiation treatment planning, as well as use of tractography as a means of quantitative sampling of diffusion or other parametric data (in the fashion of tract-based spatial statistics (TBSS).

A track set sequence contains multiple tracks, each visualized as a line. Optionally, a point may have coloring (CIELab) and/or measurements (as DICOM Real World Values (RWV)).

In DTI, the primary component of diffusion (λ_1, or axial diffusivity) and the average of the lesser components (average of ($\lambda_2 + \lambda_3$) or radial diffusivity) can reflect the state of axonal and myelin integrity. Measurements such as these may usefully be sampled and stored along a track. The following example highlights one track with associated DR and DA measurements to illustrate the structure:

```
Track Set Sequence
  Item 1 (Track Set 1)
    Track Set Number = 1
    Track Set Label = CST
    Track Set Anatomical Type Code Sequence
      Item 1 (Anatomical Type Code)
        Code Value = 1320
        Code Scheme Designator = NEU
        Code Meaning = corticospinal tract
    Track Sequence
      Item 1 (Track 1)
        Point Coordinate Data = <track data>
        Track Point Values Sequence
          Item 1 (Point Values 1)
            Track Point Value Type Code Sequence
              Item 1 (Point Value Type Code)
                Code Value = sup181_dddd03
                Code Scheme Designator = DCM
                Code Meaning = Radial Diffusivity
            Measurement Units Code Sequence
              Item 1 (Measurement Units Code)
                Code Value = 1
                Code Scheme Designator = UCUM
                Code Meaning = unity
            Floating Point Values = <values>
          Item 2 (Point Values 2)
            Track Point Value Type Code Sequence
              Item 1 (Point Value Type Code)
                Code Value = sup181_dddd04
                Code Scheme Designator = DCM
                Code Meaning = Axial Diffusivity
            Measurement Units Code Sequence
              Item 1 (Measurement Units Code)
                Code Value = 1
                Code Scheme Designator = UCUM
                Code Meaning = unity
            Floating Point Values = <values>
      Item 2 (Track 2)
      :
    Recommended Display CIELab Value = <color>
    Tracking Algorithm Identification Sequence
      Item 1 (Algorithm Code 1)
        Code Value = sup181_eeee01
        Code Scheme Designator = DCM
        Code Meaning = deterministic
      Item 2 (Algorithm Code 2)
        Code Value = sup181_eeee03
        Code Scheme Designator = DCM
        Code Meaning = FACT
    Referenced Instance Sequence
      <raw DTI image reference>
  Item 2 (Track Set 2)
  :
  Item 3 (Track Set 3)
  :
```

Point Coordinate Data
(x_1,y_1,z_1)
(x_2,y_2,z_2)
:
(x_n,y_n,z_n)

Coordinate data is stored with minimal overhead in one sequence.

DR Floating Point Values
DR1
DR2
:
DRn

Measurements are stored in records sized and ordered the same as the coordinates data, as shown here.

DA Floating Point Values
DA_1
DA_2
:
DA_n

Here radial diffusivity and axial diffusivity (DR and DA) are stored per point.

Alternately, sparse measurement data may be represented as (x,y,z) plus value

Color data may be coded per point, track, or track set

Algorithm source, type and version is stored per track set.

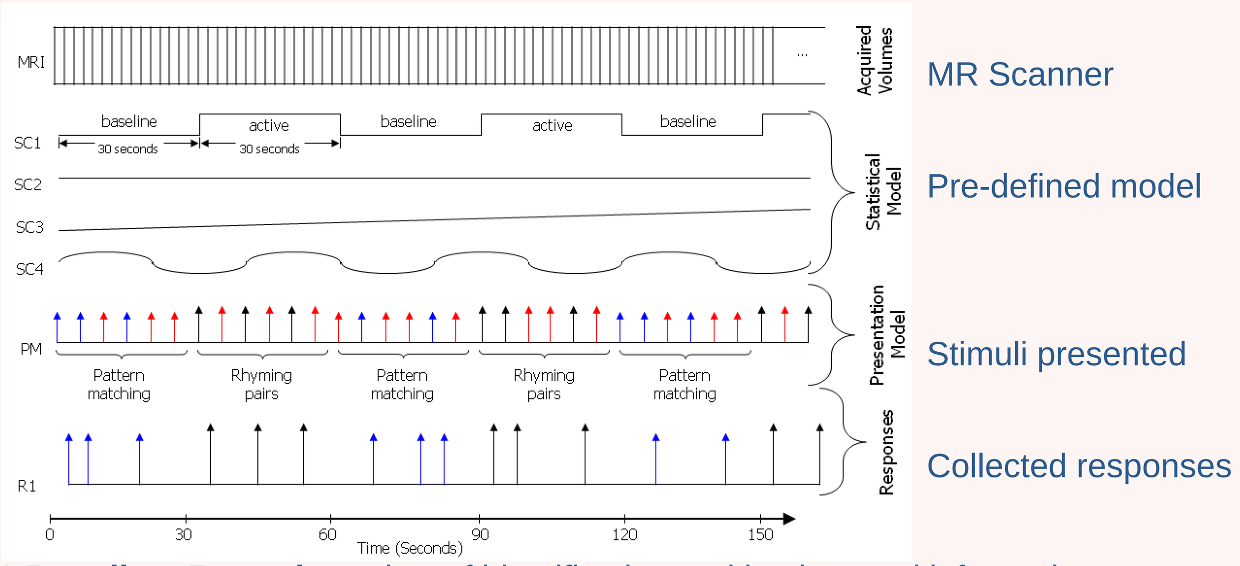
The sequence may contain multiple track sets, generally representing different anatomical nerve tracts.

A track or track set may also have associated coloring and/or summary statistics of measurements from the entire track or track set. The flexible yet efficient implementation was achieved with the help of simulations done to model storage requirements, transmission times, and decoding times for various proposed structures.

Since adoption, several manufacturers and software developers have participated in activities to demonstrate and promote the interoperability possible using DICOM TRS, through the auspices of the RSNA Quantitative Imaging Reading Room (QIRR) [2].

Paradigm Representation for fMRI

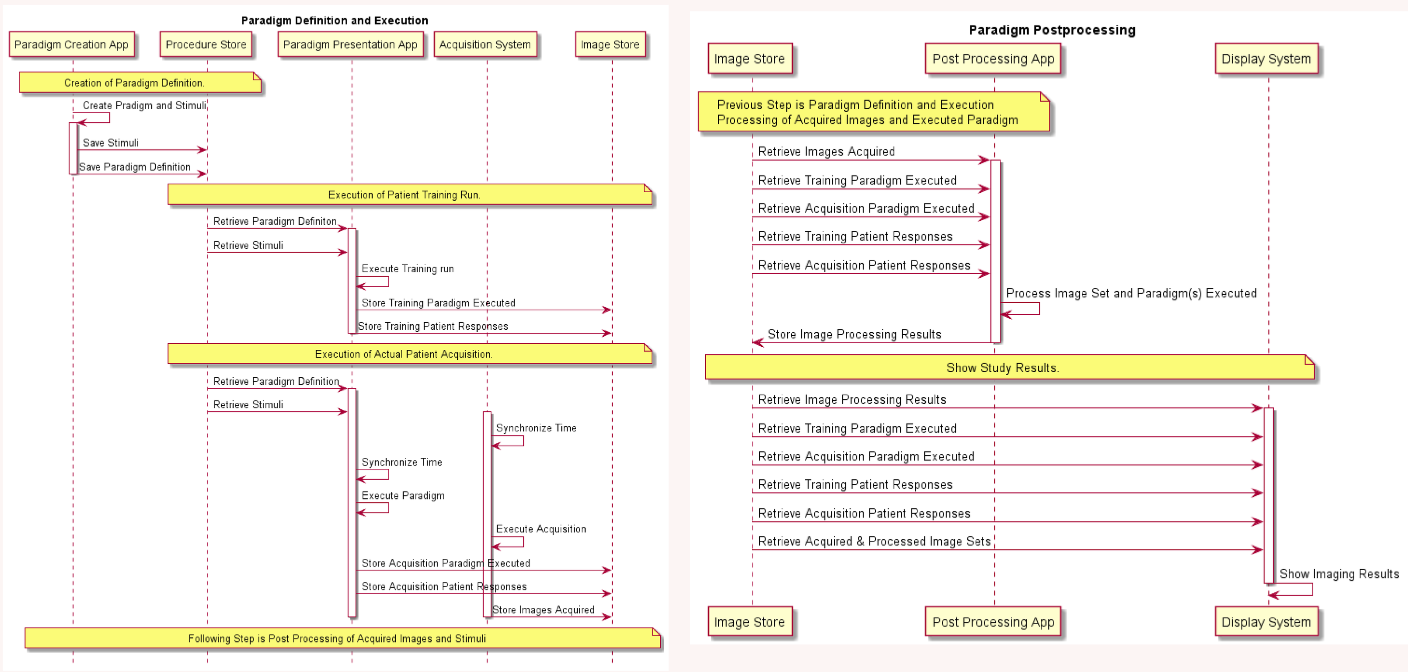
Interest in supporting functional MRI (fMRI) in the DICOM standard was expressed over fifteen years ago, when the introduction of multi-frame Enhanced MRI made DICOM PACS storage of time series data feasible [3]. The fMRI work was energized by the RSNA QIBA fMRI Biomarker Committee [4], which moved in 2009 to formalize the claims for fMRI's clinical utility. DICOM Working Group 16 began work the following year to explore how best to standardize the data. Supplement 210, Paradigm Protocol Storage [5], will define the data elements and records required for the fMRI workflow, illustrated in the example below.



A **Paradigm Record** consists of identification and background information, a Statistical Model, a Presentation Model, and Instructions. This record is associated with an MR Protocol record (see below) defining the Acquisition technique.

The **Statistical Model** defines the components contributing to the acquired activation signal (for fMRI, the BOLD effect). One or more components (SC1) represent the evoked functional activation (in task fMRI), and these have associated presentation (stimulus) records. Other components (SC2-SC4) may represent confounding factors such as respiration to be incorporated into the analysis. The Statistical Model is input to the post-processing phase.

The **Presentation Model** contains the stimulus timing (SM1), stimuli elements (words, picture and sound files, etc.), and predicted responses. Multiple records represent the presentation actions required for the functional components of interest found in the Statistical Model (e.g. 'active' versus 'baseline').



Paradigm Execution and **Patient Response** records (R1) are produced when the paradigm is performed, whether in training or during image acquisition. Acquired image time-series are post-processed along with these records to produce maps of brain activation. Parametric Map records encode functional activation as Real World Value (RWV) statistics (e.g. correlation, T value). Documented quality assurance information includes motion correction and data censoring results, activation signal strength through time, and 'soft' information from operators during acquisition and processing such as behavioral observations.

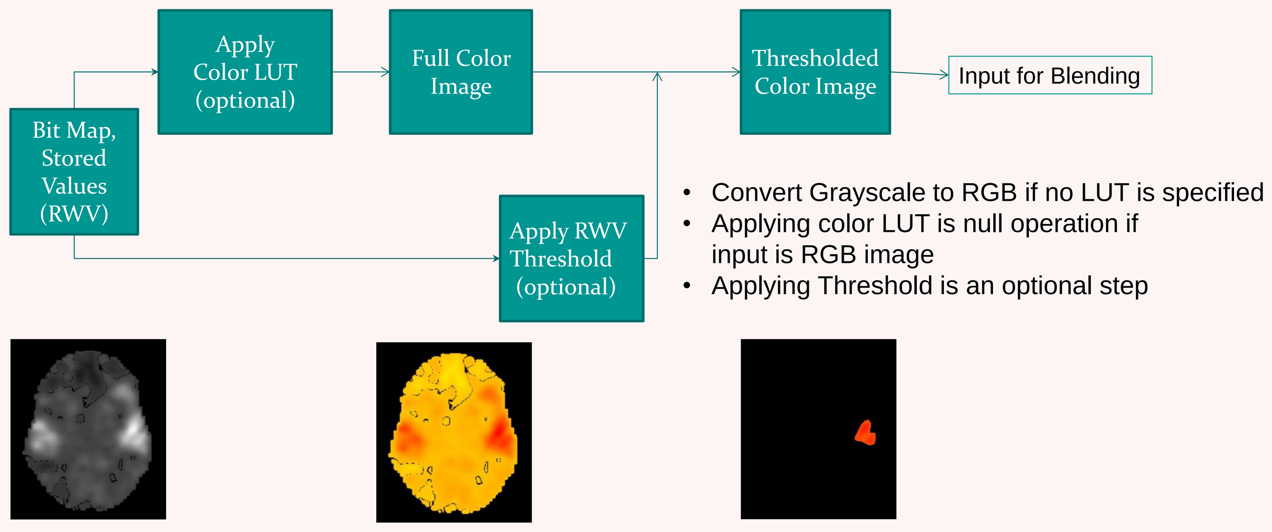
The acquisition details are found in an MR Protocol record (see below) which references the Paradigm Record.

MR Protocol Representation:

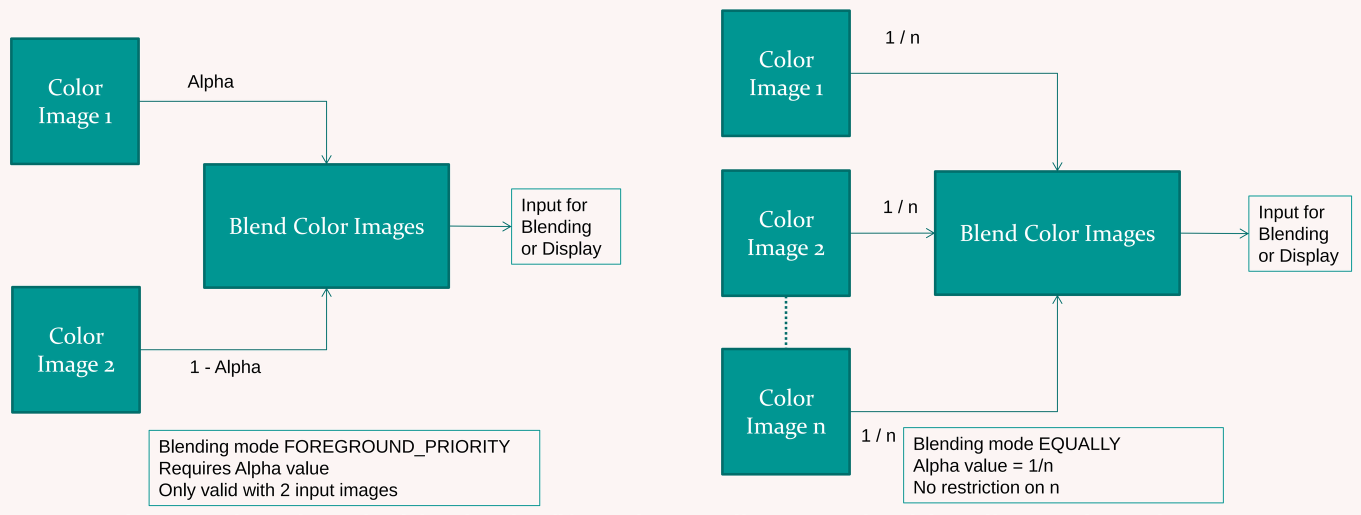
A new proposed work item focuses on addition of MR Protocol Storage IODs to the DICOM standard. This will represent MR acquisition and reconstruction programming. The record for a Protocol intended for fMRI will then reference the Paradigm Record. Synchronization of scanning and stimulus presentation for fMRI was addressed in 2015 [6] by adding extra information in acquired images.

Visualization for fMRI and more

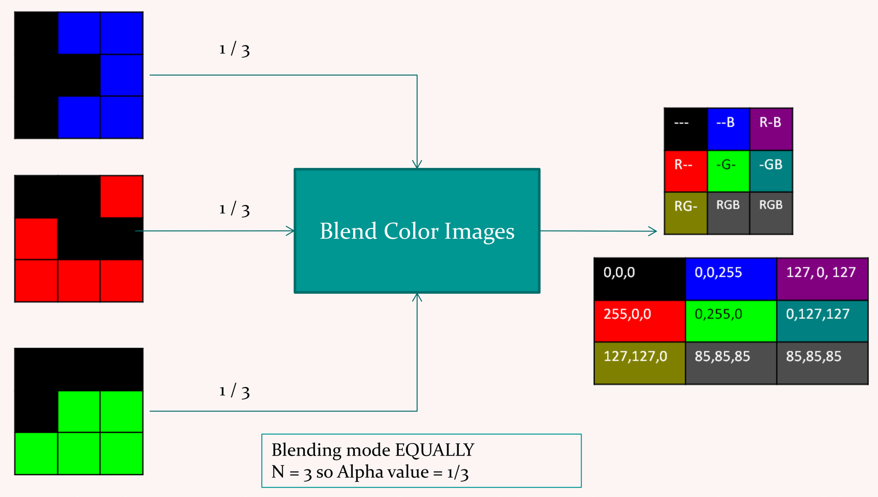
DICOM Supplement 189, Parametric Blending Presentation State Storage, was adopted in 2017 [7]. This initiative, based upon the Enhanced MR Parametric Map records, captures the common brain mapping practice of overlaying sources of quantitative functional and physiological imaging sources on anatomical data in 3D space. The 'blending' capability supports the coloring and opacity control necessary to visualize the co-location of information from multiple maps, with thresholding, and without sacrificing the quantitative nature of the original derived image results. It is generalized and applicable not only to functional MRI but also any other parametric maps encoded as Real World Values (RWV) in DICOM, such as diffusion and perfusion parameters. A thresholded color image is obtained as follows:



Two blending operations are supported: Foreground/Background, and Equally:



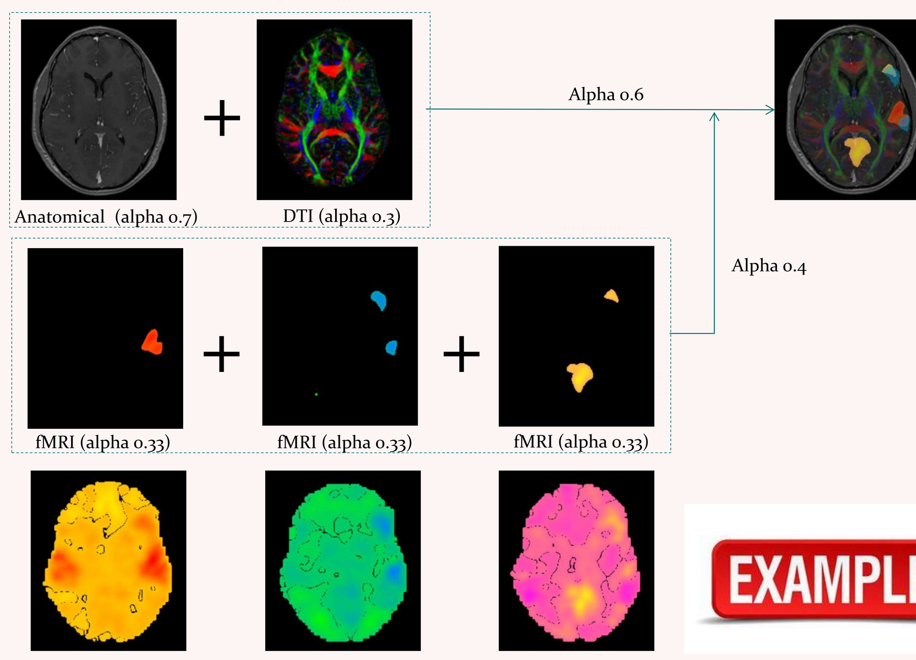
Voxels meeting threshold criteria (if any) contribute to the blending, otherwise are omitted. In this model of three images, from zero to three sources may contribute:



This result cannot be obtained through sequential pair-wise blending operations.

Multiple Blending operations may be sequentially used as needed to visualize the combined images, with thresholds on the real world value data.

A brain mapping example combines fMRI and DTI with an anatomical underlay:



The three fMRIs are blended equally, after thresholding; the DTI is overlaid on the anatomical; then the combined fMRI data is overlaid on the DTI/anatomical.

Similar visualization is possible for other parametric maps such as CBF, PET, MRS, etc.

For More Information

Scan the code at left to visit the DICOM WG-16 page for further information about the DICOM standards and status of ongoing work.

Disclosures

The authors are employees of medical imaging product/service providers.

References:

1. DICOM Supplement 181: MR Diffusion Tractography Storage SOP Class; ftp://medical.nema.org/medical/dicom/final/sup181_ft_TractographyResultsStorage.pdf
2. Federov A et al. Interoperable communication of quantitative image analysis results using DICOM standard (DICOM4QI). RSNA 2017.
3. Erberich SG. PACS-based functional magnetic resonance imaging. Comput Med Imaging Graph. 2003;27(2-3):229-40. https://www.ncbi.nlm.nih.gov/pubmed/12620313
4. RSNA QIBA fMRI Biomarker Committee; http://qibawiki.rsna.org/index.php/FMRI_Biomarker_Ctte.
5. DICOM Supplement 210: Paradigm Protocol Storage (work in progress).
6. DICOM CP-1476: Add settling phases information and Synch pulse for Functional MRI; ftp://medical.nema.org/medical/dicom/final/cp1476_ft_fMRI_phases.pdf
7. DICOM Supplement 189: Advanced Blending Presentation State Storage; ftp://medical.nema.org/medical/dicom/final/sup189_ft.pdf

Conclusions:

Progress towards full DICOM support for brain mapping faces numerous challenges. Some issues such as storage of patient-independent data elements may be implementation-dependent. Most of the work to date has potential benefits in general promotion of scanner interoperability and quantitative imaging. Considerable work remains in fMRI. Ultimately, the adoption of DICOM support for brain mapping hinges upon implementation of the standard by a broad range of manufacturers, from scanners and PACS to processing applications – motivated by the requests of informed clinical users.