Motivation

• Need to distribute results for review
• Create with multiple tools in different formats
• Reviewers without access to original tool
• Measurement technique comparisons
• Imaging bio-marker development/testing
• Image-based clinical trials, esp. oncology
• Change in measurements over time
• Clinical practice for individual patients
Results Characteristics

• What is recorded?
  – measurements – distance, volume, density, etc.
  – coordinates – what region on image measured

• Context?
  – identification of subject (patient), lesion, etc.
  – identification of reader
  – identification of technique
  – position in time (change over time, no change)
Results Organization

- Single object per measurement
- Single object for all measurements at one time
- Single object per reader per time point
- Single object per reader all time points
- Single object per image with all measurements for all readers
- ...

Use-Cases

• QIBA CT Volumetry 1B Round 2
  – lung cancer volume measurement
  – multiple independent readers
  – two time points
  – some cases no change, some with change
  – volume & automatically derived distance
    • standard DICOM SR and DICOM Segmentation format
    • clinical trials results information model
    • organized as one object per lesion per reader
  – reading tool is not distributable for review
Use-Cases

- QIBA CT Volumetry 1A
  - phantom lung nodules differing size and shape
  - multiple independent readers
  - one time point
  - two different (incompatible) reading tools used
  - distance
    - proprietary format
    - one object per image containing multiple readers & lesions
  - volume
    - variant of DICOM RT Structure Set
    - one object per reader per lesion
  - reading tools are not distributable for review
Hierarchical Model

• Subject
  – Reader
    • Time Point
      – Lesion
        » Region (→ link to image coords)
        • Measurement (e.g., Volume)
Hierarchical Model

- Subject = 0001
  - Reader = 1
    - Time Point = 2010/06/01
      - Lesion = 1
        » Volume = 355 mm³
      - Lesion = 2
        » Volume = 3896 mm³
    - Time Point = 2011/07/01
      - Lesion = 1
        » Volume = 471 mm³
      - Lesion = 2
        » Volume = 3801 mm³
  - Reader = 2
    - ...

One Annotation Per File

- Subject = 0001
  - Reader = 1
    - Time Point = 2010/06/01
      - Lesion = 1
        » Volume = 355 mm³
      - Lesion = 2
        » Volume = 3896 mm³
    - Time Point = 2011/07/01
      - Lesion = 1
        » Volume = 471 mm³
      - Lesion = 2
        » Volume = 3801 mm³
  - Reader = 2
  - ...
One Time Point Per File

- Subject = 0001
  - Reader = 1
    - Time Point = 2010/06/01
      - Lesion = 1
        » Volume = 355 mm³
      - Lesion = 2
        » Volume = 3896 mm³
    - Time Point = 2011/07/01
      - Lesion = 1
        » Volume = 471 mm³
      - Lesion = 2
        » Volume = 3801 mm³
  - Reader = 2
    - ...

One Reader per Subject Per File

- Subject = 0001
  - Reader = 1
    - Time Point = 2010/06/01
      - Lesion = 1
        » Volume = 355 mm³
      - Lesion = 2
        » Volume = 3896 mm³
    - Time Point = 2011/07/01
      - Lesion = 1
        » Volume = 471 mm³
      - Lesion = 2
        » Volume = 3801 mm³
  - Reader = 2
    - ...

<table>
<thead>
<tr>
<th>Subject</th>
<th>Reader</th>
<th>Time Point</th>
<th>Lesion</th>
<th>Volume mm³</th>
</tr>
</thead>
<tbody>
<tr>
<td>0001</td>
<td>Reader 1</td>
<td>2010/06/01</td>
<td>1</td>
<td>355</td>
</tr>
<tr>
<td>0001</td>
<td>Reader 2</td>
<td>2010/06/01</td>
<td>1</td>
<td>375</td>
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<tr>
<td>0001</td>
<td>Reader 1</td>
<td>2010/06/01</td>
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<td>3896</td>
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<tr>
<td>0001</td>
<td>Reader 2</td>
<td>2010/06/01</td>
<td>2</td>
<td>4764</td>
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<tr>
<td>0001</td>
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<tr>
<td>0001</td>
<td>Reader 2</td>
<td>2011/07/01</td>
<td>1</td>
<td>289</td>
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<tr>
<td>0001</td>
<td>Reader 1</td>
<td>2011/07/01</td>
<td>2</td>
<td>3801</td>
</tr>
</tbody>
</table>
Tabular Presentation

• Can be sorted by different columns
• Easy to add derived computations
  – e.g., % difference from mean volume
• Exportable to spreadsheet tools (e.g., Excel)
• Exportable to statistical tools (e.g., R)
• Easy to feed selected columns to chart tools
• Cells and rows can be hyperlinked to images
  – e.g., hyperlink a volume to the ROI outline
Structured vs. Unstructured

- **Structured input defines individual elements**
  - Measurements are recorded
    - As opposed to recalculated from coordinates each time
  - Measurements & units distinct & related to image
    - Coordinates linked to measurement
    - Different types of measurement coded (not free text)
  - Individual context elements distinct
    - E.g., patient, lesion, reader encoded separately

- **Unstructured annotations**
  - User enters free text (e.g., “Reader 1 Lesion 1”)
  - Text and coordinates linked, or
  - Text and coordinates co-located but not linked
Results Formats

• DICOM Structured Reports
  – general purpose hierarchical data format
  – primitives for codes, measurements, coordinates
  – references to images, segmentations
  – needs a “template” to define information model
  – no widely adopted standard templates for oncology quantitative measurements over time
  – author has defined template for internal use in contract research, and has reused it for QIBA
Results Formats

• DICOM Segmentations
  – rasterized (pixel array) of values matching image
  – encoding of lesions
    • Binary - which voxels are included in lesion
    • Probability maps – probability voxel is included
  – encoding of “label maps”
    • E.g., atlas of tissue types corresponding to voxels
  – does not contain measurements
    • intended to be referenced from a DICOM SR
DICOM RT Structure Sets

- Developed for and long history of use with Radio-Therapy Planning applications
- Generic mechanism for 3D contours
  - set of coplanar iso-contours
  - 3D patient-relative coordinates
- Image co-ordinates
  - often 1:1 correspondence of 3 coordinate with original image slices and voxels (though not required)
- Measurements
  - very limited, if any, measurements in file
  - recalculated on re-loading
  - could be referenced from a DICOM SR (though unusual)
DICOM Presentation States

- Intended for rendering, not interpretation
- Commonly implemented in PACS for simple annotation capture
- Unstructured
  - text and graphics are not semantically linked
  - text is free text, not coded, and no structured measurements
  - with discipline entering text, structured content can be parsed from free text retrospectively
Process Flow

• Create DICOM SR
  – that conform to a basic template
  – subject/reader/time point lesion/measurement

• Tabulate results
  – include hyperlinks to rendered images with ROIs
  – compute any derived statistics

• Generate charts from tables
  – e.g., scatter plots, waterfall plots
Process Flow

• ROIs
  – if SR references segmentation, use it
  – if SR contains coordinates (2D or 3D), use them
  – if not, convert coordinates to SR coordinates
    • e.g., RT Structure Set 3D coordinates to SR 2D
  – if not, convert raster to segmentation
    • e.g., LIDC Max tool PMAP to DICOM SEG

• Image Library
  – extract image characteristics for re-use
  – e.g., position, orientation, spacing, UIDs
  – store in SR Image Library template
  – saves repeating this (reading image headers) many times
Earlier Work by Others

• Aberle 1996 – Thoracic Oncology Imaging Timeline (OITL)
  – regions of interest defined during reporting
  – change in lesion size over time for single patient
  – table of lesion size
  – graphs of size change
  – visualization of size change

http://radiographics.rsna.org/content/16/3/669
Aberle 1996 - OITL
Aberle 1996 - OITL
Earlier Work by Others

• Bui 2007 – TimeLine
  – more generalized, configurable approach
  – data access and integration
  – data mapping, reorganization and clustering
  – hierarchical problem-centric views
  – emphasis on temporal chronologies & clustering
  – adaptable format mapping methods

http://dx.doi.org/10.1109/TITB.2006.884365
Bui 2007 - TimeLine
Earlier Work by Others

- Levy 2007 – LesionViewer
  - serial oncology studies
  - anatomical summary of lesion location
  - direct navigation to visualization of location
  - temporal abstraction of lesion behavior

http://dx.doi.org/10.1109/TITB.2006.884365
Levy 2007 - LesionViewer

Name: Wilson, Mark
MR Number: 55555555

Date: 03/28/06
CT Chest, Abdomen and Pelvis
Pulmonary Nodule
Dimension: 0.7cm

Date: 08/3/06
CT Chest, Abdomen and Pelvis
Pulmonary Nodule
Dimension: 0.8cm

Date: 10/10/06
CT Chest, Abdomen and Pelvis
Pulmonary Nodule
Dimension: 1.0cm

Lesion ID: 2
Location: Upper Lobe of Right Lung
Description: Pulmonary Nodule
Dimension: 0.8cm
Levy 2007 - LesionViewer

Name: Williams, Laura
MR Number: 44444444
Earlier Work by Others

- AVT 2009 – Algorithm Validation Toolkit
  - NCI caBIG *in vivo* Imaging Workspace project
  - Measurement Variability Tookit (MVT) component
    - tabulation and charting
    - interface with R statistics package
  - only supports proprietary NCI AIM format

Disclosure: author was involved in AVT RFP and sub-contractor to Siemens Corporate Research on AVT use-case development and testing

https://wiki.nci.nih.gov/display/AVT/Algorithm+Validation+Toolkit+%28AVT%29+Project+Pages
### Computation Results

<table>
<thead>
<tr>
<th>Subject Name</th>
<th>Rel Vol Difference</th>
<th>Surf Distance (Average)</th>
<th>Surf Distance (RMS)</th>
<th>Surf Distance (Max)</th>
<th>Volume Overlap [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>LTS_IMG01</td>
<td>1.33747</td>
<td>0.33584</td>
<td>0.51345</td>
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<tr>
<td>LTS_IMG02</td>
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</tr>
</tbody>
</table>

### Statistics Analysis

- **Methods:** Add, Custom, Del
- **Comparison to be Analyzed:** Mean, All Measurements
- **Statistical Method:** Mean, SD, CV

### Outlier Analysis

- **Threshold:** Add, Del
- **Comparison to be Analyzed:** Relative Volume Difference, Surface Distance (RMS), Volume Overlap
- **Outlier Criteria:** Top 25%, Bottom 25%

### Plotting

- **Charts:** Add, Del
- **Plotting title:** Blond-Altmann of Volume, Scatter of Volume, Surface Distance (RMS)

### Images

**Nominal GT**

**Annotation**