DICOS: The Case for Standardized Data in Security

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for

Boston Image Processing and Computer Vision Group (BIPCVG) Meetup #2
What is DICOS?

DICOS
Digital Imaging and Communication in Security

Largely based on

DICOM
Digital Imaging and Communication in Medicine

- NEMA standards defining the storage and transmission of security and medical images and associated information
• (Short) Philosophy about standards
• Compare/Contrast Medical and Security industries
  ▪ DICOM standards are similar, but the markets, challenges, and drivers are different
• What advantages does DICOS potentially provide?
  ▪ Facilitates a “Universal Workstation”
  ▪ Enables generic ATR (Automatic Threat Recognition) algorithms
  ▪ Encourages greater involvement by Third Parties (academics, consultants)
• Technical discussion about generic ATR algorithms
Why Have Standards?

• **Achieve order in a given context**
• **Driven by the recognition of a problem where order is lacking**
  ▪ E.g., the screwbase light bulb standard adopted in 1902
  ▪ TCP/IP, adopted in 1982 by the DoD
  ▪ SW languages, weights and measures, bicycle helmets, ISO-900*
• **Amortize the cost of the standard design over many implementations**
  ▪ Enable a market
• **Realize benefits of consistency w/open standard**
  ▪ Lower training costs, lower barrier to entry, more players and greater innovation
• **Creates some constraints**
  ▪ It becomes harder to innovate that which is standardized
  ▪ Incentive to be careful, and allow standards to evolve
How Standards Come About\(^1\)

- **General *de facto* adoption**
  - PDF
  - Google search engine?

- **Industry consortium**
  - Trade association/professional society
  - DICOM initially specified by radiologists

- **Government decree**
  - MIL-STDs used for procurement
  - HIPAA mandate for patient privacy
  - DICOS – NEMA chartered and funded by DHS

- **In all cases, it costs real $ to develop a standard**

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DICOM: Motivated by User-Demand

• Teleradiology
  ▪ 1975 – X-Rays digitized on Navy ship and sent via satellite to radiologist 3000 miles away

• Interconnection
  ▪ 1972 – CAT scan approved for human use
  ▪ 1982 – MRI approved for human use
  ▪ Hospitals want to collect and view patient images together

• American College of Radiology (ACR) sets requirements for a standard, NEMA publishes v1 in 1985
  ▪ 1992 – First demonstration of interconnected scanners and viewers (DICOM v2)
  ▪ PACS (Picture Archiving and Communication System) market emerges – $8.6B/year

• Today, DICOM supports Healthcare Enterprise (IHE)
Historical Events related to Medical/DICOM

1972 CAT scans approved
1975 Digital reporting + CAT scans
1978 ACR identifies need to xmit images+reports
1982 MRI approved and TCP/IP adopted by DoD
1992 DICOM (2) successful connect-a-thon demo
1999 IHE Established
2001 9/11 and Shoe bomb -> 100% screening checked bags
2009 Underwear bomb – People screening
2010 DICOS (1)
2010 Cargo bomb found
Ongoing Development

Align timelines at 1988

Historical Events related to Security/DICOS

1988 PanAm 103 – EDS Industry begins
2006 10-plane plot Liquids banned
2009 Underwear bomb – People screening
2010 Cargo bomb found
Ongoing Development
What to think when you hear “DICOS”

- **Hierarchy of information classes**
  - IOD, IE, Module, Attribute

- **Classes defining communication layer**
  - Service-Object Pair (SOP) – for transmitting an IE

- **Data Transmission**
  - DICOM Upper Layer Protocol for TCP/IP
  - DICOM Application Message Exchange (DIMSE)

Figure 9 DICOS v01 Composite Instance IOD E-R Model
Figure 4 DICOS Example—Owner Contains Passenger & Checked/Carry-On Bag
DICOS in a Nutshell (in theory)

**Storage**

DICOS File

encapsulates defined IE “Information Entities”

**Transmission**

DICOM Application Message Exchange (DIMSE)

DICOM Upper Layer Protocol for TCP/IP (“HL7”)

DICOS Association

established between two DICOS devices over TCP/IP (sockets)

“← →” Implies:

**Passenger Database**

**Central Viewing Workstation**

Wouldn’t this be great?

**TRX Scanner**

File or set of files containing images, reports, owner information, etc.

**EDS Scanner**

File or set of files containing images, reports, owner information, etc.

**AIT Scanner**

File or set of files containing images, reports, owner information, etc.

Umm, I guess so…

Lorena Kreda, Proprietary Information
<table>
<thead>
<tr>
<th>Topic/Feature</th>
<th>Medical</th>
<th>Security</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Standard</strong></td>
<td>DICOM</td>
<td>DICOS</td>
</tr>
<tr>
<td><strong>Motivation</strong></td>
<td>Bottom up – Radiologists</td>
<td>Top down – DHS</td>
</tr>
<tr>
<td></td>
<td>Teleradiology; HIS</td>
<td>Universal WS; 3\textsuperscript{rd}</td>
</tr>
<tr>
<td></td>
<td>Interconnection</td>
<td>Party Developers</td>
</tr>
<tr>
<td></td>
<td>Vendors resisted</td>
<td>Vendors resisting</td>
</tr>
<tr>
<td><strong>US Market Base</strong></td>
<td>~6000 Hospitals; ~37M admissions/yr; ~400M scans per yr</td>
<td>~400 Airports; ~650M passengers/yr; ~1.5B bags/yr</td>
</tr>
<tr>
<td><strong>Secondary Market</strong></td>
<td>PACS - $8.6B/yr</td>
<td>TBD</td>
</tr>
<tr>
<td><strong>Associated Infrastructure</strong></td>
<td>IHE – Workflow</td>
<td>None yet.</td>
</tr>
<tr>
<td></td>
<td>Testing – “Connect-a-thons”</td>
<td></td>
</tr>
<tr>
<td><strong>Data concerns</strong></td>
<td>Patient privacy</td>
<td>SSI; Passenger privacy</td>
</tr>
<tr>
<td><strong>Storage</strong></td>
<td>Archiving needed</td>
<td>Images not typically archived</td>
</tr>
<tr>
<td><strong>Modalities</strong></td>
<td>Many</td>
<td>Few</td>
</tr>
<tr>
<td><strong>Detection</strong></td>
<td>CAD – after scanner</td>
<td>ATR – integral to the scanner</td>
</tr>
<tr>
<td><strong>Raw data</strong></td>
<td>Not available – regarded as “secret”</td>
<td>Not available, but may be coming, more important for integral ATR</td>
</tr>
</tbody>
</table>
DICOS: What problem are we trying to solve?

• **Universal workstation – display images from multiple modalities and multiple vendors**
  - Must have enough information (LUTs, meta data, etc.) to render images exactly as they appear on the original equipment
  - Facilitates remote screening
    - *Reveal demonstrated proof of concept using DICOS in 2009 under a TSWG program*
    - *TeleSecurity Science “Common Workstation” DICOS product on website*
    - *OptoSecurity claims a similar product: “eVelocity converts X-ray raw data into vendor agnostic images that can be viewed remotely,” but does not use an open model*
  - 3rd party opportunities:
    - Improved image enhancement/analysis tools (would require TSA approval)
    - Better image targeting operator (requires raw data)

• **Third party algorithm development – independent of vendors**
  - Access scanner data so that academics, consultants, others can develop detection algorithms
  - Get more smart people tackling the detection problems
Models for Third Party Algorithm Contributions

- **Vendor-specific collaboration**
  - Third party algorithm tightly coupled with a vendor
  - Simplifies certification process
  - Scope of added value is narrow, vendors have more control
  - DICOS not required for this!
- **“Rogue” algorithms for a specific vendor**
  - Vendors understandably not excited; fairness could be a problem
  - Scope of solution is restricted to specific vendor
- **Developing generic algorithms**
  - Requires transforming data to a common reference frame
    - Spatial resolution, A/D resolution, X-Ray spectrum normalization
    - “Modality LUT” for medical transforms image data to Houndsfield Units
  - Result displayed on a universal display or original equipment?
  - Certified once per algorithm per system, offline testing helps
- **Security is a major hurdle**
  - Data from certified equipment are SSI
  - Need to frame problem such that it depends on neutral or SSI data
Normalizing X-Ray Data for Generic ATR

- ATR in simplest terms is 2D classifiers in Density-$Z_{\text{eff}}$ space (mass also important)
  - $Z_{\text{eff}}$ requires dual-energy data
  - Single energy machines classify on density
- Map data to a common reference space
- Re-sample data to a common spatial resolution
- Develop generic classifiers
- Develop new features
1. Mapping Data to a Common Reference Space

• X-Ray transmission is material-dependent and energy-dependent
  ▪ Mean energy for EDS X-Ray spectra are in the 60-110 keV range
Example X-Ray Spectra

1 mm Al (green) vs 4 mm Al (red)

(red) mean energy = 70.7 keV
(green) mean energy = 64.6 keV

1 mm Al + 1 mm Cu

mean energy = 93.4 keV
• Essential to have a common set of reference data collected on each machine of interest

<table>
<thead>
<tr>
<th>Material</th>
<th>Density (gm/cc)</th>
<th>Zeff (approximate)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ethanol</td>
<td>0.785</td>
<td>6.53</td>
</tr>
<tr>
<td>Water</td>
<td>1.0</td>
<td>7.54</td>
</tr>
<tr>
<td>Magnesium</td>
<td>1.74</td>
<td>12</td>
</tr>
<tr>
<td>Graphite</td>
<td>2.16</td>
<td>6.0</td>
</tr>
<tr>
<td>Aluminum</td>
<td>2.7</td>
<td>13</td>
</tr>
</tbody>
</table>

• Establish desired reference values for each material
  - Density is proportional to the high energy (HE) value
  - $Z_{\text{eff}}$ is proportional to the ratio of low energy (LE) to HE

• Generate mappings to transform measured HE and LE data to desired reference values
Steps to Generate Transformation LUT

**Steps to generate LUT**
- Select a reference machine – call this the “golden” machine
- Plot ROI means for calibration materials for the golden machine vs. candidate machine
- Fit a polynomial to this distribution, which gives desired output (golden value) as a function of the candidate values
- Build a LUT by solving for all possible candidate values
- “Modality LUT” in DICOS (and DICOM) designed to do this

**HE Reference Value = f(Candidate Value)**

- $y = 2 \times 10^{-8}x^3 - 0.0002x^2 + 1.3773x$
- $R^2 = 0.9991$

**LE Reference Value = f(Candidate Value)**

- $y = 3 \times 10^{-9}x^3 - 6 \times 10^{-5}x^2 + 1.0819x$
- $R^2 = 0.9999$
2. Normalizing Spatial Resolution

- Choose a voxel (pixel) dimensions that are smaller or equal to the highest resolution available
- **CT**
  - If raw (sinogram) data available, direct reconstruction algorithm to generate desired voxel size
  - If no raw data, interpolate image data using bilinear or trilinear method
- **DX**
  - Bi-linear interpolation for each available view
Algorithm development challenges

• Post-reconstruction algorithm development
  ▪ Improved segmentation, CT/AT
  ▪ Feature extraction
  ▪ Classification techniques
  ▪ Targeted false alarm reduction
  ▪ Specific new classifiers as intelligence dictates

• CT reconstruction
  ▪ Artifact reduction
  ▪ Requires access to raw data
  ▪ Research using iterative techniques

Image credit: ADSA Segmentation Challenge Final Report
• DICOS benefits from the 20 years invested in DICOM
• Security industry (DHS?, TSA?, Vendors?) needs to achieve greater clarity around the problem they wish to solve
  ▪ Most immediate: 3rd party contributions in collaboration with vendors (simple, contained, clear path to certification), but DICOS not required for this
  ▪ Medium term: Universal workstation idea is a proven concept, but CONOPS and use cases not clear
  ▪ Long term: Generic ATR algorithms operating in a data space normalized for attenuation (spectral) and spatial resolution. Hurdles related to security and access to raw data.
• Open standards increase participation and opportunities for innovation
• Aviation Security innovates by (#1) evolving detection standards (#2) and providing incentives for better performance
  ▪ Driven by the government
Thank You!

The End!

Any Questions?

DICOS could help!
Special thanks to Doug Pearl for sharing his notes and research on this topic, and to Richard Bijjani for always having time to answer my questions!
Standards Development/Maintenance Organizations

- **NEMA (1926) - National Electrical Manufacturers Association**
  - Electrical components, DICOM, DICOS

- **ISO (1947) - International Organization for Standardization**
  - Quality, paper sizes (A4), screw threads

- **ANSI (1918) - American National Standards Institute**
  - Film, programming languages, crash safety

- **NIST (1901) – National Institute of Standards and Technology**
  - Weights and measures, alloy definitions, advanced encryption (AES)
  - CTIQ Phantom

- **Explosives Detection Regulators, e.g. ECAC, TSA**
  - EDS, AT-2, LEDs, ACBS
X-Ray Spectra Variations

• Dual-energy can be achieved in multiple ways
  ▪ Two X-Ray sources running at distinct kVp, switched to illuminate a common detector array
  ▪ One X-Ray source, pulsed at distinct kVp to illuminate a common detector array
  ▪ One X-Ray source illuminating sandwiched detectors; filtration between detectors creates the HE signal on the back detector

• Elements affecting X-Ray Spectrum
  ▪ kVp
  ▪ Filtration at tank (usually Al to remove very low energy photons)
  ▪ Scintillator material (e.g., GadOx, CsI, CdWO4)
  ▪ Inter-detector filter (usually Cu), if using sandwiched detectors

• Factor affecting dynamic range (flux) of detector signal
  ▪ mA
  ▪ More flux = better SNR; poisson statistics – $\sigma = \sqrt{\text{number of photons}}$

• See spectra plots on next slide
Data Transformation Considerations

• Assumes data already linearized for water
• Normalizes in one step:
  ▪ Non-linearities due to polychromatic source
  ▪ Dynamic range differences
• “Modality LUT” is designed for this purpose and may be provided in the DICOS file
  ▪ DICOS: “The Modality LUT IE defines the Attributes that describe the transformation of manufacturer-dependent pixel values into pixel values that are manufacturer-independent.”
  ▪ DICOM adds “…(e.g. Hounsfield units for CT, Optical Density for film digitizers, etc.)”
  ▪ EDS does not typically use Hounsfield units
• Next step: Spatial transformation