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Disclosures

- Member, DICOM Working Group 7 (Radiation Therapy Extensions to DICOM)
  - Participation partially funded by AAPM
- Former Vice-Chair, Integrating the Healthcare Enterprise – Radiation Oncology (IHE-RO) Technical Committee
  - Participation partially funded by ASTRO
- Chair, Health Informatics Technology (HIT) Committee, ASTRO
- Member, ASTRO IHE-RO Oversight Committee
- Former Member, Oncology Working Group, Certification Commission on Health Information Technology (CCHIT)
- President-elect, AAPM
  - Funding by AAPM for Executive Committee activities
- Confirmed Workaholic

Outline

- Networking 101
  - Open Systems Interconnection (OSI) Model
  - Network Addressing / Hardware
- Digital Imaging and Communication in Medicine (DICOM)
  - Structure and Documentation
  - Negotiation
  - Message Structure
  - Configuration
  - Resources
- Integrating the Healthcare Enterprise (IHE)
  - IHE – Radiation Oncology (IHE-RO)
  - Resources

OSI Model

- The **Open Systems Interconnection model** (**OSI Model**) is a conceptual model that characterizes and standardizes the communication functions of a telecommunication or computing system without regard of their underlying internal structure and technology.
- The model partitions a communication system into abstraction layers.
- A layer serves the layer above it and is served by the layer below it.
- The model is a product of the Open Systems Interconnection project at the International Organization for Standardization (ISO), maintained by the identification ISO/IEC 7498-1.

From Wikipedia

OSI Model

OSI Model				
Layer		Data unit	Function[3]	Examples
Host layers	7. Application	Data	High-level APIs, including resource sharing, remote file access, directory services and virtual terminals	Mail, Internet Explorer, Firefox
	6. Presentation		Translation of data between a networking service and an application; including character encoding, data compression and encryption/decryption	ASCII, EBCDIC, JPEG
	5. Session		Managing communication sessions, i.e. continuous exchange of information in the form of multiple back-and-forth transmissions between two nodes	RPC, PAP, HTTP, FTP, SMTP, Secure Shell
	4. Transport	Segments	Reliable transmission of data segments between points on a network, including segmentation, acknowledgement and multiplexing	TCP, UDP
Media layers	3. Network	Packet/Datagram	Structuring and managing a multi-node network, including addressing, routing and traffic control	IPv4, IPv6, IPsec, AppleTalk, ICMP
	2. Data link	Bit/Frame	Reliable transmission of data frames between two nodes connected by a physical layer	PPP, IEEE 802.2, L2TP
	1. Physical	Bit	Transmission and reception of raw bit streams over a physical medium	DSL, USB

From Wikipedia

OSI Layer 1: Physical Layer

- Defines electrical and physical specifications
  - Pins, voltages, cable specifications, etc.
- Defines protocol for communication between devices over the physical media

- What's defined here?
  - Ethernet
  - Bluetooth
  - Parallel SCSI
  - FDDI

From Wikipedia

OSI Layer 2: Data Link Layer

- Provides reliable control between two devices (nodes) on a network
  - Media Access – how to gain access to the network
  - Logical Link – Packet synchronization / ordering / error checking

OSI Layer 3: Network Layer

- Translates logical addresses into physical addresses
- Creates packets (datagrams) of variable length for transmission

From Wikipedia

Media Access Control (MAC) address

- A **media access control address** (**MAC address**) is a unique identifier assigned to network interfaces for communications on the physical network segment.
- MAC addresses are used as a network address for most IEEE 802 network technologies, including Ethernet and WiFi.
- The standard (IEEE 802) format for printing MAC-48 addresses in human-friendly form is six groups of two hexadecimal digits, separated by hyphens (-) or colons (:), in transmission order (e.g. 01-23-45-67-89-ab or 01:23:45:67:89:ab).
  - First three octets identify manufacturer
  - Last three octets (five in EUI-64 format) uniquely identify device.
  - Each network interface card (NIC) must have a unique address
- MAC addresses are often used by License Managers for validating software licenses.

From Wikipedia

TCP/IP Network addressing

- Private Networks
  - 10.0.0.0 (10/8) – Allows large network with up to 2^24 nodes
  - 172.16.0.0 – 172.31.255.255 (172.16/12)
    - Allows networks of up to 2^20 nodes
  - 192.168.0.0 – 192.168.255.255 (192.168/16)
    - Allows networks of up to 2^16 nodes
- Public Networks
  - [Everything else starting from 1.0.0.0 – 254.255.255.255]

https://tools.ietf.org/html/rfc1918

Internet Protocol (IP) Address

- IPv4 – IP version 4
  - 32-bit address generally shown as 4 octets, e.g. 192.168.120.10
  - IPv4 address space was exhausted in 2011
- IPv6 – IP version 6
  - Developed in 1980 – 1995, implemented in 2006
  - 128-bit address generally shown as 8 16-bit hexadecimal parts, e.g. 2001:0DB8:AC10:FE01:0000:0000:0000:0000
  - Generally not implemented in local institutions at present, major routers keep translation tables for conversion.
- Special Addresses –
  - 169.254.0.0 – Generally used when no IP address has been specified / found.

From Wikipedia

IP Address (continued)

- Unicast
  - Sends a message from one specific sender or to one specific receiver, e.g. a point-to-point message transfer
- Broadcast
  - Allows a single sender to send a message to all destinations on a given network or group of networks. The octet 255 is reserved for this purpose.
    - 255.255.255.255 will send to all hosts on all networks
    - 192.168.0.255 will send to all hosts on the 192.168.0.xxx network

From Wikipedia

cmd> ipconfig /all

```
Windows IP Configuration

   Host Name . . . . . . . . . . . . : ro-bcurranpar
   Primary Dns Suffix  . . . . . . . : RADONC.rdo.mcvh-vcu.edu
   Node Type . . . . . . . . . . . . : Hybrid
   IP Routing Enabled. . . . . . . . : No
   WINS Proxy Enabled. . . . . . . . : No
   DNS Suffix Search List. . . . . . : RADONC.rdo.mcvh-vcu.edu

Ethernet adapter Local Area Connection:

   Connection-specific DNS Suffix  . :
   Description . . . . . . . . . . . : Intel(R) PRO/1000 MT Network Connection
   Physical Address. . . . . . . . . : 00-1C-42-78-6E-1F
   DHCP Enabled. . . . . . . . . . . : Yes
   Autoconfiguration Enabled . . . . : Yes
   IPv6 Address. . . . . . . . . . . : 2601:5cd:8000:6ef7:6dc3:4cbe:7b7f:9930(Pr
eferred)
   Temporary IPv6 Address. . . . . . : 2601:5cd:8000:6ef7:e1c4:4298:7c87:8860(Pr
eferred)
   Link-local IPv6 Address . . . . . : fe80::6dc3:4cbe:7b7f:9930%11(Preferred)
   IPv4 Address. . . . . . . . . . . : 172.20.1.104(Preferred)
   Subnet Mask . . . . . . . . . . . : 255.255.224.0
   Lease Obtained. . . . . . . . . . : July 15, 2015 9:43:12 AM
   Lease Expires . . . . . . . . . . : July 16, 2015 9:43:11 AM
   Default Gateway . . . . . . . . . : fe80::68ee:96ff:fecb:f03c%11
                                       172.20.0.1
   DHCP Server . . . . . . . . . . . : 172.20.0.1
   DHCPv6 IAID . . . . . . . . . . . : 234888258
   DHCPv6 Client DUID. . . . . . . . : 00-01-00-01-1C-DE-EC-D9-00-1C-42-78-6E-1F

   DNS Servers . . . . . . . . . . . : 172.20.0.1
   NetBIOS over Tcpip. . . . . . . . : Enabled
```

Domain Name System (DNS)

- Allows human-centric IP address to be translated into IP addresses.
- Defines a hierarchy for assigning and distributing human-centric names
- A DNS server is a member of the DNS system responsible for making translations of DNS names to IP addresses and keeping tables for such translations.
- The original DNS structure relied on a subset of ASCII characters (alphanumeric plus the hyhen). Recent work has been involved in internationalizing the namesets.
- There is a hierarchy of name servers starting at the top levels (zones) of the DNS.
- Larger institutions have at least one DNS server in their namespace and often use an external DNS server as a backup to their systems.

From Wikipedia

Special IP Addresses

- Gateway –
  - A gateway is a computer system responsible for forwarding any datagrams which are not addressed to any local system. Often these systems are given the first address in the namespace of the local network, e.g. 192.168.22.1. Today, these systems are generally special purpose routers.
- Subnet Mask –
  - Since local address spaces can be very large (e.g. 10.xxx.xxx.xxx) or small (e.g. 192.168.12.00 – 192.168.12.63), a subnet mask determines whether an address is in the local address space or should be sent to the gateway address. The subnet mask is "ANDed" with the destination's IP address and isolates the network address portion of the IP address from local host addresses. If the remaining address bits match the local network address, the host is local; if not, the packet must be sent to the gateway for forwarding.
  - Previously subnet masks were referenced by an IPv4 octet such as 255.255.255.0, indicating that the top 24 bits were the network address. A new format, known as CIDR now indicates the subnet mask by giving the first address in the network and the number of network bits, e.g. 192.168.0.0/24.

TCP/IP Ports

- A number, found in the header of datagram packets, which identifies the purpose / application associated with the information in the packet.
- "Well-known Ports" are ports in the range 0 – 1023 which have been assigned to specific applications:
  - 80 – http: (unsecure web pages)
  - 443 – https: (secureweb pages)
  - 20,21 - ftp:
  - 23 - telnet:
  - 104 - DICOM
- "Registered Ports" are in the range 1024 – 49151 and assigned by Internet Authorities for specific applications
- "Dynamic Ports" are in the range 49152 – 65535 and available for any application. Users must be careful that applications on a specific computer do not use the same ports.
  - Can often be an issue with Database applications using SQL ports.

Windows Internet Name Service (WINS)

- WINS is a Windows implementation of a name server (netBIOS), allowing configuration of networks where DNS services were not fully implemented / available.
- WINS registers clients dynamically and, while not completely as versatile as DNS, provides a more economical means of network access within an institution's systems. WINS is responsible for populating the "My Network Places" list of computers.
- Most modern networks now have DNS capabilities and may not need WINS, but it's functionalities are still inherent in Windows systems and can be useful.

https://technet.microsoft.com/library/bb727015.aspx

Dynamic Host Configuration Protocol (DHCP)

- The **Dynamic Host Configuration Protocol** (**DHCP**) is a standardized network protocol used on Internet Protocol (IP) networks for dynamically distributing network configuration parameters, such as IP addresses for interfaces and services.
- With DHCP, computers request IP addresses and networking parameters automatically from a DHCP server, reducing the need for a network administrator or a user to configure these settings manually.
- DHCP can be very general, allocating address to whatever system requests one (e.g. a wifi server in an airport) or very secure, only allowing requests to be granted for known hosts or even specified hosts on specific network ports.

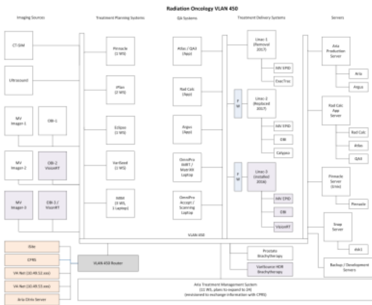
From Wikipedia

Virtual Private Network (VPN)

- A **virtual private network** (**VPN**) extends a private network across a public network, such as the Internet. It enables a computer or network-enabled device to send and receive data across shared or public networks as if it were directly connected to the private network, while benefiting from the functionality, security and management policies of the private network.[1]
- A VPN is created by establishing a virtual point-to-point connection through the use of dedicated connections, virtual tunneling protocols, or traffic encryption.

From Wikipedia

Medical Device Network – RICVAMC

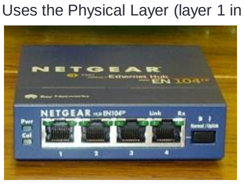


Network Hub

An **Ethernet hub**, **active hub**, **network hub**, **repeater hub**, **multiport repeater** or **hub** is a device for connecting multiple Ethernet devices together and making them act as a single network segment.

It has multiple input/output (I/O) ports, in which a signal introduced at the input of any port appears at the output of every port except the original incoming.[1]

Uses the Physical Layer (layer 1 in the OSI model)



From Wikipedia

Network Switch

- A **network switch** (also called **switching hub**, **bridging hub**, officially **MAC bridge**[1]) is a computer networking device that connects devices together on a computer network, by using packet switching to receive, process and forward data to the destination device.
- Unlike less advanced network hubs, a network switch forwards data only to one or multiple devices that need to receive it, rather than broadcasting the same data out of each of its ports.[2]
- Uses the “Data Link Layer” (layer 2 in the OSI model)

From Wikipedia

Router

- A **router**[a] is a networking device that forwards data packets between computer networks.
- A router is connected to two or more data lines from different networks (as opposed to a network switch, which connects data lines from one single network).
- When a data packet comes in on one of the lines, the router reads the address information in the packet to determine its ultimate destination.
- Then, using information in its routing table or routing policy, it directs the packet to the next network on its journey. This creates an overlay internetwork.
- Routers perform the "traffic directing" functions on the Internet. A data packet is typically forwarded from one router to another through the networks that constitute the internetwork until it reaches its destination node.[1]

From Wikipedia

Routers

From Wikipedia

Firewall

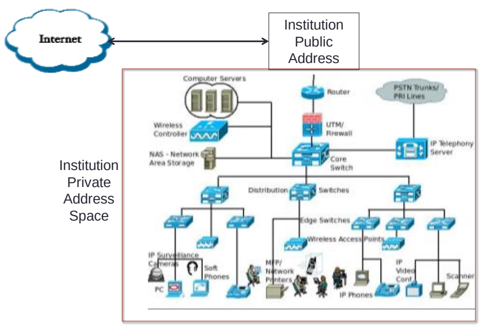
- A network security system that controls the incoming and outgoing network traffic based on an applied rule set.
- A firewall typically establishes a barrier between a trusted, secure internal network and another network (e.g., the Internet) that is assumed not to be secure and trusted.[1]
- Routers that pass data between networks contain firewall components and, conversely, many firewalls can perform basic routing functions,[2][3] and firewall appliances may also offer other functionality to the internal network they protect, such as acting as a DHCP or VPN server for that network.
- Firewalls offer varying levels of hardware and software protection depending upon models and features.

From Wikipedia

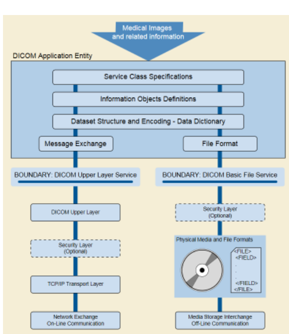
Firewall

http://www.juniper.net/us/en/products-services/security/srx-series/srx100/

Typical Institutional Address Schema



DICOM Communication Model



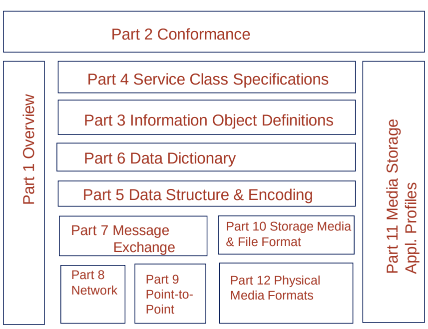
Digital Imaging and COmmunication in Medicine (DICOM)

- Developed by ACR and NEMA in the 80s – 90s
- DICOM efforts are concentrated in domain-specific working groups

INTRODUCTION	
The DICOM Standards Committee	
WG-01: Cardiac and Vascular Information	WG-16: Magnetic Resonance
WG-02: Projection Radiography and Angiography	WG-17: 3D
WG-03: Nuclear Medicine	WG-18: Clinical Trials and Education
WG-04: Compression	WG-19: Dermatologic Standards
WG-05: Exchange Media	WG-20: Integration of Imaging and Information Systems
WG-06: Base Standard	WG-21: Computed Tomography
WG-07: Radiotherapy	WG-22: Dentistry
WG-08: Structured Reporting	WG-23: Application Hosting
WG-09: Ophthalmology	WG-24: Surgery
WG-10: Strategic Advisory	WG-25: Veterinary Medicine
WG-11: Display Function Standard	WG-26: Pathology
WG-12: Ultrasound	WG-27: Web Technology for DICOM
WG-13: Visible Light	WG-28: Physics
WG-14: Security	WG-29: Education, Communication and Outreach
WG-15: Digital Mammography and CAD	WG-30: Small Animal Imaging

http://medical.nema.org/dicom/geninfo/Strategy.pdf

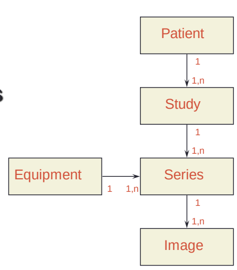
DICOM Parts



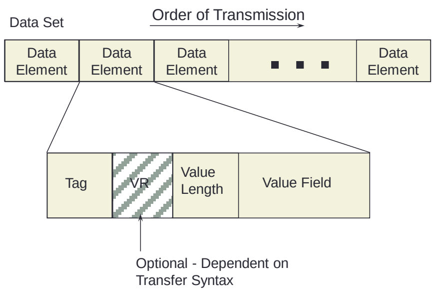
DICOM Highlights

Object-Oriented Design

- Defines Objects
- Defines Relationships
  - Database-like



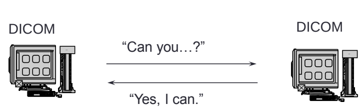
DICOM Data Stream



DICOM Services

Verb: Store → Service
Noun: CT Image → IOD
Sentence:
Store a CT Image → SOP Class

DICOM Highlights



- Network Data Transfer
  - Negotiated syntax
    - Big/Little-endian
    - What Services are supported
    - JPEG Compression

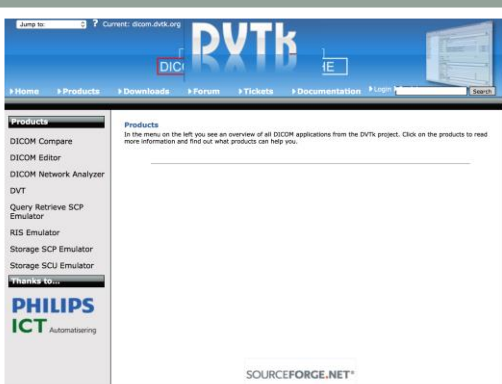
DICOM Configuration

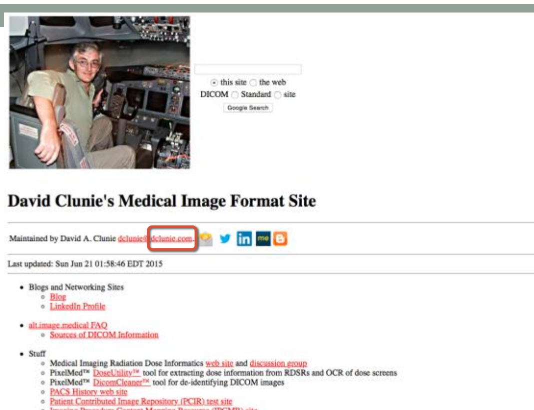
- Application Entity Title (AE_TITLE)
  - 16 character DICOM name, generally specified in UPPERCASE
- DICOM Port
  - Typically 104 is used, 105-6 are also common
- Hostname / IP Address
  - Information identifying the computer supporting the DICOM service

- Common Configuration Issues
  - Some applications cannot handle multiple DICOM definitions with either (a) the same AE_Title, or (b) the same IP Address.
  - Hospital IT has not enabled the necessary ports to be used.
  - Latency – on slow networks, there may be a delay in making a connection between two DICOM nodes. Most DICOM senders / receivers have a timeout limit beyond which the transfer is aborted.

DICOM Resources

- DVTk - DICOM Validation Tool Kit (DICOM.DVTk.org)
  - Provides API for writing your own code for reading DICOM files
  - Provides a set of applications for reading, analyzing, DICOM files
  - Open source (SourceForge.net) – Windows-based
- DICOM.NEMA.org
  - Homepage for all DICOM Activities, documentation, resources
- DClunie.com –
  - Dave Clunie is a radiologist / DICOM proponent who has developed an extensive resource site.
- MatLab – has an Imaging Toolkit capable of reading DICOM images
- ImageJ – NIH-developed resources for imaging
- Osirix – Mac-based resources for imaging





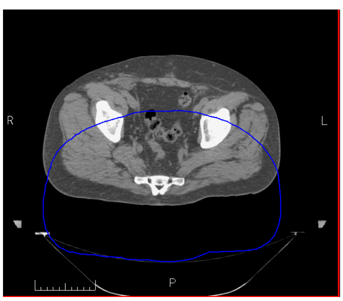
Common DICOM Issues

- Character Set Mismatches
  - Many RO vendors do not allow full ISO-100 character set
- Compression
  - Most RO vendors do not support compressed images
- Image Orientation
  - Most RO vendors do not support images with CT Gantry Angle
  - Many RO vendors do not support decubitus or oblique primary image sets
- Manufacturers have interpreted the DICOM Standard differently
  - DICOM was developed by consensus, not always one way to transfer information
- Different limits assigned to TPS information
  - # of ROIs, Contours, Points
  - Representation of a CT-Sim plan
  - Exchange of Dose Information
- "Testing" was envisioned as comparison of DICOM Conformance Statements, too complex in RO

The “New” Problem

- Physicists spend a lot of time specifying / verifying the connectivity between systems in radiation oncology, even with DICOM
- Each new release typically requires significant retesting
- Similarly, it is expensive for manufacturers to test connectivity at customer sites after product release.

COULD THIS HAPPEN TO YOU?



Actual Result of Image and Contour transfer from CT to Planning System

What is IHE?

- An effort by Users and Vendors to Develop more Robust Standards for Information Exchange
- Initiated by RSNA and HIMSS in 1997, now supported by numerous groups and vendors
- A mechanism for the Development of Protocols for Local, Regional, and National Exchange of Healthcare Information (the Electronic Healthcare Record)

4 Steps of IHE Process

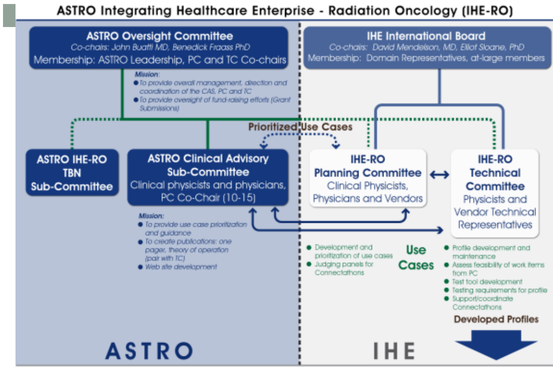
A defined, coordinated process for standards adoption. Repeated annually, promoting steady integration

- Identify Interoperability problems
- Specify Integration Profiles
- Test Integration Profiles at Connectathon
  - Vendor testing using Test Tool Suite
- Publish Integration Profiles for use in RFPs

IHE-RO

- DICOM WG-7 (April, 2004)
  - Introduction to IHE
  - Discussion on how Radiation Oncology could participate
- NEMA Radiation Therapy Section
  - At AAPM 2004, discussed need to improve interoperability in RT
- ASTRO
  - Board of Directors Proposal, June 2004
  - Kick-off, ASTRO Annual Meeting, 2004
  - First Meeting of IHE-RO PC & TC @ RSNA, 2004
  - Joint Effort led by ASTRO with AAPM, NEMA, and others
- IHE-RO Technical Committee
  - First Meeting, January, 2005 w/ DICOM WG-7

ASTRO Integrating Healthcare Enterprise - Radiation Oncology (IHE-RO)



Comment
Generally use cases are created and prioritized within the PC with consultation and advice of the ASTRO Clinical Advisory Subcommittee and then handed off to the TC for profile development. The TC reports on progress and barriers to progress as well as ideas for approaches and application. This also flows to the ASTRO Clinical Advisory Subcommittee as well as to the ASTRO IHE-RO Steering Committee.

How does IHE work?

Connectathons

- Cross-vendor, live, supervised, structured tests.
- All participating vendors' products tested together in the same place/time.
- Experts from each vendor available for immediate problem resolution. Fixes are done in minutes, not months!
- Each vendor tests with multiple trading partners (actual product to actual product).
- Testing of real-world clinical scenarios using IHE Integration Profiles.



Where can you learn more?

http://wiki.ihe.net/

Where can you learn more?

http://www.ihe.net/