Andreas Holzinger
VO 709.049 Medical Informatics
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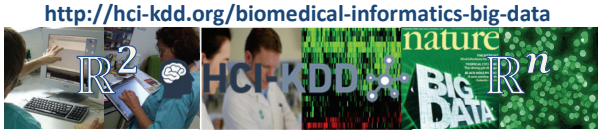
Lecture 10
Biomedical Information Systems and Medical Knowledge Management

a.holzinger@tugraz.at
Tutor: markus.plass@student.tugraz.at
http://hci-kdd.org/biomedical-informatics-big-data



Schedule

Keywords of the 10th Lecture

- Bioinformatics workflows
- Clinical workflow & management systems
- Cloud computing in healthcare
- Communication standards
- Digital Imaging and Communication in Medicine (DICOM)
- Formal methods & workflow modeling
- Health Level 7 (HL7)
- Logical Observation Identifier Names and Codes (LOINC)
- Medical multimedia
- Mobile computing in medicine
- Personal Health Record (PHR)
- Picture Archiving and Communication System (PACS)
- Quality
- Software as a Service (SaaS)
- Systems architecture
- Unified Modeling Language (UML)

Advance Organizer (1/2)

- **Bioinformatics workflow management system** = designed specifically to compose and execute a series of computational and/or data manipulation steps and/or workflows in the domain of bioinformatics;
- **Business process re-engineering (BPR)** = analysis and design of workflows and processes within an organization (=hospital). According to Davenport (1990) a BP is a set of logically related tasks performed to achieve a defined outcome/result;
- **Clinical Pathway** = aka care map, a tool used to manage the quality in healthcare concerning the standardization of care processes and promote organized and efficient patient care based on EBM;
- **Digital Imaging and Communications in Medicine (DICOM)** = a standard for handling, storing, printing, and transmitting data in medical imaging (also file format definition and a network communications protocol using TCP/IP);
- **Evidence-based medicine (EBM)** = aiming at developing mathematical estimates of benefit and harm from population-based research and apply these in the clinical routine, claiming that best research evidence on medical interventions come from experiments (e.g. randomized controlled trials);
- **Health Level Seven (HL 7)** = a Standardization Organization accredited by the American National Standards Institute (ANSI) to push consensus-based standards representing healthcare stakeholders;

Advance Organizer (2/2)

- **Hospital Information System (HIS)** = integrated information system for (administrative, financial, clinical etc.) information management in a hospital;
- **Integrating Healthcare Enterprise (IHE)** = initiative by healthcare professionals and industry to improve the way computer systems in healthcare share information (i.e. promotes the coordinated use of established standards such as DICOM and HL7);
- **National Electrical Manufacturers Association (NEMA)** = holds copyright of DICOM;
- **Paradigm** = according to Kuhn (1962) a shared view of a group of researchers, comprising 4 elements: concepts, theories, methods and instruments;
- **Picture Archiving and Communication System (PACS)** =system for handling images from various medical imaging instruments, including ultrasound (US), magnetic resonance (MR), positron emission tomography (PET), computed tomography (CT), endoscopy (ENDO), mammographs (MG), Digital radiography (DR), computed radiography (CR) ophthalmology, etc.;
- **Workflow** = consists of a sequence of connected steps, succeeding the flow paradigm, where each step follows the precedent;

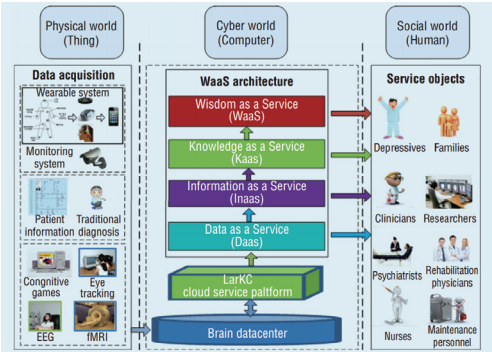
Learning Goals: At the end of this 10th lecture you …

- have an overview about workflows and workflow modeling in health care;
- got an overview of typical architectures of hospital information systems for patient records as already discussed in lecture 4;
- have understood the principles of Picture Archiving and Communication PACS-Systems;
- know how important multimedia for medicine is;
- have a basic understanding of DICOM and HL 7;
- are aware of the constraints of open source software in the medical domain;
- have got an idea of possible future systems solutions;

Slide 10-1 Key Challenges

- Lack of Integrated Systems
- Clinical Workplace efficiency
- Cloud Computing
  (Privacy, Security, Safety, Data Protection…)
- Service oriented computing
  (as electricity is already!)

Service-oriented computing example Zhong et al. (2015)



Zhong, N., Yau, S. S., Ma, J., Shimojo, S., Just, M., Hu, B., Wang, G., Oiwa, K. & Anzai, Y. 2015. Brain Informatics-Based Big Data and the Wisdom Web of Things. *Intelligent Systems, IEEE*, 30, (5), 2-7.

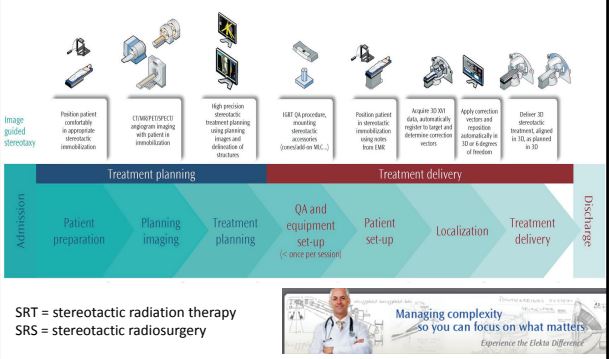
What is a clinical pathway?

What is a clinical workflow?

Example

http://www3.gehealthcare.co.uk/~/media/images/specialty/cardiology/acute-caronary-syndrome-pathway.jpg

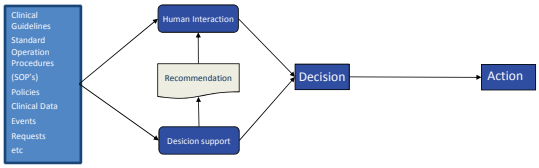
Slide 10-2 Typical Workflow in a hospital: Example Radiology



SRT = stereotactic radiation therapy
SRS = stereotactic radiosurgery

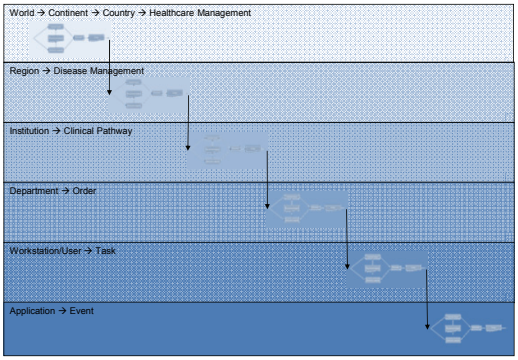
http://www.elekta.com/

Slide 10-3 Workflow > Interaction > Decision > Action



Colaert (2010): The Pain Points in Health Care and the Semantic Web, Advanced Clinical Application Research Group, Agfa HealthCare

Slide 10-4 Various Levels of Decision Support



Colaert (2010): The Pain Points in Health Care and the Semantic Web, Advanced Clinical Application Research Group, Agfa HealthCare

Slide 10-5 Workflow modeling in a nutshell

- Workflow modeling is the process of simplifying the real-world;
- Modeling is based on facts gathered during observations and we need to accept that this representation can never be perfect;
- Expectations from a model should be limited to the intentions with which it is designed for, be it problem solving or understanding of system intricacies (=elaborately complex details);

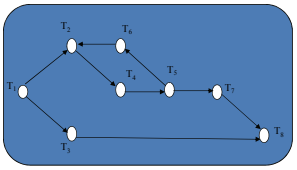
Malhotra, S., Jordan, D., Shortliffe, E. & Patel, V. L. (2007) Workflow modeling in critical care: Piecing together your own puzzle. *Journal of Biomedical Informatics, 40, 2, 81-92.*

Slide 10-6 Example: Formal workflow modeling 1/2

- A workflow is defined as a process that contains tasks T, and the respective rules on how those tasks are executed:
- Workflow W:= (T, P, C, A, S_0) where
  - T = {T_1, T_2, … T_m} A set of tasks, m≥ 1
  - P = $(p_{ij})_{m \times m}$ **Precedence matrix of the task set**
  - C = $(c_{ij})_{m \times m}$ **Conflict matrix of the task set**
  - A = ($A(T_1)$, $A(T_2)$, …,$A(T_m)$) Pre-Condition set for each task
  - $S_0 \in \{0, 1, 2, 3\}_m$ is the initial state

J. Wang, D. Rosca, W. Tepfenhart & A. Milewski (2006) Dynamic Workflow Modeling and Analysis, Monmouth University

Slide 10-7 Example: Formal workflow modeling 2/2



$T = \{T_1, T_2, \ldots, T_8\}$,

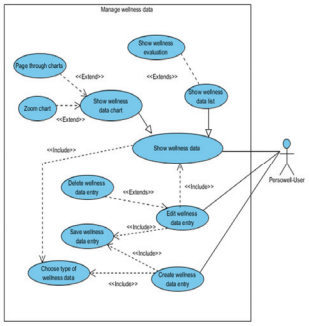
$A(T_1) = \emptyset$, $A(T_2) = \{\{T_1\}, \{T_6\}\}$, $A(T_3) = \{\{T_1\}\}$,
$A(T_4) = \{\{T_2\}\}$, $A(T_5) = \{\{T_4\}\}$,
$A(T_6) = A(T_7) = \{\{T_5\}\}$, $A(T_8) = \{\{T_3, T_7\}\}$.
$S_0 = (1, 0, 0, 0, 0, 0, 0, 0)$.

$$P = \begin{bmatrix} 0&1&1&0&0&0&0&0 \\ 0&0&0&1&0&0&0&0 \\ 0&0&0&0&0&0&0&1 \\ 0&0&0&0&1&0&0&0 \\ 0&0&0&0&0&1&1&0 \\ 0&1&0&0&0&0&0&0 \\ 0&0&0&0&0&0&0&1 \\ 0&0&0&0&0&0&0&0 \end{bmatrix} \quad C = \begin{bmatrix} 0&0&0&0&0&0&0&0 \\ 0&0&0&0&0&0&0&0 \\ 0&0&0&0&0&0&0&0 \\ 0&0&0&0&0&0&0&0 \\ 0&0&0&0&0&0&0&0 \\ 0&0&0&0&0&0&1&0 \\ 0&0&0&0&0&1&0&0 \\ 0&0&0&0&0&0&0&0 \end{bmatrix}$$

J. Wang, D. Rosca, W. Tepfenhart & A. Milewski (2006) Dynamic Workflow Modeling and Analysis, Monmouth University

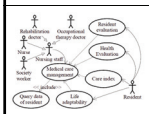
Slide 10-8 Example: Modeling in UML – Use Case Diagram

Name	Modify a wellness data entry
Purpose	The user edits the value of an existing wellness data entry
Summary	Clicking on an entry's row in the list of all wellness entries (except clicking on the info-icon) opens an input form allowing the user to modify and store the selected entry. After storing the entry on the server, an info message tells about success or possible failure. Instead of modifying the data, the user can also delete the entry using a button in this form.
Pre-conditions	The user is authenticated. The user has chosen an existing wellness data entry.
Post-conditions	The entry is updated or deleted on the server.



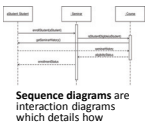
Holzinger, A., Dorner, S., Födinger, M., Valdez, A. C. & Ziefle, M. (2010) Chances of Increasing Youth Health Awareness through Mobile Wellness Applications. In: *Lecture Notes in Computer Science (LNCS 6389). Berlin, Heidelberg, Springer, 71-81.*

Slide 10-9 Modeling: Different views for different people

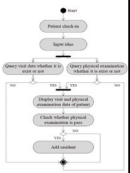


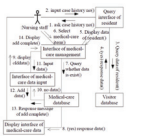
For Stakeholders **use case diagrams** describe sequences of actions, providing measurable values to actors

Class diagrams show interrelationships, inheritance, aggregation, association, operations and attributes



Sequence diagrams are interaction diagrams which details how operations are carried out, which messages are sent and at which time





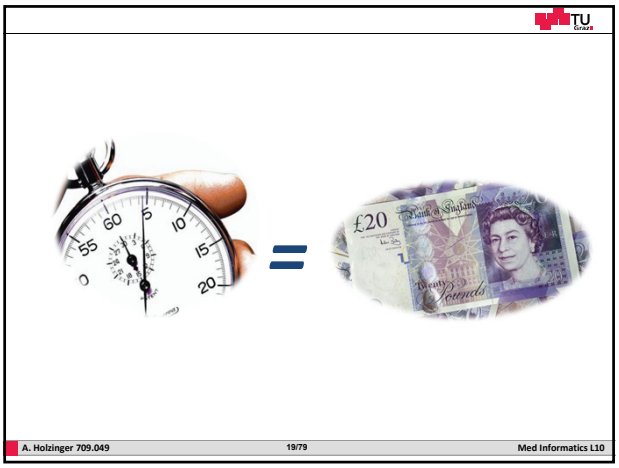
Communication/Collaboration diagrams show the message flow between objects and imply the relationships between classes

Component diagrams are used as an architecture-level artifact

Deployment diagrams model the static view of the run-time configuration of processing nodes and the components that run on those nodes; this shows also hardware & software requirements

Activity Diagrams for modelling the logic and **State Machine diagrams** show to analysers the possible states of objects and transitions that causes changes

Juan, Y. C., Ma, C. M. & Chen, H. M. (2005) Applying UML to the development of medical care process management system for nursing home residents. *International Journal of Electronic Business Management, 3, 4, 322-330.*



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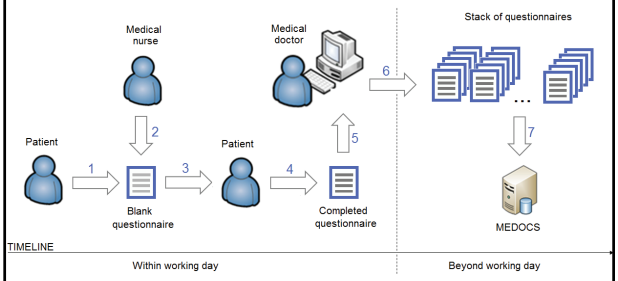
Slide 10-10 Example Clinical Workflow



Holzinger, A., Kosec, P., Schwantzer, G., Debevc, M., Hofmann-Wellenhof, R. & Frühauf, J. (2011) Design and Development of a Mobile Computer Application to Reengineer Workflows in the Hospital and the Methodology to evaluate its Effectiveness. *Journal of Biomedical Informatics, 44, 6, 968-977.*

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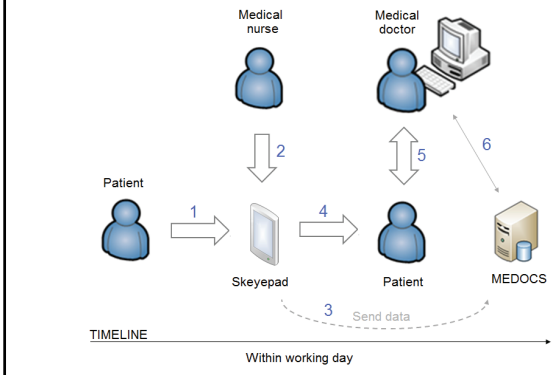
Slide 10-11 Example: WF-Optimization with mobile comp



Holzinger et al. (2011)

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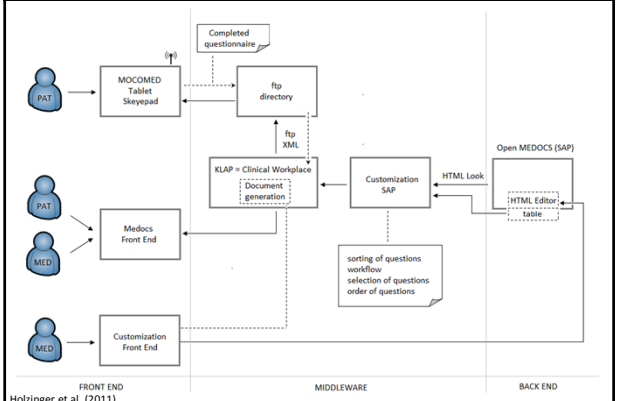
Slide 10-12 Mobile Computing Project MoCoMed-Graz



Holzinger et al. (2011)

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Slide 10-13 Important: Macrolevel – the view of the Manager

Rechenmodell zum Ausfüllen eines Fragebogens in einer Ambulanz

ohne MoCoMed (Szenario 1)		
Eingebendes Personal	Arzt (1 A)	Schreibkraft bzw. Schalter (1 B)
Personalkosten/h	€ 44,0	€ 19,0
Personalkosten/min	€ 0,73	€ 0,32
Anzahl Patienten/Tag	30	30
Zeitbedarf pro Fragebogen in min.	10	7
Ambulanztage pro Jahr	250	250
Jahreskosten Personal	**€ 55.000**	**€ 16.825**

mit MoCoMed (Szenario 2)		
Eingebendes Personal	Arzt	Schreibkraft bzw. Schalter
Personalkosten/h	€ 44,0	€ 19,0
Personalkosten/min	€ 0,73	€ 0,32
Anzahl Patienten pro Tag	30	30
Zeitersparnis pro Fragebogen in %	90%	90%
Zeitbedarf pro Fragebogen in min.	1,00	0,70
Gerätemanipulationszeit pro Fragebogen in min.		1,00
Ambulanztage	250	250
Jahreskosten Personal	**€ 7.875**	**€ 4.038**
+ Gesamtkosten MoCoMed/Jahr	€ 9.800	€ 9.800
= Jahreskosten TOTAL	**€ 17.675**	**€ 13.838**

Ergebnis		
Eingebendes Personal	Arzt	Schreibkraft bzw. Schalter
Einsparungspotential/Jahr in EUR unter den oa. Annahmen:	**€ 37.325**	**€ 2.788**
Einsparungspotential/Jahr in Std. unter den oa. Annahmen:	**848**	**147**

Entwicklungs- und Betriebskosten MoCoMed	
Kosten pro Personenmonat Entwicklung (EU-Satz)	€ 4.000
Anzahl Personenmonate Entwicklung einmalig	7
Kosten Personal Entwicklung	**€ 28.000**
Investkosten pro Gerät	€ 1.600
Anzahl Geräte	2
Kosten Geräte	**€ 3.200**
Summe Entwicklungskosten	**€ 31.200**
Kosten pro Personenmonat Wartung und Betrieb	€ 4.000
Anzahl Personenmonate Wartung und Betrieb pro Gerät pro Jahr	0,25
Anzahl Jahre (Lebenszyklus)	4
Kosten Wartung und Betrieb auf Lebenszyklus	**€ 8.000**
Gesamtkosten auf Lebenszyklus	**€ 39.200**
Gesamtkosten anteilig/Jahr	**€ 9.800**

Holzinger, A., Kosec, P., Schwantzer, G., Debevc, M., Hofmann-Wellenhof, R. & Frühauf, J. (2011) Design and Development of a Mobile Computer Application to Reengineer Workflows in the Hospital and the Methodology to evaluate its Effectiveness. *Journal of Biomedical Informatics, 44,* ***6, 968-977.***

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Slide 10-14 MoCoMED-Graz in operation

Holzinger et al. (2011)

A. Holzinger 709.049 24/79 Med Informatics L10

Slide 10-15 MoCoMedGraz Project – Benefit Summary

- This project was evaluated from a three level perspective: **patients – doctors – managers**
- Theoretical Background: Bronfenbrenner model
- Project demonstrates how both workflows and information quality can be optimized;
- thereby raising both medical quality and patient empowerment;
- Success factors for applications within the hospital include: **simplicity, usability, reliability**

Holzinger, A., Kosec, P., Schwantzer, G., Debevc, M., Hofmann-Wellenhof, R. & Frühauf, J. (2011) Design and Development of a Mobile Computer Application to Reengineer Workflows in the Hospital and the Methodology to evaluate its Effectiveness. *Journal of Biomedical Informatics, 44,* ***6, 968-977.***

Slide 10-16 Summary: Workflows in Bioinformatics

- A data-driven procedure consisting of one or more transformation processes -> nodes;
- Can be represented as a **directed graph;**
  - **Direction is time** – i.e. the order of transformations;
  - A set of transformation rules;
- The data flow origins from a source to a destination (or result) via a series of data manipulations;
- The specification is designed in a **Workflow Design System** (modeling component) and then run by a **Workflow Management System** (execution component).

Hasan, S., Daugelat, S., Rao, P. S. S. & Schreiber, M. (2006) Prioritizing genomic drug targets in pathogens: application to Mycobacterium tuberculosis. *PLoS Computational Biology, 2, 6, e61.*

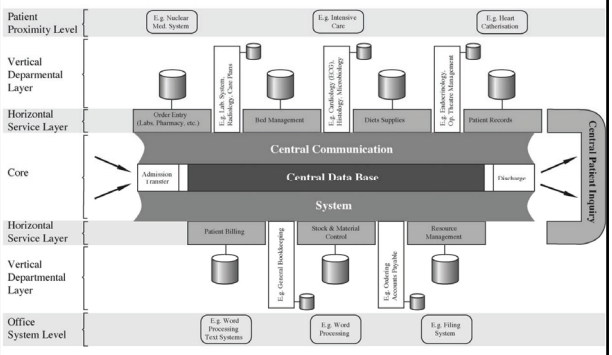
Slide 10-17 Bioinformatics Workflow Management System

- Def.: WMS = a system that defines, creates and manages the execution of workflows. Its main components include:
- 1) a graphical interface for composing workflows, entering data, watching execution, displaying results;
- 2) an data archive to store workflow descriptions, results of executions and related traces;
- 3) a registry of available services, either local or remote,
- 4) a scheduler able to invoke services included in the workflow at the appropriate time,
- 5) a set of programming interfaces able to dialogue with remote services,
- 6) a monitor tool for controlling the execution of the
- workflow,
- 7)a set of visualization capabilities for displaying different types of results.

Romano, P. (2008) Automation of in-silico data analysis processes through workflow management systems. *Briefings in Bioinformatics, 9, 1, 57-68.*

Hospital Information Systems

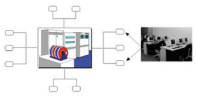
Slide 10-18 Remember: Classic Conceptual Model of a HIS



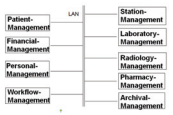
Reichertz, P. L. (2006) Hospital information systems - Past, present, future. *International Journal of Medical Informatics, 75, 3-4, 282-299.*

Slide 10-19 Architectures of Hospital Information Systems

1970+ **"Vertical Approach"** – monolithic mainframes
Central computer systems mainly for accounting, typical "data processing" ("EDV")



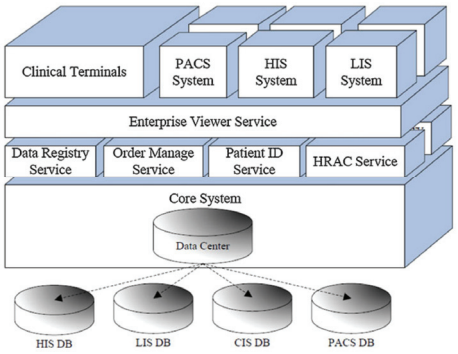
1985+ **"Horizontal Approach"** – evolutionary systems
Departmental clinical information systems, local area networks, distributed systems



2000+ **"Integrated Approach"** – open, distributed systems
Hospital Intranets, electronic patient/health record, mobile computing, "information quality focus"

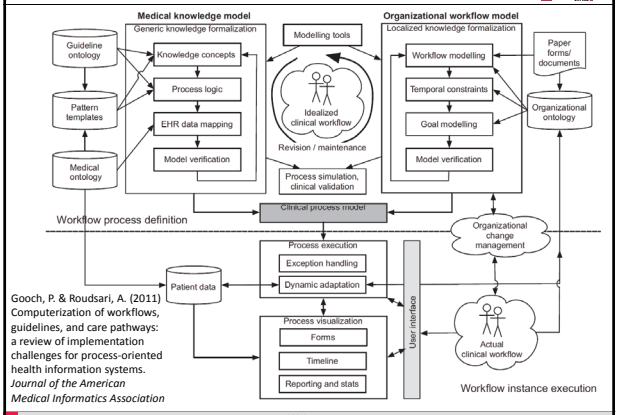
Holzinger, A. (2002) *Basiswissen IT/Informatik Band 1: Informationstechnik. Das Basiswissen für die Informationsgesellschaft des 21. Jahrhunderts. Wuerzburg, Vogel Buchverlag.*

Slide 10-20 Basic architecture of a standard HIS



El Azami, I., Cherkaoui Malki, M. O. & Tahon, C. (2011) Integrating Hospital Information Systems in Healthcare Institutions: A Mediation Architecture. *Journal of Medical Systems, (in print), 1-12.*

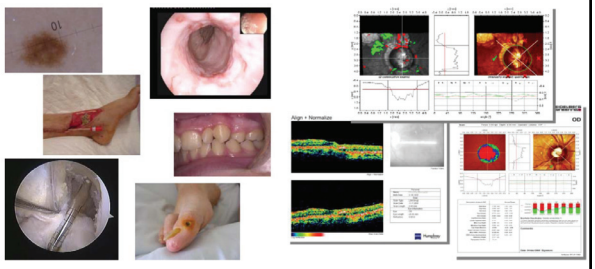
Slide 10-21 Model of Process Oriented Health Info Systems



Gooch, P. & Roudsari, A. (2011) Computerization of workflows, guidelines, and care pathways: a review of implementation challenges for process-oriented health information systems. *Journal of the American Medical Informatics Association*

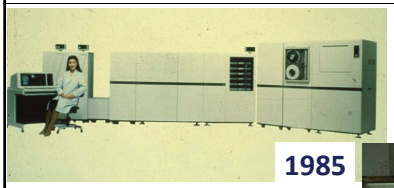
Multimedia in the Hospital

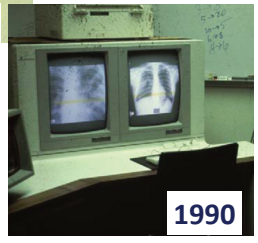
Slide 10-22 Multimedia throughout the Hospital



Bellon, E., Feron, M., Deprez, T., Reynders, R. & Van den Bosch, B. (2011) Trends in PACS architecture. *European Journal of Radiology, 78, 2, 199-204.*

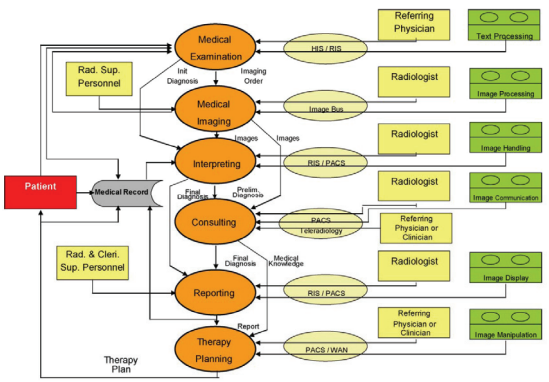
Slide 10-23 1st commercial Picture Archiving & Comm. System





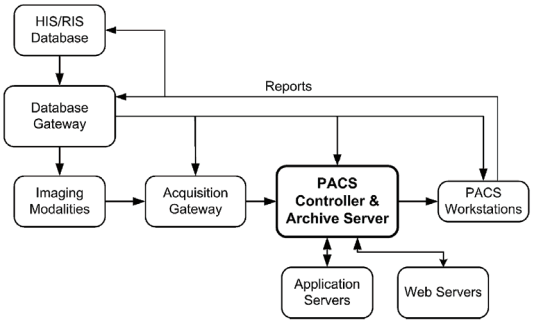
Huang, H. K. (2011) Short history of PACS (USA). *European Journal of Radiology, 78, 2, 163-176.*

Slide 10-24 Typical Workflow in a European PACS



Lemke, H. (2011) Short history of PACS (Europe). *European Journal of Radiology, 78, 2, 177-183.*

Slide 10-25 Generic PACS components and data flow



Huang, H. K. (2011) Short history of PACS (USA). *European Journal of Radiology, 78, 2, 163-176.*

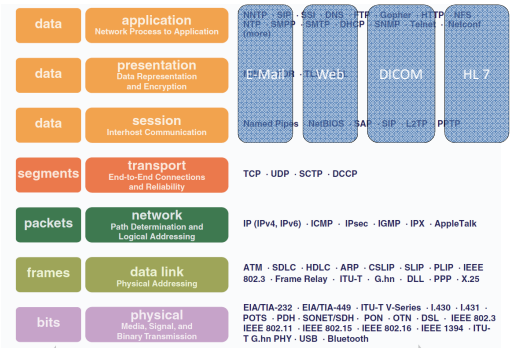
Data Standards for Communication and Representation

Slide 10-26 Data Standards for Comm. & Representation

- **DICOM 3.0 – Digital Imaging and Communication in Medicine** (1993)
  - 1) a set of protocols for network communication;
  - 2) a syntax and semantics for commands and info;
  - 3) a set of media storage services (standard compliant);
- **HL 7 - Health Level 7**
  - 1) HL 7 v2.x messaging protocol, to provide exchange of textual healthcare data between hospital information systems;
  - 2) Reference Implementation Model (RIM) contains data types, classes, state diagrams, use case models, ant terminology to derive domain-specific information models;
  - 3) Clinical Document Architecture (CDA) is a document markup standard to specify structure and semantics of clinical documents in XML;
- **LOINC - Logical Observation Identifier Names and Codes**
  - 1) Laboratory data (e.g. molecular pathology observations used for identification of genetic mutations, tumor genes, gene deletions, etc.
  - 2) Clinical Observations (e.g. non-laboratory diagnostic studies, critical care, nursing measures, patient history, instrument surveys, etc.
  - 3) Claims attachments (e.g. handles the definition of new LOINC terms and codes to manage claims-related data

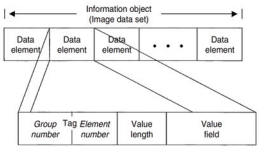
Bui, A. A. T. & Taira, R. K. (2010) *Medical Imaging Informatics. New York, Heidelberg, London, Springer.*

Slide 10-27 DICOM and HL 7

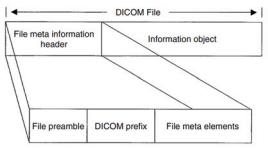


Williams, R. (2011) Network Concepts.
In: *An Introduction to Trading in the Financial Markets. San Diego, Academic Press, 201-225.*

Slide 10-28 DICOM Object containing multiple data elements



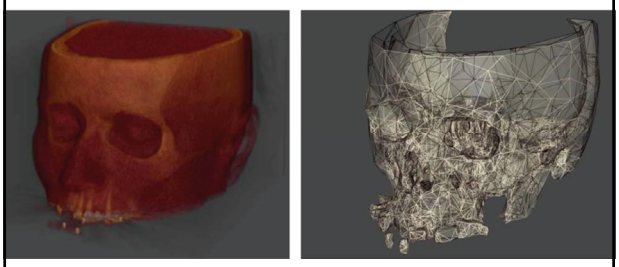
Each data element is uniquely identified by its corresponding tag composed of a group number and an element number. Pixel data of the image is stored in element 0010 within group 7FE0.



A DICOM file consists of a file meta-information header and an information object (image data set). The file meta-information header is made of a file preamble, a DICOM prefix, and multiple file meta-elements.

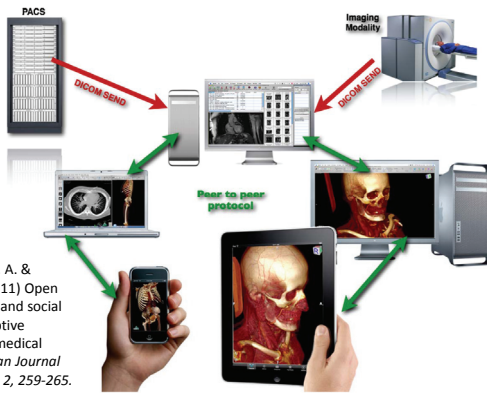
Wong, A. & Lou, S. L. (2009) Medical Image Archive, Retrieval, and Communication. In: Isaac, N. B. (Ed.) *Handbook of Medical Image Processing and Analysis (Second Edition). Burlington, Academic Press, 861-873.*

Slide 10-29 DICOM instances allowing the storage of meshes



Lemke, H. U. & Berliner, L. (2011) PACS for surgery and interventional radiology: Features of a Therapy Imaging and Model Management System (TIMMS). *European Journal of Radiology, 78, 2, 239-242.*

Slide 10-30 Image distribution workflow

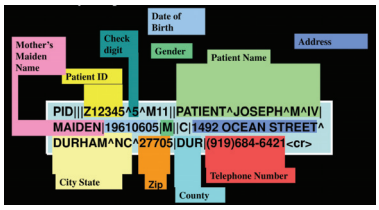


Ratib, O., Rosset, A. & Heuberger, J. (2011) Open Source software and social networks: Disruptive alternatives for medical imaging. *European Journal of Radiology, 78, 2, 259-265.*

Slide 10-31 HL7 Use Case: serum glucose lab result

Result delivered by Dr. Howard H. Hippocrates. The lab test was ordered by Dr. Patricia Primary for patient Eve E. Everywoman. The use case takes place in the US Realm.

```
MSH|^~\&|GHH LAB|ELAB-3|GHH OE|BLDG4|200202150930||ORU^R01|CNTRL-3456|P|2.4<cr>
PID|||555-44-4444||EVERYWOMAN^EVE^E^^^^L|JONES|19620320|F|||153 FERNWOOD DR.^
^STATESVILLE^OH^35292|||(206)3345232|(206)752-121||||Ac555444444||67-A4335^OH^20030520<cr>
OBR|1|845439^GHH OE|1045813^GHH LAB|15545^GLUCOSE|||200202150730|||||||||
555-55-5555^PRIMARY^PATRICIA P^^^^MD^^|||||||F|||||444-44-4444^HIPPOCRATES^HOWARD H^^^^MD<cr>
OBX|1|SN|1554-5^GLUCOSE^POST 12H CFST:MCNC:PT:SER/PLAS:QN||^182|mg/dl|70_105|H|||F<cr>
```

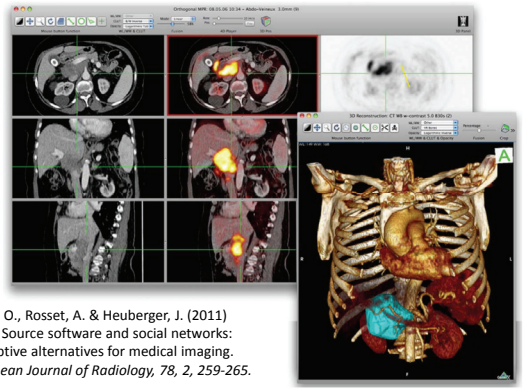


Examples: http://www.ringholm.com/docs/04300_en.htm

Slide 10-32 PACS consoles and modern workplaces

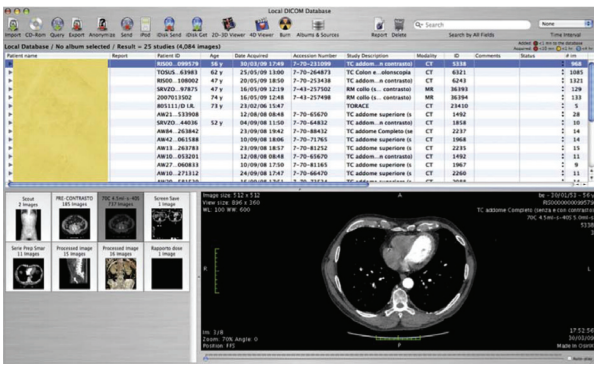
Ratib, O., Rosset, A. & Heuberger, J. (2011) Open Source software and social networks: Disruptive alternatives for medical imaging. *European Journal of Radiology, 78, 2, 259-265.*

Slide 10-33 Multimodal imaging techniques: Hybrid PET-CT



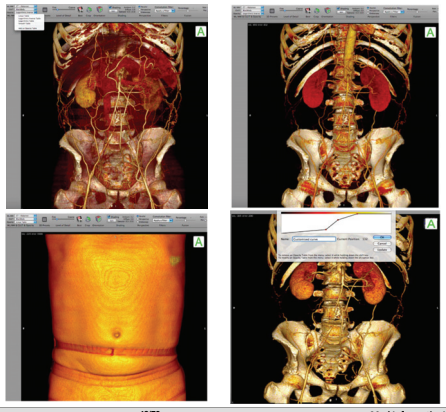
Ratib, O., Rosset, A. & Heuberger, J. (2011) Open Source software and social networks: Disruptive alternatives for medical imaging. *European Journal of Radiology, 78, 2, 259-265.*

Slide 10-34 Example: OsiriX integrated RIS–PACS interface



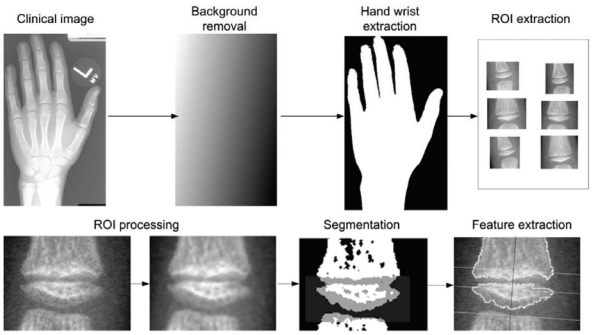
Faggioni, L., Neri, E., Castellana, C., Caramella, D. & Bartolozzi, C. (2011) The future of PACS in healthcare enterprises. *European Journal of Radiology, 78, 2, 253-258.*

Slide 10-35 Example: Application of VR in medical imaging



Faggioni et al. (2011)

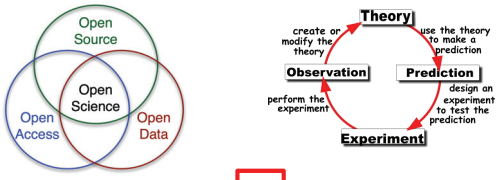
Slide 10-36 Bone age assessment DSS workflow



Piętka, E., Kawa, J., Spinczyk, D., Badura, P., Więcławek, W., Czajkowska, J. & Rudzki, M. (2011) Role of radiologists in CAD life-cycle. *European Journal of Radiology, 78, 2, 225-233.*

Open …

Open …



License	Apache	BSD/MIT	GPL	LGPL	MPL/CDDL	CPL/EPL
Reciprocity	No	No	Yes	Maybe	No	No
Modification release	No	No	Yes	Yes	Yes	Yes
Patent	Yes	No	No	No	Yes	Yes
Jurisdiction	Silent	Silent	Silent	Silent	California	New York
Freedom	PR	Free	PR	PR	Free	PR

Braun, M. L. & Ong, C. S. 2014. Open Science in Machine Learning. Implementing Reproducible Research, 343.

Holzinger, A. 2010. Process Guide for Students for Interdisciplinary Work in Computer Science/Informatics. Second Edition, Norderstedt, BoD.

Slide 10-38 Open Source: Legal and regulatory constraints

open source ≠ FDA CE

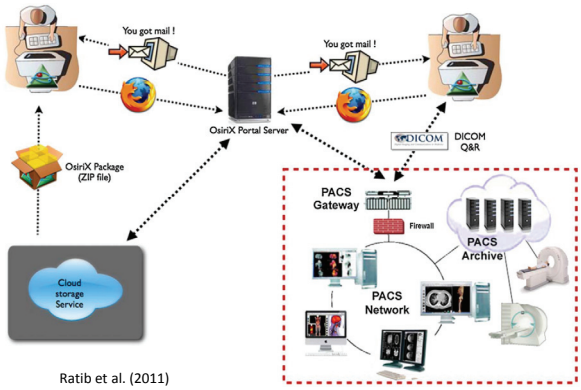
- Attention: Medical certifications such as FDA in the US and CE marking in Europe **do not apply** to Open Source software;
- These certifications require a legal commercial entity to be identified as the owner of the product and warrant the legal liability of its distribution and commercial support.
- Open Source software being often developed outside commercial enterprises; such as academic groups or university research labs, do not have the proper legal structure to apply for such certifications.
- Also, most Open Source products being distributed free of charge lack the legal binding between the provider and the user that is required for software distribution under FDA and CE certification.

Ratib et al. (2011)

Slide 10-39 Future outlook

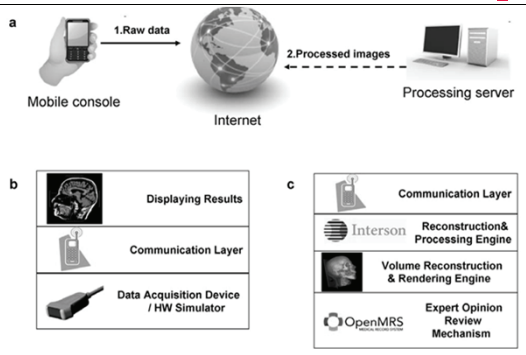
- 1) the world (even the hospital world ;-) of tomorrow will be **mobile …**
- 2) the data will be stored in the cloud as well as software-as-a-service will be used (Key problem: **Privacy, Security, Safety and Data Protection).**
- 3) Search tools will be integrated within the clinical workplace to provide a quick **overview first,** and then zoom and filter on demand …
- 4) Integrated ML will enable **knowledge discovery with the doctor-in-the-loop …**

Slide 10-40 Future cloud computing solutions



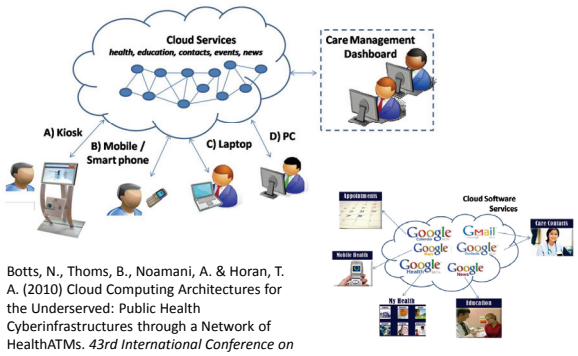
Ratib et al. (2011)

Slide 10-41 Future System Architecture: Cloud Ultrasound



Meir, A. & Rubinsky, B. (2009) Distributed Network, Wireless and Cloud Computing Enabled 3-D Ultrasound; a New Medical Technology Paradigm. *Plos One, 4, 11, e7974.*

Slide 10-42 Future: Software as a Service (SaaS)



Botts, N., Thoms, B., Noamani, A. & Horan, T. A. (2010) Cloud Computing Architectures for the Underserved: Public Health Cyberinfrastructures through a Network of HealthATMs. *43rd International Conference on System Sciences (HICSS). 1-10.*

Example : k-Anonymization of Medical Data

87 % of the population in the USA can be uniquely re-identified by Zip-Code, Gender and date of birth

Hospital Patient Data

Birthdate	Sex	Zipcode	Disease
1/21/76	Male	53715	Flu
4/13/86	Female	53715	Hepatitis
2/28/76	Male	53703	Brochitis
1/21/76	Male	53703	Broken Arm
4/13/86	Female	53706	Sprained Ankle
2/28/76	Female	53706	Hang Nail

Voter Registration Data

Name	Birthdate	Sex	Zipcode
Andre	1/21/76	Male	53715
Beth	1/10/81	Female	55410
Carol	10/1/44	Female	90210
Dan	2/21/84	Male	02174
Ellen	4/19/72	Female	02237

Sweeney, L. 2002. Achieving k-anonymity privacy protection using generalization and suppression. International Journal of Uncertainty, Fuzziness and Knowledge-Based Systems, 10, (05), 571-588.

Anonymization of Patient Data

- **K-Anonymity** … not fully protected against attribute disclosure
- **L-Diversity** … extension requiring that the values of all confidential attributes within a group of *k* sets contain at least *l* clearly distinct values
- **t-Closeness** … extension requiring that the distribution of the confidential attribute within a group of *k* records is similar to the confidential attribute in the whole data set
- More in the upcoming 11th lecture !

Thank you!

Sample Questions (1)

- How is a workflow defined?
- How can a workflow be described formally?
- Why is workflow modeling important in health care?
- Please describe the different tools of the Unified Modeling Language (UML) on some medical examples!
- Which benefits can be gained by optimization of workflows?
- Which three stakeholders have which interests within an Hospital?
- Please describe the basic idea of a typical bioinformatics workflow management system!
- What is the difference of system quality versus information quality?
- What are the advantages/disadvantages of the three basic system architecture approaches of hospital information systems?
- Which functional parts does the classic conceptual model of a HIS include?
- In which aspects does the process-oriented health information systems model differ from the classic conceptual model?
- Please describe the typical workflows within a PACS System?
- What are the typical modalities of a PACS System?

Sample Questions (2)

- What are the generic PACS components and the respective data flows?
- What are the typical advantages/disadvantages of the six PACS implementation models?
- Why are communication standards important for biomedical informatics?
- Please describe the purpose and advantages of DICOM?
- What is the basic idea of HL7?
- Why is open source software problematic in the medical domain?
- What are the advantages/disadvantages of cloud computing for health care?
- What are the advantages/disadvantages of the paradigm "Software as a Service"?
- What is an electronic Personal Health Record?
- Which is still the biggest problem of such PHRs?

Appendix: Bioinformatics Workflow Management Systems

- **BioExtract** = for creating and customizing workflows; you can query online sequence data, analyze it using an array of informatics tools, create and share custom workflows for repeated analysis, and save the resulting data and workflows in standardized reports; http://www.bioextract.org
- **CellProfiler** = open source modular image analysis software developed at the Broad Institute; algorithms for image analysis; http://www.cellprofiler.org
- **Discovery Net** = was one of the earliest examples of scientific workflow systems (e-Science project by the Imperial College London), having many features, e.g. chemical compounds represented in the widely used SMILES (Simplified molecular input line entry specification) format can be imported and rendered using three-dimensional representation or the structural formula, of historic interest, see: http://www.computer.org/portal/web/csdl/doi/10.1109/HPDC.2002.1029946
- **Ergatis** = to create, run, and monitor reusable computational analysis pipelines, contains pre-built components for common bioinformatics analysis tasks. These components can be arranged graphically to form highly-configurable pipelines. Each analysis component supports multiple output formats, including the Bioinformatic Sequence Markup Language (BSML), http://ergatis.sourceforge.net
- **GenePattern** = genomic analysis platform that provides access to 150+ tools for gene expression analysis, proteomics, SNP analysis, flow cytometry, RNA-seq analysis as well as standard data processing tasks. A web-based interface provides easy access to these tools and allows the creation of multi-step analysis pipelines that enable reproducible in silico research; http://www.broadinstitute.org/cancer/software/genepattern
- **Triana** = open source problem solving environment developed at Cardiff University that combines an intuitive visual interface with powerful data analysis tools. Already used by scientists for a range of tasks, such as signal, text and image processing, Triana includes a large library of pre-written analysis tools and the ability for users to easily integrate their own tools. is an open source problem solving environment developed at Cardiff University that combines an intuitive visual interface with powerful data analysis tools; http://www.trianacode.org

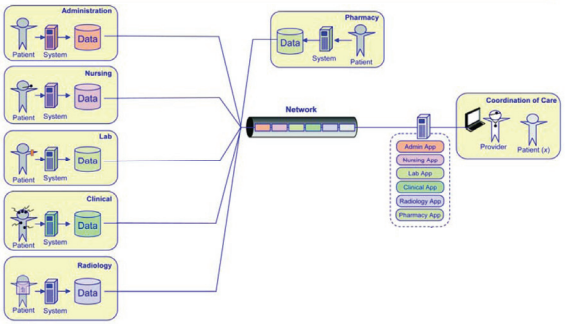
Some useful links

- http://www.gimias.org/download/sampledata (some useful sample data)
- https://www.biomedtown.org/biomed_town/MSV/reception/wikis/Data (on-line community open and free to anyone has a professional or educational interest in biomedical research & practice)
- http://rad.usuhs.edu/medpix/index.html (Medical Image Database)
- http://www.incits.org (International Committee for Information Technology Standards)
- http://medical.nema.org (about DICOM)
- http://www.aycan.de/main/lp/dicom-bilder-zum-download.html (DICOM examples for download)
- http://www.ringholm.com/docs/04300_en.htm (HL7 Message Examples)
- http://www.openehr.org (Open HER – good UML examples)
- http://www.sparxsystems.com/uml-tutorial.html (UML 2.0 Tutorial)
- http://www.agilemodeling.com/essays/umlDiagrams.htm (Excellent description of UML diagrams)
- http://www.wfmc.org (Workflow Management Coalition)

Appendix: Open Source in medical imaging

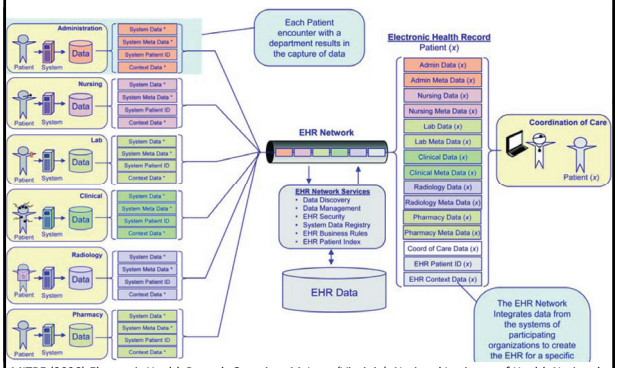
http://www.idoimaging.com

Appendix: Electronic Health Records (1)



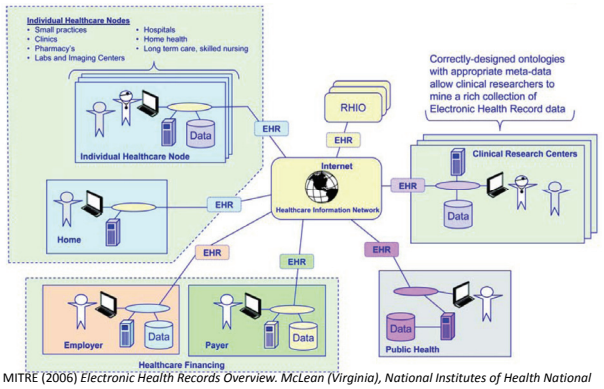
MITRE (2006) *Electronic Health Records Overview. McLean (Virginia), National Institutes of Health National Center for Research Resources.*

Appendix: Electronic Health Records (2)



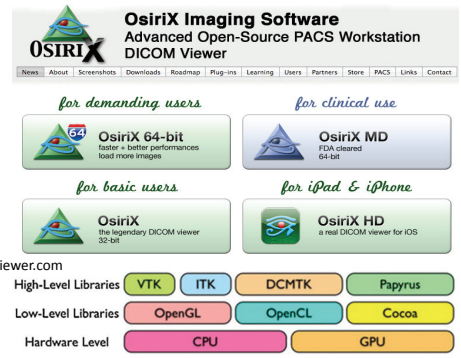
MITRE (2006) *Electronic Health Records Overview. McLean (Virginia), National Institutes of Health National Center for Research Resources.*

Appendix: Electronic Health Records (3)



MITRE (2006) *Electronic Health Records Overview. McLean (Virginia), National Institutes of Health National Center for Research Resources.*

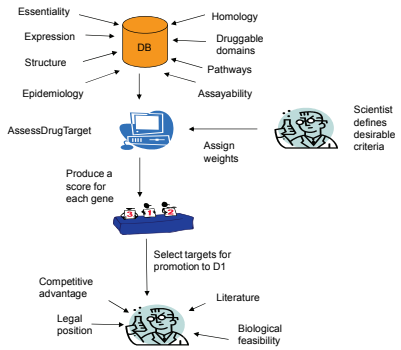
Appendix: OsiriX Open Source component architecture



http://www.osirix-viewer.com

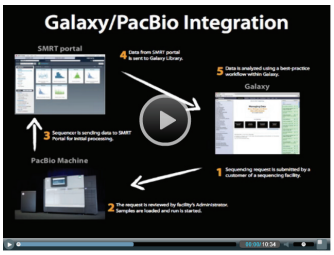
Rosset, A., Spadola, L. & Ratib, O. (2004) OsiriX: an open-source software for navigating in multidimensional DICOM images. *Journal of Digital Imaging, 17,* ***3, 205-216.***

Example: Drug Target Identification



Hasan, S., Daugelat, S., Rao, P. S. S. & Schreiber, M. (2006) Prioritizing genomic drug targets in pathogens: application to Mycobacterium tuberculosis. *PLoS Computational Biology, 2, 6, e61.*

Bioinformatics Workflow Management System



http://screencast.g2.bx.psu.edu/pacBio-demo

Goecks, J., Nekrutenko, A., Taylor, J. & Team, T. G. (2010) Galaxy: a comprehensive approach for supporting accessible, reproducible, and transparent computational research in the life sciences. *Genome Biology, 11, 8, R86.*

Blankenberg, D., Kuster, G. V., Coraor, N., Ananda, G., Lazarus, R., Mangan, M., Nekrutenko, A. & Taylor, J. (2010) Galaxy: A Web-Based Genome Analysis Tool for Experimentalists. *Current Protocols in Molecular Biology. John Wiley & Sons, Inc.*

Quality – Quality – Quality

- Experts consider health IT key for improving efficiency and quality of health care processes.
- Please, carefully determine between:
- Quality of Systems

  and
- Quality of Data
- Quality of Information
- Quality of Knowledge
- Quality of Action

Chaudhry, B., Wang, J., Wu, S. Y., Maglione, M., Mojica, W., Roth, E., Morton, S. C. & Shekelle, P. G. (2006) Systematic review: Impact of health information technology on quality, efficiency, and costs of medical care. *Annals of Internal Medicine, 144,* ***10, 742-752.***

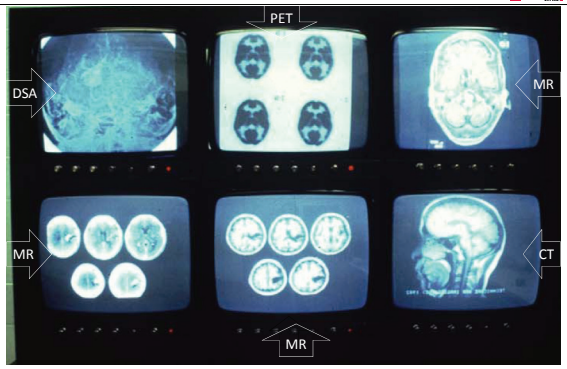
PACS R&D Progress and R&D Topics

Decade	R&D progress	R&D topics
1980s Late 1980s	Medical imaging technology development Imaging systems integration	CR, MRI, CT, US, DR, WS, storage, networks PACS, ACR/NEMA, DICOM, high-speed networks
Early 1990s Late 1990s – present 2000s – present	Integration of HIS/RIS/PACS Workflow & application servers Imaging Informatics	DICOM, HL7, Intranet and Internet IHE, ePR, enterprise PACS, Web-based PACS Computer-aided diagnosis (CAD), image contents indexing, knowledge base, decision support tools, image-assisted diagnosis and treatment

- CR = Computed Radiography (vs. Direct Radiography (DR)); MRI = Magnetic resonance imaging; CT = Computed Tomography; US = Ultrasonography; WS = Web services;
  ACR= American College of Radiology; NEMA = National Electrical Manufacturers Association;

Huang, H. K. (2011) Short history of PACS (USA). *European Journal of Radiology, 78, 2, 163-176.*

1st PACS 1985: Multi modality images on 6 CRTs



Huang, H. K. (2011) Short history of PACS (USA). *European Journal of Radiology, 78, 2, 163-176.*

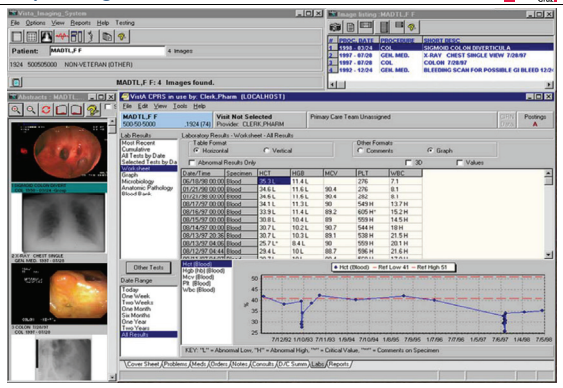
Pros/Cons of six PACS implementation models

Method	Advantages	Disadvantages
1. Home-grown system	Built to specifications, state-of-the-art technology, continuously upgrading, not dependent on a single manufacturer	Difficult to assemble a team, one-of-a-kind system, difficult to service and maintain
2. Two-team effort	Specifications written for a certain clinical environment, implementation delegated to the manufacturer	Specifications over ambitious, underestimate technical and operational difficulty, manufacturer lacks clinical experience, expensive
3. Turnkey	Lower cost, easier maintenance	Too general, not state-of-the-art technology
4. Partnership	System will keep up with technology advancement, health center does not have to worry of the system becoming obsolete, manufacturer has long-term contract to plan ahead	Expensive to the health center, manufacturer may not want to sign a partnership contract with a lesser prominent center, center has to consider the longevity and stability of the manufacturer
5. ASP	Minimize initial capital cost, may accelerate potential return on investment, no risk in technology obsolescence, provide flexible growth, no space requirement in data center	More expensive over 2–4-year time frame comparing to a capital purchase, customer has no ownership in equipment
6. Open source	Healthcare provider purchases its computer and communication equipment, use open source software, good for special PACS application server, lower cost	Open source software may not be robust for daily clinical use, maintenance and upgrade of the software may be a problem, may not be good for a full large-scale PACS

ASP = application service provider model

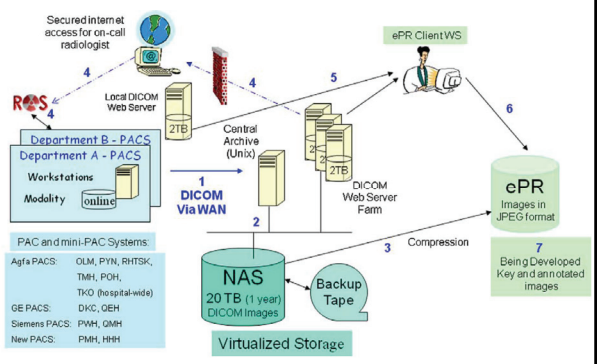
Huang, H. K. (2011) Short history of PACS (USA). *European Journal of Radiology, 78, 2, 163-176.*

Example: Images within the EPR



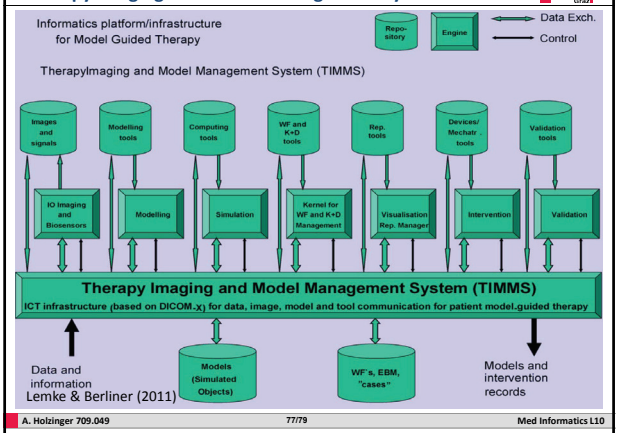
Huang, H. K. (2011) Short history of PACS (USA). *European Journal of Radiology, 78, 2, 163-176.*

Ex.: The Hong Kong Hospital Clinical Information System



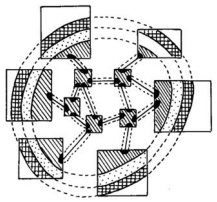
Huang, H. K. (2011) Short history of PACS (USA). *European Journal of Radiology, 78, 2, 163-176.*

Therapy Imaging and Model Management System: TIMMS

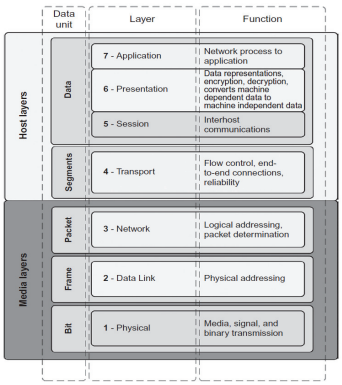


Lemke & Berliner (2011)

ISO/OSI Layer Model (ISO 7498) Communication Standards



Zimmermann, H. (1980) OSI reference model-The ISO model of architecture for open systems interconnection. *IEEE Transactions on Communications, 28,* ***4, 425-432.***



Paulsen, K. (2011) Networked Storage. *Moving Media Storage Technologies. Boston, Focal Press, 429-467.*

Big Fact: Personal Health Records: Poor Usability

- 300+ different systems in the US
- Only 1% of the US population have access (2008)
- "Most EHR are 100 % bad." (Forrester Research, 2008)
- Biggest obstacles:
  - Cost factors
  - Poor usability
- Need for UCD
- Need for proactive wellness management

Alagoez, F., Valdez, A. C., Wilkowska, W., Ziefle, M., Dorner, S. & Holzinger, A. (2010) From cloud computing to mobile Internet, from user focus to culture and hedonism: The crucible of mobile health care and Wellness applications. *5th International Conference on Pervasive Computing and Applications (ICPCA). IEEE, 38-45.*

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