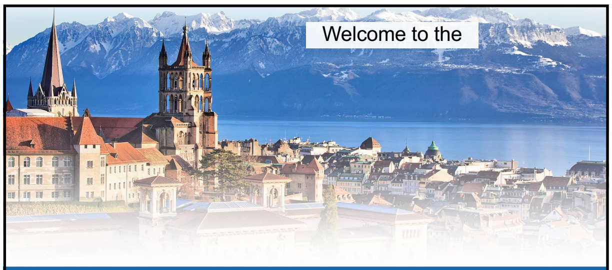


MEDICIS-Promed Leman School on Preclinical and Clinical Imaging with Radioisotopes

12-16 March 2018
Geneva/Lausanne
Europe/Zurich timezone

Starts 12 Mar 2018, 08:30
Ends 16 Mar 2018, 18:00
Europe/Zurich

Geneva/Lausanne

John Olivier Prior
Osman Ratib
Renaud Blaise Jolivet

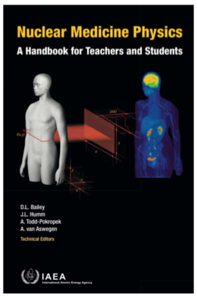
Monday March 12, 2018 : CHUV

	Registration and Welcome Coffee		*Auditorium Charlotte Olivier, CHUV*	08:30 - 09:00
09:00	**Introduction to Medical Imaging**	*Prof. J. Prior*	*Auditorium Charlotte Olivier, CHUV*	09:00 - 09:30
10:00	**Physics in Nuclear Medicine**	*F. Cicone*	*Auditorium Charlotte Olivier, CHUV*	09:30 - 10:15
	Medical Imaging Techniques (CT-IRM)	*N. Ryckx*	*Auditorium Charlotte Olivier, CHUV*	10:15 - 11:00
11:00	**Medical Imaging Techniques (SPECT/PET)**	*S. Gnesin*	*Auditorium Charlotte Olivier, CHUV*	11:00 - 11:45
12:00	**Lunch@Cafeteria BH08**		*Cafeteria BH08, CHUV*	11:45 - 12:45

Monday March 12, 2018 : CHUV

13:00	**Radiochemistry of Radiometals**	*T. Denoël*	*Auditorium Charlotte Olivier, CHUV*	12:45 - 13:30
14:00	**Small-Animal Imaging Techniques**	*D. Viertl*	*Auditorium Charlotte Olivier, CHUV*	13:30 - 14:15
	Visit of the PET/SPECT/CT room and the Radiopharmacy area	*D. Viertl et al.*	*CHUV*	14:15 - 15:00
15:00	**Coffee break**		*CHUV*	15:00 - 15:30
16:00	**Cellular Immunotherapy:Challenges from Bench to Bedside**	*L. Kandalaft*	*Auditorium Charlotte Olivier, CHUV*	15:30 - 16:15
17:00	**Theranostics in the Era of Modern Oncology**	*N. Schafer*	*Auditorium Charlotte Olivier, CHUV*	16:15 - 17:00

Introduction to Medical Imaging



740 pages

https://www-pub.iaea.org/MTCD/Publications/PDF/Pub1617web-1294055.pdf

https://humanhealth.iaea.org/HHW/MedicalPhysics/e-learning/Nuclear_Medicine_Handbook_slides/index.html

Chapter 12: Computers in Nuclear Medicine

Set of 140 slides based on the chapter authored by
J. A. Parker
of the IAEA publication (ISBN 78–92–0–143810–2):
Nuclear Medicine Physics:
A Handbook for Teachers and Students

Objective:

To familiarize the student with the fundamental concepts of computers and their application to nuclear medicine.

IAEA
International Atomic Energy Agency

Slide set prepared in 2015
R. Fulton (Westmead Hospital and University of Sydney)

12.2 STORING IMAGES ON A COMPUTER
12.2.2 Data representation

- Digital images are composed of individual picture elements, pixels, which represent a single point in the image. Each pixel is represented by a number or a series of numbers. There are several methods of representing each number.

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Nuclear Medicine Physics: A Handbook for Teachers and Students – Chapter 12 – Slide 6/140

12.2 STORING IMAGES ON A COMPUTER
12.2.2 Data representation

Integer numbers

- A group of binary digits (bits) can be interpreted in several different ways. The simplest is as a positive integer, numbers 0, 1, 2, 3, etc.

Binary	Decimal
000	0
001	1
010	2
011	3
100	4
101	5

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12.2 STORING IMAGES ON A COMPUTER
12.2.3 Images and volumes

- Images can be represented by 2-D functions. If x and y are taken to be horizontal and vertical, a 2-D function, $f(x, y)$, gives the value of the image at each point in the image.
- Ever increasingly, imaging equipment produces not a single image, but a 3-D volume of data, e.g. right to left, anterior to posterior and caudal to cephalic. A volume of data can be represented as a 3-D function, $f(x, y, z)$.
- One of the challenges of data visualization is to facilitate the input of 3-D data using the 2-D channel afforded by the human visual system.

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12.2 STORING IMAGES ON A COMPUTER
12.2.3 Images and volumes

Continuous, discrete and digital functions

- A computer can represent only digital functions, where both the independent and dependent variable(s) are digital. Digital values provide a good model of continuous values if the coarseness of the digital representation is small with respect to the standard deviations of the continuous values. For this reason, digital images often provide very similar representations of the continuous world.
- Nuclear medicine is intrinsically digital in the sense that nuclear medicine imaging equipment processes scintillation events individually.

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12.2 STORING IMAGES ON A COMPUTER
12.2.3 Images and volumes

Matrix representation

- The surface of the gamma camera can be visualized as being divided into tiny squares. An element in a 2-D matrix can represent each of these squares. A 3-D matrix can represent a dynamic series of images or single photon emission computed tomography (SPECT) data collection. A 3-D matrix is equivalent to a 3-D digital function, $f(x, y, z)$. Both representations are equivalent to the computer program language representation, $f[z][y][x]$.

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12.3 IMAGE PROCESSING
12.3.1 Spatial frequencies

Basis functions

- A function, $f(t)$, can be made up of a sum of other functions, e.g. a constant, a line passing through the origin, a parabola centred at the origin, etc. Such a sum of functions can be written as a polynomial, i.e. the sum of K powers of t:

$$f(t) = \sum_{k=0}^{K-1} a_k t^k \qquad (12.1)$$

- The terms t^k are basis functions, with coefficients a_k. Selecting different coefficients a_k, a large number of functions can be represented.

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12.3 IMAGE PROCESSING
12.3.1 Spatial frequencies

Fourier transform

- The Fourier transform equations can be written compactly using complex exponentials:

$$F(\omega) = \int f(t) e^{-i\omega t}\, \mathrm{d}t \qquad (12.3)$$

$$f(t) = \frac{1}{2\pi} \int F(\omega) e^{i\omega t}\, \mathrm{d}\omega \qquad (12.4)$$

where $i = \sqrt{-1}$

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12.3 IMAGE PROCESSING
12.3.4 Filtering

- Conceptually, the purpose of filtering is to alter the frequency components of a signal.
- The data are thought of in terms of their frequency or spatial frequency content, not in terms of their time or space content.
- The most efficient process in general is (i) Fourier transform, (ii) multiply by a filter and (iii) inverse Fourier transform.
- Convolution performs this same operation in the time or space domain but, in general, is less efficient.

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12.3 IMAGE PROCESSING
12.3.4 Two- and three-dimensional processing

- Two dimensional processing is exactly analogous to 1-D processing with the 1-D variables t and ω replaced with the 2-D variables x, y and k_x, k_y. For 3-D processing, t is replaced by x, y, z, and ω is replaced by k_x, k_y, k_z. Four-, five-, six-, etc. dimensional processing can be performed similarly.
- A property of the Fourier transform equations is separability - the transform with respect to x can be performed first followed by the transform on y. A 2-D transform can be performed by first doing the transform on the rows, and then doing the transform on the columns. All that is needed is a 1-D Fourier transform subroutine.

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12.3 IMAGE PROCESSING
12.3.5 Band-pass filters

- Band-pass filters maintain a range of frequencies while eliminating all other frequencies.
- An ideal band-pass filter is exactly one for some range of frequencies and exactly zero for the remaining frequencies. There is a very sharp transition between the pass- and the stop-zones.
- In general a sharp edge in one domain will tend to create ripples in the other domain. Ideal band-pass filtering often creates ripples near sharp transitions in a signal. It is, therefore, common to make the transition from the pass-zone to the stop-zone more gradual.

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12.3 IMAGE PROCESSING
12.3.5 Band-pass filters

Low-pass, noise suppression and smoothing filters

- A low-pass filter is a type of band-pass filter that passes low frequencies and stops high frequencies.
- In an image, the high spatial frequencies are needed for detail.
- Zeroing or suppressing the high spatial frequencies compared to the lower frequencies smooths the image, by suppressing the image noise.
- Low-pass filters both smooth an image and decrease the noise in an image.

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12.3 IMAGE PROCESSING
12.3.5 Band-pass filters

Low-pass, noise suppression and smoothing filters

- A common method of implementing a low-pass filter is as a convolution with a small kernel. Below is a 3-by-3 smoothing kernel, also commonly called a 9-point smoothing kernel. Each point in the smoothed image is made up of the scaled sum of nine surrounding points.

3x3 smoothing kernel

1	2	1
2	4	2
1	2	1

- Each point in the smoothed image is made up of the scaled sum of nine surrounding points.

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12.3 IMAGE PROCESSING
12.3.5 Band-pass filters

Low-pass, noise suppression and smoothing filters

- Below at left is a 5x5 smoothing kernel. Each point is made up of the scaled sum of 25 surrounding points.

1	2	3	2	1
2	4	8	4	2
4	8	16	8	4
2	4	8	4	2
1	2	3	2	1

Smoothing

-1	-1	-1	-1	-1
-1	-1	-1	-1	-1
-1	-1	25	-1	-1
-1	-1	-1	-1	-1
-1	-1	-1	-1	-1

Sharpening

0	0	-1	0	0
0	-1	-2	-1	0
-1	-2	17	-2	-2
0	-1	-2	-1	0
0	0	-1	0	-0

Unsharp mask

0	-1	0	1	0
0	-1	0	1	0
0	-1	0	1	0
0	-1	0	1	0
0	-1	0	1	0

X gradient

- Three other kernels commonly used in image processing are also shown. The next slide shows the effect of the smoothing filter on an image.

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12.3 IMAGE PROCESSING
12.3.5 Band-pass filters

Low-pass, noise suppression and smoothing filters

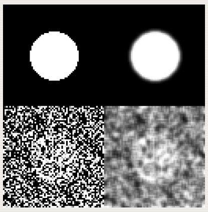

FIG. 12.2. The upper left quadrant shows a circular region of constant intensity; the upper right shows the effect of applying a 5-by-5 smoothing kernel; the lower left shows a very noisy version of the circular region; the bottom right shows the effect of applying a 5-by-5 smoothing kernel.

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12.3 IMAGE PROCESSING
12.3.5 Band-pass filters

Low-pass, noise suppression and smoothing filters

- The filter is sometimes shown in terms of the square of the filter, $1/(1+(k/k_0)^{2n})$.
- In that case, the filter reaches the value of half at the cut-off frequency.
- The filter is sometimes defined with an exponent of n instead of $2n$

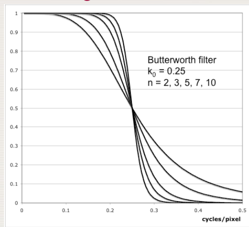

FIG. 12.3. This figure shows the square of the Butterworth filter in the spatial frequency domain with a cut-off equal to 0.25 cycles/pixel and n equal to 2, 3, 5, 7 and 10.

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12.3 IMAGE PROCESSING
12.3.5 Band-pass filters

High-pass and edge-detection

- Edges, and more generally detail, in an image are encoded with high spatial frequencies. Large regions of constant intensity are coded with low spatial frequencies. Thus, a high-pass filter will tend to emphasize the edges in an image.

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12.3 IMAGE PROCESSING
12.3.5 Band-pass filters

High-pass and edge-detection

- Below is the 5x5 sharpening filter kernel from a previous slide and its effect on two images.

-1	-1	-1	-1	-1
-1	-1	-1	-1	-1
-1	-1	25	-1	-1
-1	-1	-1	-1	-1
-1	-1	-1	-1	-1

5x5 sharpening kernel

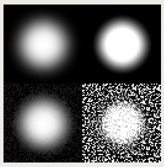

FIG. 12.4. The upper left quadrant shows a smooth circular region; the upper right shows the effect of applying the 5-by-5 sharpening kernel. Note the sharpening effect; the lower left shows a circular region with a small amount of noise; the bottom right shows the tendency of the sharpening kernel to amplify noise.

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12.4 DATA ACQUISITION
12.4.1 Acquisition matrix size and spatial resolution

- For a normal large FOV Anger camera, a 256 × 256 matrix is more than sufficient for most imaging situations.
- For clinical imaging, a 128 × 128 matrix is often sufficient. For rapid dynamic images that are often very count limited, a 64 × 64 matrix can be used.
- For vertex to thigh imaging, a 1:4 matrix, e.g. 256 × 1024, will cover 160 cm. When including the legs, a non-power-of-two matrix may be most logical.
- While memory and storage were once expensive and limited, nowadays the selected matrix size should be large enough to ensure that image quality is not compromised.

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12.4 DATA ACQUISITION
12.4.2 Static and dynamic planar acquisition

- Many of the processes of interest in nuclear medicine involve a changing pattern of distribution of a radiopharmaceutical in the body. In matrix mode, a sequence of images collected over time allows visualization and measurement of the biodistribution of the radiopharmaceutical. Each image is often called a frame of data. Collection of a sequence of images over time is called a dynamic acquisition; collection of an image at a single point in time is called a static acquisition.

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12.4 DATA ACQUISITION
12.4.5 Gated acquisition

- Data acquisition can be gated to a physiological signal. Owing to count limitation, if the signal is repetitive, the data from multiple cycles are usually summed together.
- A gated, static acquisition will have three dimensions - two spatial and one physiological.
- A gated dynamic acquisition will have four dimensions - two spatial, one time and one physiological.
- A gated SPECT or PET acquisition will have a different four dimensions - three spatial and one physiological. A gated dynamic SPECT or PET acquisition will have five dimensions - three spatial, one time and one physiological.

12.4 DATA ACQUISITION
12.4.5 Gated acquisition

Cardiac-synchronized

- Gated cardiac studies were one of the early studies in nuclear medicine. Usually, the electrocardiogram is used to identify cardiac timing.
- For evaluation of systolic and early diastolic events, it is better to sum cycles using constant timing from the R-wave than to divide different cycles using a constant proportion of the cycle length.
- However, with constant timing, different amounts of data are collected in later frames. Normalizing the data for the number of cycles contributing to each frame can ameliorate this problem.

12.4 DATA ACQUISITION
12.4.5 Gated acquisition

Respiratory-synchronized

- Gating to respiration has been used in nuclear medicine both to study respiratory processes and to ameliorate the blurring caused by breathing.
- Successful synchronization has been based on chest or abdominal position changes, and on image data.
- Chest and abdominal motion often correlate with the respiratory cycle, although detection of motion and changes in diaphragmatic versus chest wall breathing also pose problems. Although difficult to measure, respiratory gating is becoming more common in PET and CT.

12.4 DATA ACQUISITION
12.4.6 List mode

- Instead of collecting data as a sequence of matrixes or frames, the position of each scintillation can be recorded sequentially in a list. Periodically, a special mark is entered into the list, typically every 1 ms, that gives the time and may include physiological data such as the electrocardiogram or respiratory phase.
- List mode data requires more storage space than matrix mode. For example, a 1 million-count frame of data collected into a 256-by-256 matrix will require 64k memory locations. In list mode, the same data will require 1 million memory locations. However list mode contains some additional information, the order of event arrival.

12.4 DATA ACQUISITION
12.4.6 List mode

- List mode data can be easily converted (framed) into matrix mode data.
- There it offers useful flexibility, in that it can be reframed as many times as desired to create a matrix mode study with any desired matrix size and any desired frame rate. Even the frame rate can be varied during the study if desired.
- This is useful if the optimum frame rate is not known in advance.

12.5 FILE FORMAT
12.5.4 Nuclear medicine data requirements

- There are two types of information in a nuclear medicine study - image information and non-image information.
- The general purpose image and movie formats described above usually lack capabilities that would be optimal for medical imaging.

12.5 FILE FORMAT
12.5.4 Nuclear medicine data requirements

Non-image information

- There is unique nuclear medicine information that must be carried along reliably with the images.
- This information includes identification data, e.g. name, medical record number; study data, e.g. type of study, pharmaceutical; how the image was acquired, e.g. study date, view; etc. This information is sometimes called meta-information.
- Most general image formats are not flexible enough to carry this information along with the image.

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12.5 FILE FORMAT
12.5.5 Common nuclear medicine data storage formats

Digital Imaging and Communications in Medicine (DICOM)

- DICOM is the most widely accepted radiological imaging format. DICOM began as ACR-NEMA, a collaboration between the American College of Radiology and the National Electrical Manufacturers Association.
- DICOM is often thought of as a file format; however, the standard covers communication more broadly. It defines a transmission protocol, a query and retrieval standard, and workflow management. Unfortunately, it is overly complex, non-self-describing, and has a heavy 2-D image bias (see Sec. 12.6.4).

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12.6 INFORMATION SYSTEM
12.6.2 Hospital Information System

- A hospital information system is a large distributed database. Data come from clinical laboratories, nuclear medicine and financial systems, etc.

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12.6 INFORMATION SYSTEM
12.6.3 Radiology Information System

- The radiology information system (RIS) supports scheduling, performing, reporting of procedure results and billing. When nuclear medicine is a division of radiology, the RIS usually also functions as the nuclear medicine information system.
- However, nuclear medicine procedures have some unique characteristics, such as studies that extend over several days, which may not be well handled by a general purpose RIS.

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12.6 INFORMATION SYSTEM
12.6.4 Picture Archiving and Communication System

- The image information from the imaging equipment is usually stored in a picture archiving and communication system (PACS) that is separate from but coordinated with the radiology/nuclear medicine information system. DICOM is the predominant standard for PACSs.

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12.6 INFORMATION SYSTEM
12.6.4 Picture Archiving and Communication System

Study

- The top level of organization in DICOM is the study. This level of organization comes from the organization of the health care system. Health care providers request services from radiology/nuclear medicine by a request for a consultation. Imaging or another service is performed and a report, ideally including image information, is returned to the provider. Each study is linked to a single patient, but a patient can have any number of separate studies.

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12.6 INFORMATION SYSTEM
12.6.4 Picture Archiving and Communication System

Sequence

- Sequence is the next level of organization in DICOM. Sequence comes from a sequence of images; for a volume of image data, sequence is the top level of organization. For example, it is common to collect a sequence of axial images. A more general name for this level of organization would be dataset.

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12.6 INFORMATION SYSTEM
12.6.4 Picture Archiving and Communication System

Image

- Originally, DICOM used a 2-D image as the basic atom. Other data structures are composed of a number of images. Metadata are included with each image, defining the structure of the image, patient information, data collection information and relation of the image to other images. Somewhat more recently, a multiframe format was defined in DICOM. One file may contain information from a volume of data, from a time series, from a gated sequence, from different photopeaks, etc.

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12.6 INFORMATION SYSTEM
12.6.4 Picture Archiving and Communication System

Image (continued)

- Nuclear medicine tends to use the multiframe format much more commonly than other modalities.
- Describing the organization of a dataset in terms of multiple images is a particularly awkward feature of DICOM.

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12.6 INFORMATION SYSTEM
12.6.4 Picture Archiving and Communication System

N-dimensional data

- It is unfortunate that DICOM selected the image as the basic atom of organization.
- Even before it was introduced, it was apparent that an N-dimensional data model would be more appropriate. Nuclear medicine and MRI often dealt with 1-D curves, 2-D images, 3-D volumes, 4-D gated or dynamic volumes, etc. However, radiology tended to be film based, and volume data such as CT was anisotropic, so some of the early developers had an image based orientation.

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12.6 INFORMATION SYSTEM
12.6.7 Security

- Health information is private. Although the privacy of health information is often a relatively minor concern for the general public, it is a major concern for politicians, who make rules about the security needed for medical information. Within the information community, computer security is largely a solved problem, although vigilance is necessary, because there are always hackers trying to exploit any security holes. Furthermore, with aggregation of private health information, the potential extent of a security breach becomes catastrophic. Security depends not only on computer systems, but also on humans who are often the weak link.

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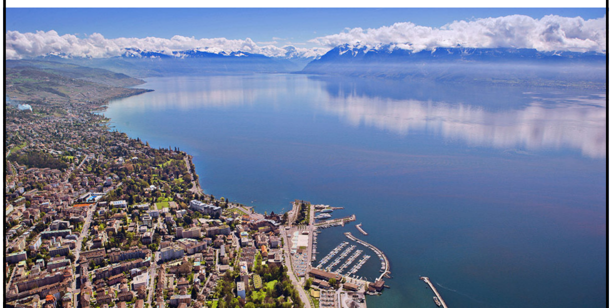
Thank you for your attention



And have a great week in the Lemanic Region!