1: Introduction to the course

- How is the course organized?
  1. What is Bio-imaging?
  2. How can SNR and CNR be optimized?
  3. What is the importance of biomedical imaging?
  4. Examples
    - Tour of the Imaging Centre (CIBM)

After this course you
  1. know the course organization and coverage of topics;
  2. know the contribution of bio-imaging to life science and why it is an interdisciplinary effort.
  3. know the main elements required for bio imaging;
  4. are able to perform contrast to noise and signal to noise calculations;
  5. are familiar with noise error propagation calculations

---

How is the course organized?

Course web site (moodle, physics, master):
moodle.epfl.ch/course/view.php?id=250
If you are not enrolled yet:
Enrollment key = bioimaging19

Copies of parts of the presentation
Will be provided on moodle (pdf)
Please take notes during lecture !!

Exercises (Fri 15:15 CE 104):
Handed out by assistant on day of lecture
Available on moodle
Solution of selected problems of prior week

If you miss a course …
The course given was filmed and is available on youtube
the link is provided on moodle for each lecture
What is the content of this course?

<table>
<thead>
<tr>
<th>Theme</th>
<th>Elements</th>
</tr>
</thead>
</table>
| **Introduction**  
(Lectures 1-2) | Definition and importance of bio-imaging  
Ultrasound imaging  
Basis of x-ray imaging |
| **X-ray imaging**  
(Lectures 3-7) | Interactions of photons with matter/Radioprotection  
X-ray imaging (computed tomography)  
Emission computed tomography  
Positron emission tomography  
Tracer dynamics |
| **Magnetic resonance I**  
Basics  
(Lectures 8-10) | Basis of magnetic resonance effect  
T₁ and T₂ relaxation  
Spectroscopy  
Echo formation |
| **Magnetic resonance II**  
Advanced topics and contrast mechanisms  
(Lectures 11-13) | Elements of image formation  
Biophysics of BOLD  
Contrast agents  
Diffusion tensor imaging |

Links

- **Life science @ EPFL**
  - Systems and signals
  - Image processing
  - Mathematical and computational models in biology
- **Physics**
  - Neural networks and biological modeling
  - Classical electrodynamics

What supplemental reading/material is recommended?

I will provide pdf versions of the lecture on moodle.

Handouts without your personal notes will not be complete.

To complete the Handouts:

1. personal notes during course
2. incorporate insights gained during exos

Course text:

Andrew Webb
"Introduction to biomedical imaging"  
(250p. ~EUR 110, available as ebook at the library EPFL)
USD 60+ on amazon.com
- Is more complete on MRI
- Excellent reference text for later use

Other Text books

- Zhang-Hee Cho, Joie J. Jones, Manbir Singh  
  "Foundations of Medical Imaging"
- William R. Hendee, E. Russel Ritenour  
  "Medical Imaging Physics"
  "The Essential Physics of Medical Imaging"

For a shorter text: Penelope Allisy-Roberts, Jerry Williams  
"Farr’s Physics for Medical Imaging"  
(200p., small, ~EUR 50)
USD 30+ on amazon.com
A lot of focus on simple x-ray (not covered in the course)
1-1. What is Biomedical Imaging?

Definition of bio-imaging

Localized measurement of a contrast generating biophysical effect in body/organ of living system

What is measured (some useful definitions)

Image = nxm matrix of pixels
Pixel = picture element
3D image = kxnxm matrix of voxels
Voxel = volume element

Important:
Contrast between voxels/pixels
In principle n,m,k can be unlimited...

What is Contrast?

Ability to distinguish tissue features against noise
Contrast = difference in signal between tissues one wishes to distinguish
In reality one needs to deal with Contrast-to-noise

Resolution, Sensitivity/Contrast

Is there a free lunch for imaging?

What is the difference between signal-to-noise and contrast-to-noise ratio?

To obtain good measurements (not only in imaging) we need good signal to noise ratio

Definition

Signal-to-noise ratio (SNR)

\[ SNR = \frac{S}{\sigma} \]

SNR provides a means to estimate the precision with which the signal S is measured

It is possible to have excellent SNR but no CNR (when?)

To discriminate two signals \( S_1 \) and \( S_2 \) we need more than just good signal to noise ratio. The ability to discriminate the two is assessed using the contrast to noise ratio

Definition

Contrast-to-noise ratio (CNR)

\[ CNR = \frac{S_1 - S_2}{\sigma} \]

CNR provides a means to estimate the precision with which the signal \( S_1 \) can be discriminated from \( S_2 \).
1-2. How can we optimize SNR?

It is possible to optimize SNR by performing N repeated measurements $S_i$. The precision of the average $\langle S \rangle = \sum S/N$ depends on the square root law (4 measurements improve the precision by twofold):

$$ S = S + \epsilon_i $$

where $\langle \epsilon_i \rangle = \sigma^2$, $\langle \epsilon_i \rangle = 0$.

$S$ is the true signal (unknown)

$$ \langle S \rangle = \sum S/N = S + \sum \epsilon_i/N $$

$$ \Delta S = \langle S \rangle > - S = \sum \frac{\epsilon_i}{N} \quad \Delta S^2 = \frac{\langle \epsilon_i \rangle^2}{N^2} $$

This is well-known from statistics (SEM) ⇒ results in increased measurement time

$$ \langle S \rangle^2 = N \sigma^2 $$

$$ \langle \Delta S \rangle = \frac{\sigma}{\sqrt{N}} $$

How can we optimize CNR?

Optimizing contrast = choice of experimental parameters (e.g., protocol) to maximize the difference in two tissue signals $S_1$ and $S_2$.

complex and empirical procedure

some effects can be predicted/calculated, if the signal behavior can be modeled.

Error propagation calculation

Let the signal $S$ be a function $S(k, t)$

k is a tissue property (signal decay rate)

t an experimental parameter (such as time).

Approach:

1. Determine $dS/dk$.
2. Find $t_0$ where $dS/dk$ is maximal by taking derivative rel. to $t$

Example:

$$ S(k, t) = S_0 e^{-kt} $$

$$ \frac{dS(k, t)}{dk} = -S_0 ke^{-kt} $$

Maximum is where derivative with respect to $t$ is zero

For an exponentially decaying signal, the optimal time of measurement is equal to $1/\text{decay rate}$

How critical is the choice of $t_0$?

$$ \frac{d}{dt}(S_0 e^{-kt}) = 0 $$

$$ = -S_0 e^{-kt} (1-kt) = 0 $$

$$ t_0 = 1/k $$. 

1-8
1-3. What is the importance of Bio-Imaging?

Life Sciences are unthinkable without Bio-Imaging
Assessment of biological processes with minimal perturbation of the system

Examples:
Humans, animals, cell/organ preparations

Modalities:
x-ray
computed tomography
positron emission tomography
magnetic resonance
ultrasound
electrical imaging (EEG, MEG)
onoptical imaging

Development of Bio-Imaging capabilities, modalities and effects
... unthinkable without physics

What are essential ingredients of bio-imaging?

1. Life Sciences
2. Physics
3. Engineering/Good instrumentation
4. Mathematics
5. Chemistry

Multi-disciplinarity is important!
What is the perfect imaging modality?

1. Easy to use
2. Portable
3. Highly sensitive/good contrast

⇒ Does this exist?

In reality, every imaging method/modality has its strengths and limitations.

In this course you will learn to appreciate these and the reasons behind.

1-4. Examples

**Autoradiography**

Autoradiography of a brain slice

Autoradiography of a monkey brain (visual cortex)
What are the distinct advantages of Bio-imaging compared to tissue analysis?

**Imaging advantages**
relative to histology or invasive tissue analysis
1. Rapid acquisition of the information
2. Non-destructive, i.e. minimal perturbation
3. In situ or in vivo
4. Repetitive (longitudinal) studies possible

**Examples: Biomedical Imaging**
http://nobelprize.org/educational_games/physics/imaginglife/narratives.html

- 3D rendering of tumor for surgical planning (MRI)
- Metastasis localization (PET)
- fMRI of whole brain activation