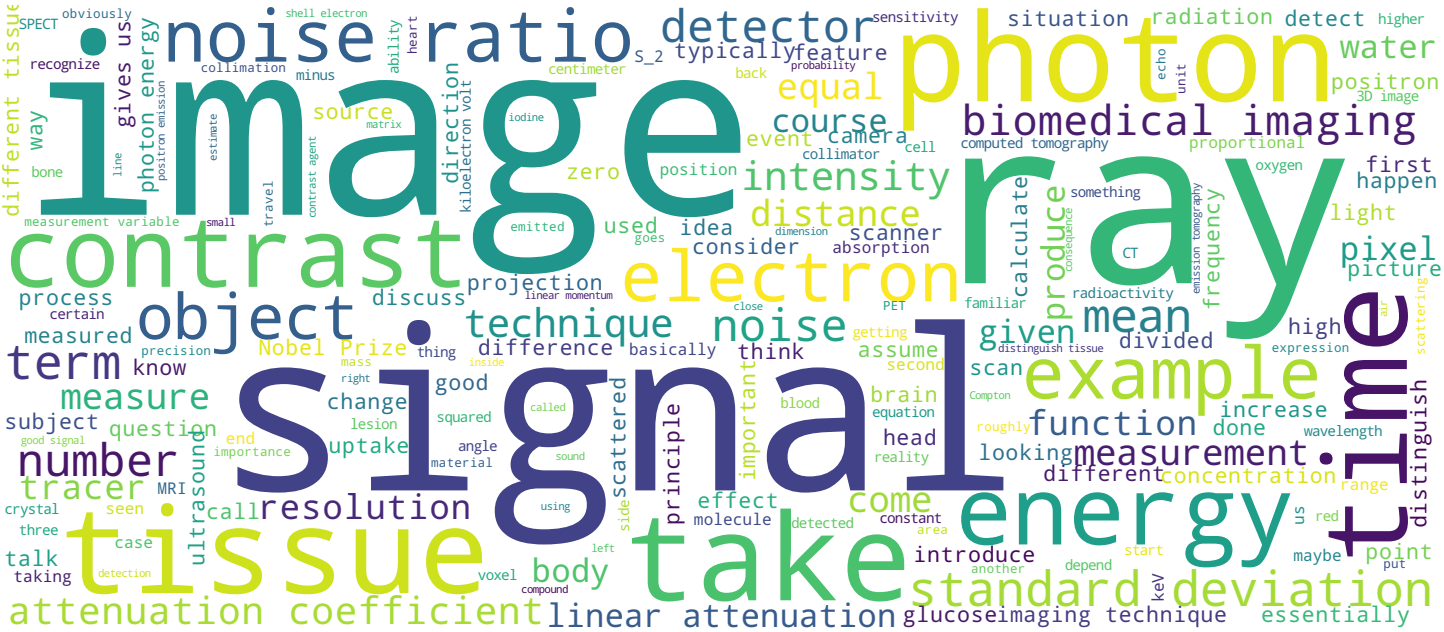
1.1 What is Biomedical Imaging ?

Fundamentals of Biomedical Imaging

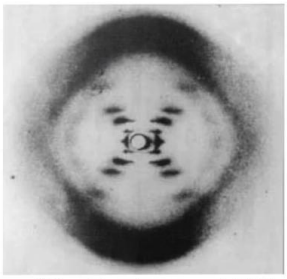
Prof. Rolf Gruetter



Search MOOC

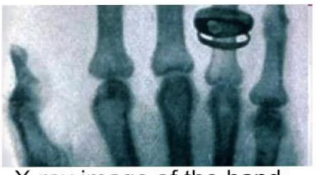
Video

What do these images represent ?

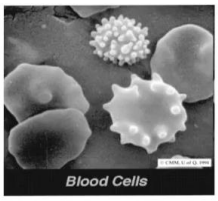


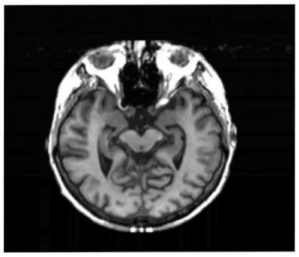
Data: Rosalind Franklyn

X-ray diffraction image of DNA crystals
Watson, Crick, Wilkins (Nobel 1962)



X-ray image of the hand
Röntgen (1901) / Cormack & Hounsfield (1979)





1-5

Let's look at these four images. What do they represent? Are you familiar with them? Look at the four images a little bit and give it a thought. Maybe you recognize all of them, are familiar with all of them? Maybe you have seen three, or maybe just two? Or maybe you recognize one, you are familiar with one, or maybe you can't recognize all of them? It's not critical. But let's look at these images what they are. Take the first one: this is actually the X-ray diffraction pattern of DNA taken by Rosalind Franklin. This data is an image of a molecule DNA, and this image was used by Watson and Crick to propose the double-stranded structure of the DNA helix, the helical structure. So this is a representation of something inside the body by an image. Let's take this image here. This is actually a very well known image, very famous, taken in 1895. It is the hand of the wife of Wilhelm Conrad Röntgen. It is befitting that Röntgen received the first Nobel Prize in Physics. Röntgen is also the father of biomedical imaging. Think about it. First Nobel Prize in Physics awarded to the father of biomedical imaging. It gives you some idea about the importance of biomedical imaging.

Notes

Summary

0m 04s

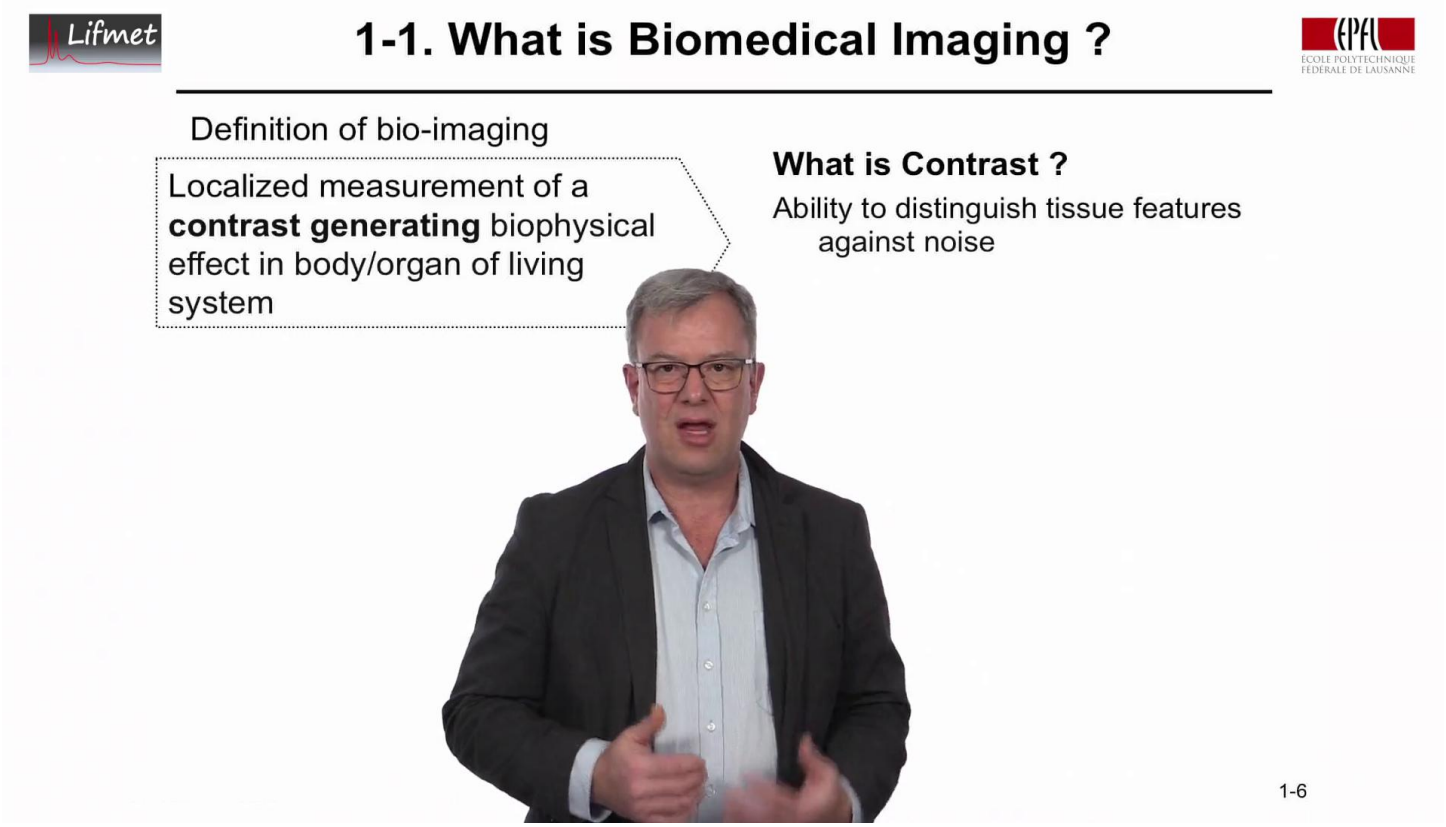
1-1. What is Biomedical Imaging ?

Later on X-ray images, the X-ray technique for computed tomography, Cormack and Hounsfield shared the Nobel Prize in 1979. We will talk about that technique in more details. Well, take this image of blood cells. This is the work of Ruska, who received the Nobel Prize in 1986 for the development of electron microscopy. These are images done by an electron microscope from red blood cells. And last but not least, what you see down here, that's an MRI of the head-- we can see the eyeballs here [inaudible]. This is an MRI of a head. For the development of MRI as an imaging technique, Lauterbur and Sir Peter Mansfield, the latter one a physicist, received the Nobel Prize for Physiology and Medicine in 2003. Together, what these images illustrate is the importance of basic sciences, fundamental sciences, physical sciences and engineering in developing biomedical imaging technologies that are being so widely used today, such as in medical diagnosis and research. I will start here with a definition of biomedical imaging which is slightly different than what we might consider as imaging. Take, for example, this device here. We all are pretty familiar with smartphones; we take pictures with it.

Notes

Summary

1m 31s

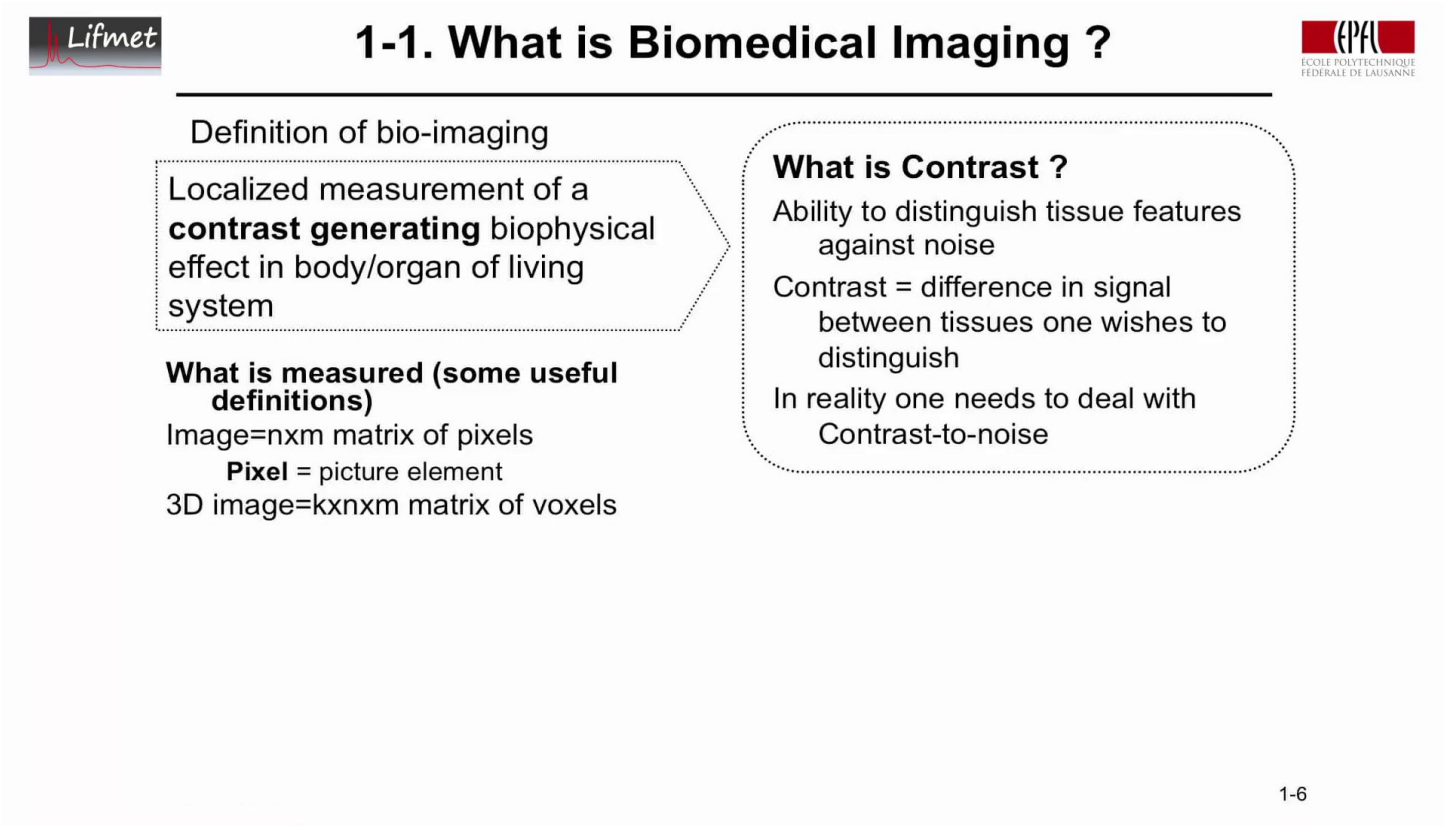


That is taking a picture. Strictly speaking, it's taking a picture of people, so those are life beings, so one could call it biomedical imaging. But that's not the biomedical imaging that we consider. That's taking pictures. So we'll take here a more general definition of biomedical imaging, or bio-imaging, and it is a localized measurement of a contrast generating biophysical process or effect in the body or organ of a living system. And we will constrain ourselves in this course to techniques that are capable of obtaining this information from a live being, be it an animal, a plant or a human, but it has to be alive and not extracted. So, if we go on, then we have to turn here contrast generating. So what is contrast? What do we understand under the term *contrast*? We all know what images are. Contrast is the ability to distinguish tissue features against noise. In all techniques, imaging techniques or otherwise measurement techniques we have some level of noise. We need to have enough contrast, that is, features to distinguish different tissues or the lesions against normal tissue, against the noise background. Then we can say something relevant about what's going on.

Notes

Summary

3m 01s

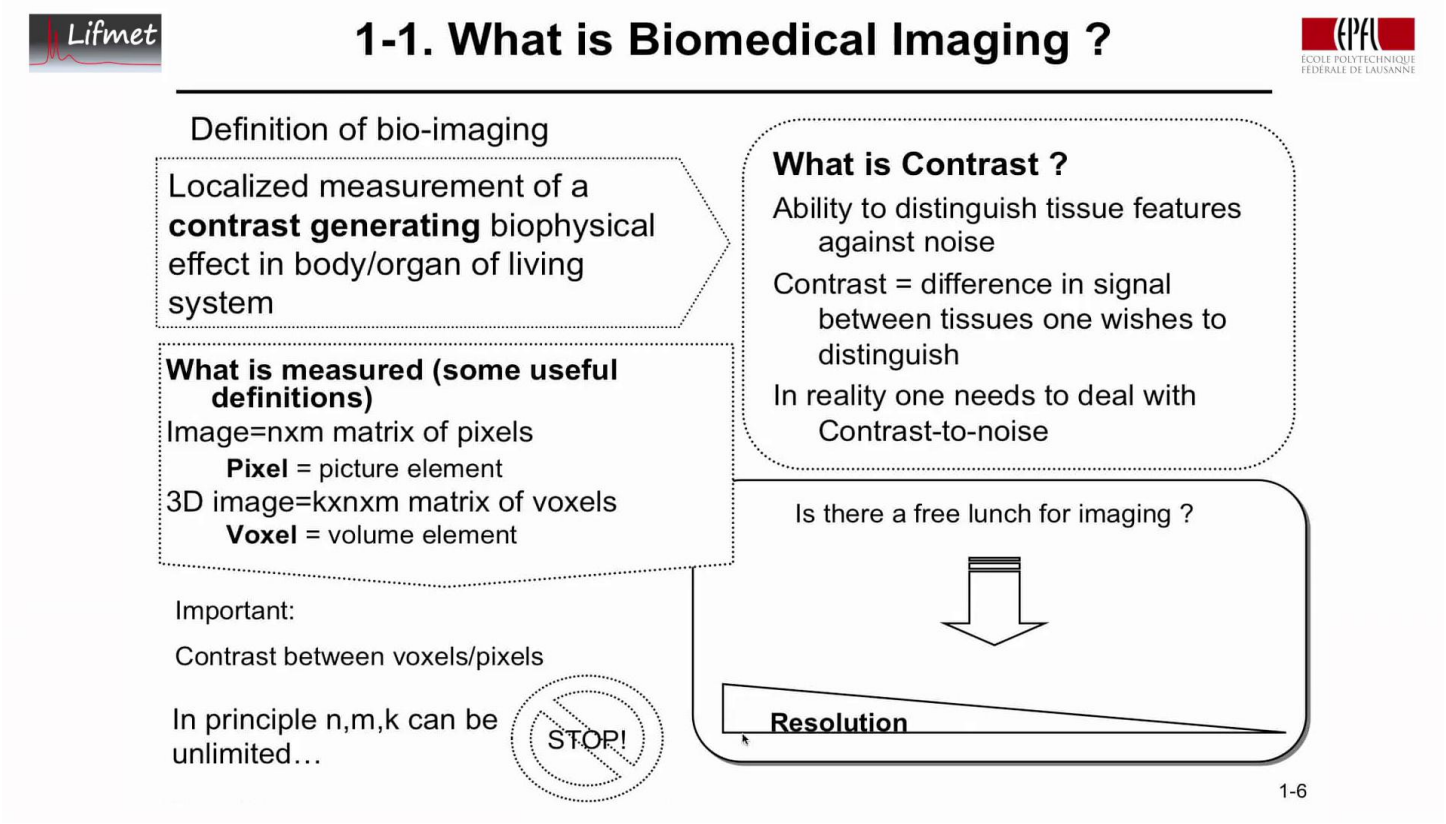


So essentially contrast is difference in signal between the two types of tissues that one wishes to distinguish. Can we see a difference, then we have contrast. In our classical images, such as the smartphone that you've just seen before, we have excellent contrast, so we can distinguish the features. We can take a picture of you, and you are easily able to recognize different people. So in reality we don't have that much signal-to-noise ratio as we have with cameras, so in reality for imaging techniques, we have to deal with contrast-to-noise ratios or the contrast to noise has to be considered. So this is the importance of contrast. So now we would go to what is being measured, and here I want to introduce some useful definitions. Typically when we take an image, a 2D image, it's *(n x m)* matrix of pixels. Where does the term *pixel* come from? Well, the term *pixel* is a condensed version of the double word *picture element* so people thought it is too long to say when they talk about picture and then at some point defined it as pixel. Or we have a 3D image which is a *(k x n x m)* matrix of voxels. I'd guess for now you can figure out what are voxels.

Notes

Summary

4m 33s

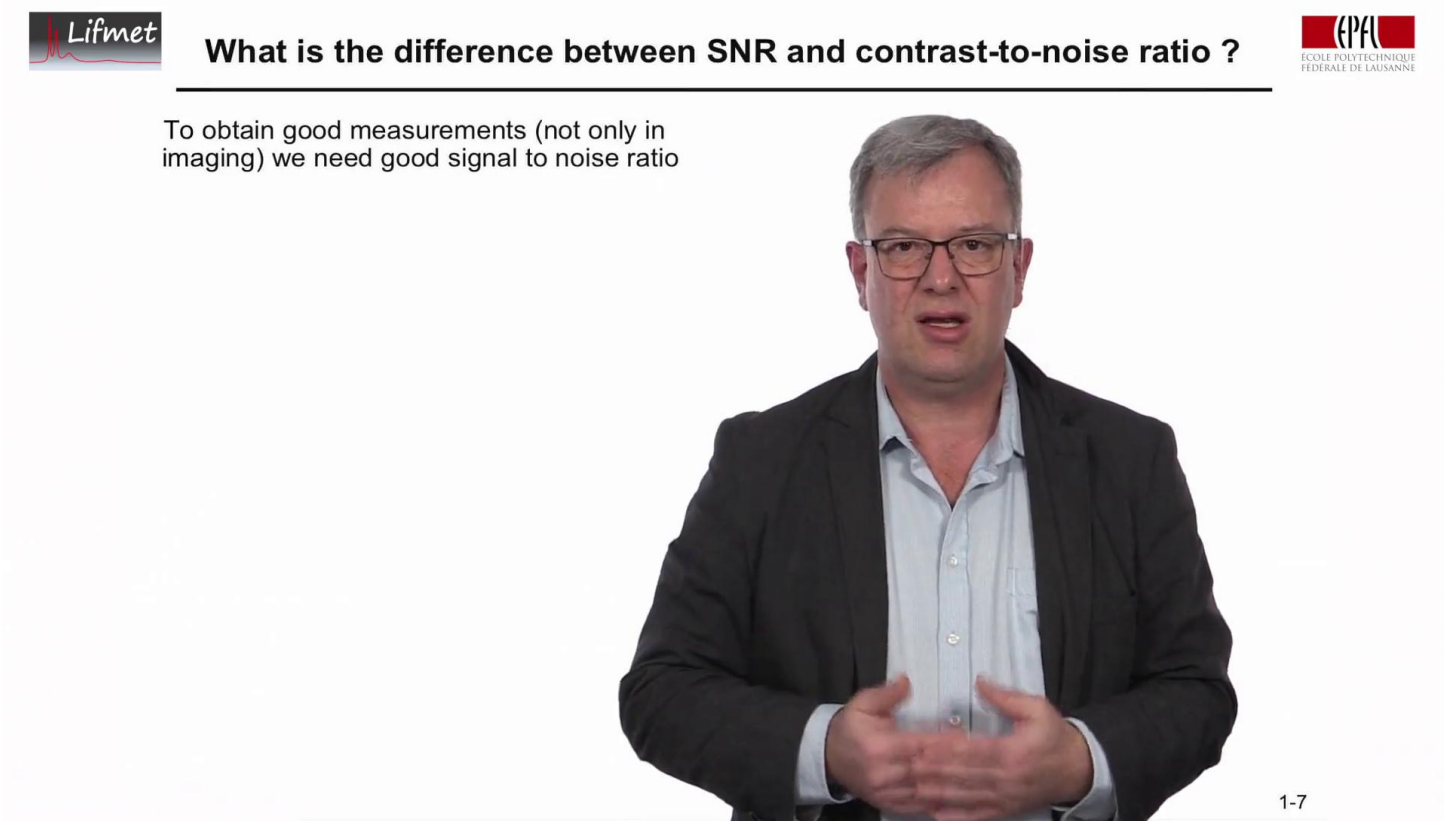


And, indeed, *voxel* is the short version of *volume element*. So these are some of the features that we measure. Now, what is important for the imaging techniques is the contrast between either voxels for a 3D image or pixels. Typically in this course we are going to restrain ourselves to 2D images. We are going mainly if we mean voxels, we really talk about pixels. We won't generalize the techniques to 3D imaging. But what is important is, we want to be able to distinguish tissue 1 from tissue 2, say, in the neighboring voxel or pixel of the image. Now, in theory there is nothing that prohibits us from generating matrixes with infinite dimensions. We can have n, m, k for a 3D image-- with technology we can make it as large as we want. But stop, there is a problem here. They just can't have it all. So, to rephrase it, is there a free lunch for imaging? And what we see is that no, there isn't. And the general principle is this: If we have here on this graphic we have good resolution on the left, poor resolution on the right. So we would like to have really excellent resolution. We can do that-- the techniques allow us to do it in principle.

Notes

Summary

5m 58s

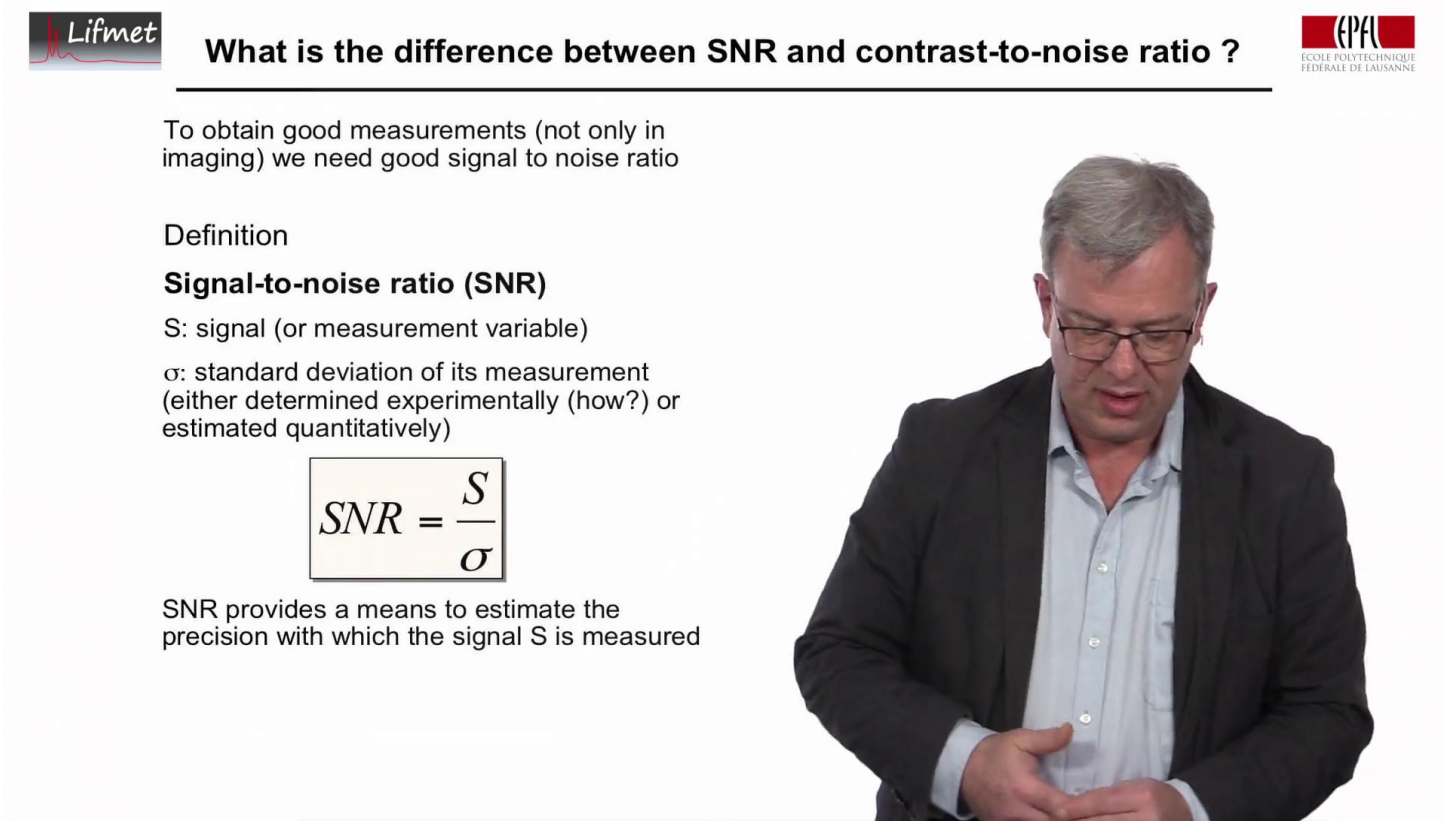


So we could have excellent resolution, that is, very small voxel dimensions. The price that we pay is that in that end we typically have poor sensitivity or contrast. If you want to have a lot of sensitivity, then usually you have to pay the price with resolution. So it's this trade-off between resolution on the right side and sensitivity/contrast on the other side that are fighting against each other, and depending on what we want to be able to discern, we are trading off one against the other. And it's always this trade-off that stays with us, and that's inherent in all of the imaging techniques. So now comes the question. We've talked about contrast. Now comes the question: what is signal-to-noise ratio, SNR, and contrast-to-noise ratio? How do they differ? These are two very essential terms with which we characterize the precision or quality of an image and the ability to distinguish tissue features. So now I think we are all in agreement that if you don't have a good signal-to-noise ratio, it's pointless to continue. If you just see noise, then your image just has noise, and you cannot see anything. So you need a good signal-to-noise ratio. It is an essential, necessary condition.

Notes

Summary

7m 29s



Multifying here the signal-to-noise ratio (SNR), let's look at the signal, or the measurement variable. Sometimes it's not the direct signal that we've imaged, but it is a variable that's derived from the image, and we'll consider the standard deviation of its measurement. Standard deviation of the measurement of this signal or the measurement variable means typically it's the variation that's either determined experimentally-- Now, how can we do that? It's experimental determination. So, one way is to repeat the measurement many times and to see how much the same measurement varies over time. This gives us an indication on a variance and therefore on σ, the standard deviation. In some techniques, we can actually quantitate the standard deviation of the measurement and do a calculation quantitatively for the SNR. That brings us to the first important definition that the signal-to-noise ratio is the signal divided by the standard deviation of the noise. This gives us an idea of the variance. So therefore this is a means to estimate the precision with which the signal is measured, how much does it fluctuate scan to scan.

Notes

Summary

9m 01s

What is the difference between SNR 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)

S: signal (or measurement variable)

σ: standard deviation of its measurement (either determined experimentally (how?) or estimated quantitatively)

$$SNR = \frac{S}{\sigma}$$

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)

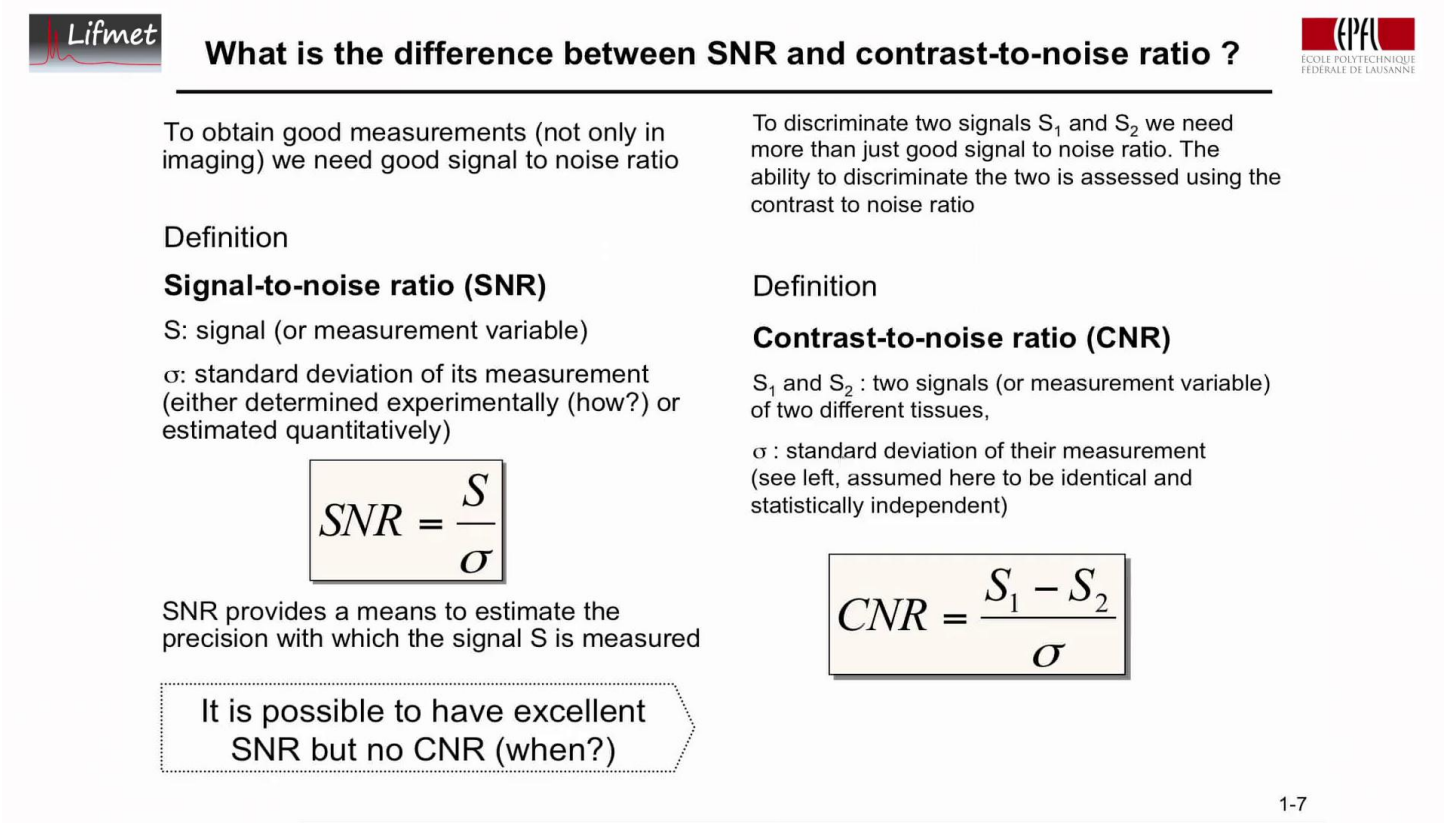
1-7

So now, it is in principle possible to have outstanding signal-to-noise ratio but very poor contrast-to-noise-ratio. And you think of the situation. We'll take the camera here, and let's say we take a picture of you or of the lecture hall, or of some scene, and we take a very long exposure time. So in a CCD device we collect a lot of photons until we saturate the detector of the camera. Then we have excellent signal-to-noise ratio. We basically have no noise, we have just signal, but when we saturate, we basically are overloading on all aspects. The camera is getting white image, so this is an excellent SNR, signal-to-noise ratio, but we won't be able to discern any features with it. So we have no contrast. We can't see if there are people in the picture, if it is a landscape, etc. So, while signal-to-noise ratio has to be good-- it's a necessary condition, it is not a sufficient condition. So we need to be able to distinguish two signals-- we call it, let's say, S_1 and S_2, and we want to have for each one of them good signal to-noise ratio-- let's assume we have that-- but we also need to introduce here the contrast-to-noise ratio. And this is the definition I want to bring in here about.

Notes

Summary

10m 26s



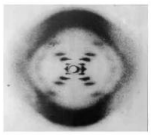
So let's take S_1 and S_2. Those are two signals from two different tissues or measurement variables, again, it can be calculated, variables, from the images, but two features that we are extracting from the tissue, and, let's say, one and two are two different tissues. Here again the standard deviation like on the left here, for the signal-to-noise ratio, here is the standard deviation, and we'll introduce now for S_1 and S_2-- that's the standard deviation of those two tissues, of those two voxels that we want to distinguish have the same standard deviation, so σ the same, and the noise is statistically independent. That's two statistically independent measurements. That's what we assume. Then we define the contrast-to-noise ratio as the difference in the two signals divided by the standard deviation of the noise.

Notes

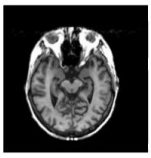
Summary

12m 01s

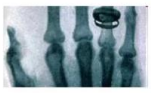
Credits



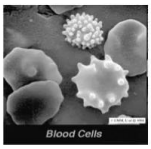
Rosalind Franklin
Cold Spring Harbor Laboratory Library and Archive
http://undsci.berkeley.edu/article/dna_checklist



Keith A. Johnson, M.D., Harvard Medical School
http://www.med.harvard.edu/aanlib/cases/caseM/mr3/022.gif



Wilhelm Röntgen
http://patientinfo.myesr.org/html_frontend/index.php?module=gallery&action=&picture_id=24



Centre for Microscopy and Microanalysis - University of Queensland
http://academics.wellesley.edu/Chemistry/Chem102/antibiotics/immune.html

This means we have a signal 1, we have a signal 2. We have a standard deviation. If those two signals differ by not much more than the standard deviation of the noise. We essentially cannot even mathematically discriminate between the two signals, S_1 and S_2. So we won't be able to discriminate between the two tissue types and not detect the lesion or not detect the different tissue types. So this is a means to estimate the precision by which we can detect changes in the signal between two tissues.

Notes

Summary

12m 59s