# Medical signal processing

Signal?

*signal*: contains information (information: new knowledge, that decreases the uncertainty).

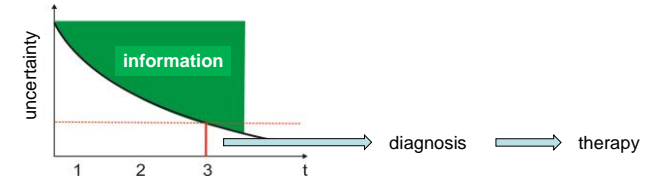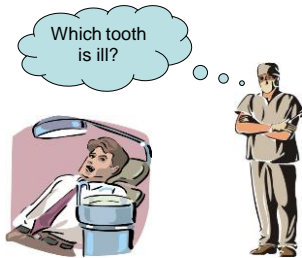signal

*noise*: everything, that is not signal.
Relative!

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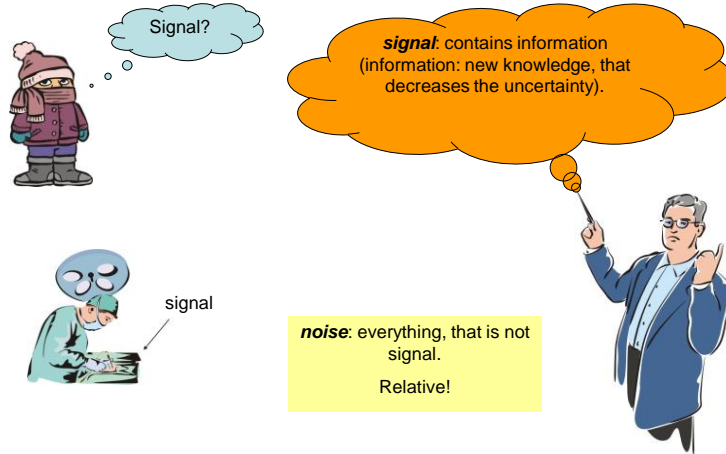
# Information

information:

1. Enters.
2. Complaint?
3. Which?

1. A patient.
2. I've a toothache.
3. Third molar.

uncertainty

information

1    2    3    t

diagnosis ⟹ therapy

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# Information content

Which tooth is ill?

1. Upper? - not. Only 16 possible places. Decreasing uncertainty.

2. On the left? - not. 8 possible places.

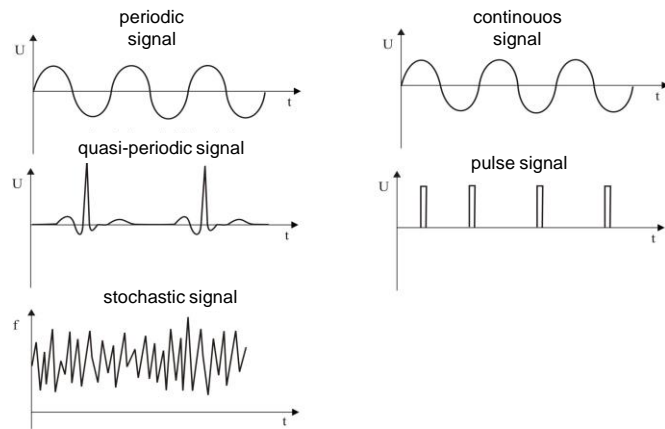32 possible answers! The uncertainty is enough large.

Five right questions are necessary to indentify the place!
**Information content**: **5 *bit*** ($2^5 = 32$)

Bit: unit of the information.

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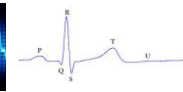# Classification of the signals 1.

Electric signals
(e.g. ECG, EEG, EMG, etc.)

Non-electric signals
(e.g. blood pressure, temperature, etc.)

transformation

electric signal

Equipments are based on electricity!

processing

2016.03.04.
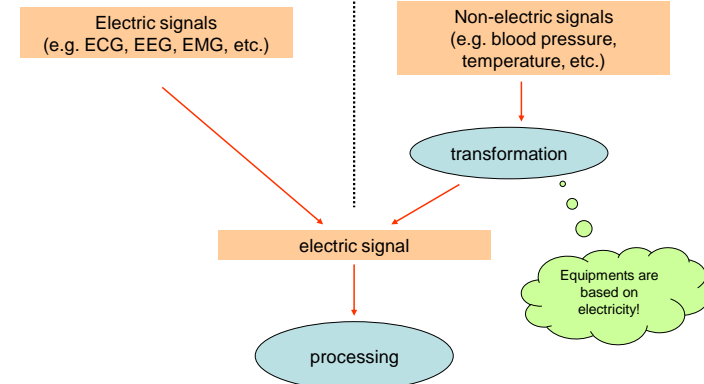
## Classification of the signals 2.

periodic signal

continouos signal

quasi-periodic signal

pulse signal

stochastic signal

## Classification of the signals 3.

**analog signal**

**digital signal**
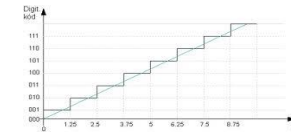
sound          ecg

Every value is possible in a certain range .

Only a finite no. of values are possible.

height:          measurement          height: 175 cm

analog signall          (only discret values)

## Signal and noise

**Noise is random normally**!

Signal to noise ratio:

The quantity used to characterize the strength of the signal and the noise.

Ideal case: there is no noise!

Real measurements: noise is always present!

Higher value is better!

How can we increase?

increasing the signal

decreasing the noise

## Signal processing

signal source (patient) — signal (usually not electric) — detector (transducer) — electric signal — amplifier — signal formatter or discriminator — display

a

signal source (patient) — signal (usually not electric) — detector (transducer) — electric signal — amplifier — analogue-digital-converter — computer

Monitor

b

2
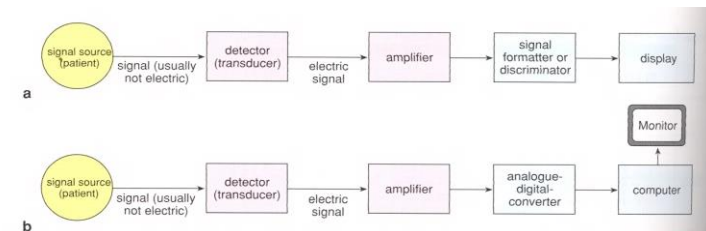
## Elements in electric circuit

**passive**

resistor

capacitor
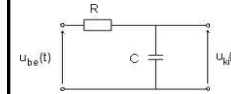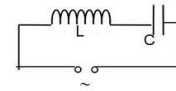
inductivity

**active**

diode

transistor

## Electric circuits

A unit that consists of elements.

simple
(consists of passive elements only)

RC circuit

LC circuit

complex
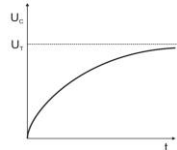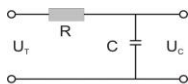(consists of passive and active elements)

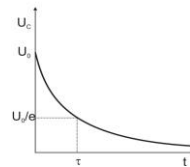integrated
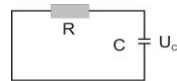circuit

amplifier

## DC behavior of a RC-circuit

charging

discharging

$$U_C = U_T \cdot \left(1 - e^{-\frac{t}{RC}}\right)$$
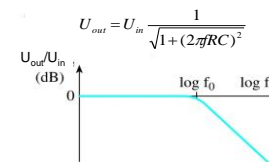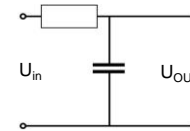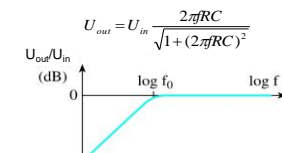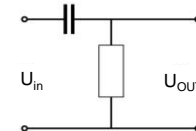
$$\tau = RC$$

$\tau$ = time constant

$$U_C = U_0 \cdot e^{-\frac{t}{RC}}$$

## AC behavior of a RC-circuit
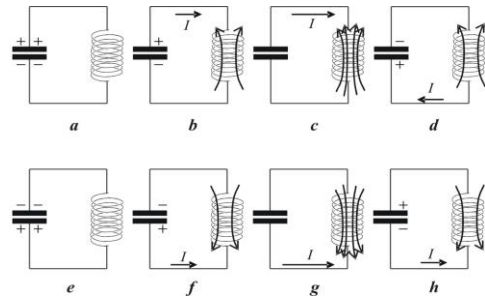
Lowpass filter

$U_{in}$   $U_{OUT}$

$$U_{out} = U_{in} \frac{1}{\sqrt{1 + (2\pi f RC)^2}}$$

$U_{out}/U_{in}$ (dB)   log $f_0$   log f

Highpass filter

$U_{in}$   $U_{OUT}$

$$U_{out} = U_{in} \frac{2\pi f RC}{\sqrt{1 + (2\pi f RC)^2}}$$

$U_{out}/U_{in}$ (dB)   log $f_0$   log f

## Resonant circuit (LC-circuit)

Electric (in the capacitor) and magnetic (in the coil) field

The electric and the magnetic field peridically are built up and destroyed.
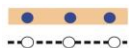


$$f = \frac{1}{2\pi\sqrt{LC}}$$

## Resonance

Energy excange between two oszcillating systems is possible only if the resonant frequency of the two systems is enough close to each other.
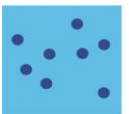
Tacoma bridge (1940)



## Semiconductors

n-type       p-type
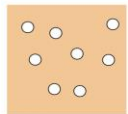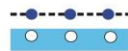
conductance band

valence band
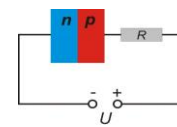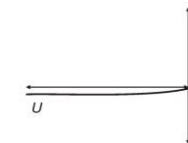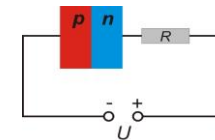
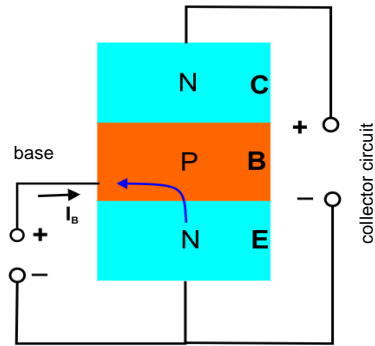the net charge is zero!



## Working of a diode

forward direction     reversed direction
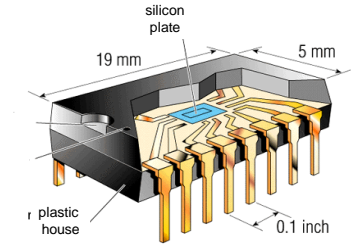
## *The transistor*

It is built up from 3 layers.

base

N    C

P    B

N    E

$I_B$

collector circuit

NPN transistor (there is PNP too)

## *Integrated circuits (IC)*

silicon plate

19 mm

5 mm

plastic house

0.1 inch
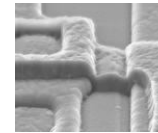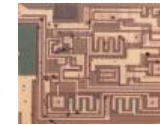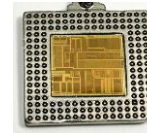
Transistors, diodes, resistors and capacitors are formed on a semiconductor plate producing a complicated electric circuit.

## *The development*

Microprocessor Transistor Counts 1971-2011 & Moore's Law

Transistor count

curve shows transistor count doubling every two years

Date of introduction
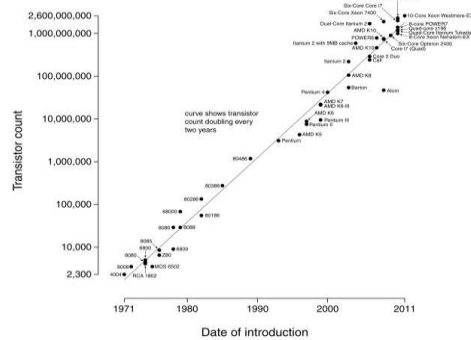
There are about $10^{11}$ neurons in the brain.

## *Detectors*

sound          microphone                                    hair cells

blood pressure monitor          elektric signal

pressure

light          photodiode                                    cones and rods

szcintillation head
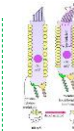
## Biological signals



## Amplifier
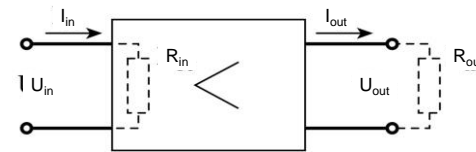


**Amplifier only if**

$$P_{out} > P_{in}$$

Power gain: ($A_P$)

Voltage gain: ($A_U$)

$$A_P = \frac{P_{out}}{P_{in}}$$

$$A_U = \frac{U_{out}}{U_{in}}$$

## The decibel scale

Instead of the simple proportion we use frequently the logaritmic of them. This is the decibel-scale.

$$n = 10 \cdot \lg \frac{P_{out}}{P_{in}} \ (\text{dB})$$

$$P = \frac{U^2}{R}$$

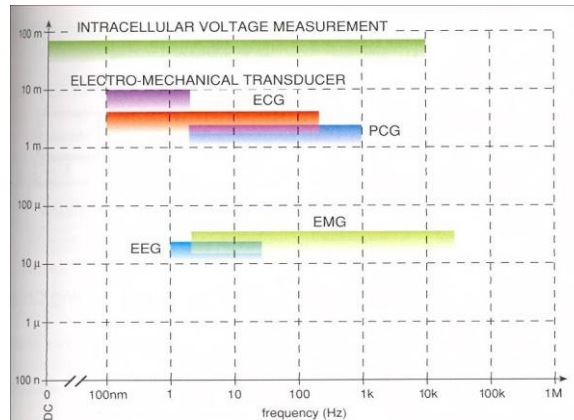$$A_P = \frac{U_{out}^2 / R_{out}}{U_{in}^2 / R_{in}} = \frac{U_{out}^2}{U_{in}^2} \cdot \frac{R_{in}}{R_{out}} = A_U^2 \cdot \frac{R_{in}}{R_{out}}$$

$$n(dB) = 10 \cdot \lg A_U^2 + 10 \cdot \lg \frac{R_{in}}{R_{out}} = 20 \cdot \lg A_U \left( + 10 \cdot \lg \frac{R_{in}}{R_{out}} \right)$$

## Fourier theoreme

$$y(t) = \sum_k a_k \sin(k \cdot \omega_0 \cdot t + \Phi_k)$$

Every periodic signal may be decomposed into the sum of sinusiodal signals.



An ecg signal and it's frequency components.

## Transfer characteristics

The amplification (in decibel) as the function of the frequency.

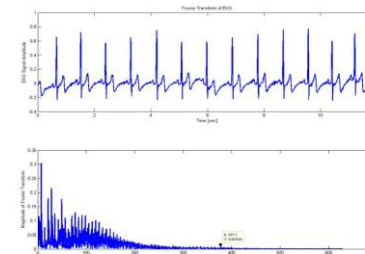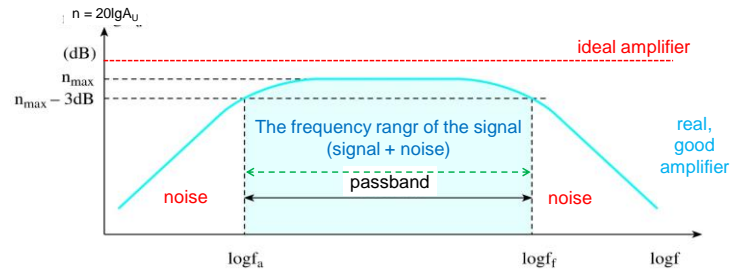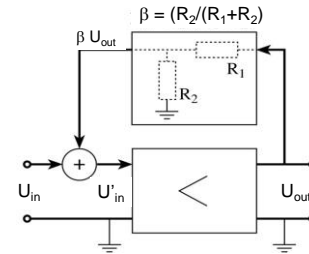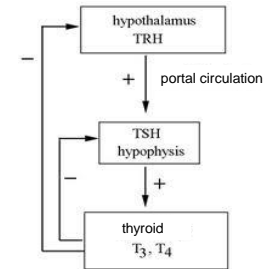In the presence of the noise the real amplifier is better.



$n = 20 \lg A_U$

(dB)

$n_{max}$

$n_{max} - 3dB$

ideal amplifier

The frequency rangr of the signal (signal + noise)

passband

noise

noise

real, good amplifier

$\log f_a$   $\log f_f$   $\log f$

## Feed-back

$\beta = (R_2/(R_1+R_2))$



$\beta \, U_{out}$

$R_1$

$R_2$

$U_{in}$   $U'_{in}$   $U_{out}$

$U'_{in} = U_{in} \pm \beta \cdot U_{out}$

$A_{U,F} = \dfrac{U_{out}}{U_{in}} = \dfrac{A_U}{1 \pm \beta \cdot A_U}$

hypothalamus TRH

portal circulation
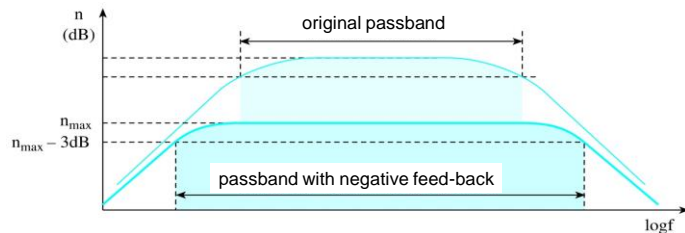
TSH hypophysis

thyroid $T_3, T_4$

feed-back in the body

## Negative feed-back

The feed-backed part of the output is added to the input after inversion.

$A_{U,NF} = \dfrac{U_{out}}{U_{in}} = \dfrac{A_U}{1 + \beta \cdot A_U}$

n (dB)

original passband

$n_{max}$

$n_{max} - 3dB$

passband with negative feed-back

$\log f$

## Advantage of the negative feed-back

$A_{U,F} = \dfrac{U_{out}}{U_{in}} = \dfrac{A_U}{1 + \beta \cdot A_U}$ usually $\beta \cdot A_U \gg 1$, so $A_{U,F} \approx \dfrac{A_U}{\beta \cdot A_U} = \dfrac{1}{\beta}$

The properties (gain, transfer band) depend on feed-back elements only.

Consueqencies:

1. The parameters (gain, transfer band) are well defined.
2. Noise level decreases on the output.
3. Stability increases.

## Pozitive feed-back

The feed-backed part of the output is added to the input.

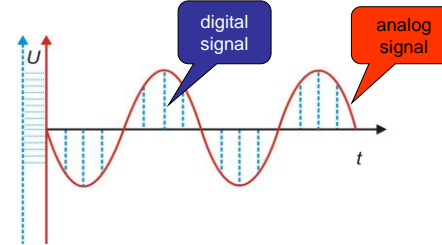$$A_{U,PF} = \frac{U_{out}}{U_{in}} = \frac{A_U}{1 - \beta \cdot A_U}$$

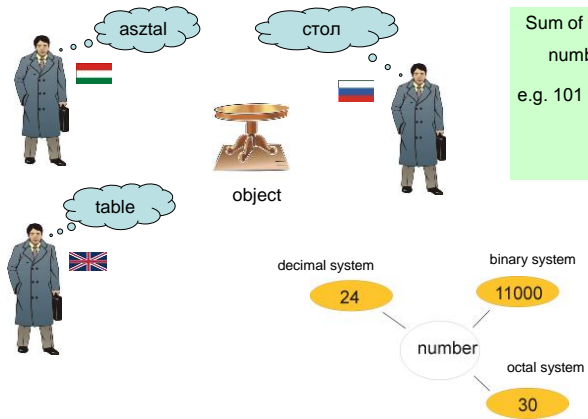if $\beta A_U = 1$ the system is unstable, oscillation.

**Oscillators: used to produce electric signal.**

## Digitazing the signal

Digital signal: a signal characterized by digital value and determined at a given time peridically (sampling).

digital signal

analog signal

$U$

$t$

## Binary system of the numbers

asztal

стол

table

object

Sum of the powers of 2.
numbers: 0 and 1.

e.g. 101 = $1 \cdot 2^2$
$+ 0 \cdot 2^1$
$+ 1 \cdot 2^0$

decimal system
24

binary system
11000

number

octal system
30

## Shannon principle
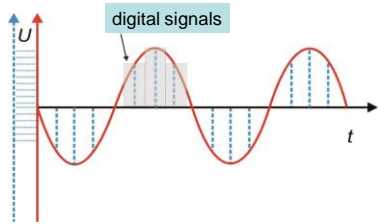
$$f_{sampling} \geq 2 \cdot f_{signal}$$

If the sampling doesn't fulfill this requirement, false frequncies appear.

sampling points

$U_{analog}$

t
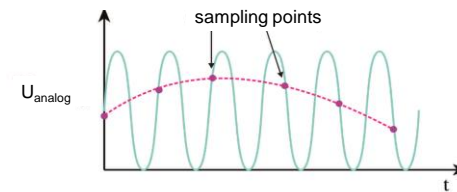
## Role of the resolution

quantization noise:
noise due to the quantization.



digital signals

$U$

$t$

Due to the quantization series of squere pulses appear. The fequency range of them is different from the original one.
Higher resolution decreases this noise.

## Role of the noise level

original image
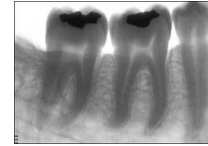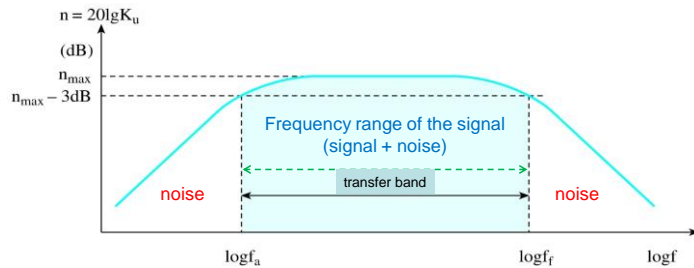


noise level

Richly detailed images, sufficient information.

Increasing noise level decreases the information obtained from the image.

To decrease the noise level is an important part of the signal processing.

## Planning a good amplifier

Base: Noise is present in the whole frequency range.



$n = 20\lg K_u$

(dB)

$n_{max}$

$n_{max} - 3dB$

Frequency range of the signal (signal + noise)

transfer band

noise

noise

$\log f_a$
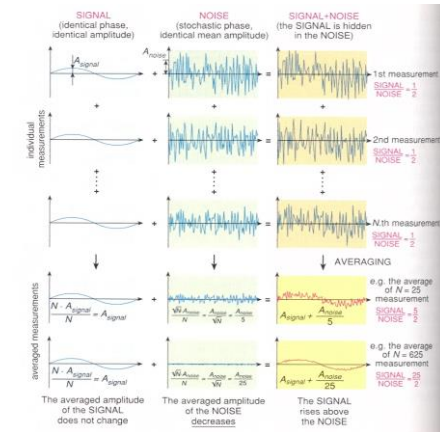
$\log f_f$

$\log f$

The signal to noise ratio increases
due to the decreasing amplification out of the transfer band.
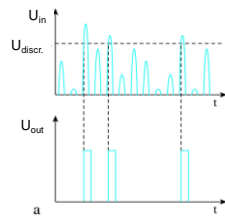
## Decreasing the noise by averaging
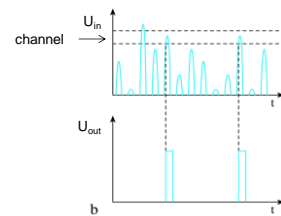
Base:

Noise is random while the signal is not.



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## *Pulse signals*

Base: The amplitude of the noise pulses is different in average.

Integral discriminator (ID)

$U_{in}$
$U_{discr.}$

t

$U_{out}$

a
t

Signal is produced only over a certain level.

Differential discriminator (DD)

$U_{in}$
channel →

t

$U_{out}$

b
t

Signal is produced if the amplitude is in the channel.

## *Displays*

CRT (not frequenty used nowadays)
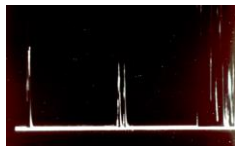
OLED

LCD

XEL-1

## *Displaying a time process*

H8

U

t

Time is on the horizontal axis and amplitude of the signal is on the vertical axis.

## *Information in an image*
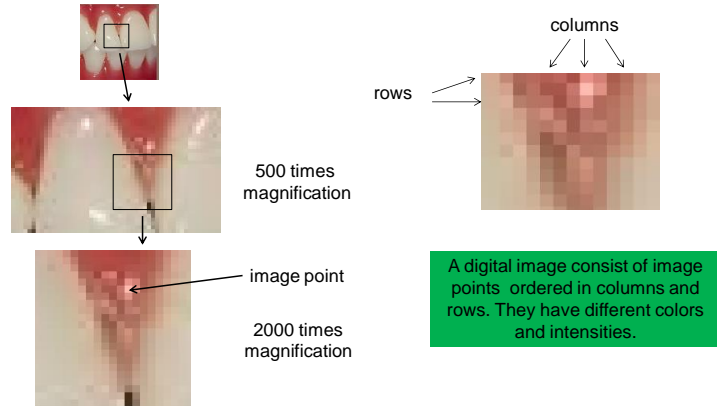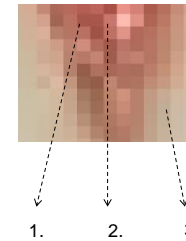
What is on the photo?

„ A landscape, a beautiful garden."

In fact:

How much is the absorption ability and the reflectivity of the different objects.

## Structure of an image

columns

rows

500 times
magnification

image point

2000 times
magnification

A digital image consist of image
points ordered in columns and
rows. They have different colors
and intensities.

## Physical content of an image

Every image point corresponds to a small part
of the body. This part normally is a square.
This is a *pixel*. The pixel is cosidered to be
homogeneous.
The properties of an image point are related to
some physical characteristics of the pixel.

1.    2.    3.

The 1. and the 2. pixel have the same
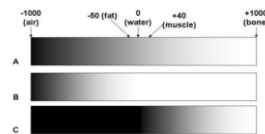absorption ability, but the reflectivity is
different.
The absorption ability of the 3. pixel is
diferrent, too.

## X-ray image

What information is in this image?
The x-ray absorption ability of the pixel is
recorded in the image point.
Practically the µ value.

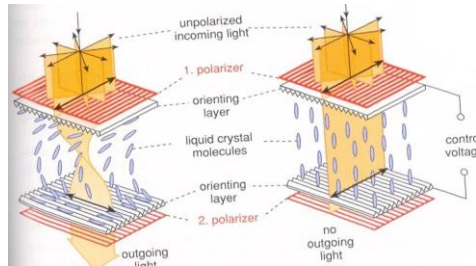Gray scales of a CT image at
different „windows".

## 3D image

Every image point corresponds
to a certain volume of the body.
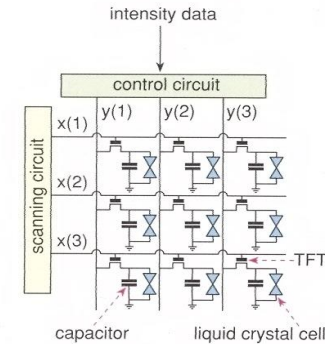This volume normally a cube.
this is the *voxel*.

The properties of an image
point are related to some
physical characteristics of the
voxel.

11

## LCD (Liquid Crystal Display)
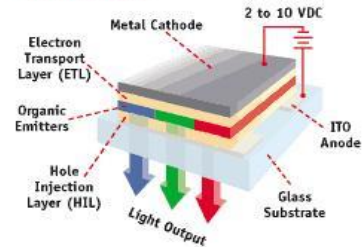
Structure and working of a single pixel (cell)



## TFT (-LCD) display



A very thin (transparent) transistor layer switches each pixel. This improves the speed.

## O(rganic)LED displays



LED: Light Emitting Diode

This is the structure of a unit cell (an image point) of the display.
The recombination of the electrons and holes produces the light. The color corresponds to the energy difference of them.
(Of cource one of the electrodes must be transparent.)

## Comparison of displays

|  | CRT | LCD | TFT-LCD (LED) | Plasm | OLED |
|---|---|---|---|---|---|
| brightness (cd/m$^2$) | ~100 | 200-300 | 200-300 | 400-1000 | A few 100 |
| Contrast ratio | > 1000:1 | ~ 600:1 | 600:1 (but LED: 1000000:1) | > 1000:1 | > 1000:1 |
| Viewing angle | whole range | ~140-160 degree | ~140-160 degree | ~160 degree | whole range |
| Frame rate | <1 ms | 8-20 ms | <8 ms | <1 ms | <1 ms |

## Flexible displays

## Transparent displays

## Application of the CCD



## Unit cell of a CCD