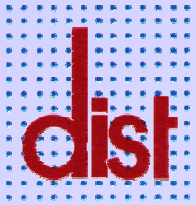


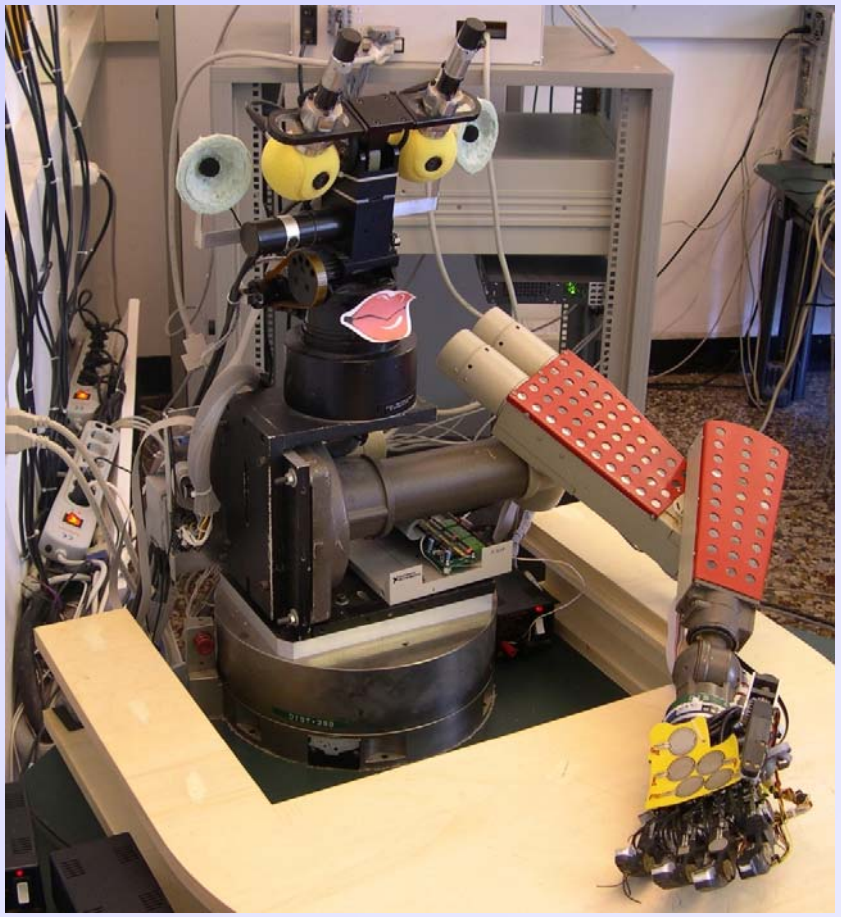
Sensorimotor development

Lorenzo Natale

Robotica Antropomorfa, Ottobre 2004

System’s Architecture

5 d.o.f. head
6 d.o.f. arm
6 d.o.f. hand
1 d.o.f. trunk



binocular vision
microphones
inertial sensor
proprioception (motor encoders, hall-effect encoders)
force sensor at the wrist
touch sensors on the hand (FSR)

An example

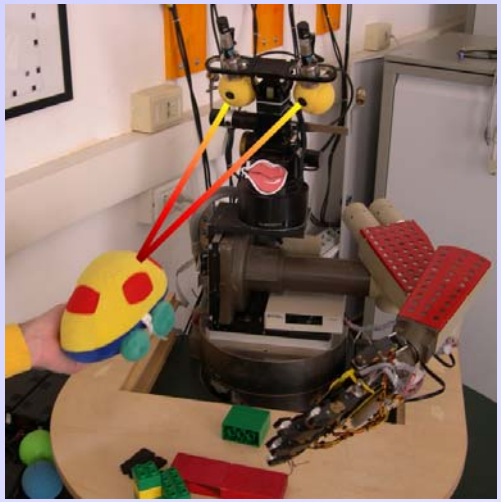
Goals: so far…

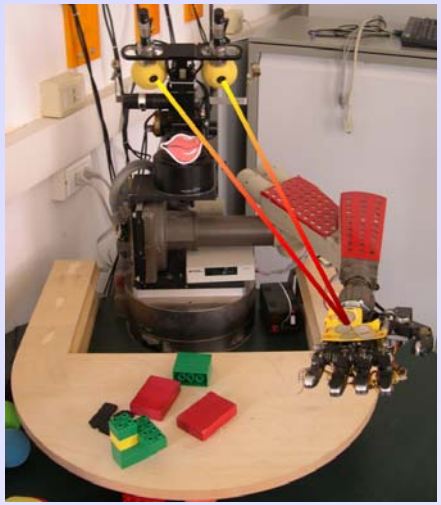
- Visually guided eye movements (head/eye coordination)
- Inertially controlled eye movements
- Orienting towards an auditory stimulus
- Reaching towards a visually identified target
- Grasping

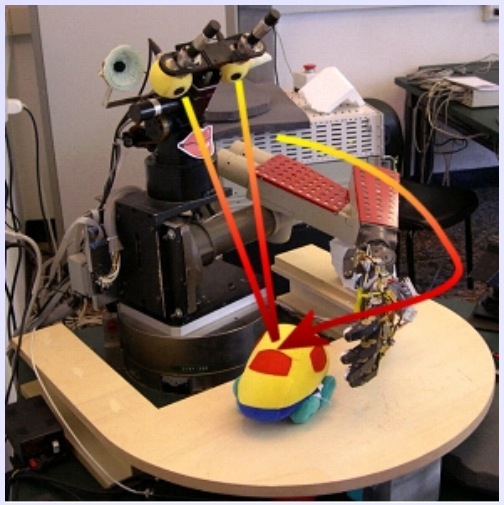
Sensori-motor coordination in a nutshell

- Whenever the brain has to fulfill a given motor task, it needs to convert sensory information into an appropriate motor command
- In general terms this transformation can be represented as a function:

$$\Delta q = f(s)$$







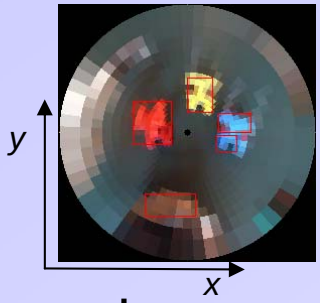
LIRA-Lab

Goals: so far…

- Visually guided eye movements (head/eye coordination)
- Inertially controlled eye movements
- Orienting towards an auditory stimulus
- Reaching towards a visually identified target
- Grasping

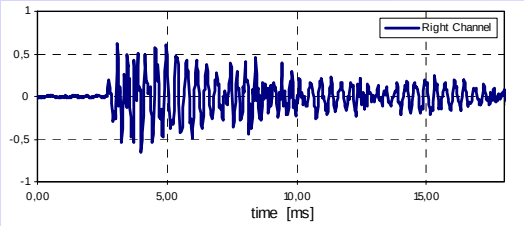
What is sound localization ?

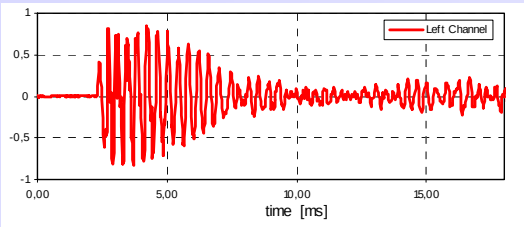
- visual information is spatially organized



$$s = f(x, y)$$

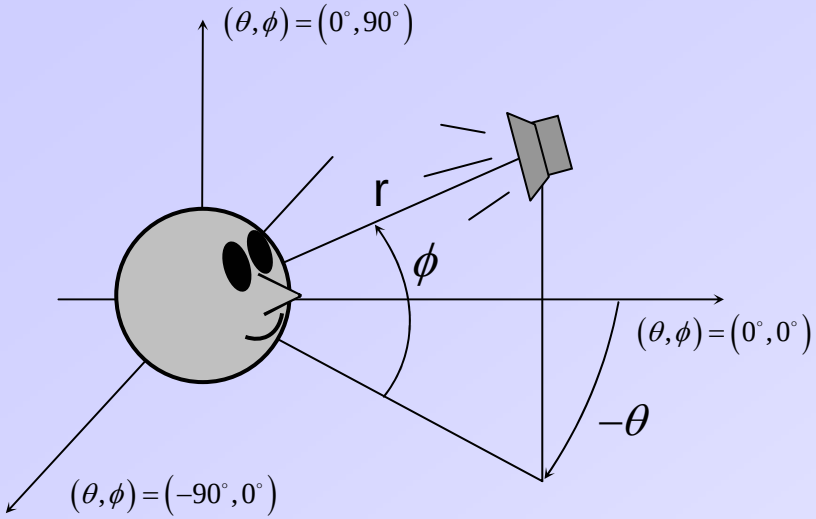
- we need some sort of computational process to extract spatial information from the sound signal



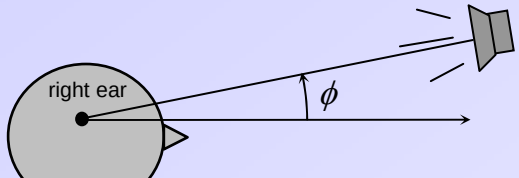


$$s = f(t) \xrightarrow{?} (x, y)$$

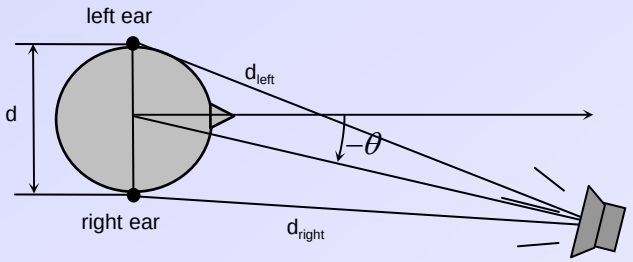
Head-Related Transfer Function (HRTF)



a) Head centric reference frame



b) Lateral view



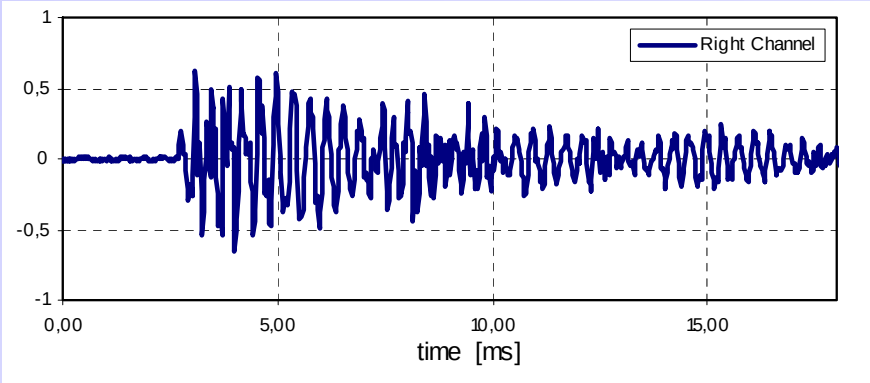
c) Top View

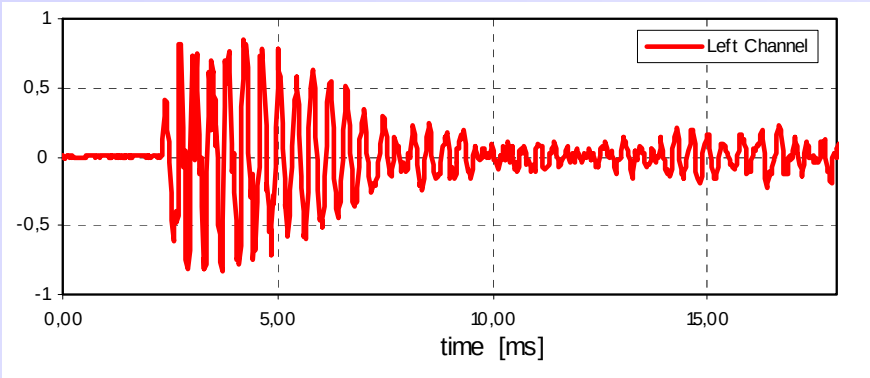
$$Y_R = H_R(f,\theta,\phi,r)\cdot X(f)$$

$$Y_L = H_L(f,\theta,\phi,r)\cdot X(f)$$

$$\longrightarrow \quad H(f,\theta,\phi,r) = \frac{H_R(f,\theta,\phi,r)}{H_L(f,\theta,\phi,r)}$$

LIRA-Lab


Right Channel
1
0,5
0
-0,5
-1
0,00
5,00
10,00
15,00
time [ms]

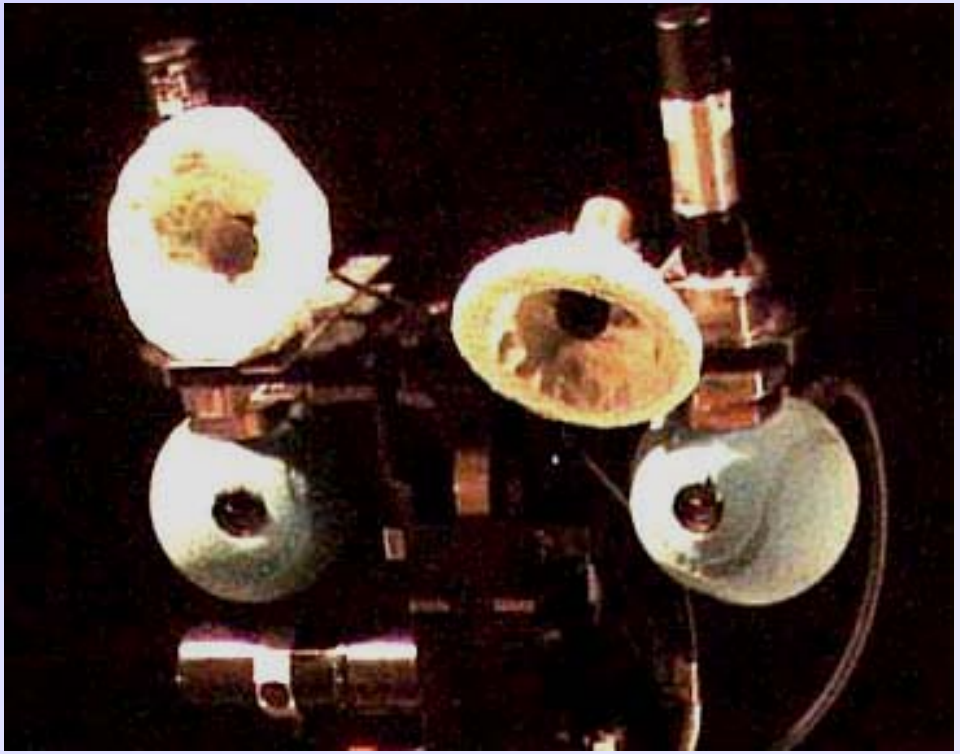

Left Channel
1
0,5
0
-0,5
-1
0,00
5,00
10,00
15,00
time [ms]

LIRA-Lab

Our approach …

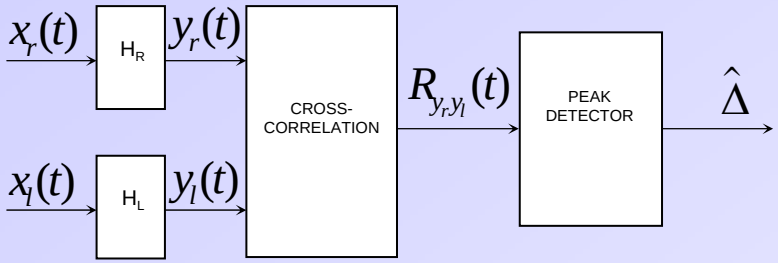
Estimation of the shift between the signals – ITD, horizontal position

Asymmetric external ears – ILD is “strictly” related to the elevation of the sound source

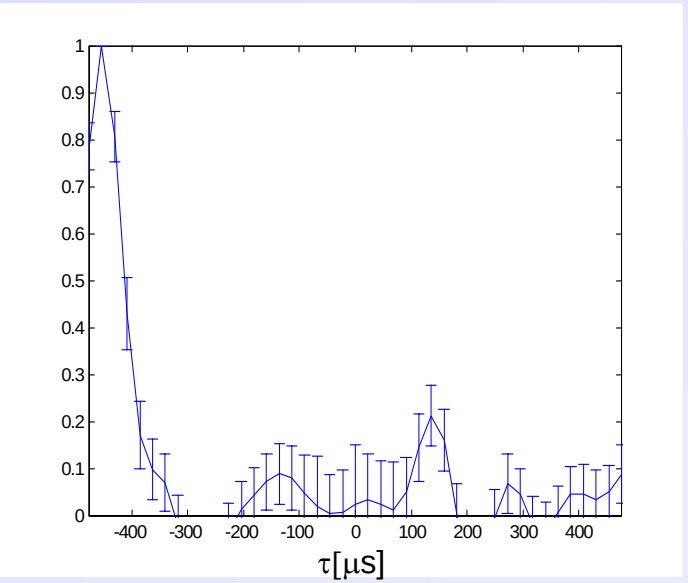


Computation of the ITD

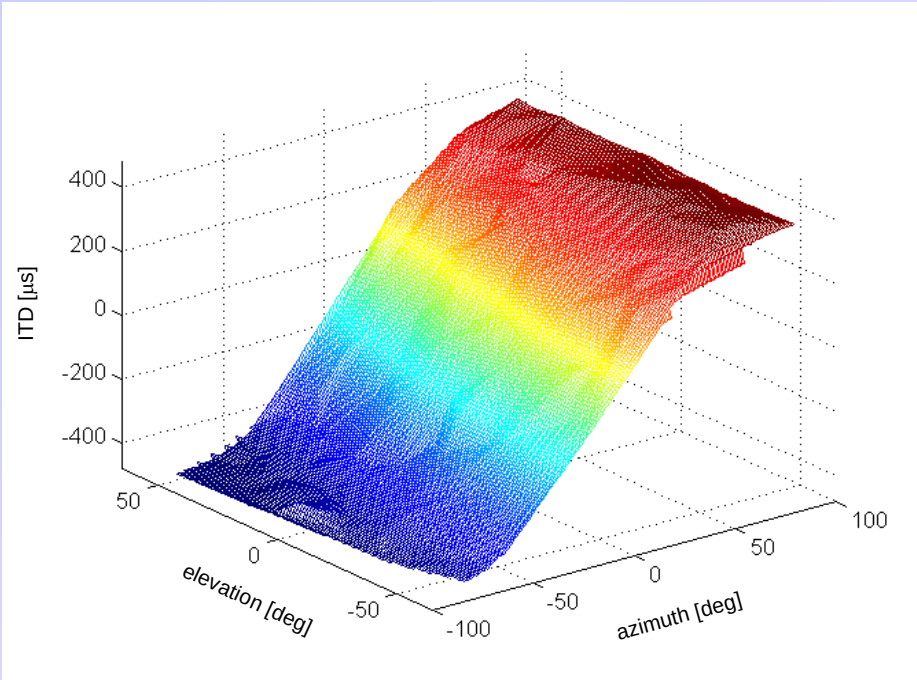
- Generalized correlation method (Knapp 1976)

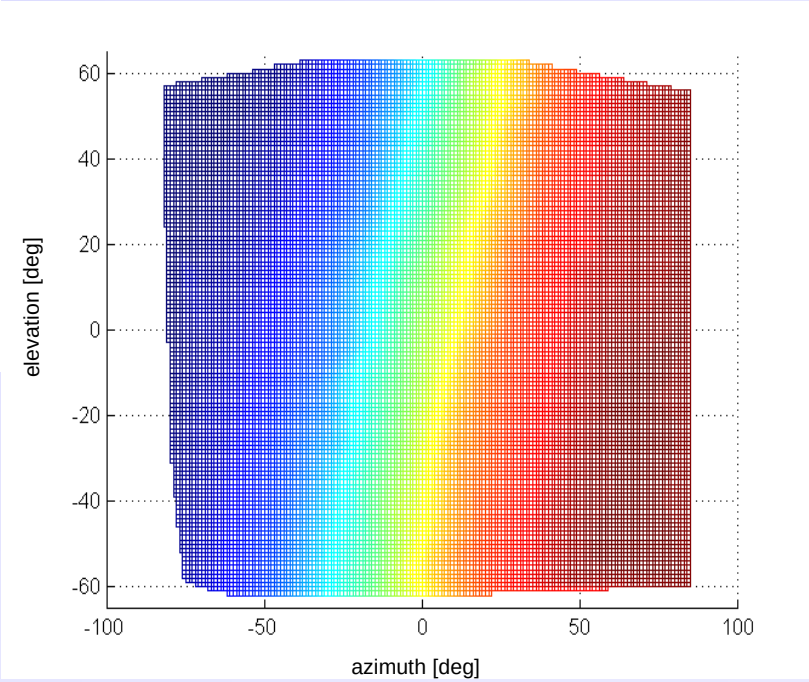


$$R_{y_r y_l}(\tau) = \frac{1}{T-\tau}\int_{-T/2}^{T/2-\tau} y_r(t+\tau)\, y_l(t)\, dt$$



Spatial variation of the ITD



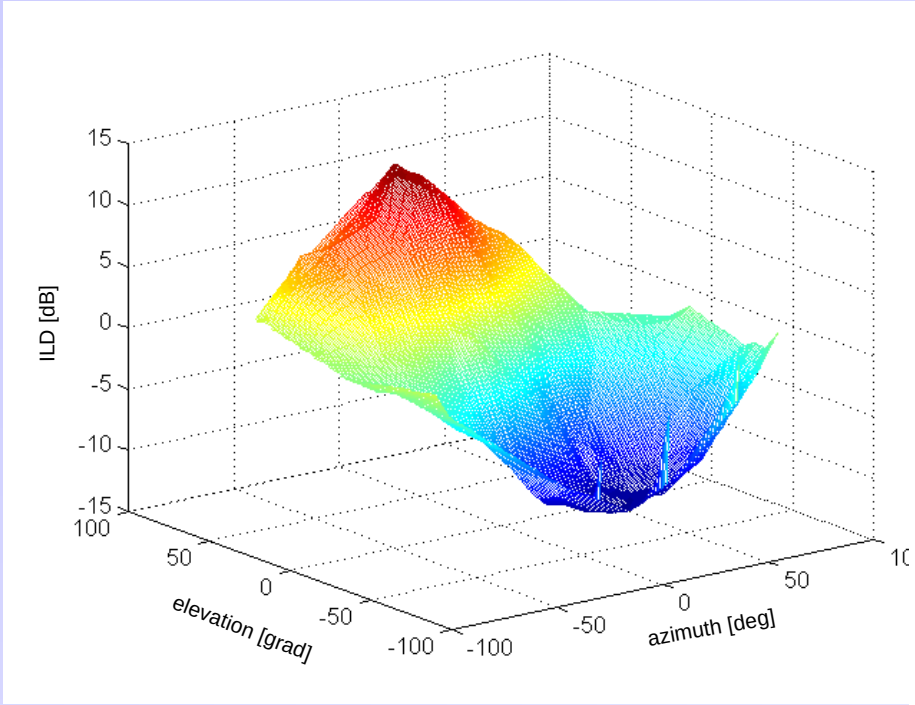


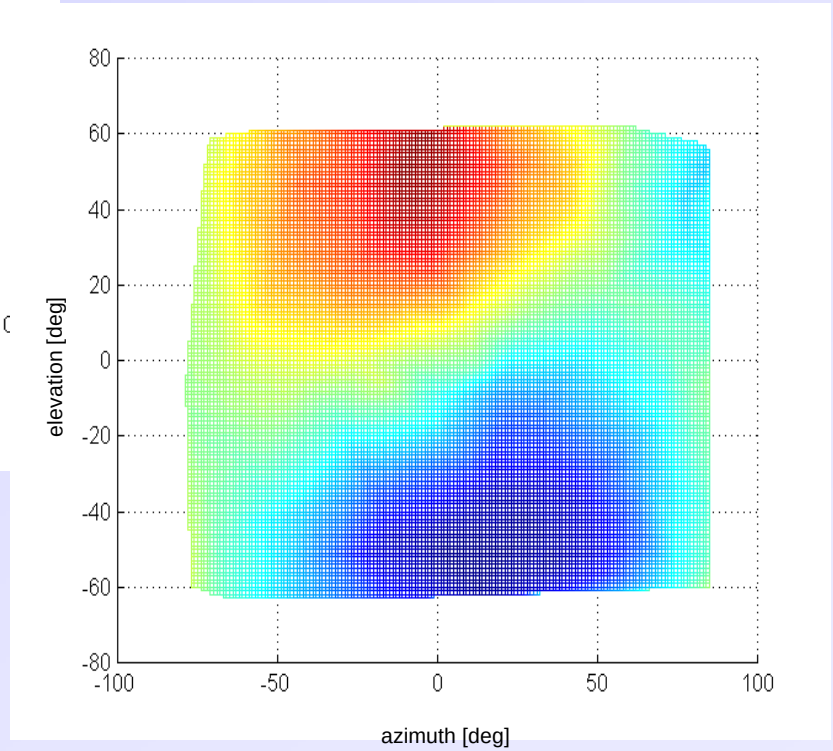
Computation of the ILD

- Ear lobes – directionally dependent response
- Band pass filter (3-10 kHz)

$$ILD = 10 \cdot \log \frac{\int S_r(f)df}{\int S_l(f)df}$$

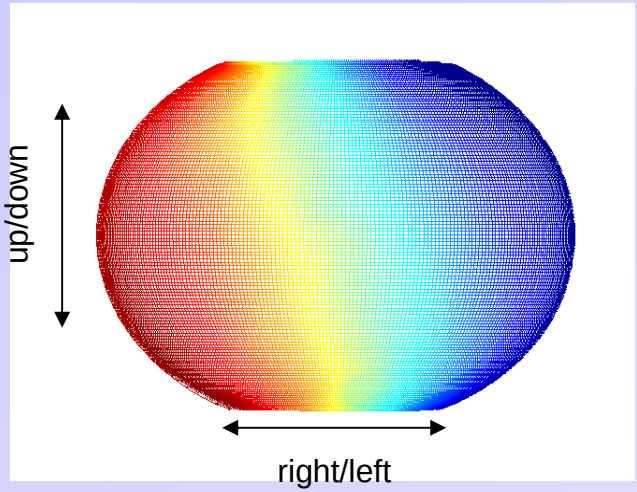
Spatial variation of the ILD



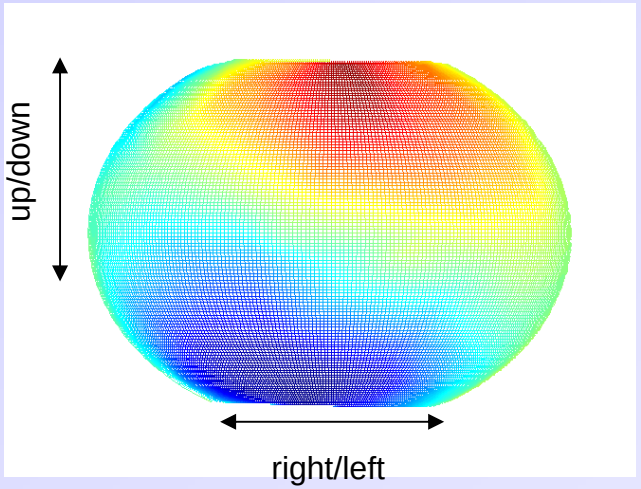


Babybot vs Barn Owl

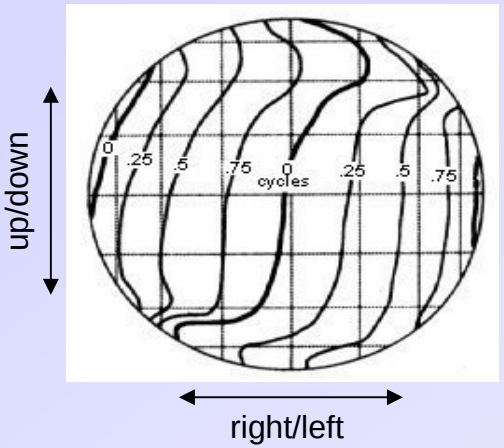
ITD (babybot, white noise)



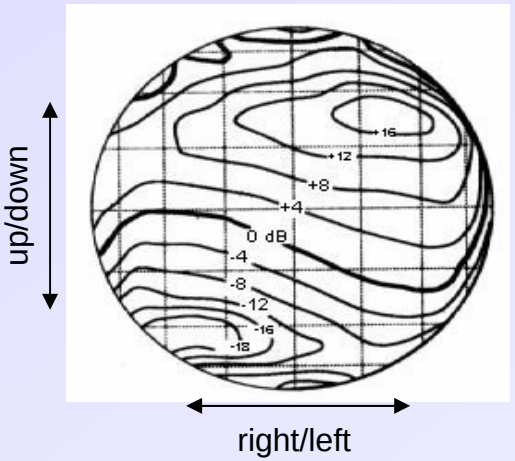
ILD (babybot, white noise)



IPD (barn owl, at 6 kHz)



ILD (barn owl, at 6 kHz)



LIRA-Lab

Gaze control

- Convert sensory information (i.e. auditory percept) into a sequence of motor commands to fixate the target
- Detect and fixate the target in a reasonable amount of time (<200ms)

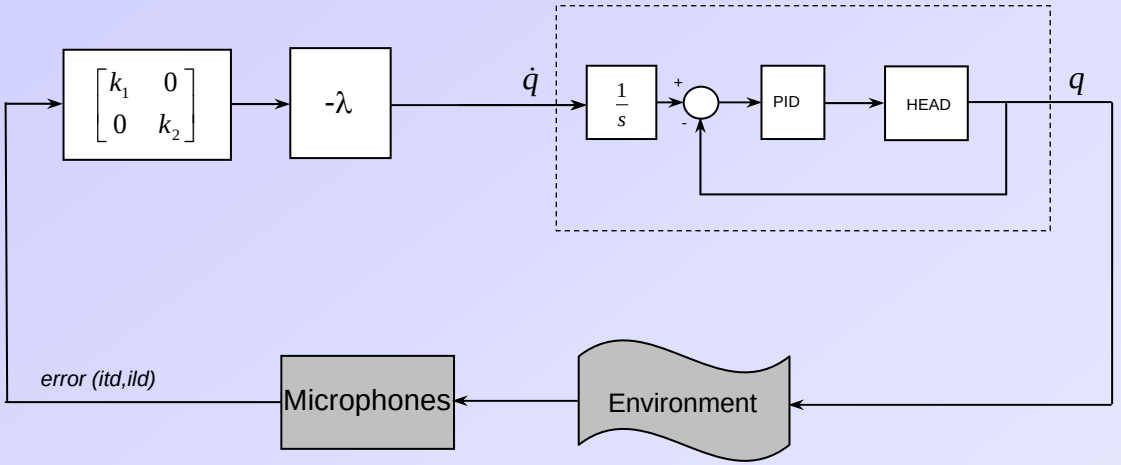
Control of the neck

- 2 dof only
- two kind of controllers:

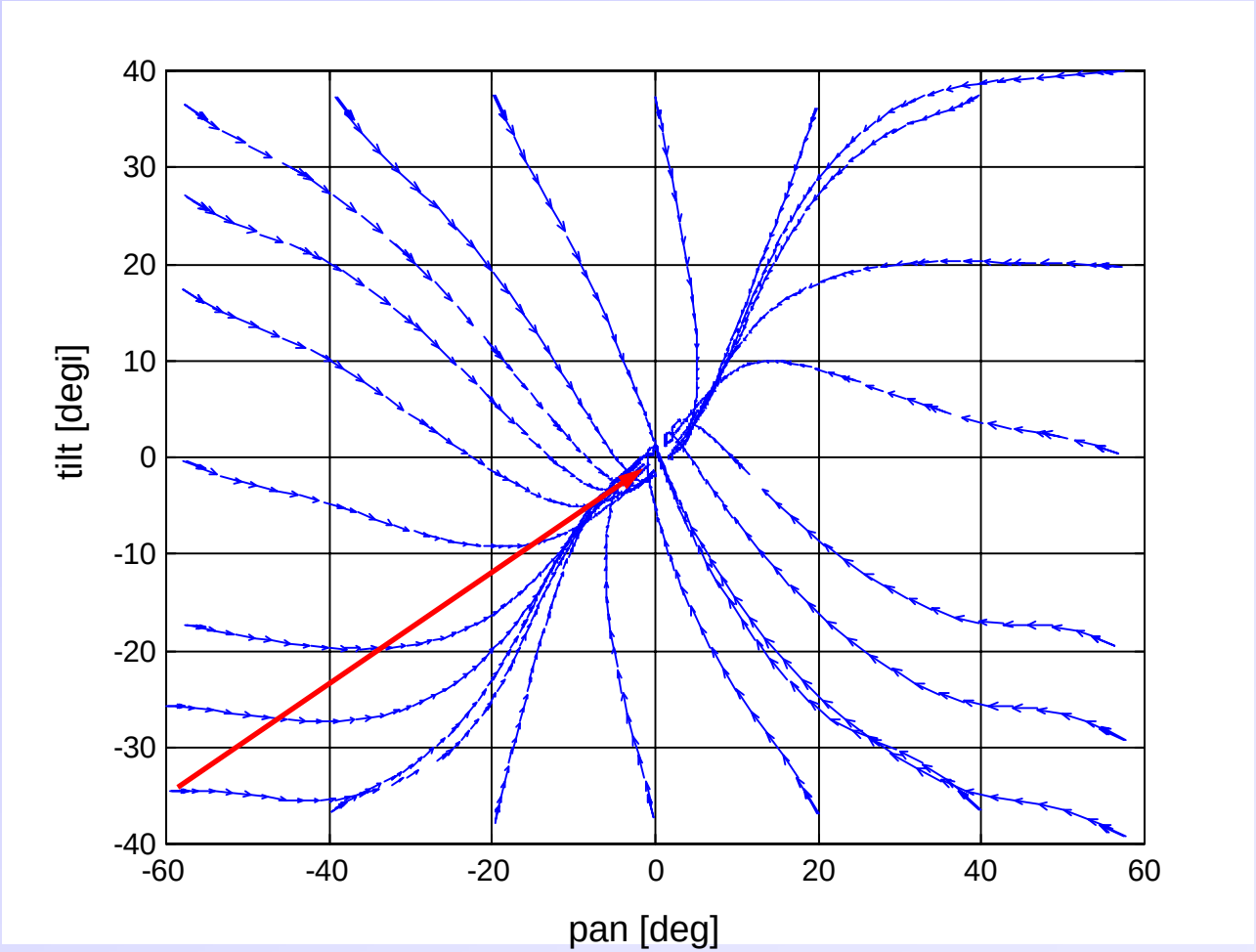
→ closed loop – whenever continuous information is available: smooth tracking of a target (no learning)

→ open loop – otherwise: a non-linear computation is necessary to convert the sensory signal into a motor command (learning)

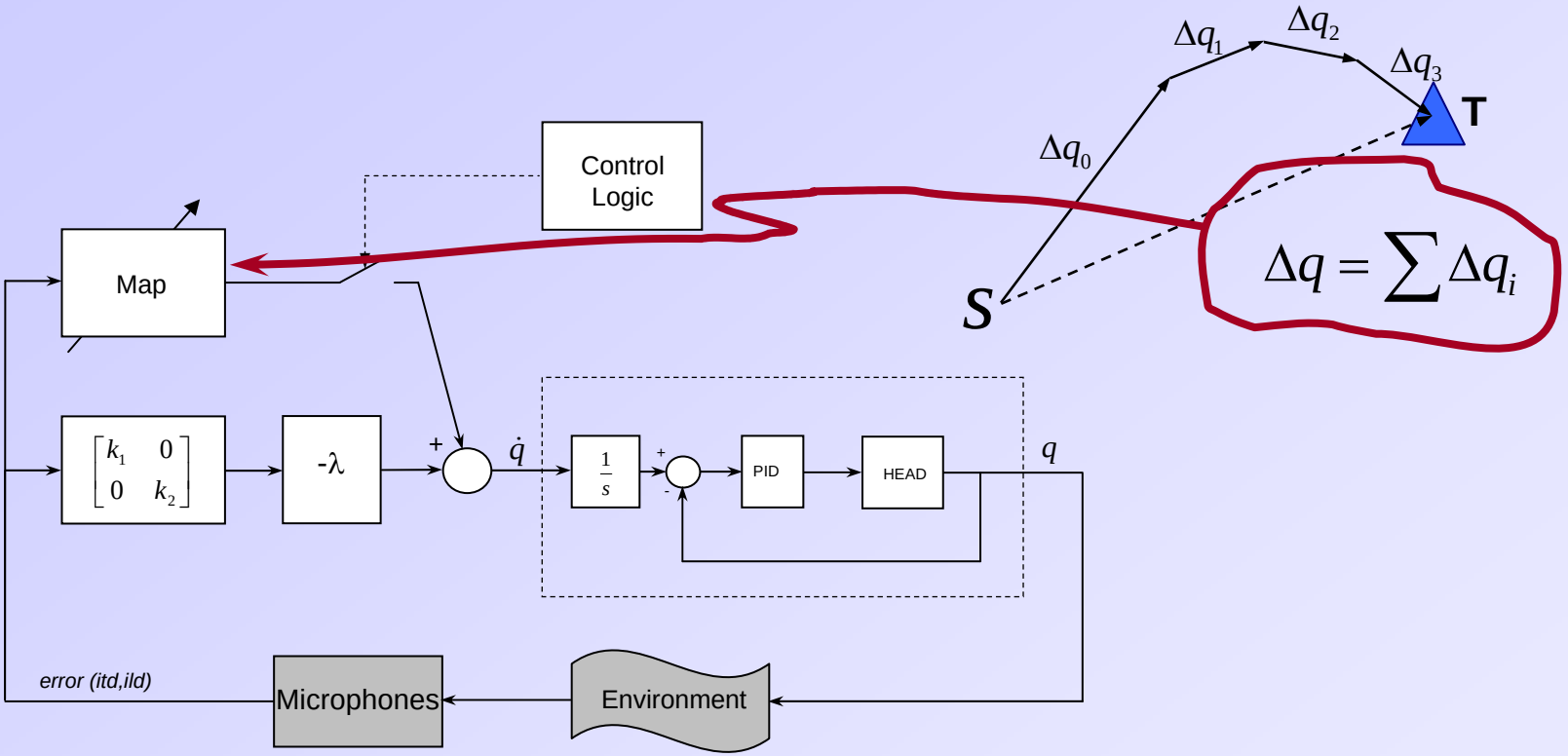
Control schema (1)
closed loop



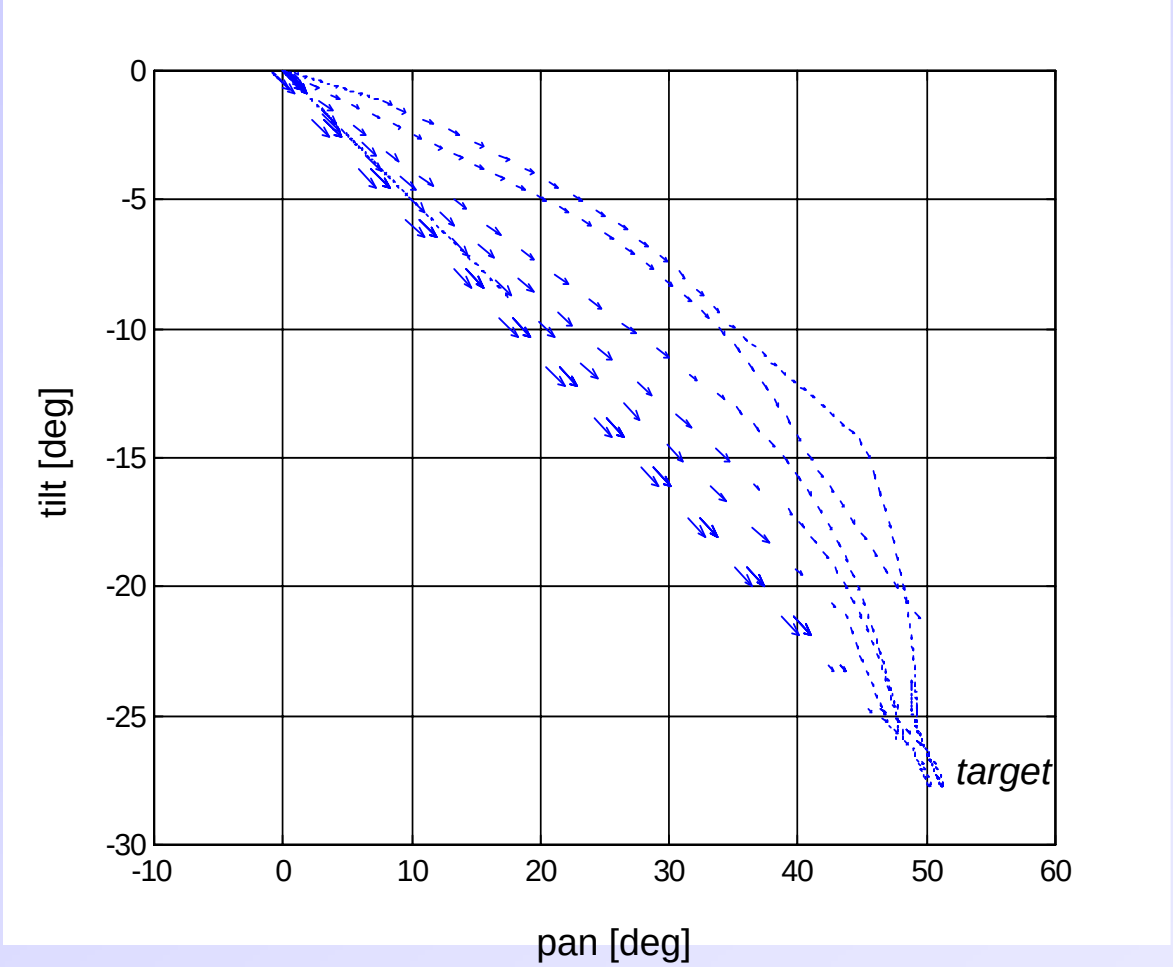
Closed loop trajectories



Control schema (2)

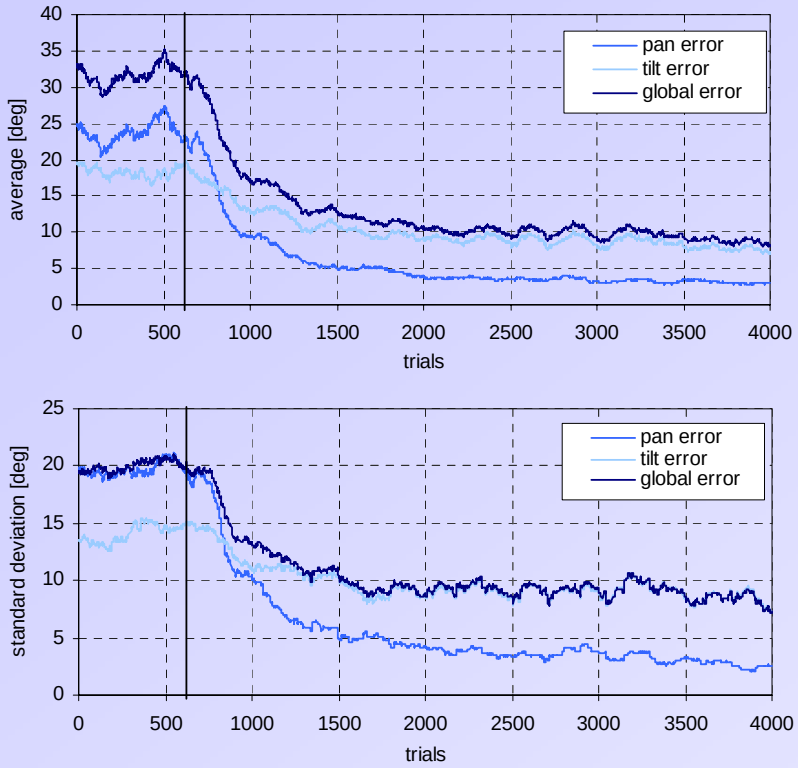


Learning (1)

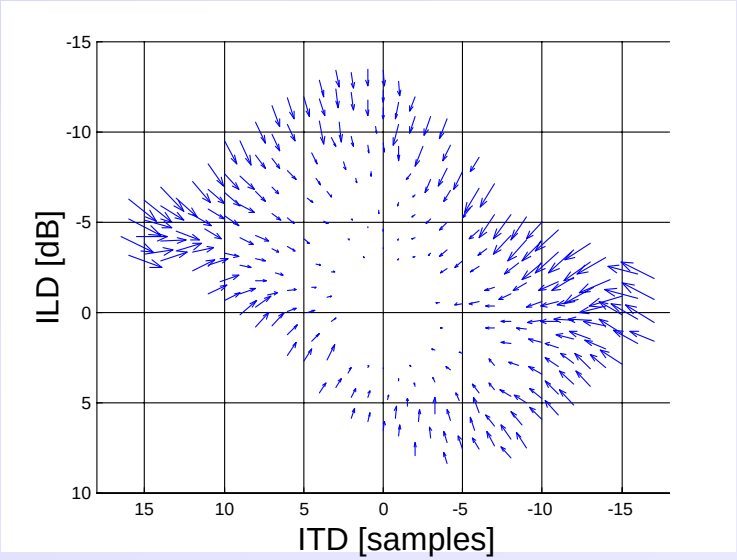


LIRA-Lab

Learning (2)

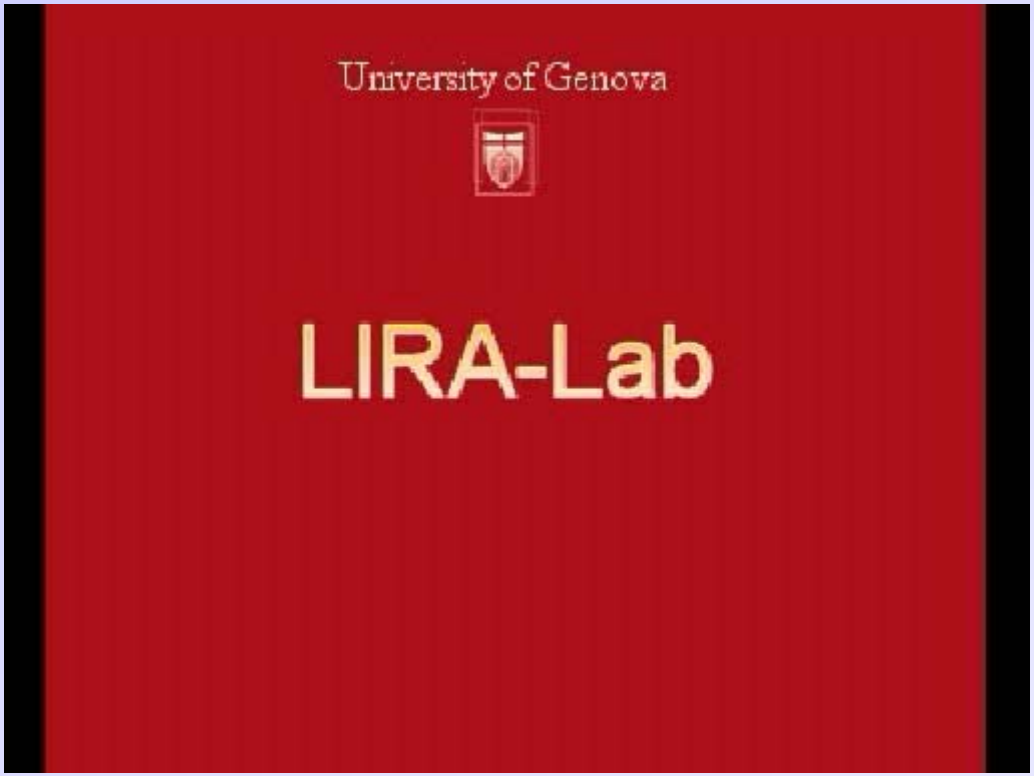


Map
(lookup table)



LIRA-Lab

Clips (1)



Clips (2)