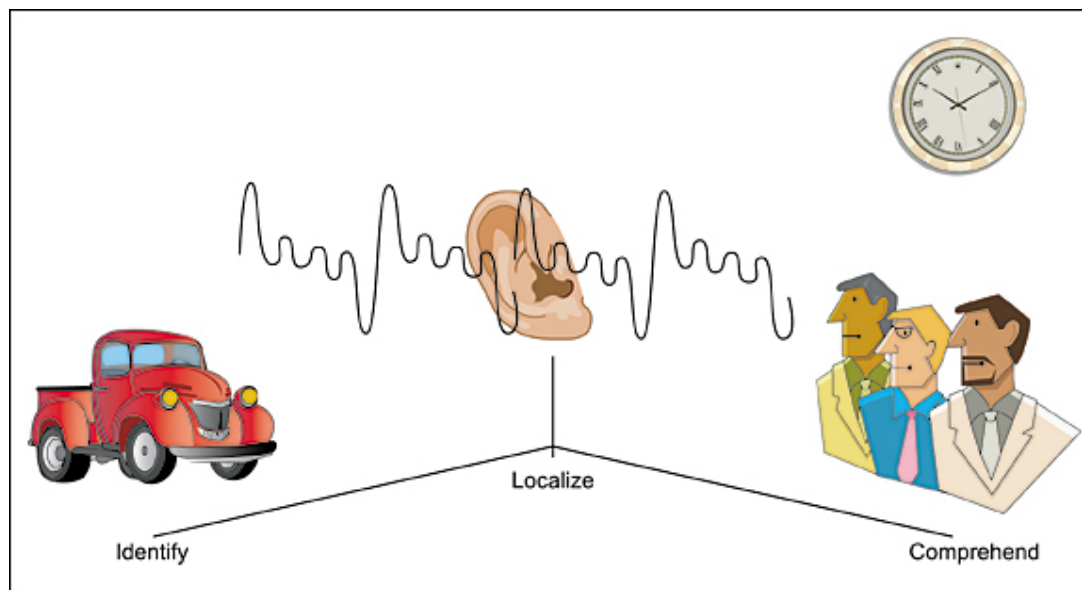


# Functions of Hearing



- But how do we know what sounds belong to what source, if more than one sound is present?
- Imagine identifying all shipping traffic from the motion of two buoys...

*How do we analyze sound, and what are the underlying neural mechanisms?*

# How can we study hearing?

- Physics (Acoustics)
- Anatomy and Physiology
- Psychology
- Psychophysics: Establishing a quantitative relationship between physical and psychological variables (Fechner, 1801-1887).

## Physical

*Sound*

Intensity

Frequency

Spectral distribution

Temporal characteristics

## Psychological

*Auditory sensation*

Loudness

Pitch

Timbre

# Subjective and objective variables

- Subjective measures
  - Loudness estimation, pitch matching, judgments of “sound quality”, etc.
  - Require introspection
  - Subject to non-sensory biases
- Objective measures
  - Stimulus detection, discrimination
  - A measure of performance: There must be a correct answer.
  - Effects of bias can be separated from sensitivity using *Signal Detection Theory*.

# Frequency Selectivity in Hearing

Any periodic waveform can be described in terms of a sum of simple sinusoids (Fourier).

The ear operates in a similar manner: Sound is broken down into constituent frequency components.

Helmholtz (1863) confirmed that it is possible to “hear out” individual sinusoidal components within a complex tone.

[Compare with vision.]

## Demonstration I: Canceled harmonics

*This is an example of synthetic and analytic listening. At first the complex is heard as a whole with a single pitch. Then, individual harmonics are emphasized by gating them on and off.*

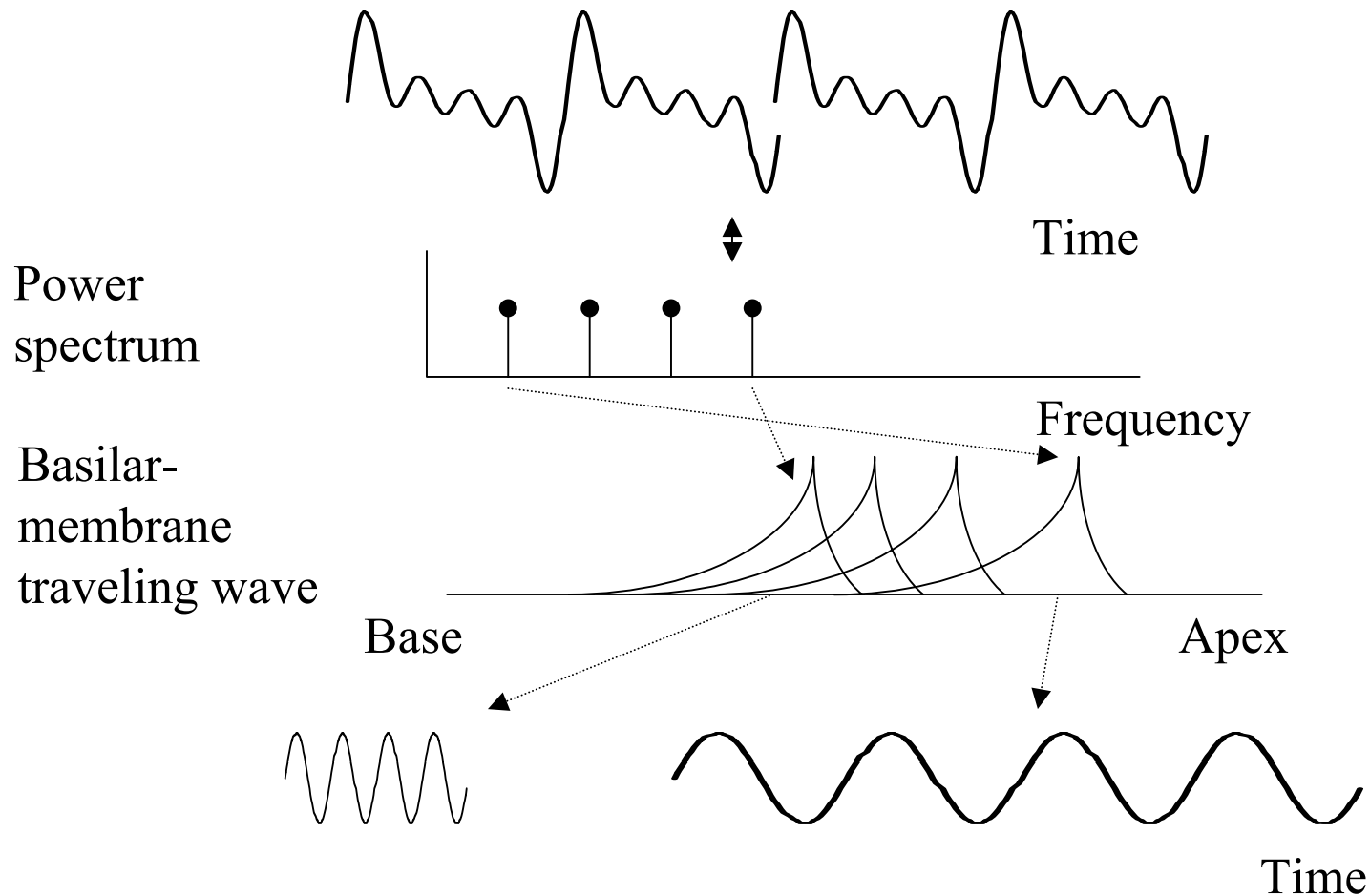
Frequency differences play a major role in the perceptual organization of concurrent and consecutive sounds.

- Demonstration II: Hear out a melody in the presence of distractors

**M E L O D Y**  
**D I S T R A C T O R S**

- Demonstration III: East African xylophone music.  
(Note that the pitches of both xylophones remain the same after filtering.)

Frequency-to-place mapping in the cochlea enables the separation of different frequency components. [Cochlear traveling wave – von Békésy (1960).]



# Masking

- Masking is an everyday phenomenon which occurs when frequency selectivity fails, and we are no longer able to resolve, or hear out, one stimulus (the signal) in the presence of another (the masker).
- This phenomenon can be used to probe the limits of frequency and intensity resolution, using objective measures.

# Intensity Coding and Loudness

Hearing occurs over an impressive range of frequencies and levels:

20 – 20,000 Hz (i.e., 10 octaves) for young, normal-hearing listeners

[Compare this with sensitivity of less than 1 octave in the electromagnetic spectrum (light).]

Dynamic Range of Hearing:

0.00002 Pa (0 dB SPL) – Absolute threshold

20 Pa (120 dB SPL) – Feeling (pain) threshold

Recovery from stimulation usually occurs within 0.2 seconds.

[Compare this with up to 20 minutes in vision.]



# **Theme 1: Masking and nonlinearity**

How is sound transformed in the cochlea?

How can we measure frequency selectivity?

What is the relationship between frequency selectivity measured physiologically and our own abilities, as measured in psychoacoustic tests?

What are neural mechanisms underlying masking?

## **Theme 2: Cellular Mechanisms in the Cochlear Nucleus**

- Neural coding beyond the auditory nerve not well established, but vital for an understanding of perception. (Auditory psychophysics tended to obsess on cochlear mechanisms – best understood.)
- Progress can be made on many fronts: Anatomy, in vivo and in vitro physiology, modeling and perceptual studies.

This theme looks at neural processing in the CN and its possible functions.

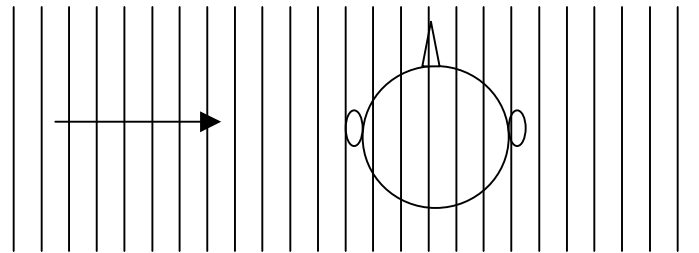
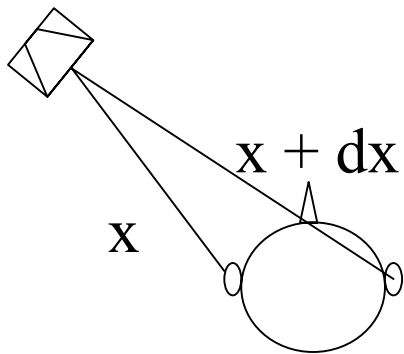
# Spatial Hearing

Two ears give us the potential to compare two different acoustic waveforms.

This comparison allows us to localize sounds in space, often with remarkable accuracy.

Differences between the ears:

- Interaural time differences (ITDs)
- Interaural level differences (ILDs)



## **Theme 3: Binaural interactions**

How are level and timing differences used to create the perception of source location?

How are neurons able to code differences as small as  $10\ \mu\text{s}$  in the timing between the two ears?

How do binaural cues help us to cope in a noisy environment?

# Pitch and Temporal Coding

Most periodic sounds (and some aperiodic ones) elicit an sensation of pitch.

Pitch forms the basis of most music and is also an important aspect of speech.

The relationship between pitch and frequency is relatively simple for pure tones (sinusoids). What about complex stimuli with many frequencies?

Demonstration IV: Spectral and “virtual” pitch

# **Theme 4: Pitch and Temporal Coding**

How are temporal patterns coded in the auditory system?

How is pitch extracted?

How can we explain the phenomenon of the “missing fundamental”?

What role does pitch play in the perceptual organization of sounds?

# Theme 5: Neural Maps and Plasticity

- How is sound coded in higher levels of the auditory system – are there maps for higher-order percepts, such as pitch, loudness, and spatial location?
- To what extent can the auditory system be reorganized to cope with lesions?
- What techniques are available to study cortical processing in humans and animals?

# Speech Coding and Hearing Impairment

Speech is a very robust stimulus: It must be very severely degraded for intelligibility to suffer.

Even listeners with moderate-to-severe hearing loss can generally understand speech in a quiet environment.

Hearing impairment often leads to difficulties understanding speech in the presence of competing sounds.



# Effects of Cochlear Hearing Loss

- Elevated absolute thresholds
- Normal uncomfortable loudness levels, leading to *loudness recruitment*
- Reduced frequency selectivity
- Poorer temporal resolution in some tasks

Demonstration V: Simulated effects of loudness recruitment and impaired frequency selectivity on speech perception.