Chapter 6: Fundamentals of Psychoacoustics

- Psychoacoustics = auditory psychophysics
- Sound events vs. auditory events
  - Sound stimuli types, psychophysical experiments
  - Psychophysical functions
- Basic phenomena and concepts
  - Masking effect
    - Spectral masking, temporal masking
  - Pitch perception and pitch scales
    - Different pitch phenomena and scales
  - Loudness formation
    - Static and dynamic loudness
  - Timbre
    - as a multidimensional perceptual attribute
  - Subjective duration of sound

Psychophysical experimentation

- Sound events ($s_i$) = physical (objective) events
- Auditory events ($h_i$) = subject’s internal events
  - Need to be studied indirectly from reactions ($b_i$)
- Psychophysical function $h=f(s)$
- Reaction function $b=f(h)$
Sound events: Stimulus signals

- Elementary sounds
  - Sinusoidal tones
  - Amplitude- and frequency-modulated tones
  - Sinusoidal bursts
  - Sine-wave sweeps, chirps, and warble tones
  - Single impulses and pulses, pulse trains
  - Noise (white, pink, uniform masking noise)
  - Modulated noise, noise bursts
  - Tone combinations (consisting of partials)
- Complex sounds
  - Combination tones, noise, and pulses
  - Speech sounds (natural, synthetic)
  - Musical sounds (natural, synthetic)
  - Reverberant sounds
  - Environmental sounds (nature, man-made noise)

Sound generation and experiment environment

- Reproduction techniques
  - Natural acoustic sounds (repeatability problems)
  - Loudspeaker reproduction
  - Headphone reproduction
- Reproduction environment
  - Not critical in headphone reproduction
  - Anechoic chamber (free field)
    - Room effects minimized
    - Not a natural environment
  - Listening room
    - Carefully designed, relatively normal acoustics
  - Reverberation chamber
    - Special experiments with diffuse sound field

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Psychophysical functions

- Sound event property to auditory event property mapping

\[ h = a \log(s) \] \hspace{1cm} \text{Weber, Weber-Fechner law}

\[ h = c s^k \] \hspace{1cm} \text{(e.g., loudness)}

Experimental concepts: Thresholds

- Threshold values
  - Absolute thresholds (e.g., threshold of hearing)
  - Difference thresholds (just noticeable difference, JND)

Example: Threshold of perception:
- 50%, 75%, etc. thresholds
**Experimental concepts**

- Comparison of percepts
  - Magnitude estimation
  - Magnitude production
- Probe tone method
  - Generation of a probe tone to make test tone audible/noticeable
  - Modulation, canceling, interference
- Classification and scaling of percepts
  - Nominal scale (rough, sharp, reverberant, ...)
  - Ordinal scale (percepts have ordering)
  - Interval scale (numeric scale, no zero point defined)
  - Ratio scale (numeric scale, zero point defined)
- Multidimensional scaling
  - Semantic differentials: low – high, dull – sharp, ...

**Psychoacoustic experiments**

- Description of auditory events
  - Oral or written description
- Method of adjustment
  - Adjusting a stimulus to correspond to a reference
- Selection methods
  - Forced choice methods (select one!):
    - Two alternative forced choice (TAPC, 2AFC)
- Method of tracking
  - Tracking with varying stimulus
    - Bekesy audiometry
- Bracketing method
  - Descending and ascending bracketing
- Yes/no answering
- Reaction time measurement
  - Indicates the difficulty of decision task
Békésy audiometry

- Slow frequency sweep and level tracking

Typical psychoacoustical test types

- AB test
  - Set in preference order / select one
  - AB hidden reference (one must be recognized)
- AB scale test
  - As AB but assign numeric values for A and B
- ABC test
  - A is fixed reference (anchor point) for assigning values for B and C
- ABX test
  - Which one, A or B, is equal to X?
- TAFC (2AFC)
  - Two alternative forced choice

- Formation of a listening test panel
- Formation of a description language
Masking effect

- "A loud sound makes a weaker sound imperceptible"
- Categories and aspects of masking
  - Frequency masking
  - Temporal masking
  - Time-frequency masking
  - Frequency selectivity of the auditory system
  - Psychophysical tuning curves
  - Critical band
    - Bark bandwidth
    - ERB bandwidth

- Masking tone and test tone

Frequency masking

- Masking by white noise

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Frequency masking

• Masking by narrow-band noise (0.25, 1, 4 kHz)

Frequency masking

• Frequency masking as a function of masker level
Frequency masking

- Frequency masking by lowpass and highpass noise

Frequency masking

- Frequency masking by 1 kHz sinusoidal signal
Frequency masking

- Frequency masking by a complex tone (harmonic complex)

Temporal masking

- Masking before and after a noise signal
**Temporal masking**

- Beginning of postmasking

![Graph showing the beginning of postmasking](image)

- Postmasking as a function of time
  - For 200 ms long masker
  - For 5 ms long masker

![Graph showing postmasking as a function of time](image)
**Time-frequency masking**

- Masking of a tone burst in time and frequency by a time-frequency block of noise

**Temporal masking**

- Masking due to an impulse train
**Frequency selectivity of hearing**

- Masking curves tell much about auditory selectivity
- Psychophysical tuning curves match with physiological curves

![Graph showing masking curves](image)

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**Critical band experiment**

- Experiment: loudness vs. bandwidth of noise

![Diagram for critical band experiment](image)

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Critical band

- Loudness vs. bandwidth of noise
  - Loudness increases when bandwidth exceeds a critical band

![Critical band graph](image1)

Critical band (Bark band) vs. frequency

- Critical band (Bark band) $\Delta f_G$ vs. mid frequency
- Ref: just noticeable tone frequency change vs. frequency

![Critical band (Bark band) vs. frequency graph](image2)
**Critical band:** 24 Bark bands (Zwicker)

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**ERB band experiment**

- **ERB = Equivalent Rectangular Bandwidth**
- Loudness of a tone is measured as a function of frequency gap in masking noise around the test tone
- ERB band is narrower than Bark band, especially at low frequencies
Pitch scales

- Pitch = subjective measure of tone height
- Mel scale
  \[ m = 2595 \log_{10}(1 + f/700) \] or
  \[ m = 1000 \log_2(1 + f/1000) \]
- Bark scale
  \[ z/Bark = 13 \arctan(0,76 f/\text{kHz}) + 3.5 \arctan(f/7,5\text{kHz})^2 \]
  \[ \Delta f_{EB}/\text{Hz} = 25 + 75 [1 + 1,4(f_c/\text{kHz})^{0.69}] \]
  \[ z/Bark = 7 \ln \left( f/650 \text{Hz} + \sqrt{1 + (f/650 \text{Hz})^2} \right) \]
  Inverse function: \[ f/\text{Hz} = 650 \sinh(z/7 \text{ Bark}) \]
- ERB scale
  \[ ERB = 24,7 + 0,108 f_c \]
  \[ R_{ERB} = 21,3 \log_{10}(1 + f/228,7 \text{ Hz}) \]
  Inverse: \[ f/\text{Hz} = 228,7 (10^{R_{ERB}/21,3} - 1) \]

Logarithmic pitch scale

- Logarithmic scale used in music and audio
- Frequency ratios more important than absolute frequencies
- Octave and ratios of small integers important
Comparison of pitch scales

• Pitch scales are related to place coding on the basilar membrane, although they are measured by psychoacoustic experiments

Comparison (log reference) of:
  – logarithmic scale
  – ERB scale
  – Bark scale
  – linear scale
Comparison of pitch scales

• Comparison (linear reference) of:
  – logarithmic scale
  – ERB scale
  – Bark scale
  – linear scale

Pitch

• Continues in file KA6b