Temporal resolution

Modulating a sinusoid

carrier
(fine structure)

modulator
(envelope)

= amplitude-modulated wave

Domain of temporal resolution

- Fine structure and envelope
  - fine structure – relatively fast – reflects spectral components of sounds in the sound waveform, and periodicity (in some definitions)
  - envelope is the slower stuff
  - think of all waves as being made by multiplying an envelope against a carrier

Fine structure and envelope

Envelope – reflects changing amplitude of signal e.g., over multiple cycles for periodic sounds
Caveat about ‘temporal resolution’

• Typically defined as reflecting perception of variations over time in ...
  – *envelope* (and there are different ways to define envelope)
  – rather than *fine-structure*

• But at least in theory, could concern temporal variations, for example, in frequency of a sinusoid

Both kinds of temporal features preserved in the auditory nerve

Joris et al. 2004

Limits to temporal coding of fine structure

• Frequency coding by phase-locking
  – Declines in precision from 1.5 kHz (700 µs), absent above 5 kHz (200 µs)

Temporal Resolution for envelope most often tested in two ways

• Both involve *modulation* of the amplitude of waveforms ...
  – Gap detection
  – Amplitude modulation
  – but this almost always results in spectral changes.
  – In other words, you usually cannot change the temporal (envelope) properties of a signal without also changing its spectrum
  – leading to a difficulty of interpretation unless special measures are taken
The need to eliminate spectral cues

- Modulating signals in envelope usually results in spectral changes (broadening, known as *splatter*)
  - e.g., effect of 10 ms gap in spectrum of 1 kHz sinusoid
- Need to avoid listeners hearing spectral changes

### Effects of AM on spectrum

- **100 Hz AM of 1 kHz sinusoid**
  - Spectral sidebands at 900 and 1100 Hz
- **100 Hz AM white noise**
  - Spectrum remains flat

### Three possibilities

- Modulate wideband noise stimuli
- Minimise audibility of spectral changes by
  - keeping any sidebands in the same auditory filter as the original signal – allows use of low AM rates with sine carriers
  - and/or adding masking noise to make spectral changes inaudible
- Modulate wideband noise stimuli and filter into bands afterwards
  - but can change extent/form of modulation

### Gap thresholds

- Pick the sound with the gap – vary the gap duration to find threshold
- Thresholds for wide-band noise are around 3 ms
Effects of noise spectrum on gap detection

Wider noise bandwidth gives smaller gap thresholds.

Frequency location of noise (UCF parameter) has little effect. May be because wide bandwidth allows listeners access to information from large numbers of filter channels.

AM detection - TMTF

- TMTF – temporal modulation transfer function
- Analogous to an ordinary transfer function or frequency response
  - dealing with frequencies of modulation rather than frequencies of a sinusoidal waveform directly
- Analytic approach to temporal resolution
  - Considers temporal modulation across different frequencies of sinusoidal AM
  - As for gap thresholds, wide-band noise is an ideal signal because of the lack of spectral changes.
  - Fixed modulation rate – vary depth of modulation to determine minimum detectable depth

10 Hz modulation rate

- Thresholds expressed in dB as $20 \log(m)$ where $m$ is modulation index

TMTF data

- $m = 1$ gives 0 dB
- $m = 0.05$ gives -26 dB

The function looks very much like a low-pass filter (here inverted)

Upper limit of amplitude modulation detection between 500 and 1000 Hz
Translating to the clinic: Auditory neuropathy

Temporal resolution in Auditory Neuropathy (AN)

- AN defined by intact OHCs and normal OAEs but lack of CAP and ABR responses.
- Near normal audiometric thresholds but often severe problems with speech perception
- Retro-cochlear impairment
- Likely to involve disruption of phase-locking in auditory nerve

Rance, McKay and Grayden, 2004 (Ear & Hearing)

- Compared children with normal hearing, SNHL, and AN
- Measured
  - Frequency selectivity (simple notched noise method)
  - Sinusoid frequency discrimination
  - TMTFs
  - CNC word phoneme recognition
Temporal resolution and temporal frequency coding seems impaired in AN

- And both correlate highly with speech scores
- While auditory filtering seems near-normal in many of the AN subjects

A model of temporal resolution – the temporal window

FIGURE 5.9 A block diagram of a model of temporal resolution.

Effects of temporal window on signals

FIGURE 5.11 Examples of the influence of the sliding temporal integrator on the envelopes of sounds. The panels on the left show inputs to the sliding temporal integrator. The panels on the right show the corresponding outputs.

Envelope in speech – one source of cues to consonants

Decision device looks at evidence of level changes at output – a model of within-channel temporal resolution
Key Points

- Measures of temporal resolution relate to signal envelopes.
- Measures must control spectral artefacts.
- Gap detection and TMTF main measures:
  - Both indicate limits in region of 1 to 3 ms in normal hearing.
- Temporal window model can account reasonably well for within-channel temporal resolution.