“Hearing aids in the noisy world: benefits and challenges"

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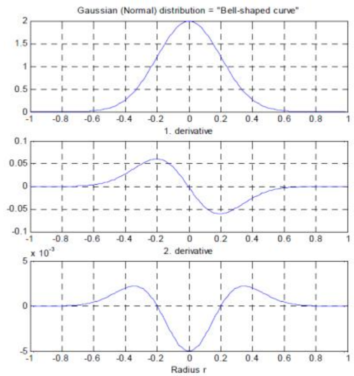
Motivation

We may not need to understand how the auditory system works so as to make an artificial replica of it.

But we do need to understand how the auditory system works so as to better understand the problem that needs to be solved & borrow from nature

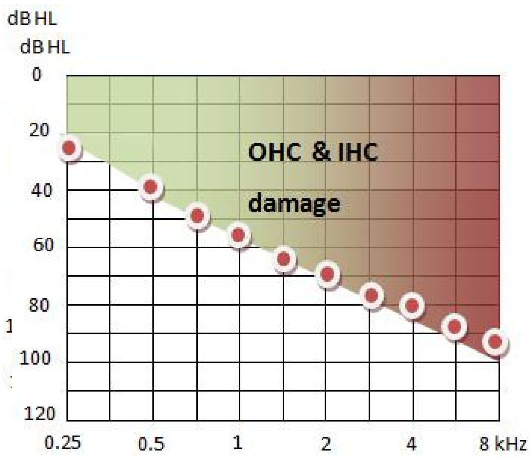


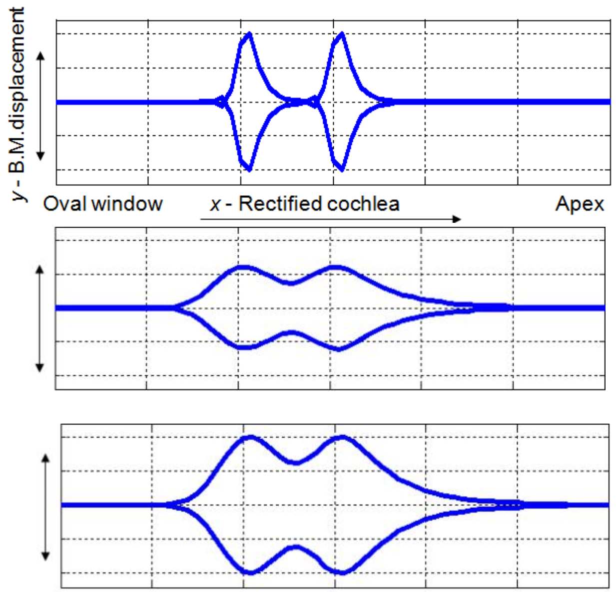
developer's perspective: solving the problems given the characteristics and constraints of the HA – specific implementation and functioning.

Content

- Some basic facts as to the problem of speech in noise (SiN) for hearing impaired (HI)
- The main hearing aid (HA) features influencing and influenced by noise
    - Directional microphone
    - Noise reduction
    - Compression
    - Classifier
- Developer’s questions
- Conclusion

Hypotheses about cochlear functions



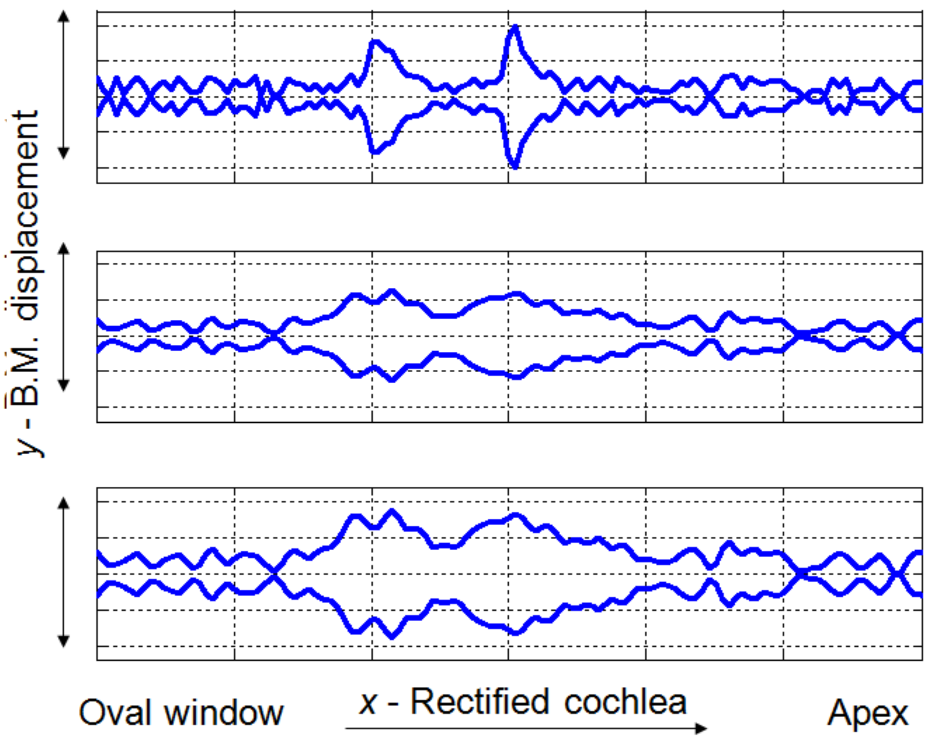


- displacement from 2 tones close in frequency.
- OHC damage only: smaller, rounder peaks from 2 tones close in frequency.
- HA: enlarges peaks but cannot sharpen (after Venema, 2008).

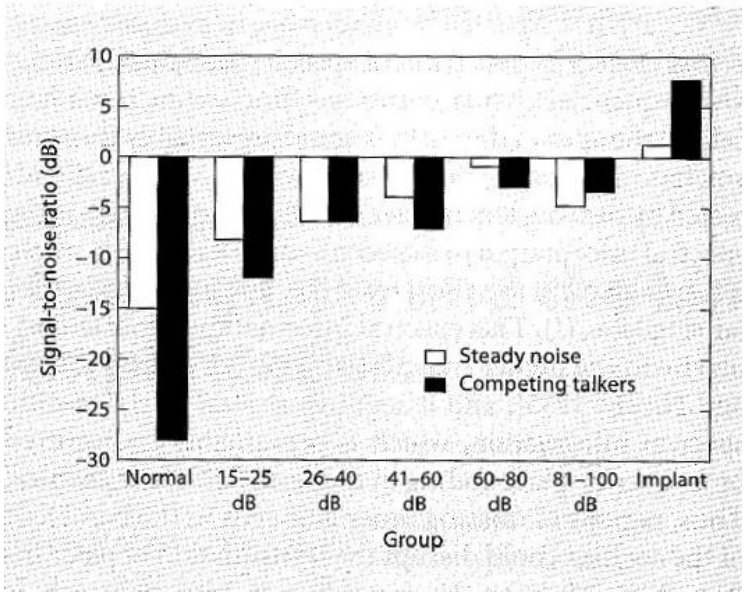
- The severity of the hair cell loss varies with frequency, the basal end of the cochlea being more prone to it.
- When HL exceeds 60 dB, at least some IHC loss can be assumed. Not even amplification can help here.

SiN: challenges for the hearing impaired

Simple amplification with HA does not work for all speech sounds & listening situations.



…and the problem is hearing loss dependent



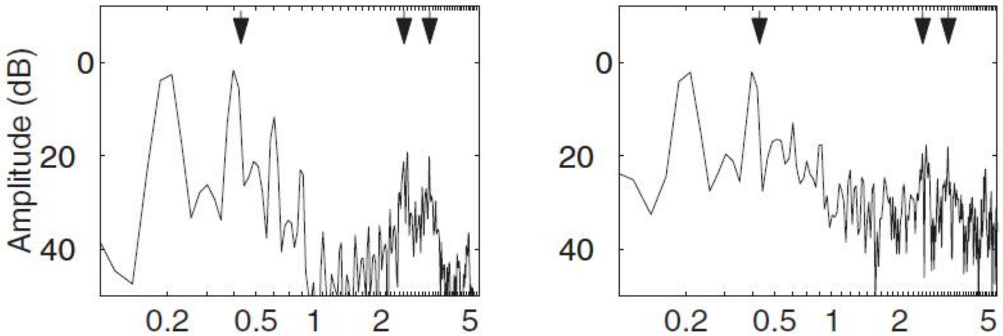
From Turner, 2006: SNR required for 50% correct understanding of spondee words for various listener groups (av. Hearing levels at 0.5,1 and 2 kHz). Speech was amplifed to audible levels for all subjects.

SiN: challenges for the HA

From the signal point of view:

Dubbelboer & Houtgast, 2007: “In order to improve speech intelligibility in noise one should know:

- how speech is physically changed
- which of these changes are most detrimental, and
- how the most detrimental changes can be counteracted, without introducing new distortions. “

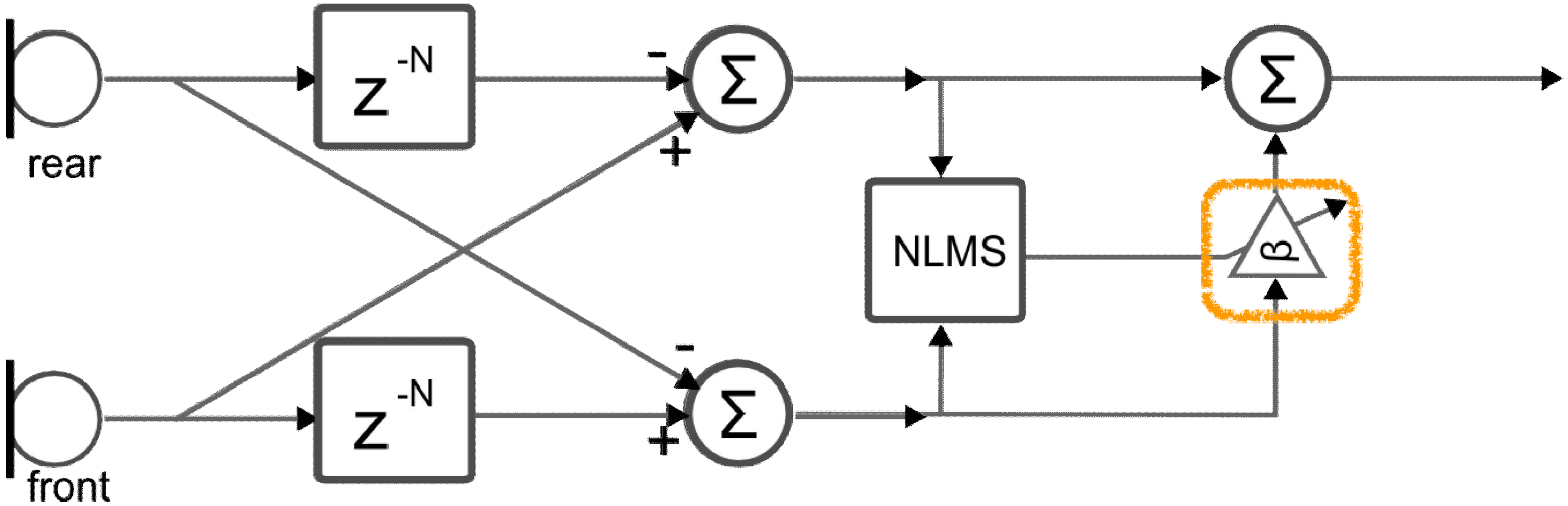


- Fourier transform of the vowel [i], first three formants are shown a) in quiet b) in pink noise at 6 dB SNR (from Assmann & Summerfield, 2003)

The goal of HA functioning in noise: estimate the type and the amount of noise and separate it from the speech signal.

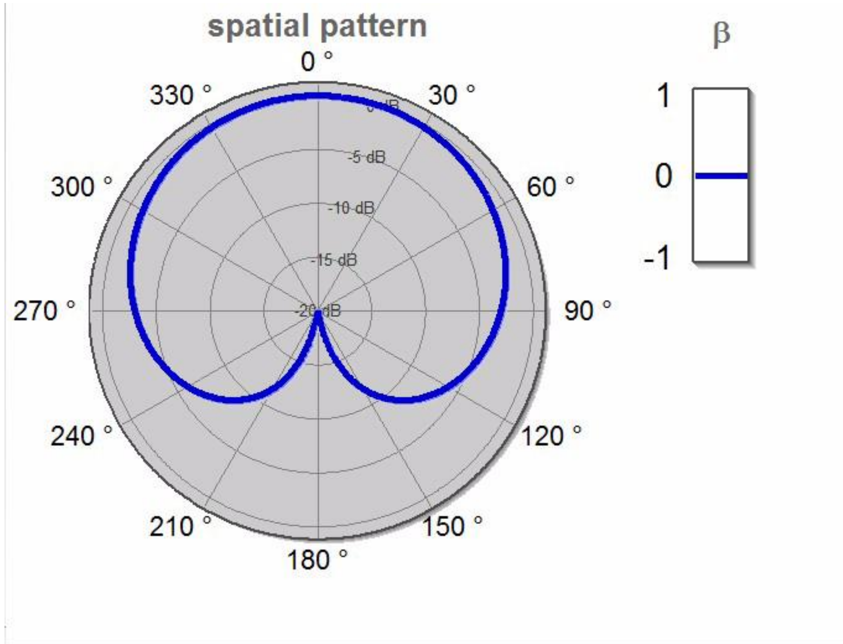
SiN with HA: Adaptive differential beam forming

Principle introduced by Elko and Pong (1995)



The adaptation parameter β is optimized to achieve a minimum output level of the beamformer.

SiN with HA: Adaptive differential beam forming



Free field, ideal directivity patterns.

The direction of the spatial notch is moving with the adaptation parameter β.

The adaption takes place across a number of independent frequency channels → precise frequency dependent head shadow effects compensation (Fischer et al.,2012)

By limiting β, one can control the directionality - an extension of Elko's principle enables stearing to the rear with β (Aubreville, 2013).*

Effect: Mapping the range of β from [-2;-1) to (-1;0] with flipping of beam pattern signals.*

β	1	0	-1	-2
direction	front	front	omni	rear
notch	+/- 90°	180°	---	0°

SiN with HA: Situation dependent activation of beam forming

Situation	Beamformer strength	Beam direction
Frontal speech in noise	**+++**	front
Speech in quiet	**+**	front
Speech from the side (e.g. car)	**o**	omni
Speech from the back (e.g. car)	**++**	back
Music	**o**	omni
Wind	**o**	omni (in low frequencies)

SiN with HA: Noise reduction

fan noise
microphone noise

street noise

noises with very slow modulation

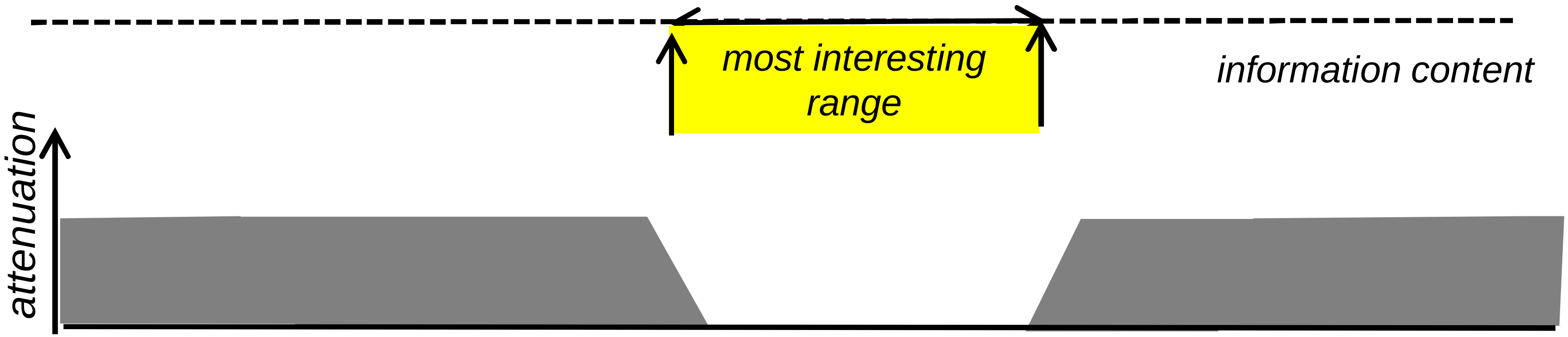
speech and
speech interferers

transient noises

impulse like noises
fast changes

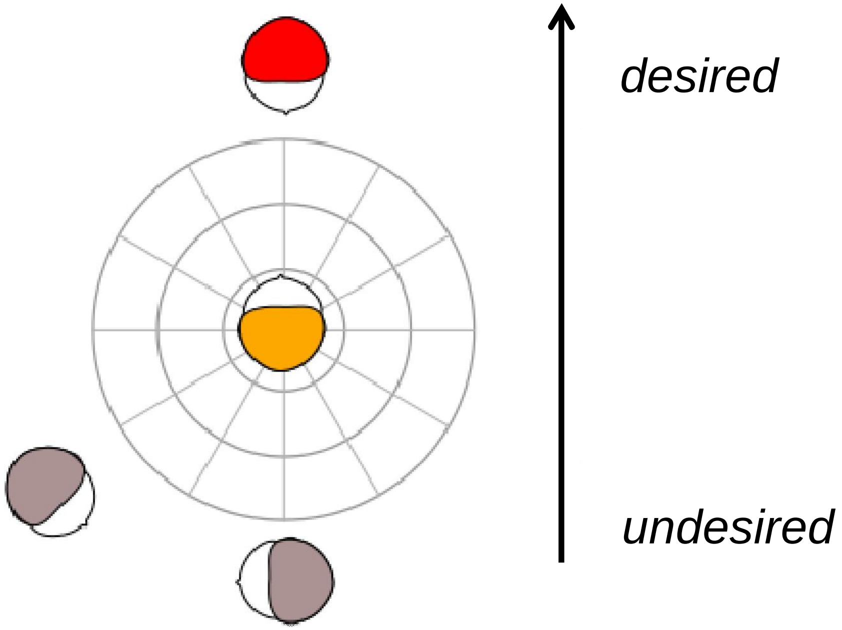
modulation analysis

information content



SiN with HA: Direction dependent noise reduction

What happens when the interfering signals have speech-like modulation properties?
We change the separation criterion to direction of arrival where signal coming from the front is regarded as a desired target signal and everything else is assumed to be ‚noise‘.

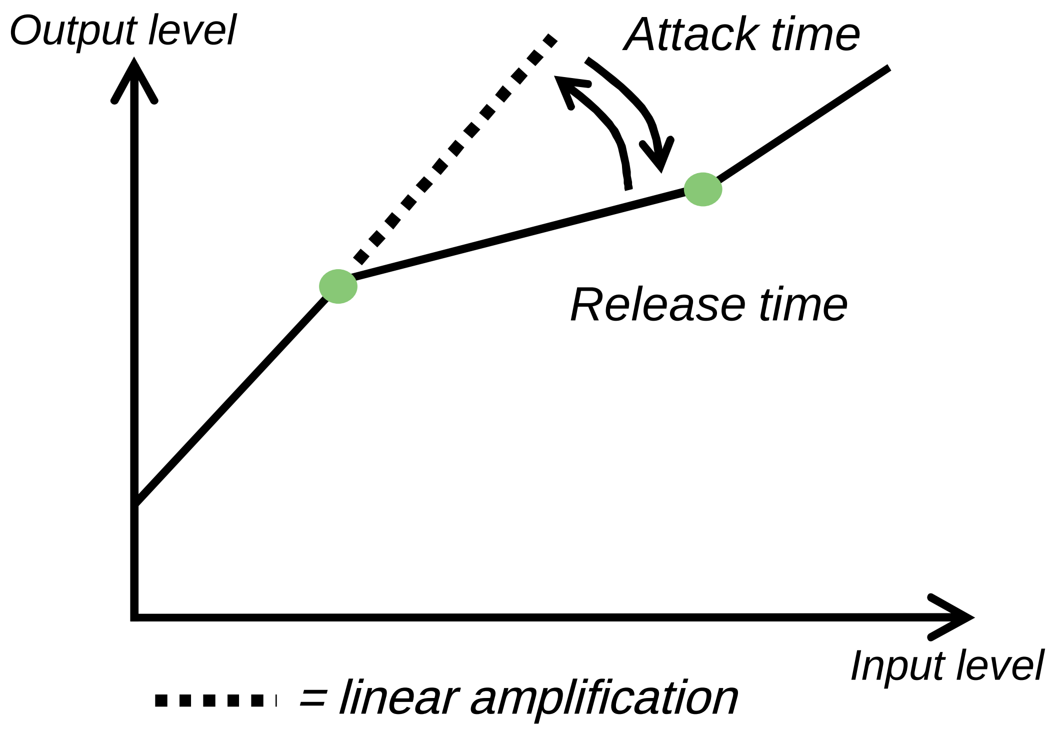


For details see (Fischer et al.,2012)

SiN with HA: Integrated noise reduction

Situation	Attenuation
Speech in quiet	None (classifier decision)
Speech in steady noise	Attenuate with care (speech modulation, direction dependent noise reduction possible)
Speech in babble noise	Attenuate with care (speech modulation, direction dependent noise reduction possible)
Music	None (classifier decision)
Steady noise	Modulation based attenuation
Transient noise	Modulation based attenuation

SiN with HA: Compression



Characteristic gain curve: More gain for soft than for loud input levels.

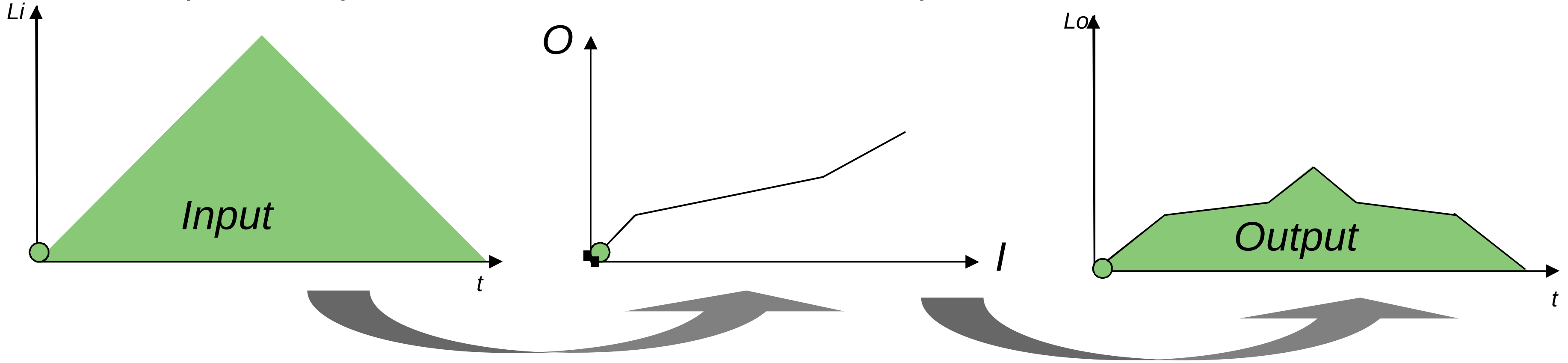
Attack time: Time needed for the gain for the loud input signal to drop (to the wished for value).

Release time: Time needed for the gain for the soft input level to come back to its full value.

(From Pape, 2013)

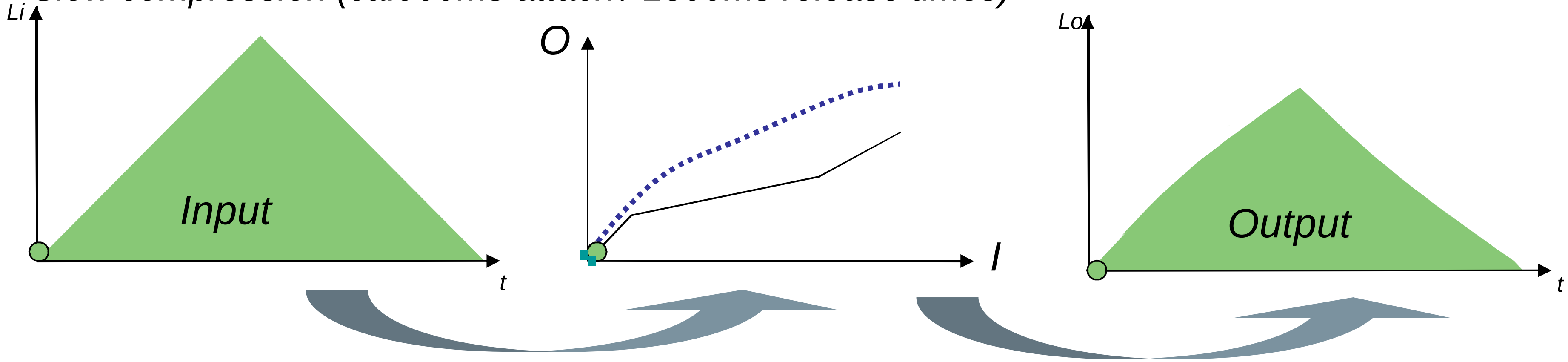
SiN with HA: Compression

Fast compression (10ms attack / 100ms release times)



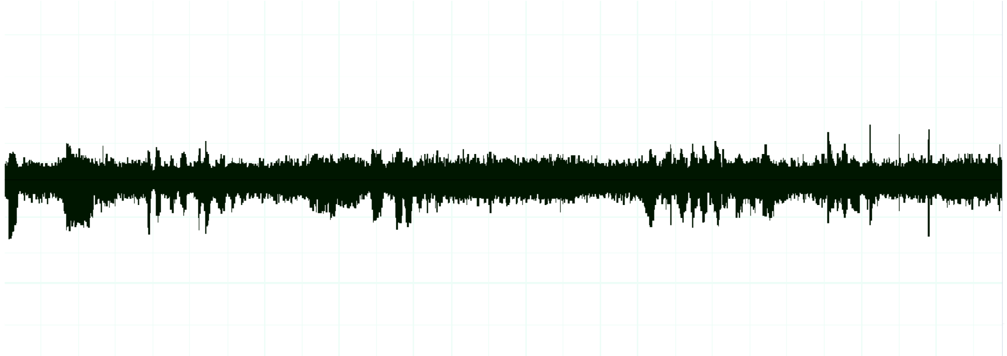
Fast reaction to loud sounds, loss of sound quality.

Slow compression (ca.900ms attack / 1500ms release times)

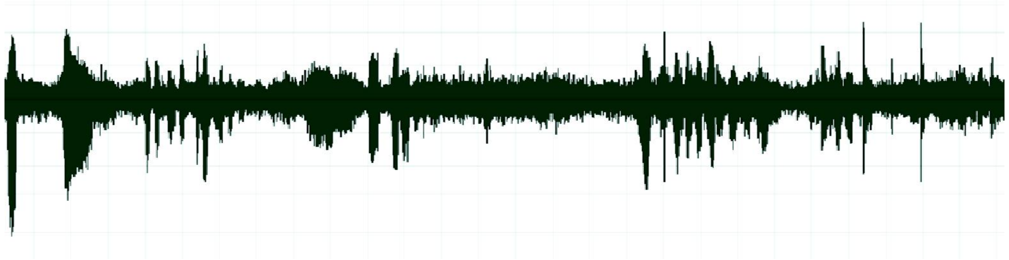


High sound quality, but short, loud sounds will be overamplified.

SiN with HA: Compression



Fast compression
Speech envelope fuses with the noise and difficult to understand.



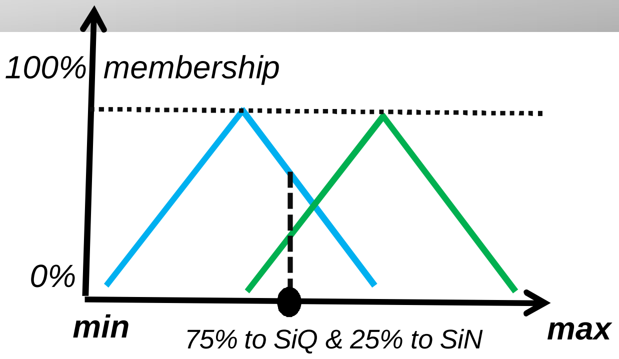
Slow compression
Speech envelope remains raised from the noise and thus easier to understand.

Speech in cantine noise – better speech understanding with slow compression. This may change for a different type of noise!

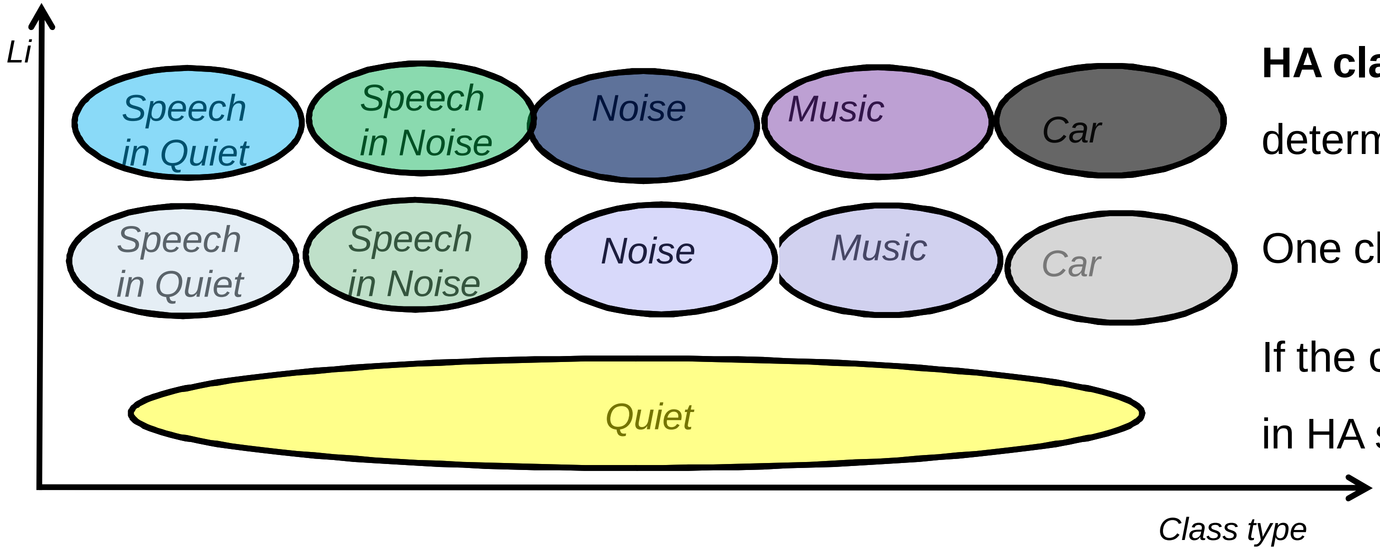
SiN with HA: Compression

Situation	Dynamic range estimation of input signal	Compression speed
Speech in quiet	~30 dB	fast
Speech in stationary noise	~5 dB	slow
Speech in fluctuating noise	~5-15 dB	fast
Music (radio music)	~5 dB	slow
Noise	~5-30 dB	fast
…..		

SiN with HA: The classifier



One possibility for classes' mix: fuzzy logic (triangular) membership functions.



HA classifier: A very clean & deterministic class distinction.

One class at the time.

If the class fails & the differences in HA settings are big – a problem.

'Human classifier': Transitions (happy being in between the classes) & on-line class-definition changes.

SiN with HA: developer‘s questions for each feature:

What benefit if it works?

This depends on for example…

How good are we at classifying each of these situations?

How quickly does the situation change and do we follow?

What will happen in ambiguous situations?

What are the differences between settings in two classes and

how to change between them smoothly?

Who determines which situation is there: the HA or the patient?

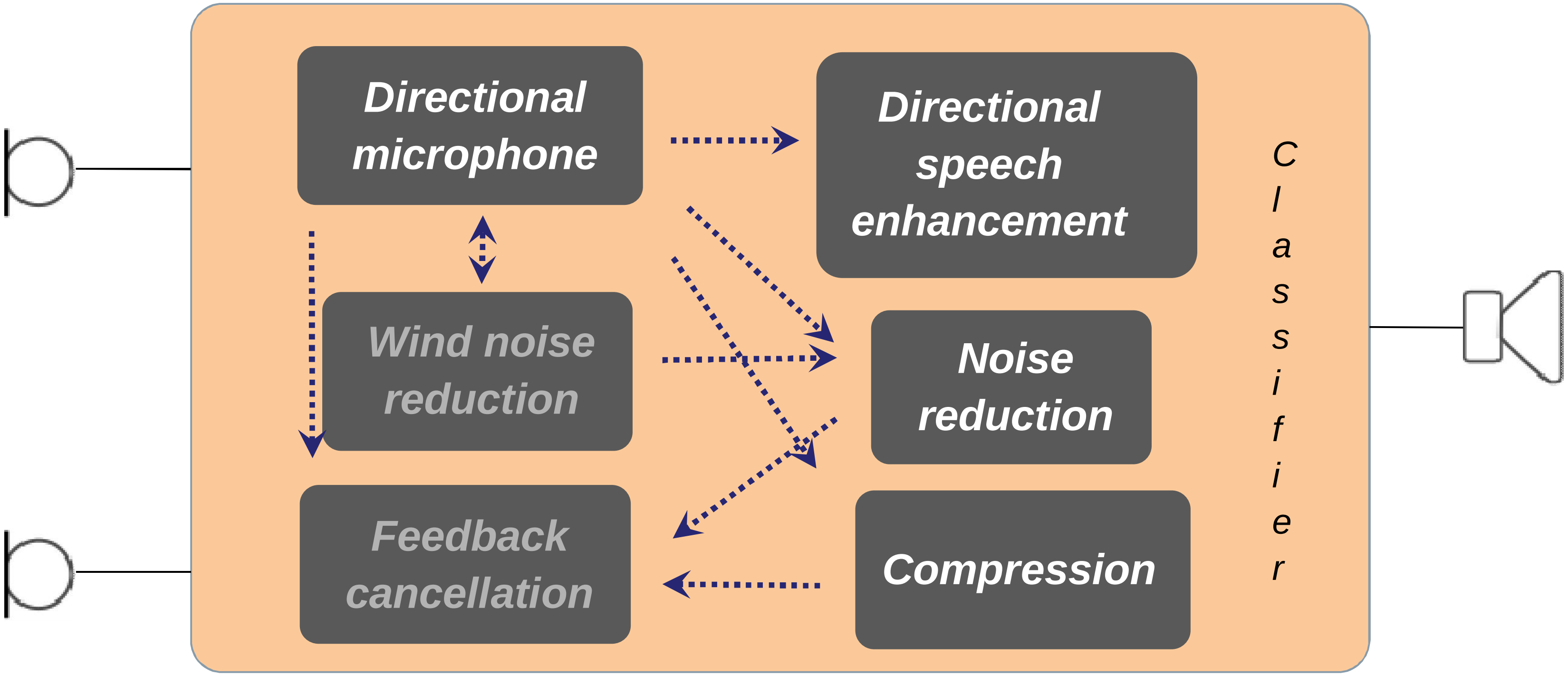
How reliable are the real life /lab tests?

SiN with HA: developer‘s questions for each feature:

What happens if a „faulty“ (direction, noise reduction, compression…) is imposed on a certain situation? For example….

Directional microphone	Noise reduction	Compression
- no ability to listen to anything falling outside that direction	-musical noise artefacts	- artefacts
- loss of spatial cues from any other direction	- loss of localisation cues and spatial impression	-unnatural sound impression
-gain loss in low frequent channel or	-loss of natural sound impression (always includes noise, eg reverb - important for spatial impression)	- loss of protection for loud, short sounds
- microphone noise due to compensation for the gain loss	- loss of SI due to ---what exactly? Still unclear why no SI benefit!	- it cannot restore selectivity in noise (not an expansion)
- Some subjects may do worse than others	-Some subjects may do worse than others	-some subjects may do worse than others

SiN with HA: altogether!



- Not only that one algorithm (feature) has to be correctly parametrised for each situation, they all have to work in synchrony.

SiN: influential factors

Up till now, we described influential factors from the signal point of view.

Factors from the point of view of the listener in a noisy situation:

- Individual limits of e.g. hearing thresholds, spectral and temporal selectivity, informational masking and working memory capacity as well as learned strategies and templates i.e. prior knowledge and expectations.

- The wish

SiN in HA: Conclusion

Each HA feature estimates a specific situation on the basis of estimation of some signal characteristics. Ideally, feature benefit depends on how successful the estimation is. However → *This may work in ideal, specific situations, but in a HA each solution has to work in any situation (i.e. if nothing else - degrade gracefully)!*

Additionally,

1) In view of individual‘s abilities:

Every person has learned templates and strategies how to cope in noisy situations (ITDs, ILDs, loudness perception, timbre, lip reading, visual imagining, position of the head but also auditory scene analysis and/or purely cognitive associations) and the HA should profit from these and not destroy them.

2) In view of that individual heart‘s desires:

More often than not, we analyse and experience the **same** *situation differently, just by wishing it.The HA should allow for this!*

SiN in HA: the future

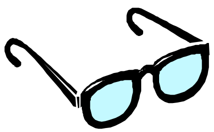
Individualisation on all fronts:

- HA learning: the HA should have the ability to learn and change its behaviour, helped by any other relevant information (GPS, body movement, classification, eyes...)

- Patient learning: training programs and education about the need for acclimatisation and re-learning. Must be fun & free or it will not work.

- Interaction between the HA and the patient: tools to override the decisions of the HA…

- Towards individual‘s limits and capacities influencing the parametrisation of the HA…



A world of difference...

The END

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