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Binaural integration of neural activity patterns using a coincidence gate

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1. Introduction

The auditory image model (AIM) (Patterson et al., 1992) has the stated purpose of summarizing all of the signal processing that the auditory system employs to produce the initial perception of a complex sound; this is the meaning of the term 'auditory image' in this model. However, your initial image of a source includes its direction, and to this point in time, the publicly available versions of AIM have been strictly monaural. Recently, we have begun a project to produce a binaural version of AIM.

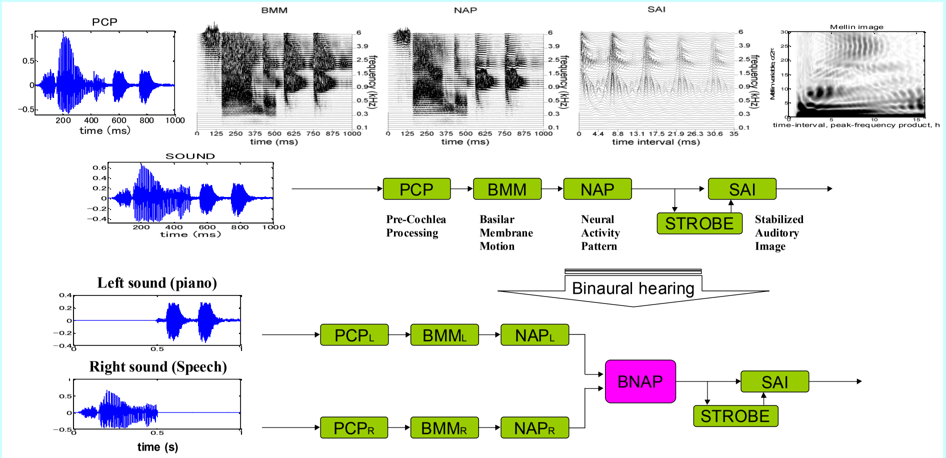


Figure 1. Modules in AIM and a strategy for binaural integration of neural activity patterns (NAPs).

2. Coincidence gate

An idea of the 'coincidence gate' (Patterson et al., 2006) is a mechanism for implementing the traditional delay-line version of binaural processing. There is an array of coincidence gates (CGs) for each frequency channel and they detect different combinations of inter-aural time difference (ITD). When coincidence occurs the neural activity is gated out of the delay lines into the corresponding channel of a direction-specific auditory image. In this way the appropriate micro-components of the neural activity flowing from the left and right cochleas is sorted into images with direction.

The coincidence gate is expected to work well for click trains in middle to high-frequency channels. In the lower frequency bands, the pulses are blurred by the impulse response of basilar membrane motion. To solve this problem the CG concept was extended to include channel interaction. Specifically, the occurrence of coincidence in one frequency channel is propagated to lower frequency channels to increase the probability of the lower gate opening. This enhances the detection of clicks in the lower channels considerably.

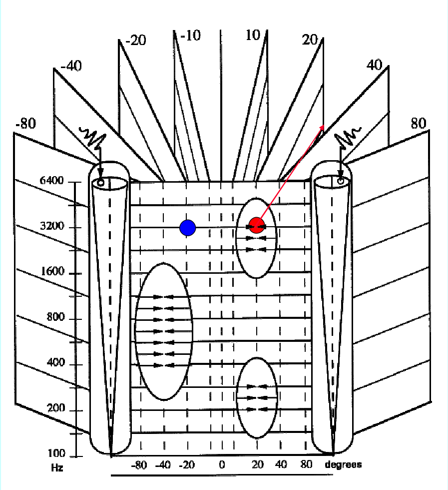


Figure 2. Coincidence gate scheme based on interaural time difference (ITD) between NAPs from both ears.

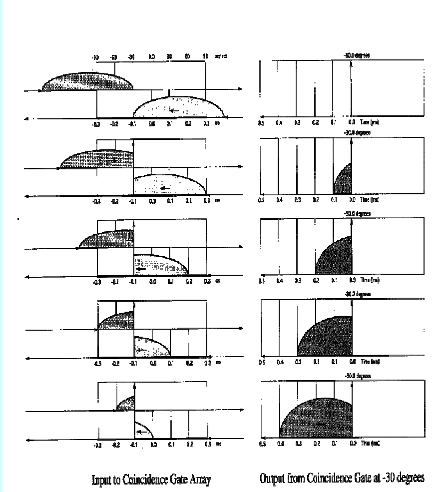
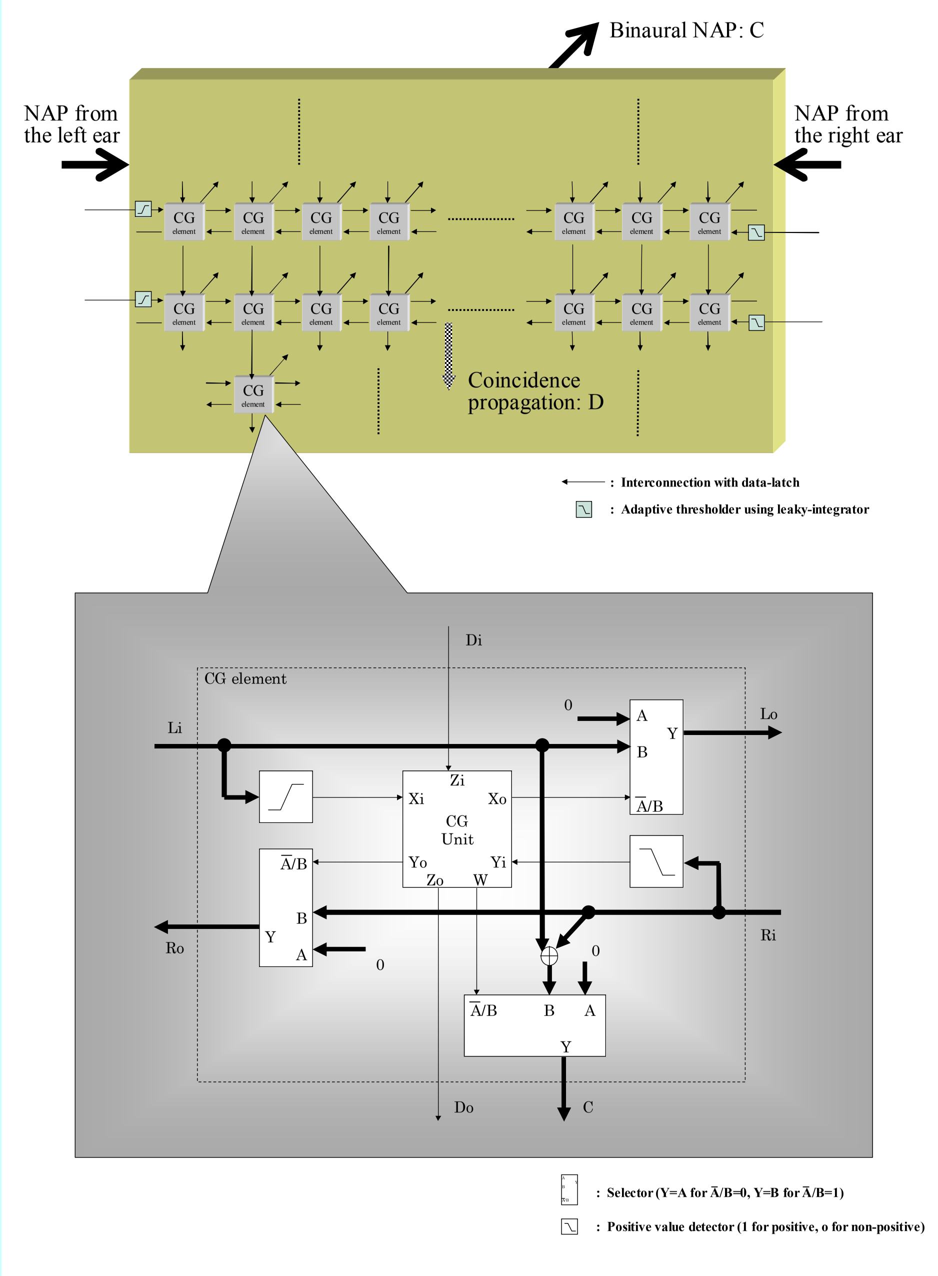


Figure 3. A schematic example of the basic operation in the coincidence gate.

3. An implementation of coincidence gate

The CG scheme was implemented with shift-registers and binary logic controller to make it efficient, from an analogy of Figure 2. The function module is called CG element. Each CG element was interconnected with data-latches. NAPs were previously reshaped by adaptive threshold to obtain individual NAP pulses clearly.



Truth table of CG unit

Zi	Xi	Yi	Zo	Xo	Yo	W
0	0	0	0	0	0	0
0	0	1	0	0	1	0
0	1	0	0	1	0	0
0	1	1	1	0	0	1
1	0	0	1	0	0	1
1	0	1	1	0	0	1
1	1	0	1	0	0	1
1	1	1	1	0	0	1

Figure 4. Top diagram shows an implementation of the coincidence gate scheme with array of coincidence gate elements. Each element is interconnected with data-latches. Middle diagram shows the details of the coincidence gate element. NAP activities are detected by thresholders and NAP flow is controlled by selectors according to a coincidence gate unit. Bottom table defines the control logic of the coincidence gate unit.

4. Computer simulations

Settings of computer simulation (Figure 5):
- Two sounds located in 45 degree left and 45 degree right,
- The left sound was a piano sound, the right one was speech sound,
- Both sound with 20 kHz of sampling frequency

Figure 6. shows profiles of BNAP onto some axes. The left two panels of Fig. 7 show the NAPs from left and right ears. The right two panels of Fig. 7 show the results of binaural integrated NAPs for the directions of each sound by the coincidence gate scheme.

The results show that each NAP was separated clearly. In general, when both sounds did not have any overlap in time, the separation of NAPs into binaural NAPs were clear.

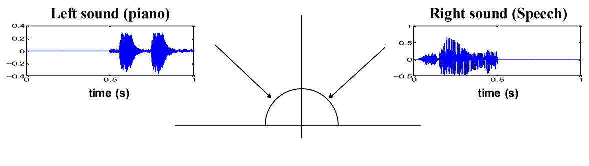


Figure 5. Sound source locations in computer simulation (two sounds were virtually located in 45 degree left and 45 degree right, respectively. The right sound preceded the left one, without overlap portion in time.)

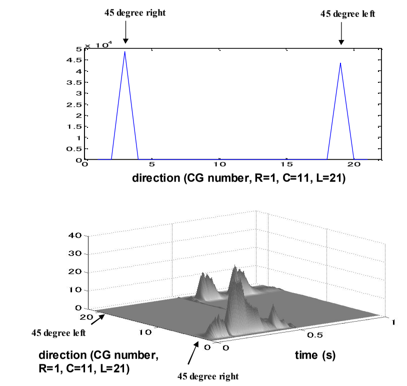


Figure 6. Profiles of the binaural NAP onto axes of direction and time. Binaural NAPs were obtained only at the correct directions (#3 in direction is for 45 degree right, #19 for 45 degree left).

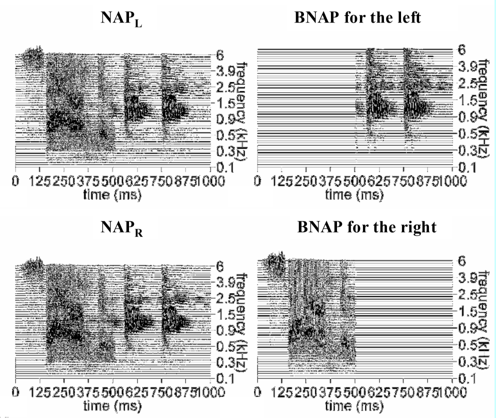


Figure 7. NAPs from both ears and the separated binaural NAPs by the coincidence gate scheme. The fidelity of separated BNAPs was good.

5. Conclusions

- The coincidence gate scheme with the coincidence information propagation was implemented. That consisted of arrays of the CG elements controlled by the CG unit. The CG unit was a simple logic gate. This unified structure worked sufficiently fast.
- Computer simulations indicated the coincidence gate scheme worked well when sounds were not overlapped in time. The case of heavily overlapping is still investigated.

References

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