

Time-Frequency Analysis for Audio Workshop  
**Matching the Analysis Scheme to the Signal**

Fritz Menzer ([fritz.menzer@epfl.ch](mailto:fritz.menzer@epfl.ch))  
Communication Systems, 5<sup>th</sup> year  
Ecole Polytechnique Fédérale de Lausanne

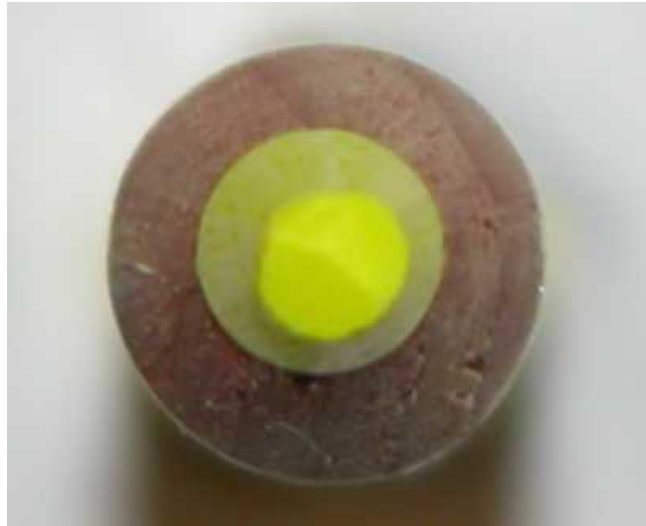
15th April, 2004

# Overview

<b>1</b>	<b>Introduction</b>	<b>3</b>
<b>2</b>	<b>Perfect Reconstruction - who cares?</b>	<b>4</b>
2.1	Definition of perfect reconstruction . . . . .	4
2.2	Do we need perfect reconstruction? . . . . .	5
<b>3</b>	<b>Harmonic Band Wavelet Transform</b>	<b>7</b>
3.1	Coefficient modeling . . . . .	10
3.2	Advantages / Drawbacks . . . . .	11
<b>4</b>	<b>From HBWT to inharmonic sound modeling</b>	<b>12</b>
4.1	Taking filters from different PR filterbanks . . . . .	13
4.2	Why aliasing is not a problem . . . . .	14
4.3	Method Overview . . . . .	17
4.4	Sounds . . . . .	18
<b>5</b>	<b>Time-Frequency Analysis and Granular Synthesis</b>	<b>19</b>
5.1	Time-domain effects . . . . .	25
5.2	Scale of all grains in a 1024-band full-tree wavelet decomposition . . . . .	26
<b>A</b>	<b>References</b>	<b>27</b>

# 1 Introduction

- If you know what you're looking at, you can examine it more precisely.



## 2 Perfect Reconstruction - who cares?

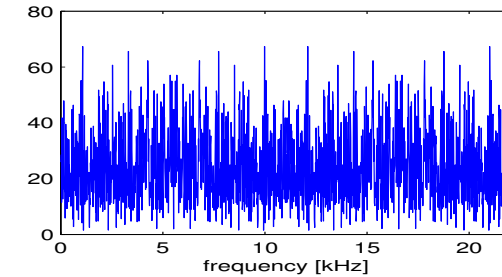
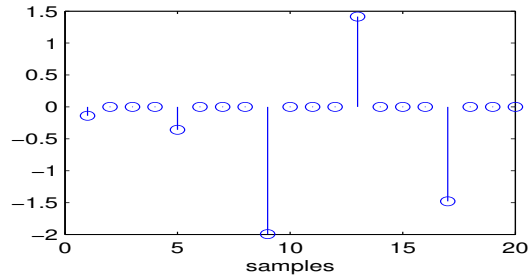
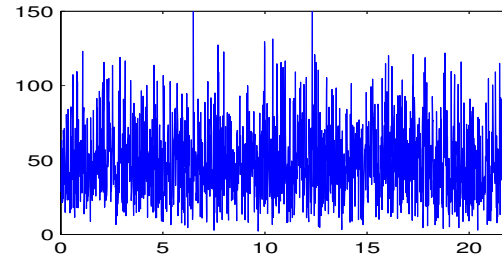
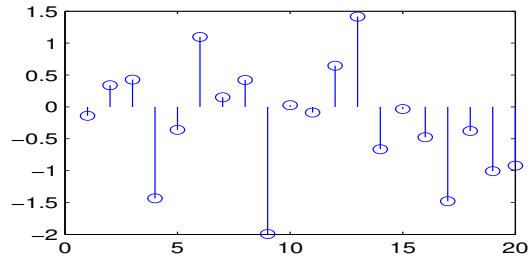
### 2.1 Definition of perfect reconstruction

- Definition: **Perfect Reconstruction (PR)** method: method providing direct and inverse transforms  $\mathcal{T}$  and  $\mathcal{T}^{-1}$  such that for any signal  $s$ ,

$$\mathcal{T}^{-1}(\mathcal{T}(s)) = s$$

- FFT based methods, Cosine Modulated Filterbanks and Wavelet transforms are usually PR methods.
- Simple operations like filtering or distortion do not necessarily allow PR (i.e. it may be impossible to find  $\mathcal{T}^{-1}$ ).  
Example: Quantisation obviously does not allow to reconstruct the original signal perfectly.

## 2.2 Do we need perfect reconstruction?



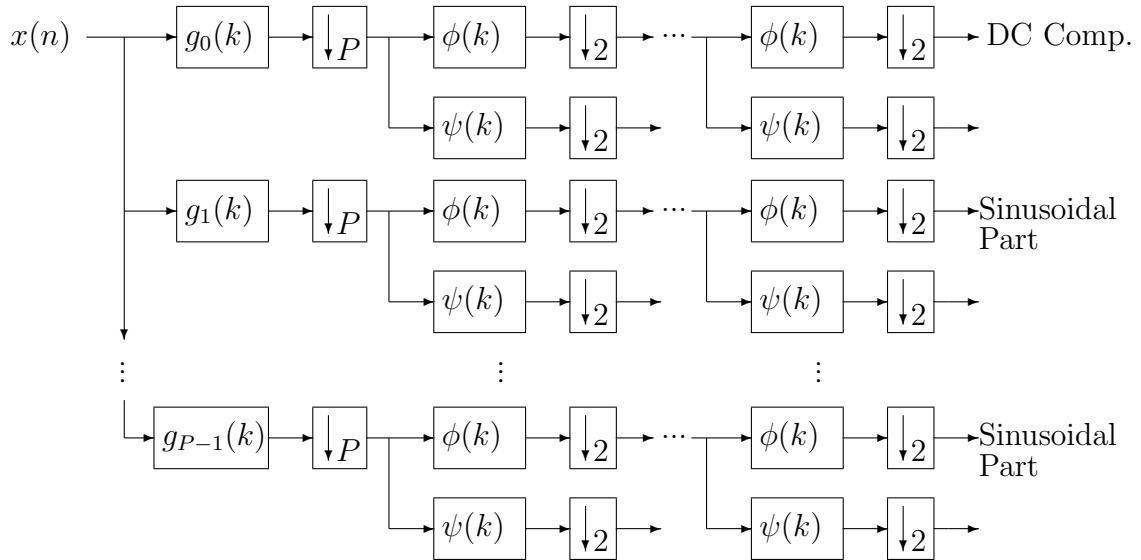
Noise  
Noise, down- and upsampled by 4

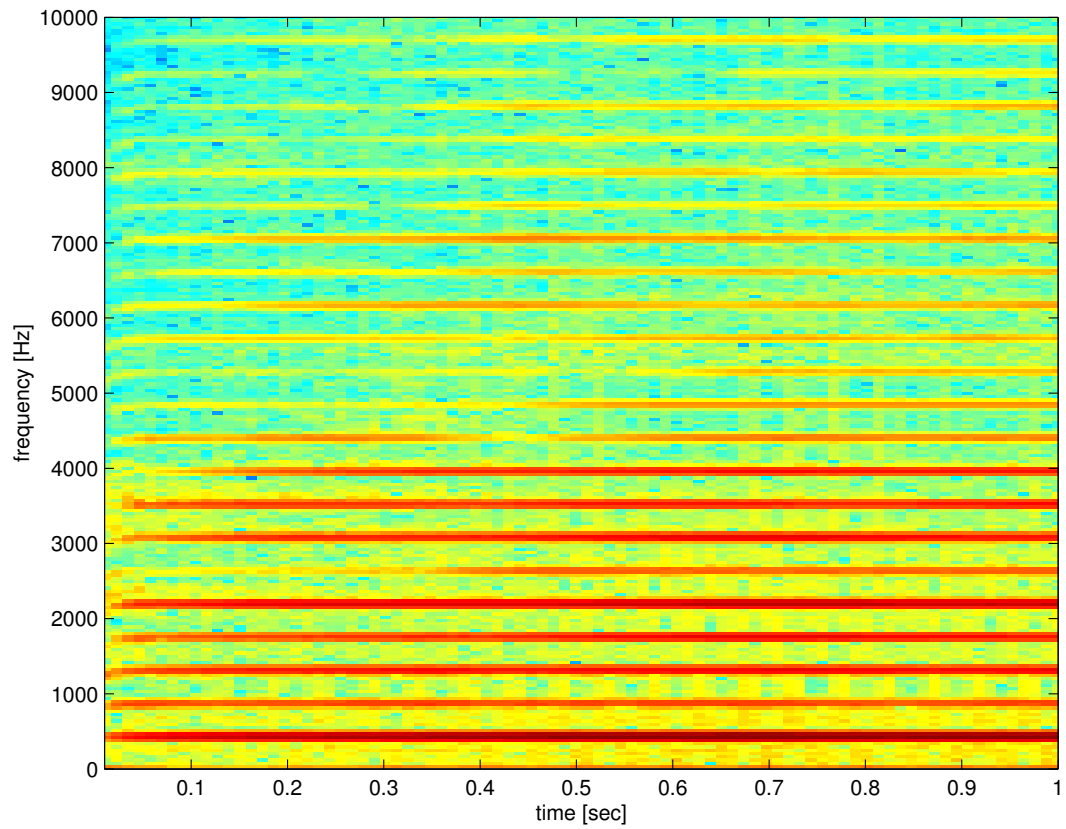
## Do we need perfect reconstruction?

- Not needed for:
  - Modifying a signal
  - Handling noise
  - If the nature of the signal is known
- Why use PR methods for compression?
  - Generality (ideally any signal can be treated)
  - Localising the source of errors!

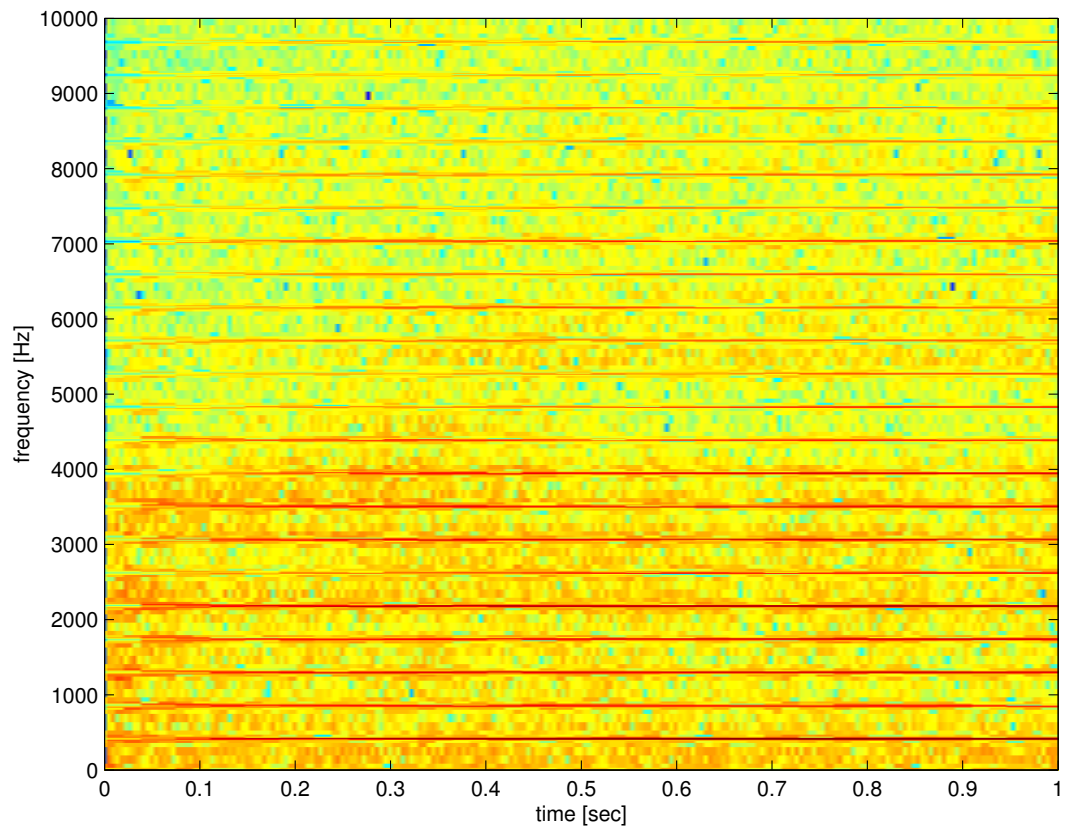
### 3 Harmonic Band Wavelet Transform

(Polotti and Evangelista, 2000)



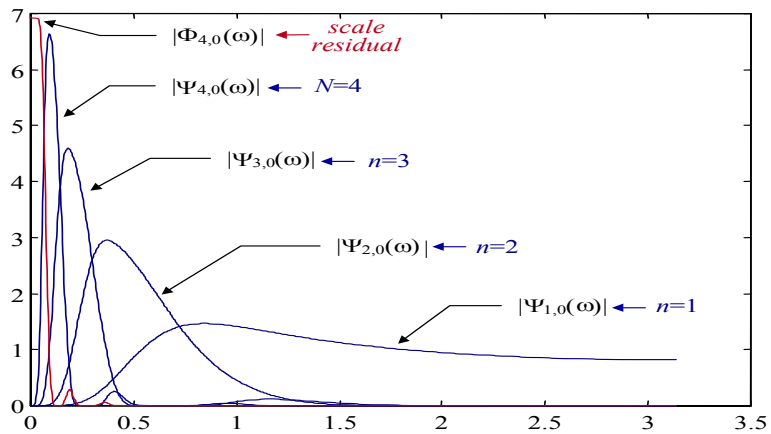






### 3.1 Coefficient modeling

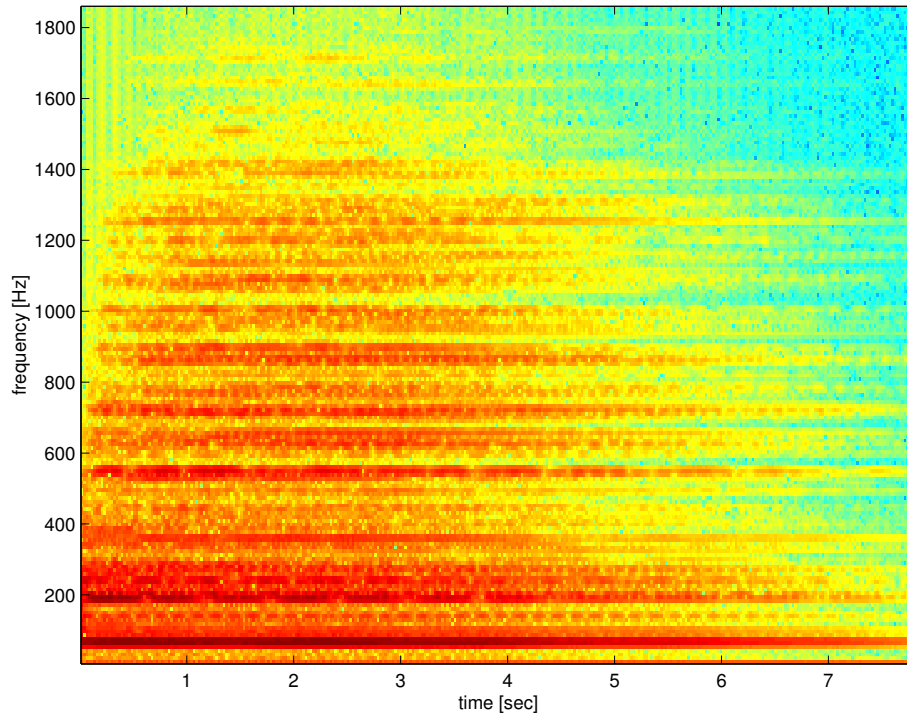
- Wavelet Transform
- Model the scale residual sinusoidally
- Model the wavelet coefficients using LPC



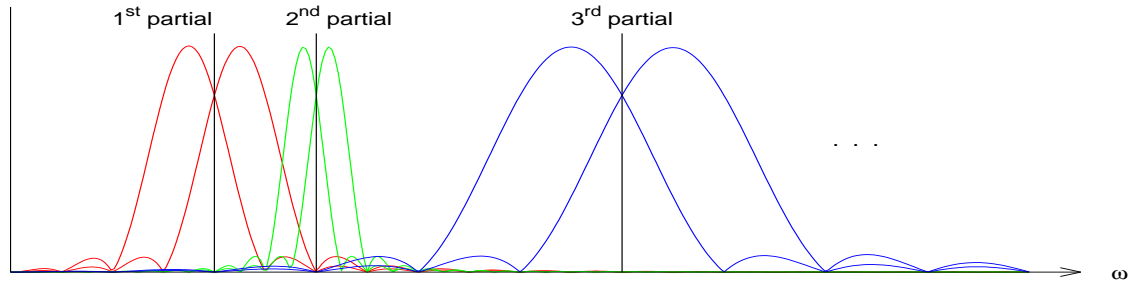
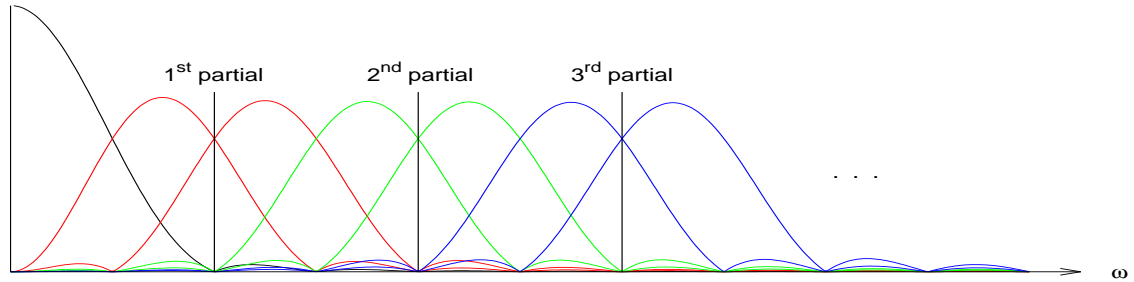
### 3.2 Advantages / Drawbacks

- + Meaningful adaptation of frequency and time resolution
  - ⇒ Visually better resolution
- + Reasonable model for the coefficients
  
- Works only for monophonic, harmonic sounds
- No model for the transients

## 4 From HBWT to inharmonic sound modeling



## 4.1 Taking filters from different PR filterbanks



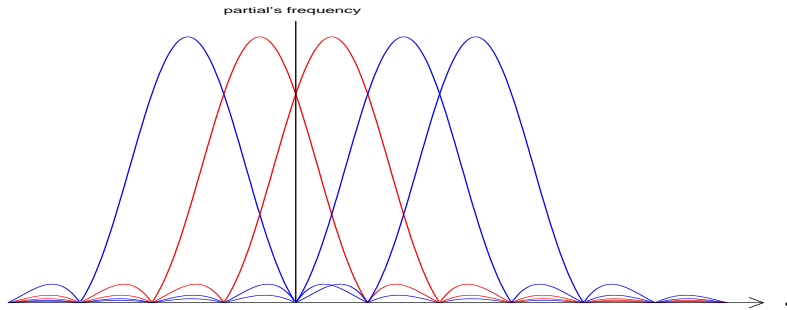
## 4.2 Why aliasing is not a problem

If a sinusoid of the form

$$\sin\left(\frac{\hat{k}\pi}{P}t + \varphi\right)$$

is the input to a P-channel cosine modulated filterbank, only two bands will output nonzero coefficients:

$$|H_k(e^{j\frac{\hat{k}\pi}{P}})| \neq 0 \Leftrightarrow k \in \{\hat{k} - 1, \hat{k}\}$$



$\Rightarrow$  there is no aliasing of the sinusoidal part, but only of the part that we model as noise!

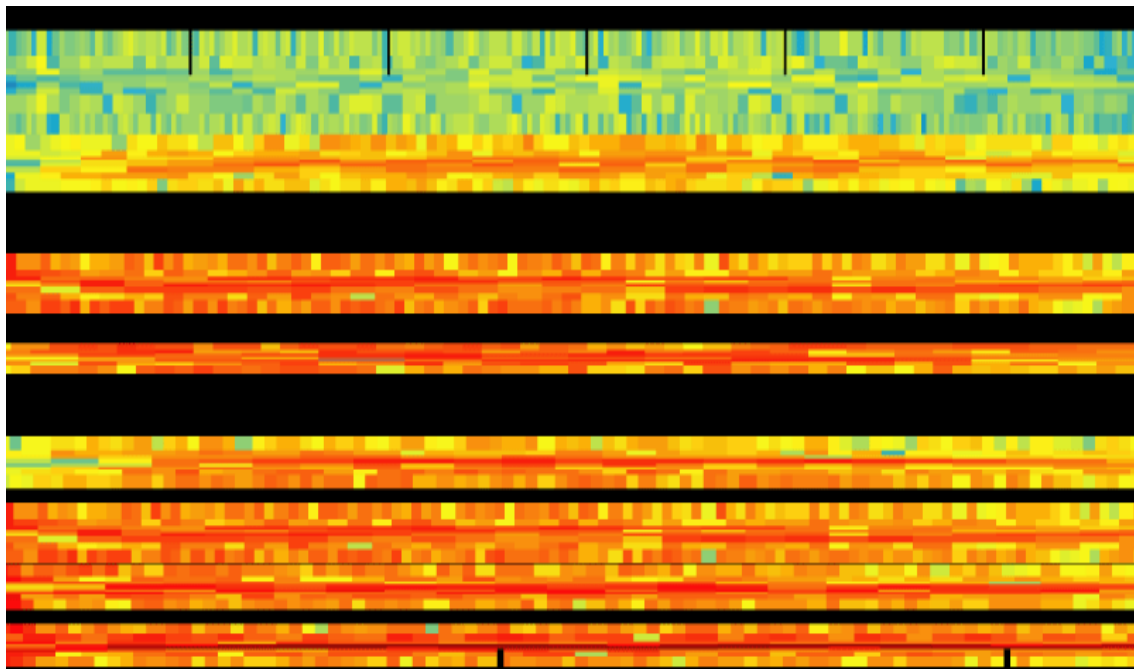
1. The first step in the process of creating a business plan is to conduct a market analysis. This involves identifying the target market, understanding the needs and preferences of customers, and assessing the competitive landscape. A thorough market analysis provides valuable insights into the potential size and growth of the market, as well as the key factors that will influence success.

2. Once the market analysis is complete, the next step is to define the business's mission and vision. The mission statement should clearly articulate the company's purpose and the value it aims to provide to its customers. The vision statement, on the other hand, should describe the long-term goals and aspirations of the business, providing a clear direction for the organization's future.

3. The third step in the process is to develop a detailed business model. This involves identifying the revenue streams, determining the cost structure, and outlining the operational strategy. A well-defined business model is essential for understanding the financial viability of the business and for attracting investors and lenders.

4. The fourth step is to create a marketing and sales strategy. This involves identifying the most effective channels for reaching the target market, developing compelling promotional messages, and establishing a sales process. A clear marketing and sales strategy is crucial for driving customer acquisition and revenue growth.

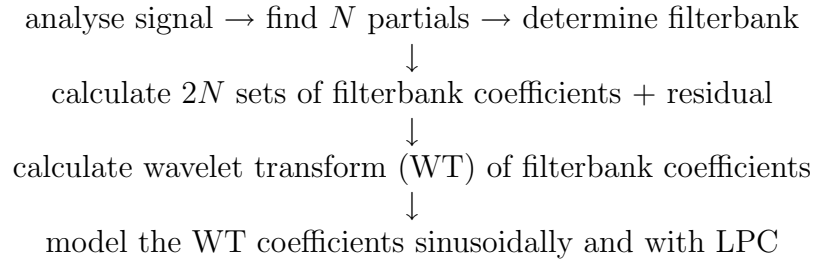
5. The fifth and final step is to develop a financial plan. This involves projecting the company's financial performance over a period of time, typically three to five years. The financial plan should include a detailed budget, a cash flow statement, and a break-even analysis. A well-developed financial plan is essential for demonstrating the financial viability of the business to investors and lenders.



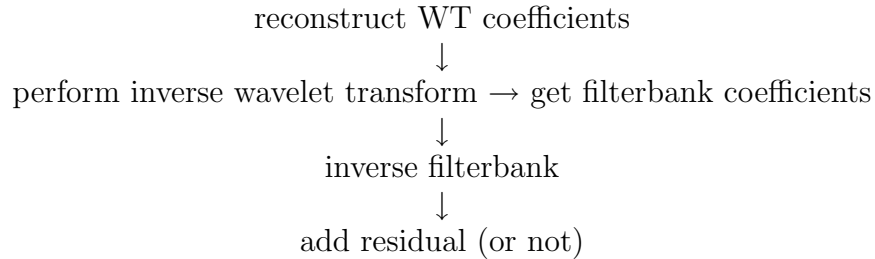


### 4.3 Method Overview

#### Analysis



#### Synthesis



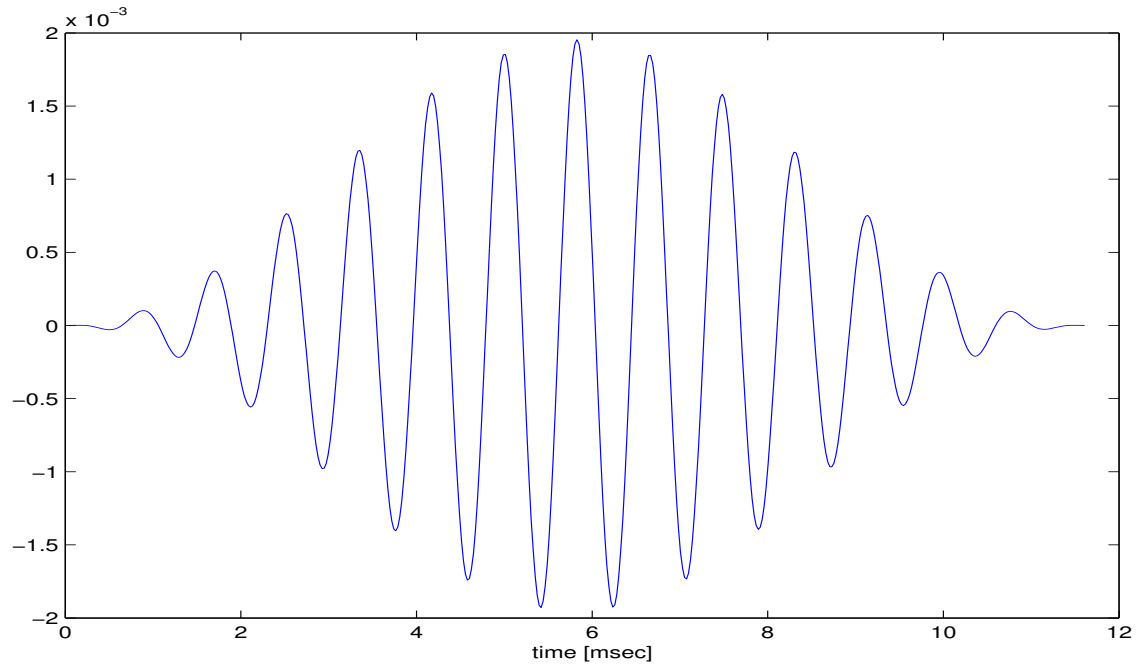
## 4.4 Sounds

- Original Gong
- Reconstructed from the Filterbank Coefficients
- Synthesized from model parameters
- 1 octave pitch-shifted Gong
- Time-stretched Gong
- Sinusoidal-only Gong
- First wavelet scale only
- Harmonic Gong

## 5 Time-Frequency Analysis and Granular Synthesis

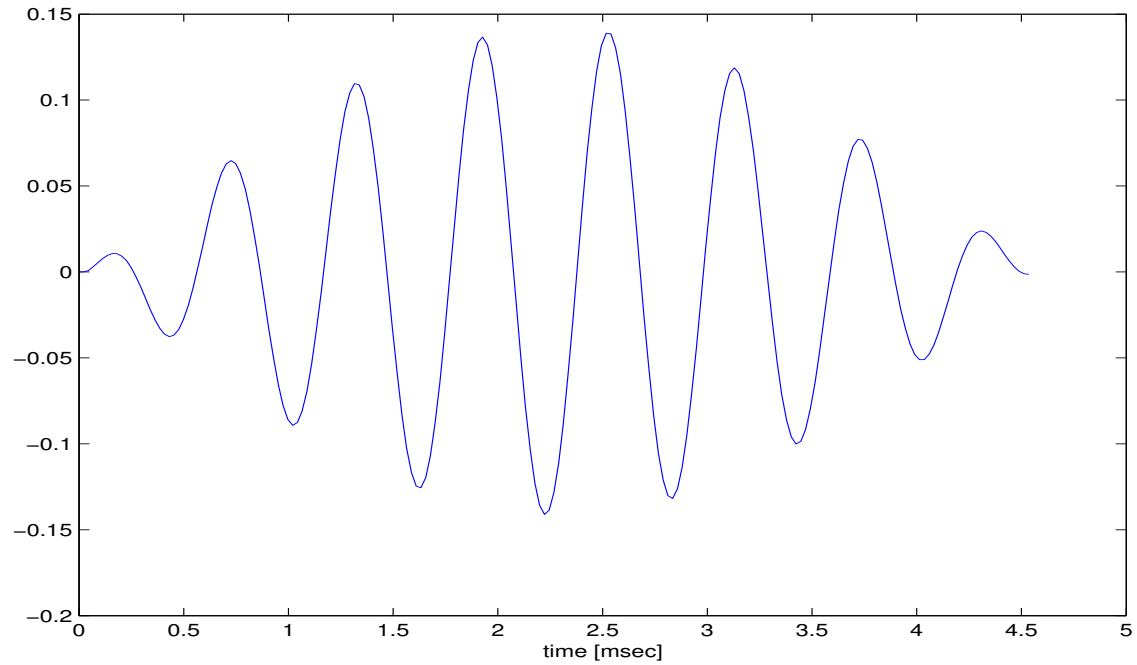
- Any Time-Frequency Transform implements a sort of Granular Synthesis.
- Each coefficient corresponds to a grain
- Grains are played at precise instants (instead of randomly)
- To produce a grain, set all coefficients to zero, except one that will be set to one. Then perform the inverse transform.

# Windowed FFT (STFT) grain



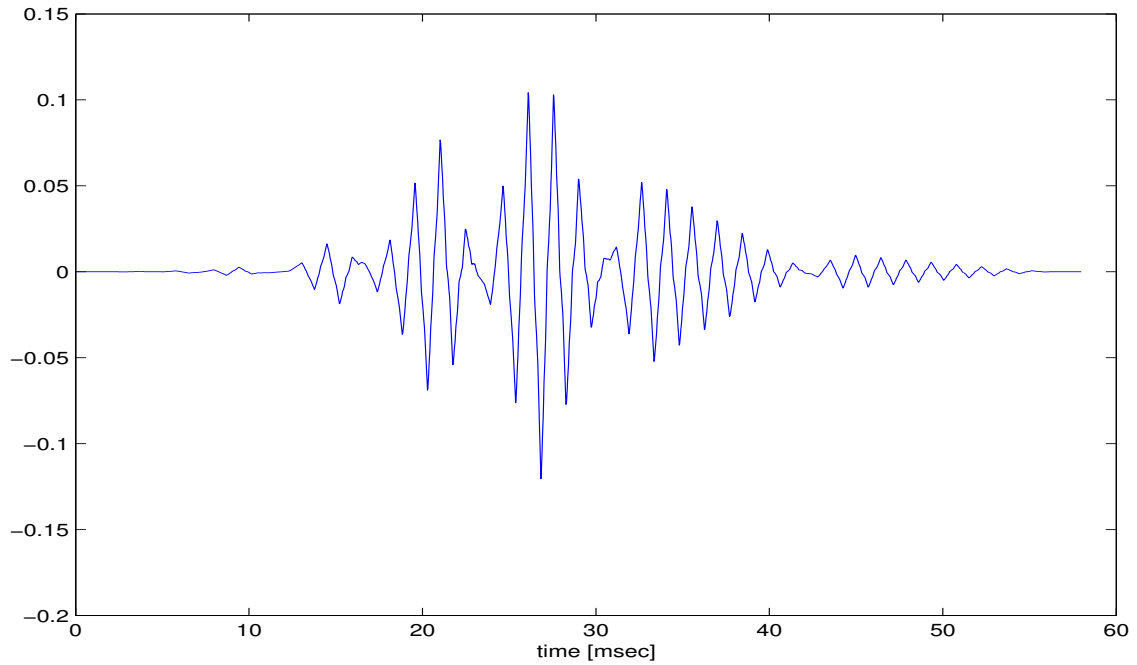
play

## Cosine Modulated Filterbank grain



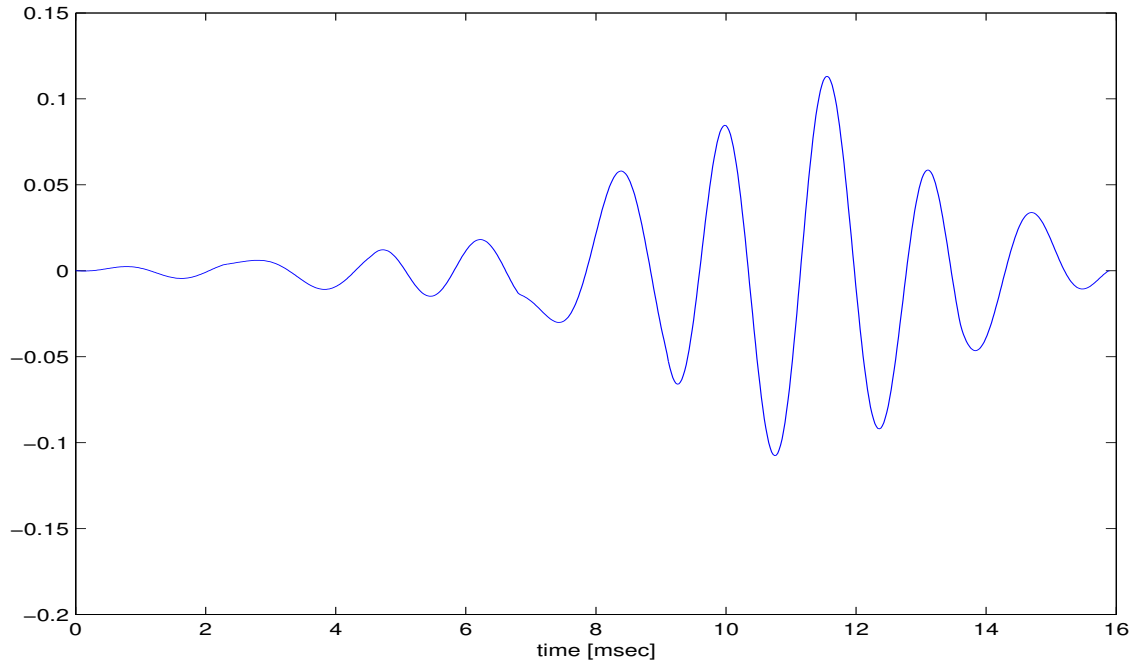
play

# Full-tree wavelet “grain”



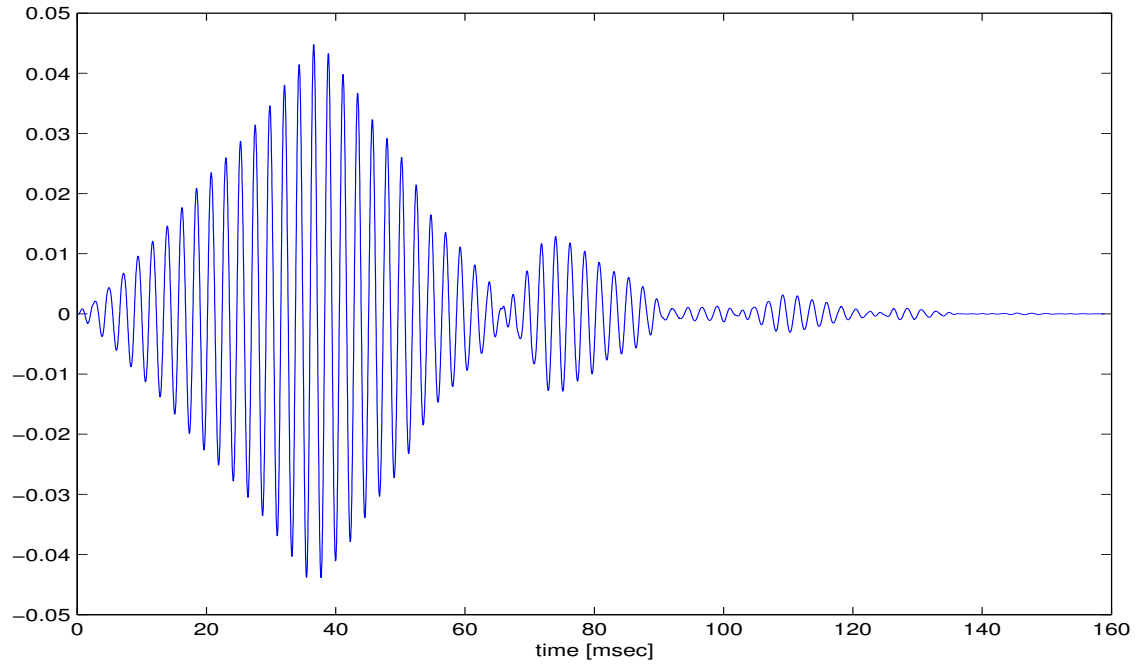
play

# HBWT grain (noise part)



play

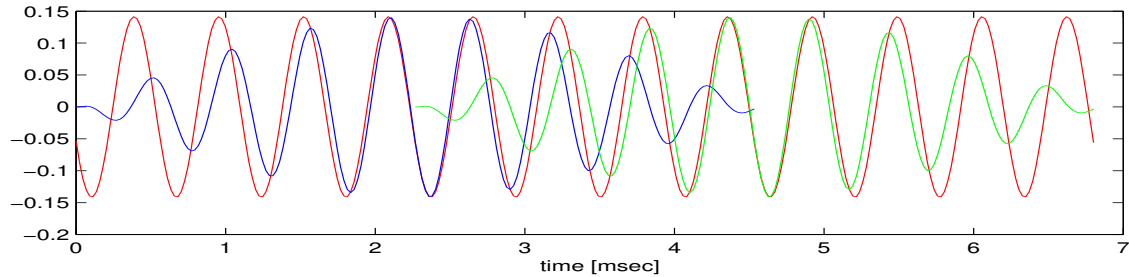
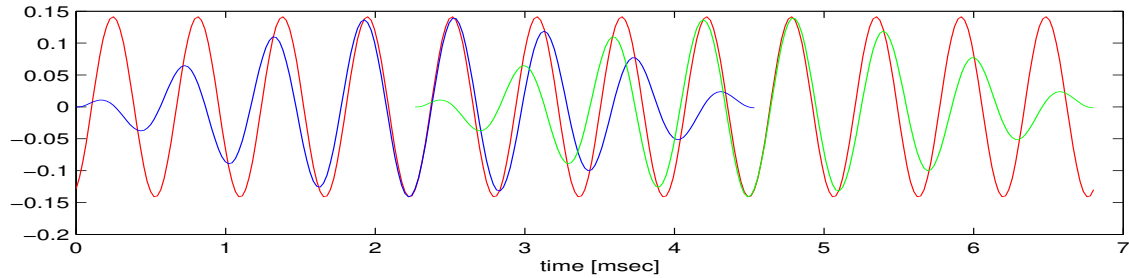
# HBWT grain (sinusoidal part)



play



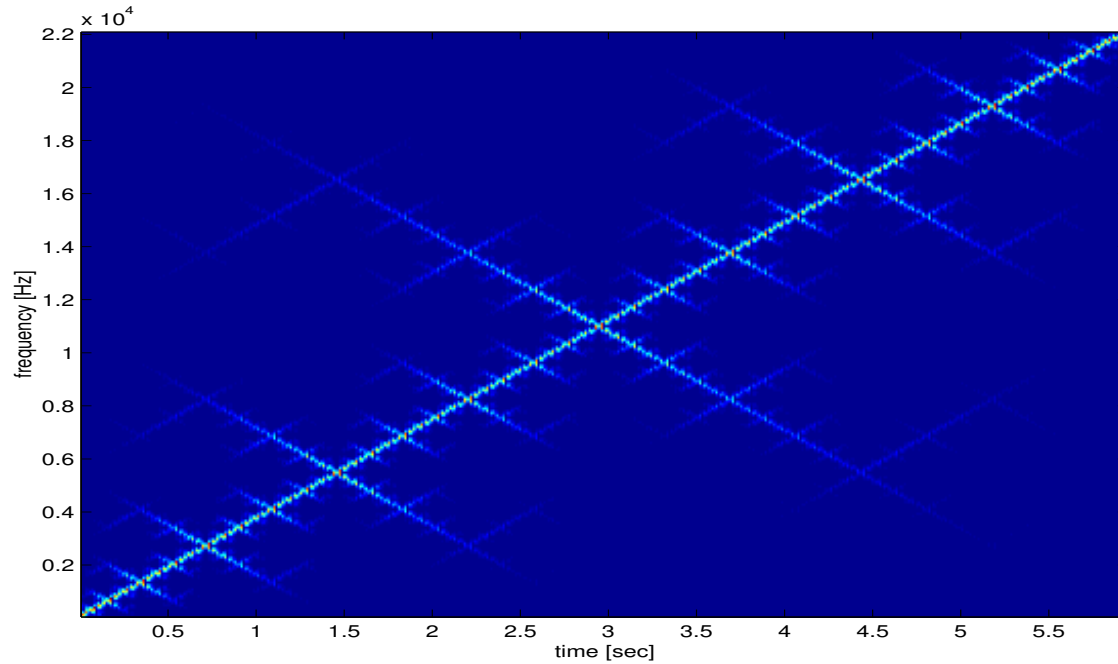
## 5.1 Time-domain effects



Channel 8: one grain played continuously

Channel 9: one grain played continuously

## 5.2 Scale of all grains in a 1024-band full-tree wavelet decomposition



play

## A References

- Article on Harmonic Band Wavelet Transform by Polotti and Evangelista  
<http://lcavwww.epfl.ch/publications/publications/2000/PolottiE00b.pdf>
- DAFx 2002 paper on adaptation to inharmonic sounds  
<http://lcavwww.epfl.ch/publications/publications/2002/PolottiE02.pdf>
- Some material (presentation slides, Matlab functions and pure data objects)  
<http://www.xsmusic.ch/>