Allocating, Detecting and Mining Sound Structures

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28th Sept., 2012

[1] Funded by Audio.Miner (WWTF Vienna)

The notion of sound object

AudioMiner: Vienna-based interdisciplinary project.
Exploring applications of modern mathematical methods in MIR.

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$\longrightarrow$ but what is a sound object?

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Sound object, sound structure or Gestalt?

- G. Monaci, P.Vandergheynst, "Audiovisual Gestalts," 2012
- I. Zannos (Ed.):Music and Signs – Semiotic and Cognitive Studies in Music, 1999 (M. Leman)
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Object, Structure or Gestalt: interpretation depends on representation!

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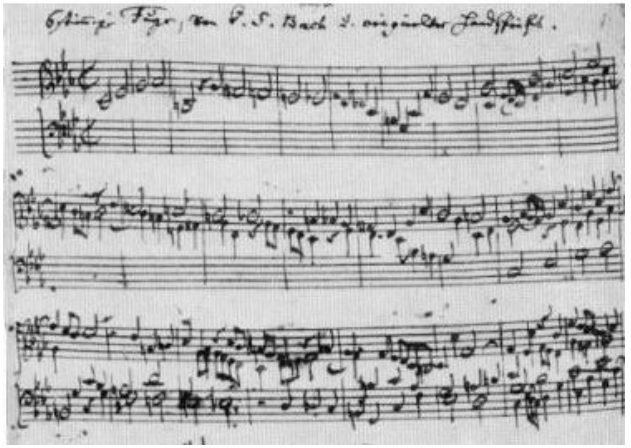
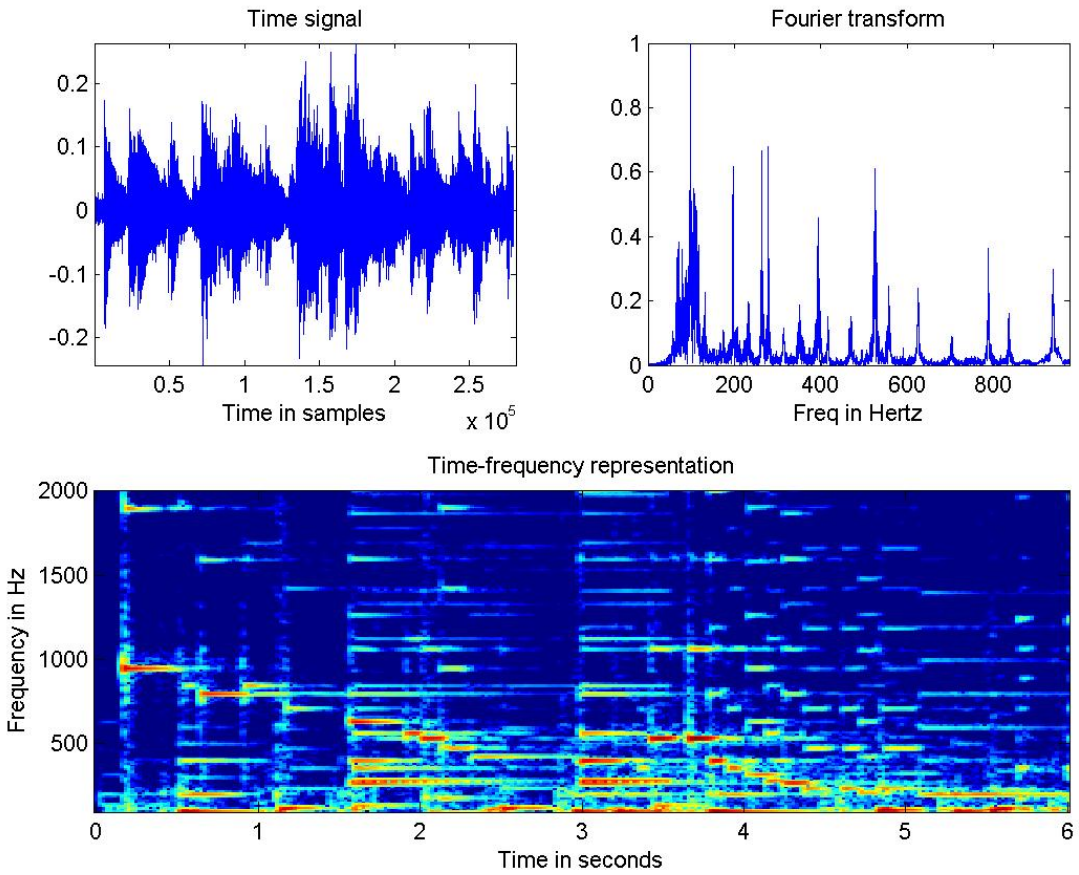


Time, Frequency, and Time-Frequency

$$f[n] = \sum_n c_n \delta_n = \sum_k \hat{c}_k (\cos 2\pi kn + \sin 2\pi kn)$$



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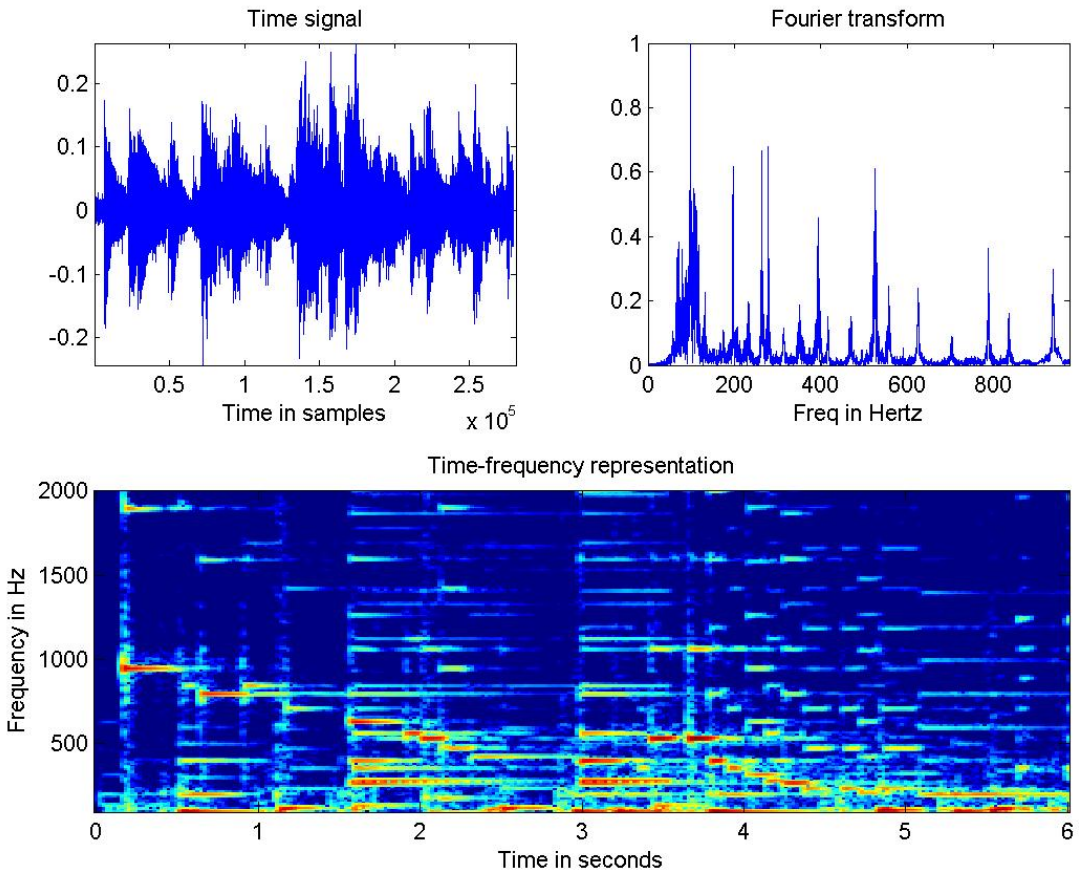
$$f[n] = \sum_n c_n \delta_n = \sum_k \hat{c}_k (\cos 2\pi kn + \sin 2\pi kn) = \sum_{n,k} c_{n,k} \varphi_{n,k}$$



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- Sound objects should be visible as distinct from a more textural background.
- More sophisticated representations of sound signals than classical representations do exist now:
  - Adaptivity in the transformation parameters: sharpen the visual and assure a perfect connection between signal and representation (invertibility).
  - Bayesian coefficient priors highlight particular structures by means of informed analysis.

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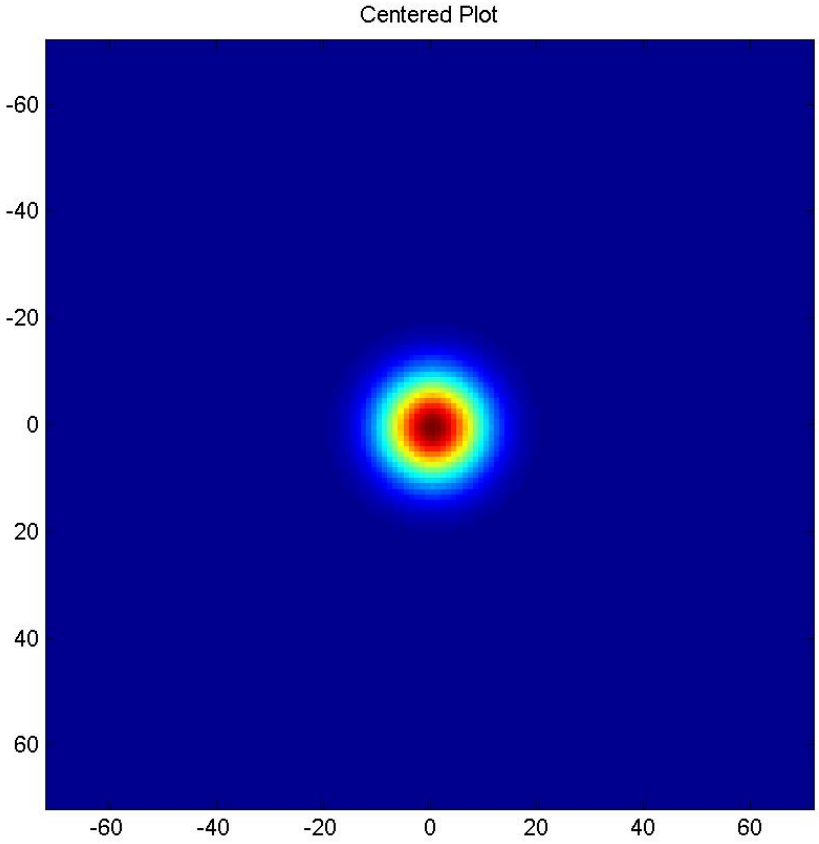
Time-Frequency analysis: Principles

- FFT-based time-variant analysis
- Mathematical frame theory always provides perfect reconstruction
- $f = \sum_{n,k} \langle f, \varphi^t_{n,k} \rangle \varphi^t_{n,k}$
- $\varphi_{n,k} := M_{kb} T_{na} \varphi$
- Choice of involved parameters (φ, a, b) is vital for the quality of representation

Time-Frequency analysis: Principles



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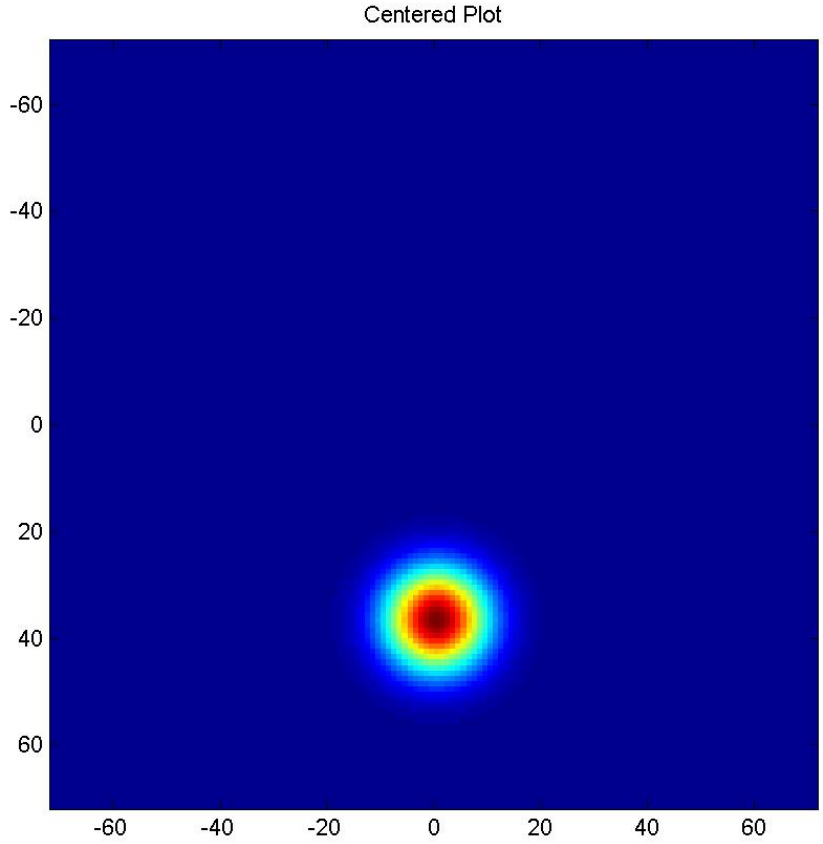

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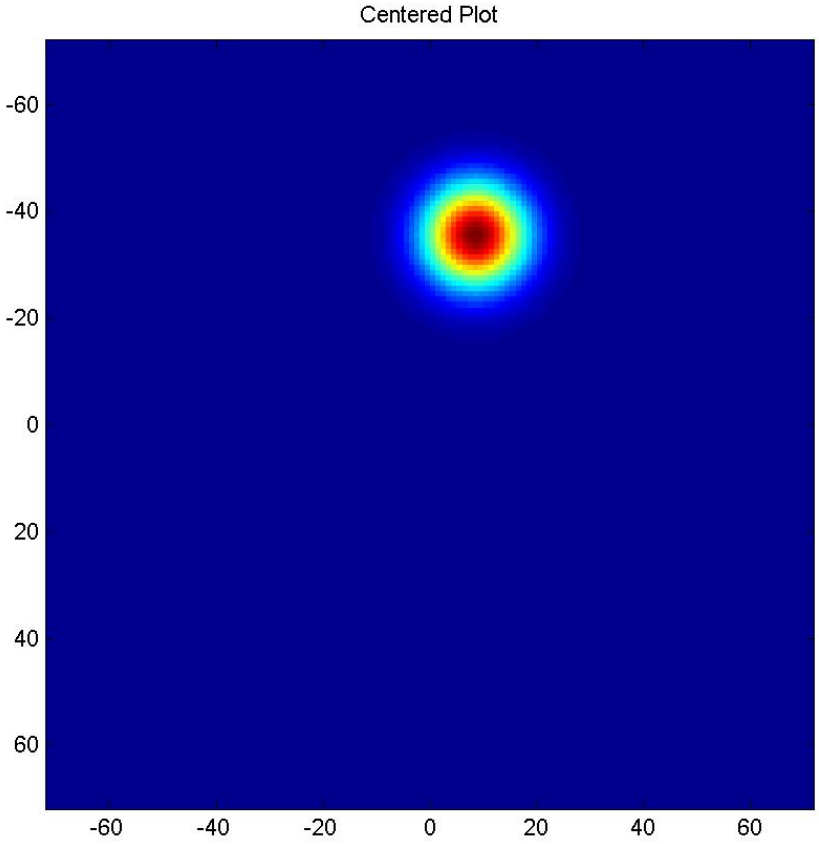

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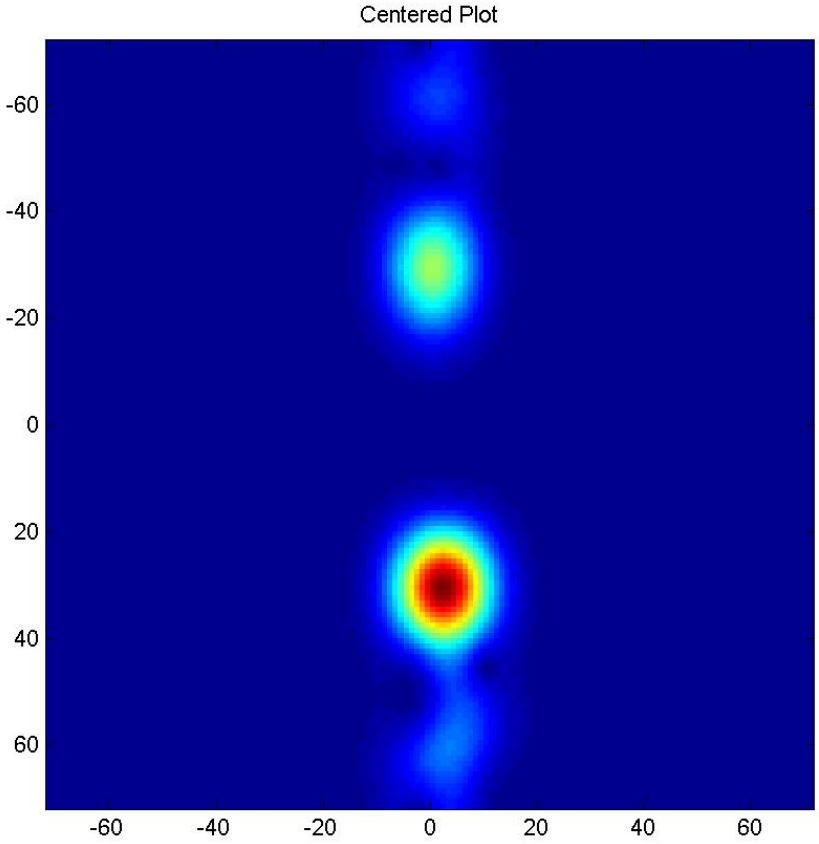

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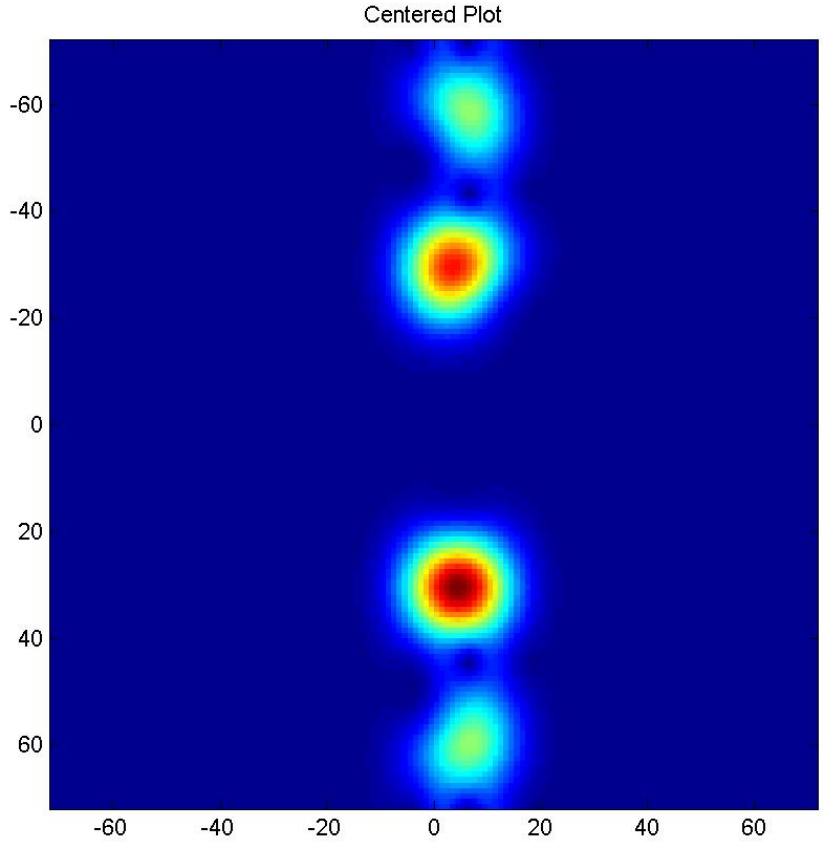

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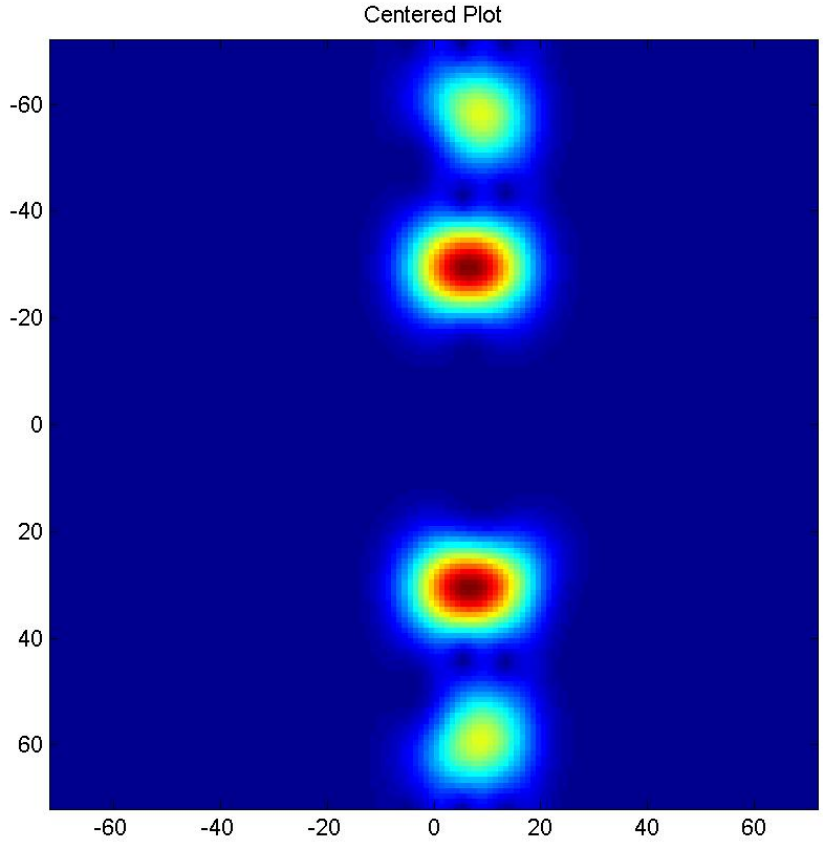

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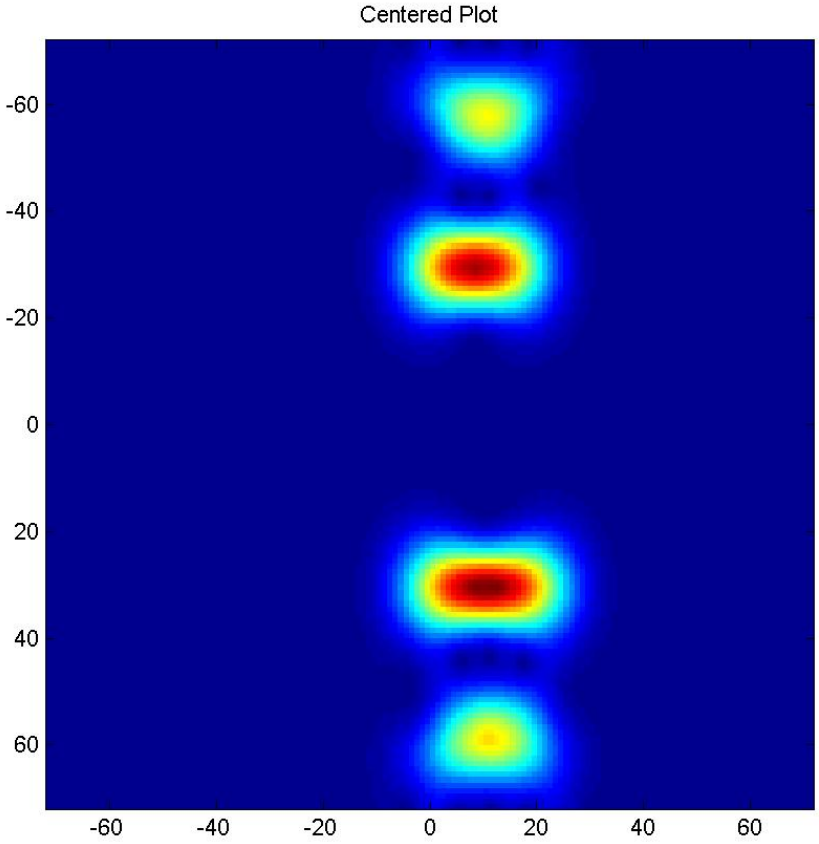

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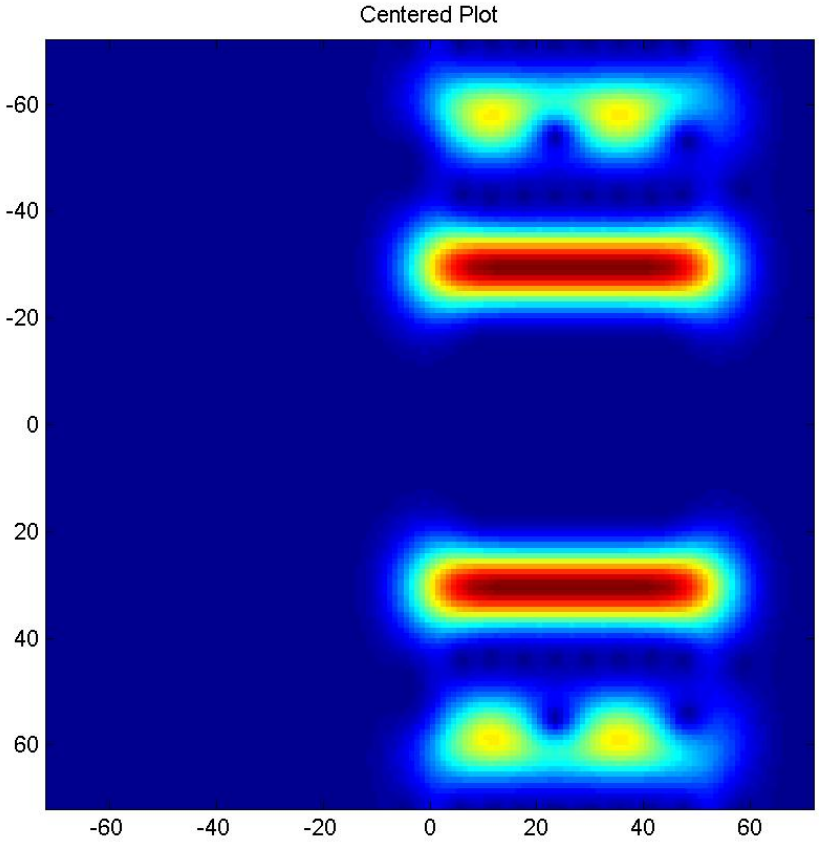

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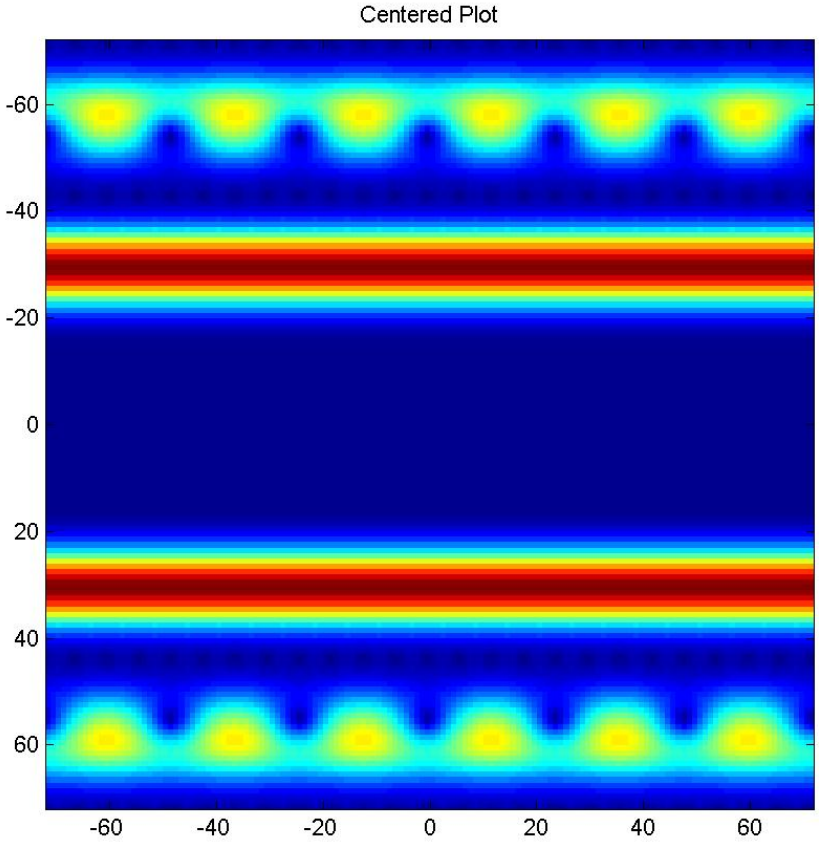
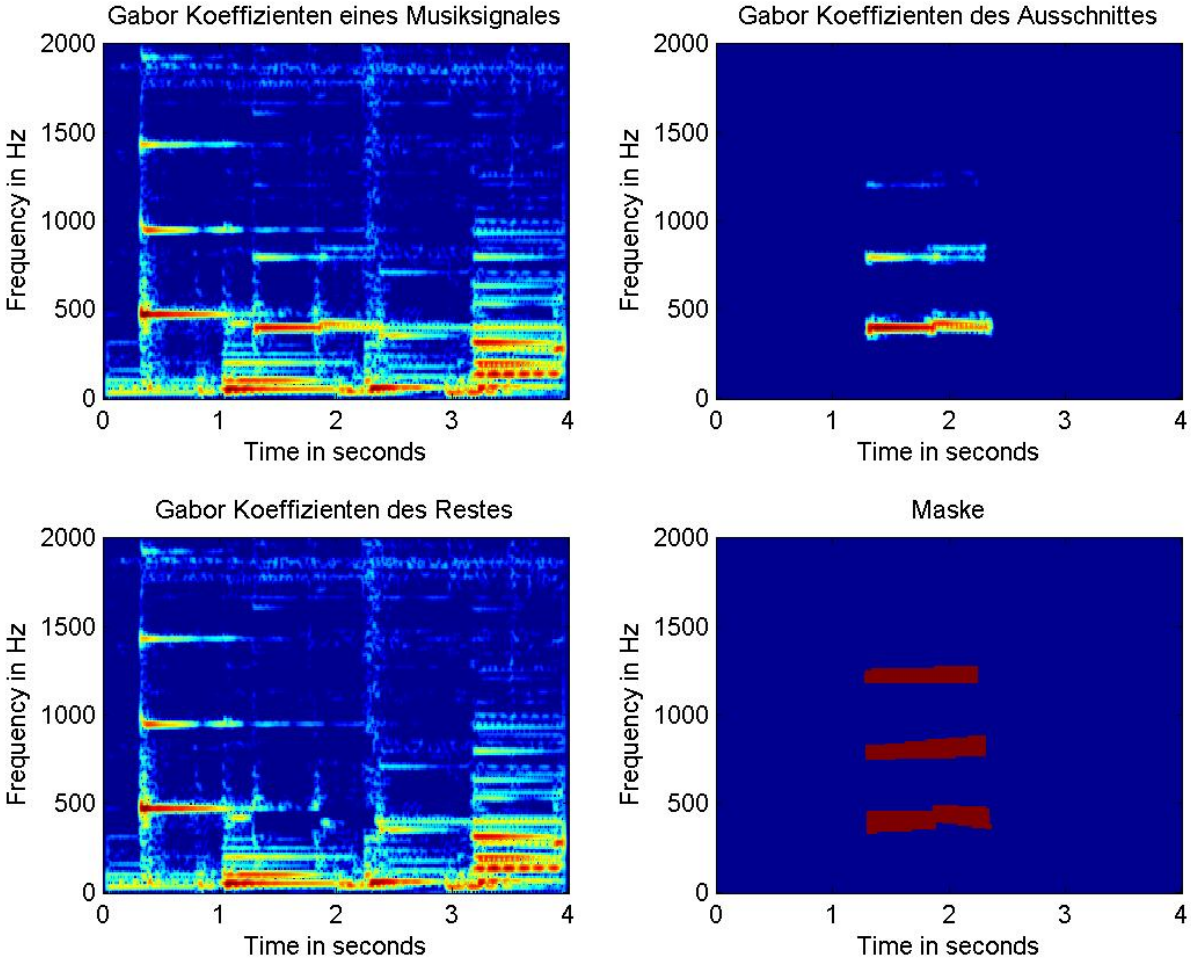


Time-frequency Multipliers



(*Listen!*)

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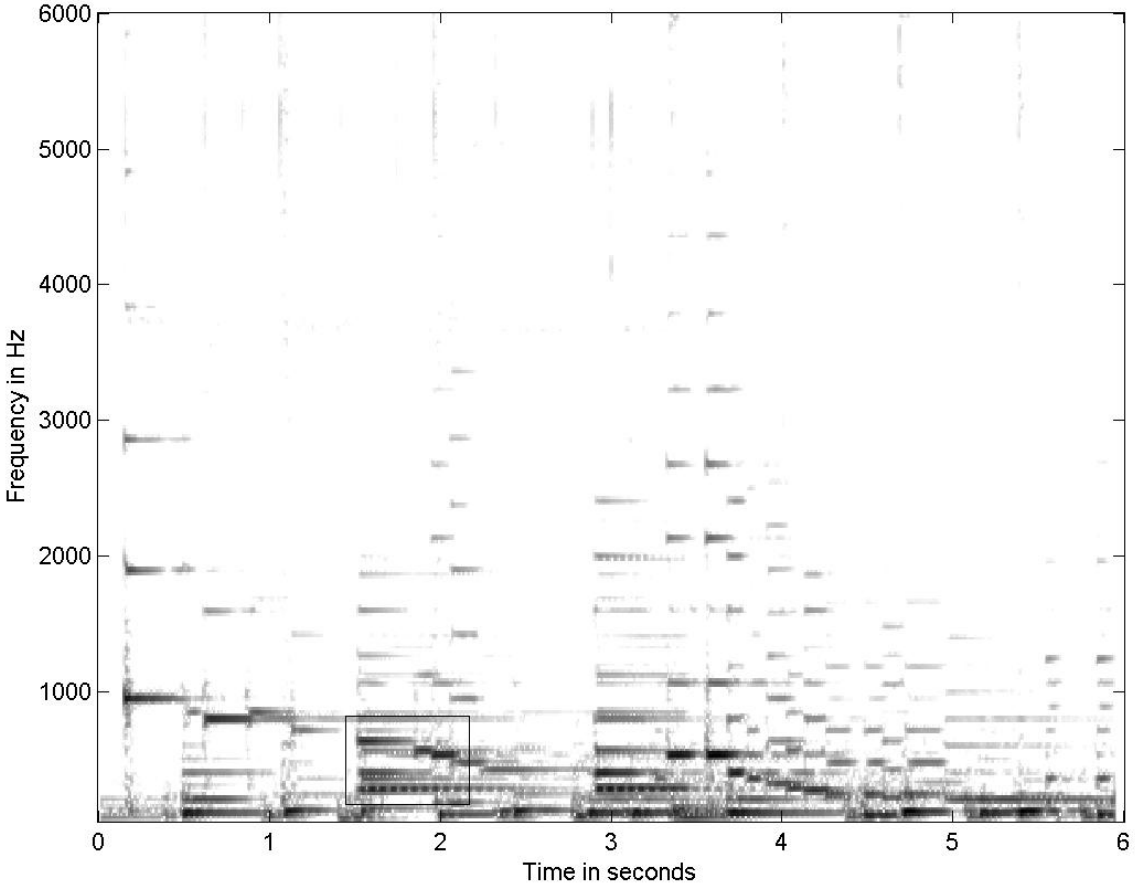

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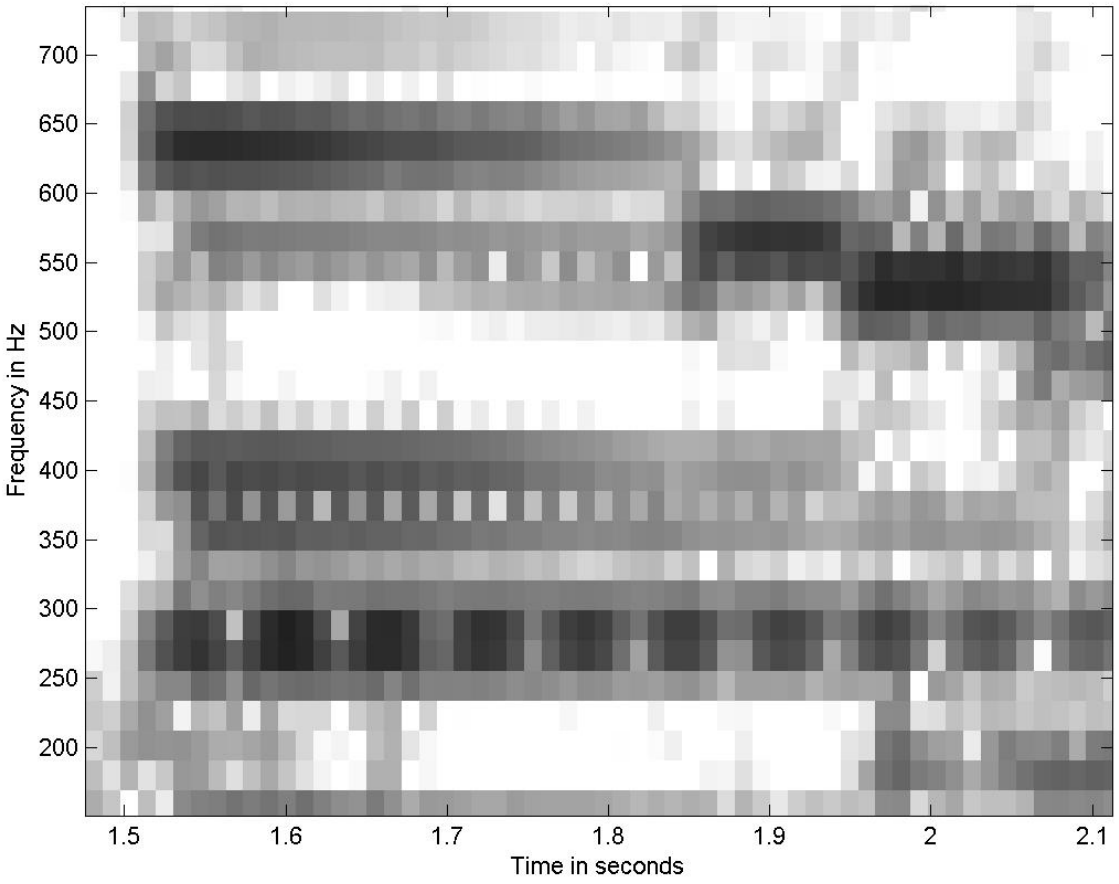

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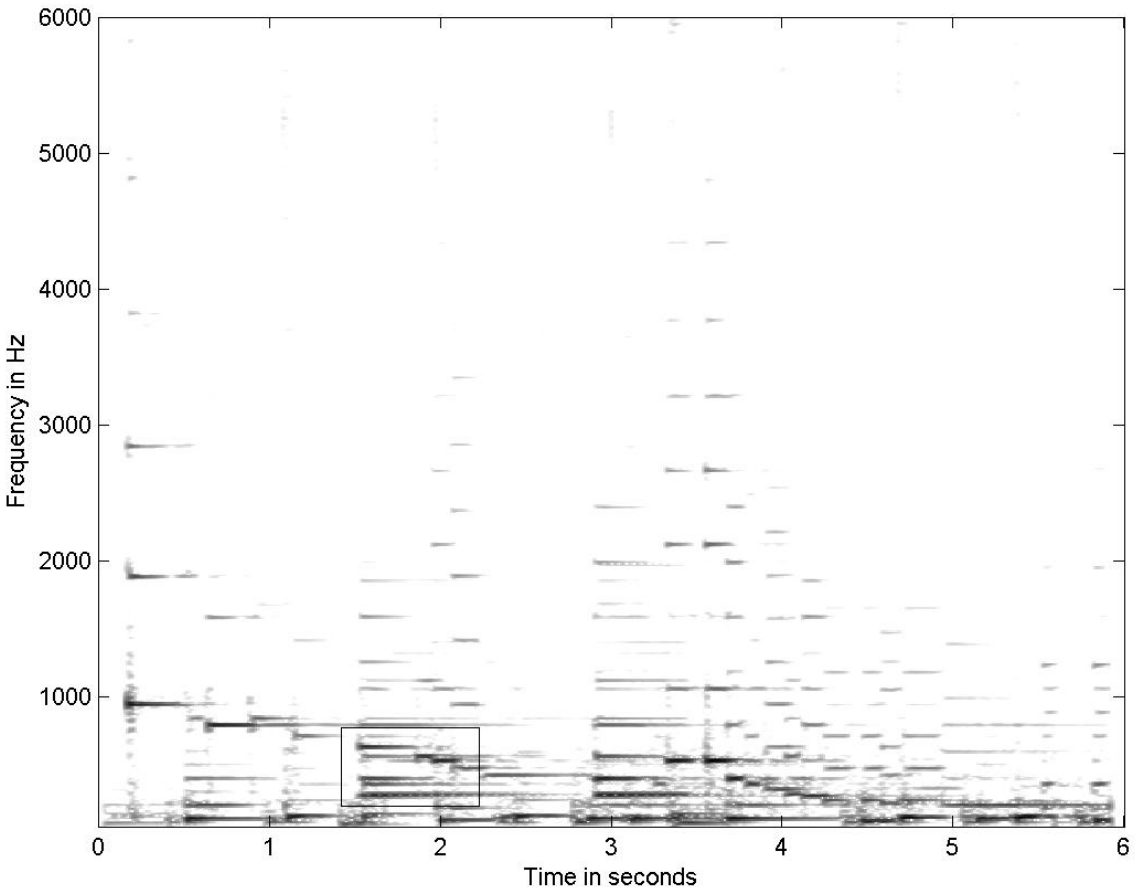

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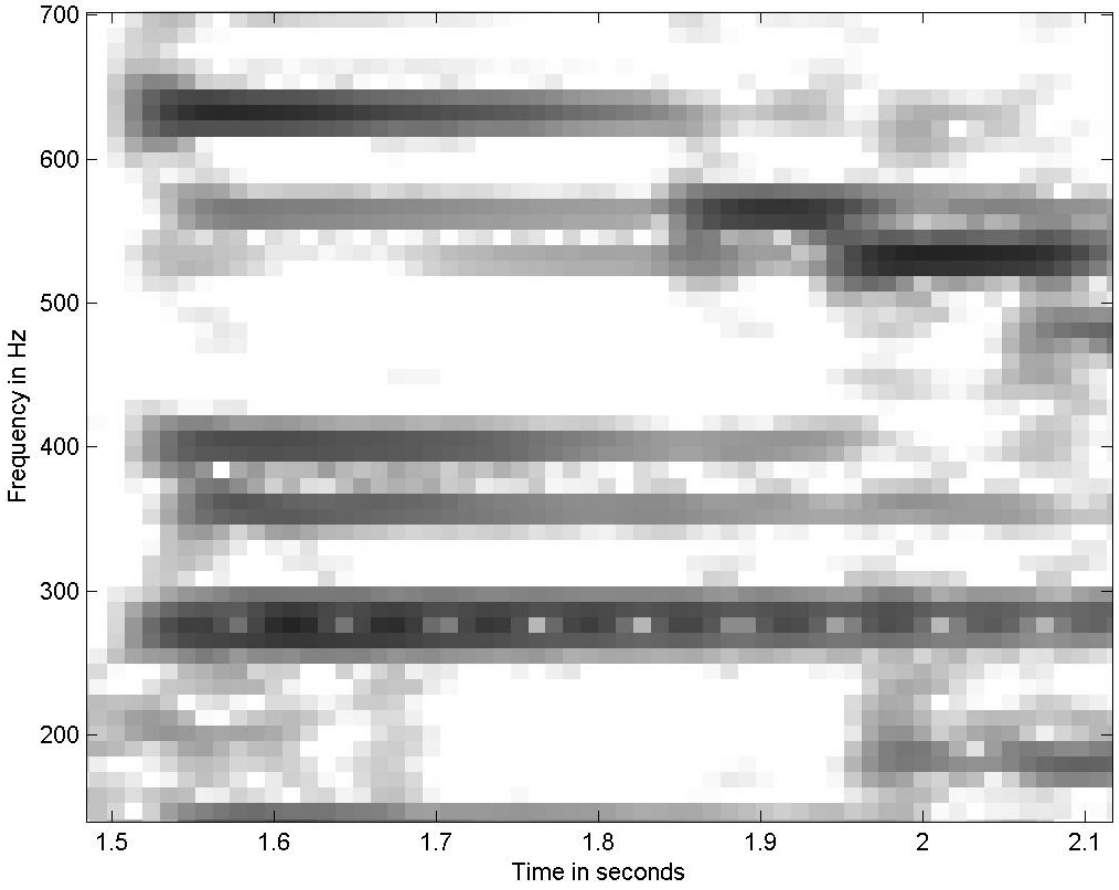

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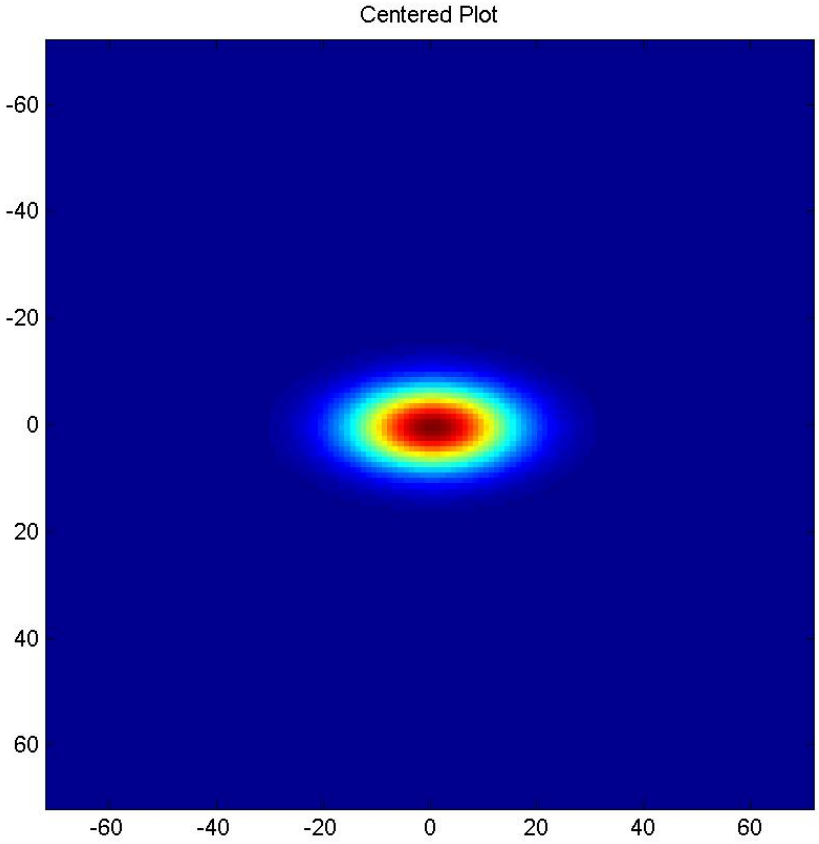
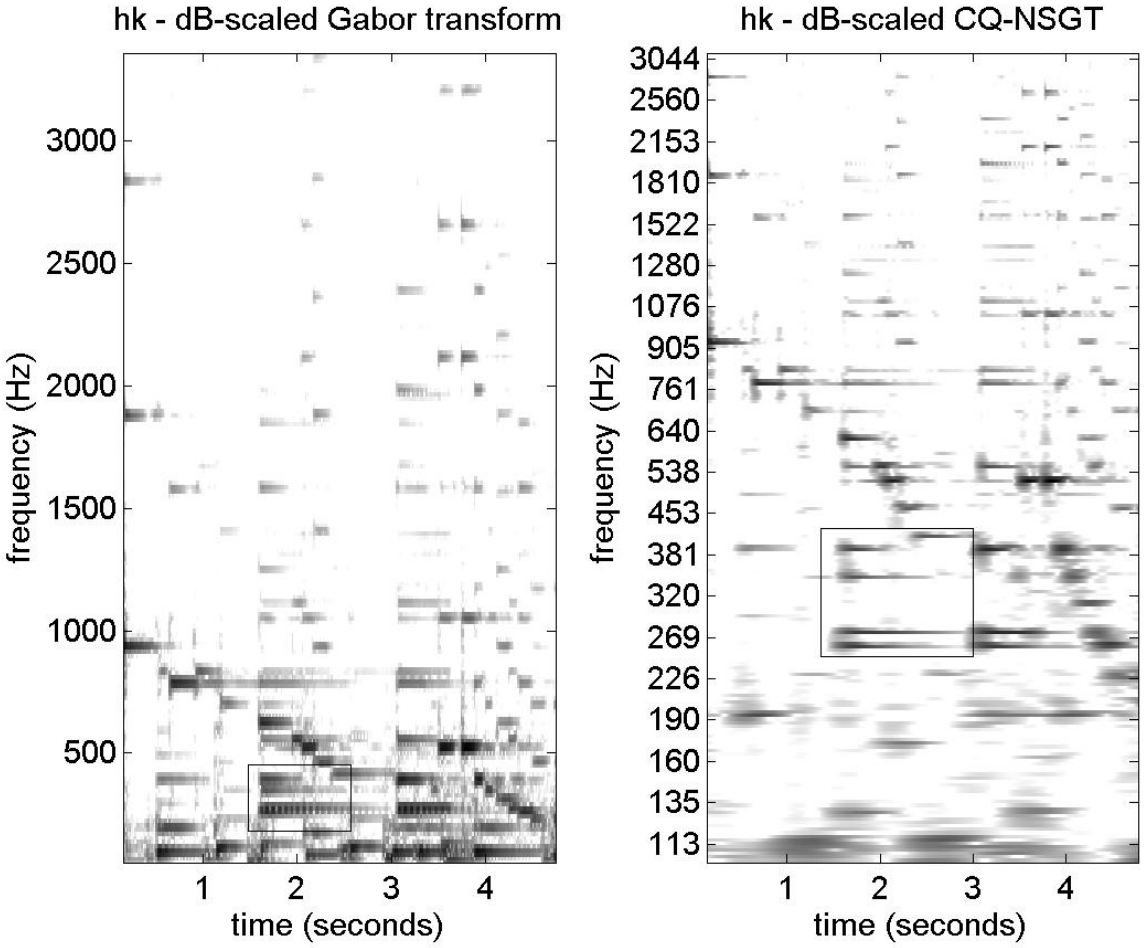


Adaptive signal representations



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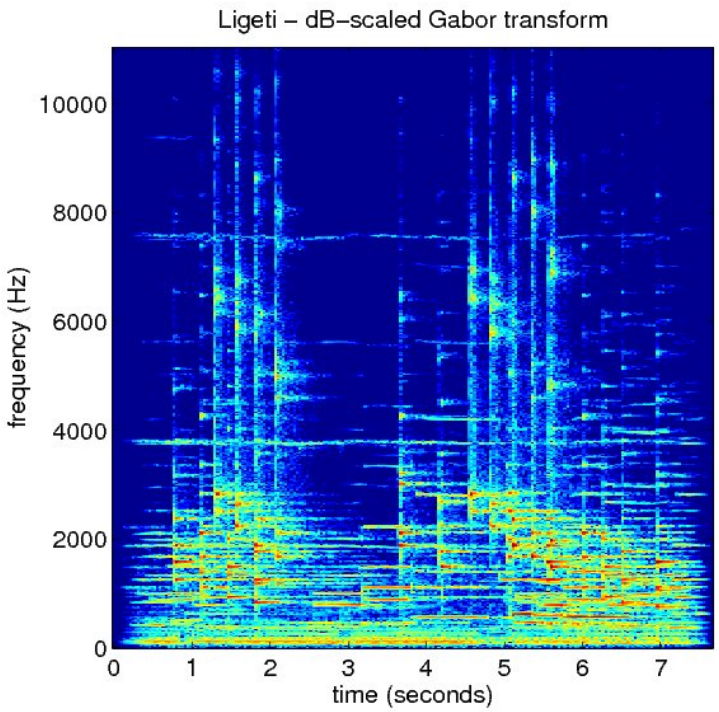

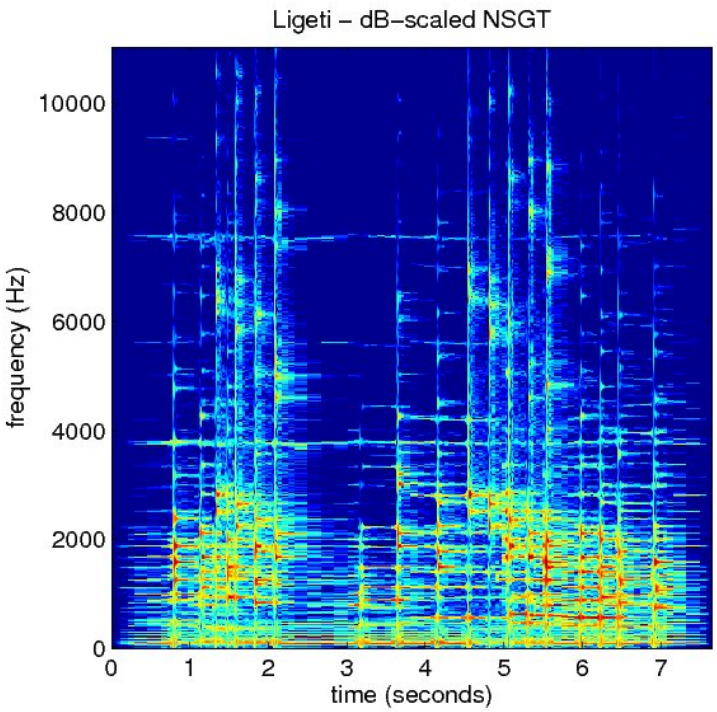

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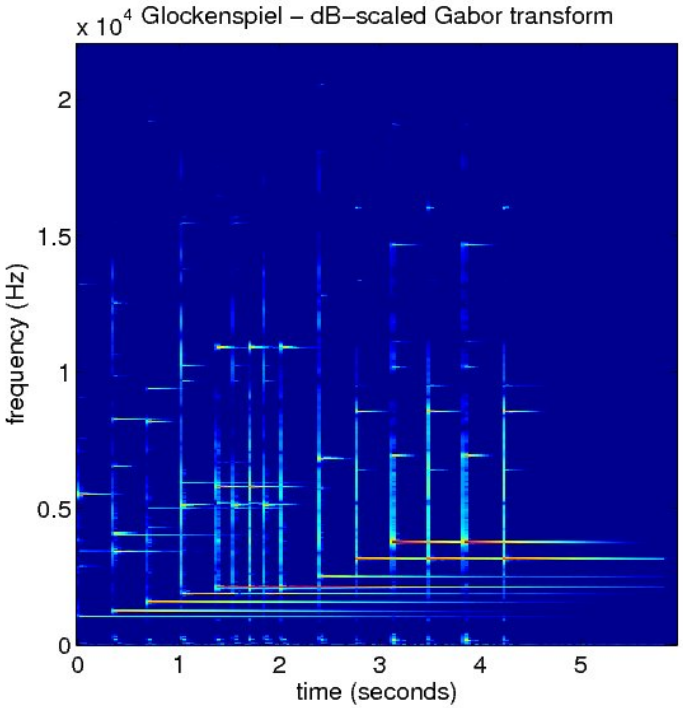

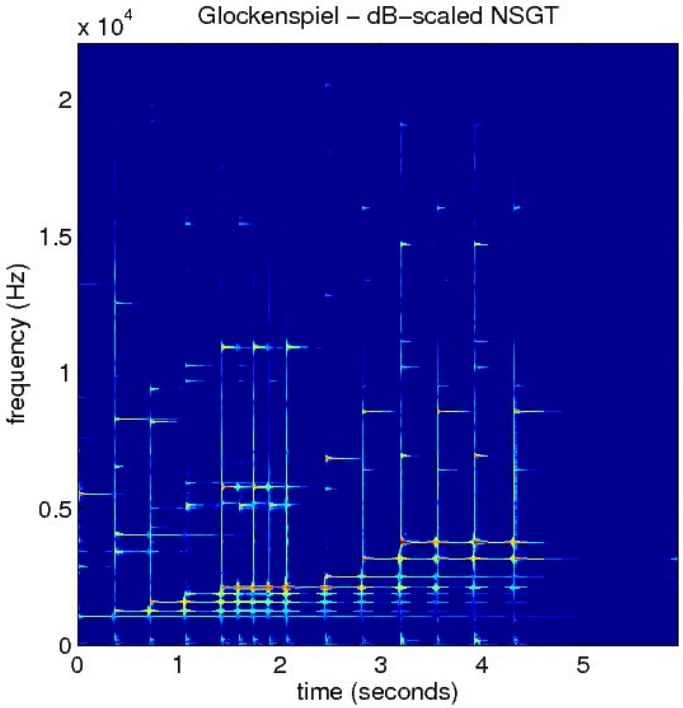

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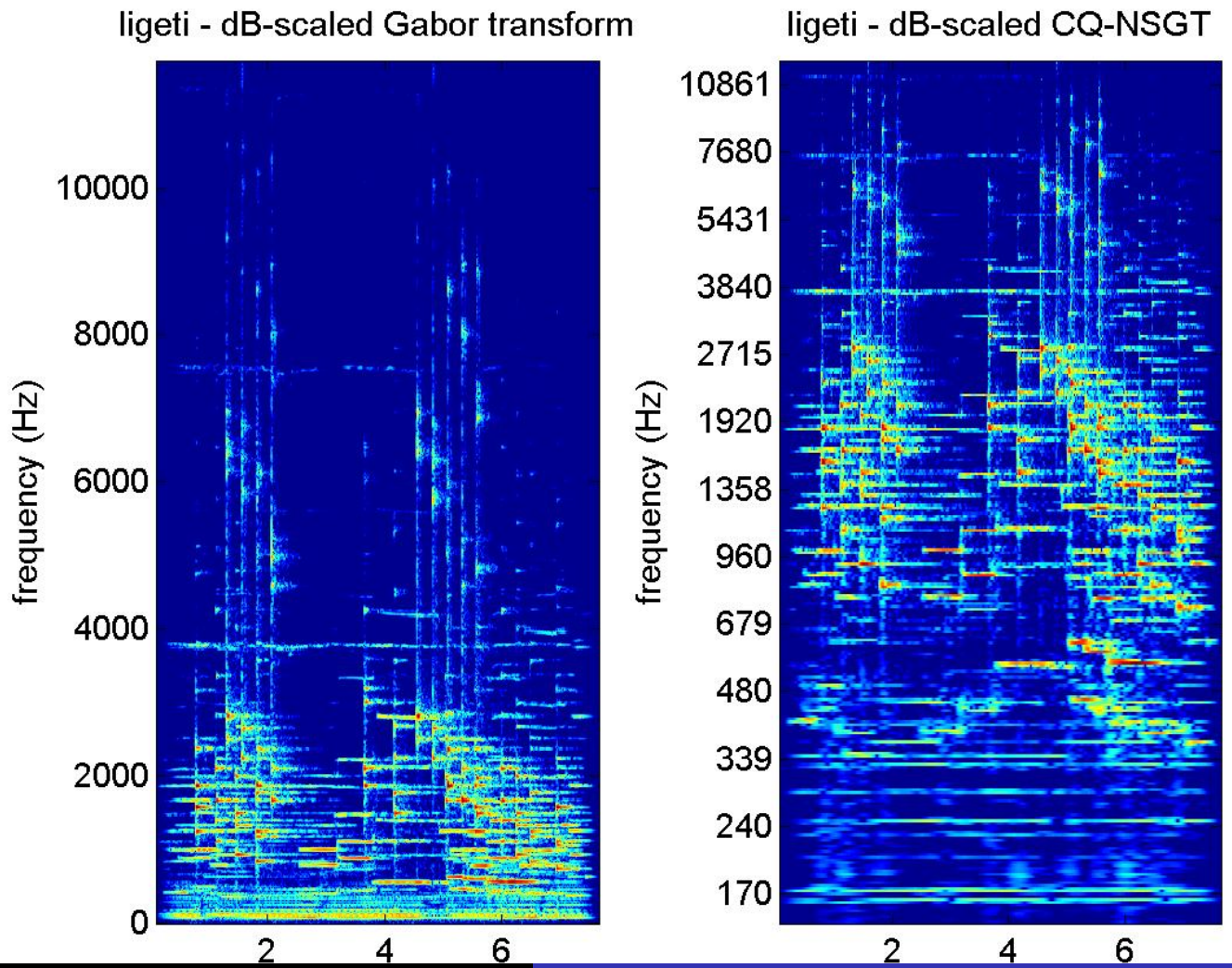
Exploring non-stationarity on the frequency side



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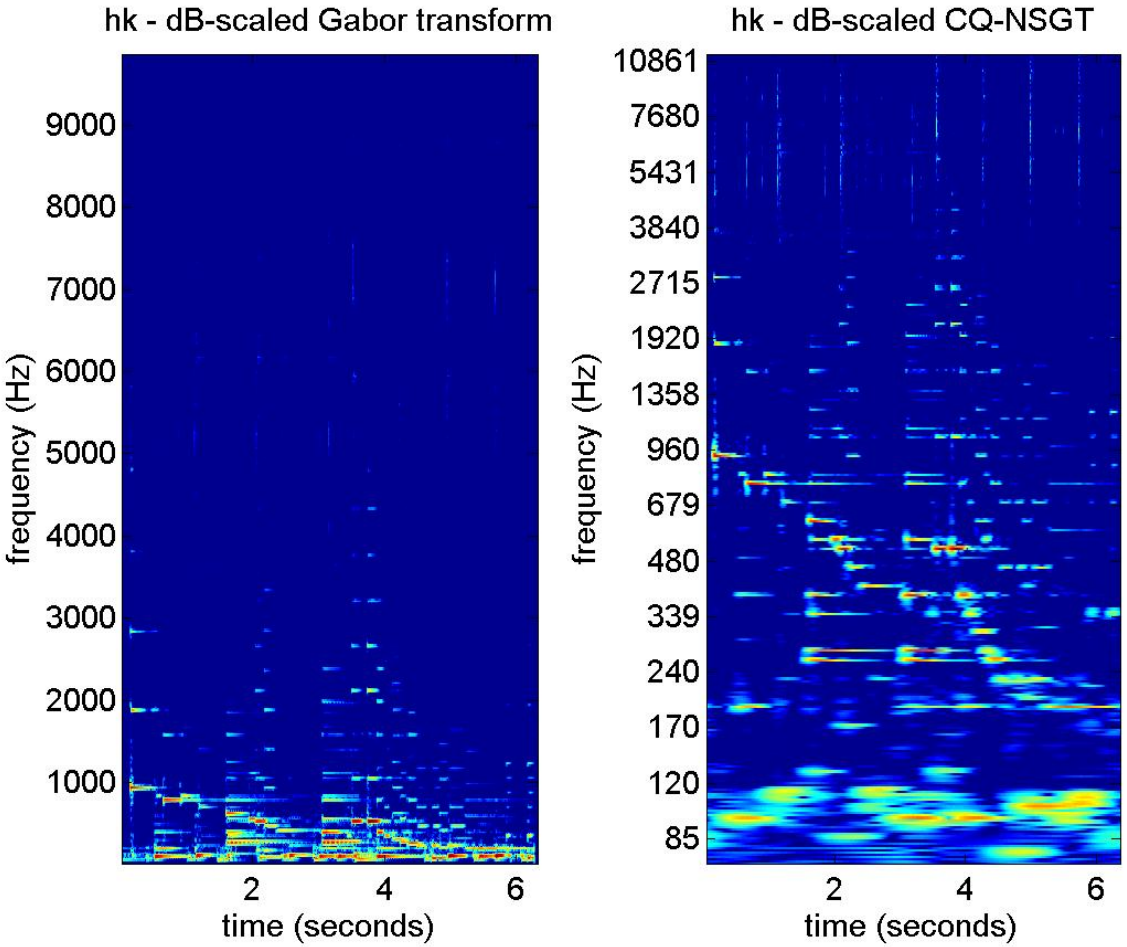

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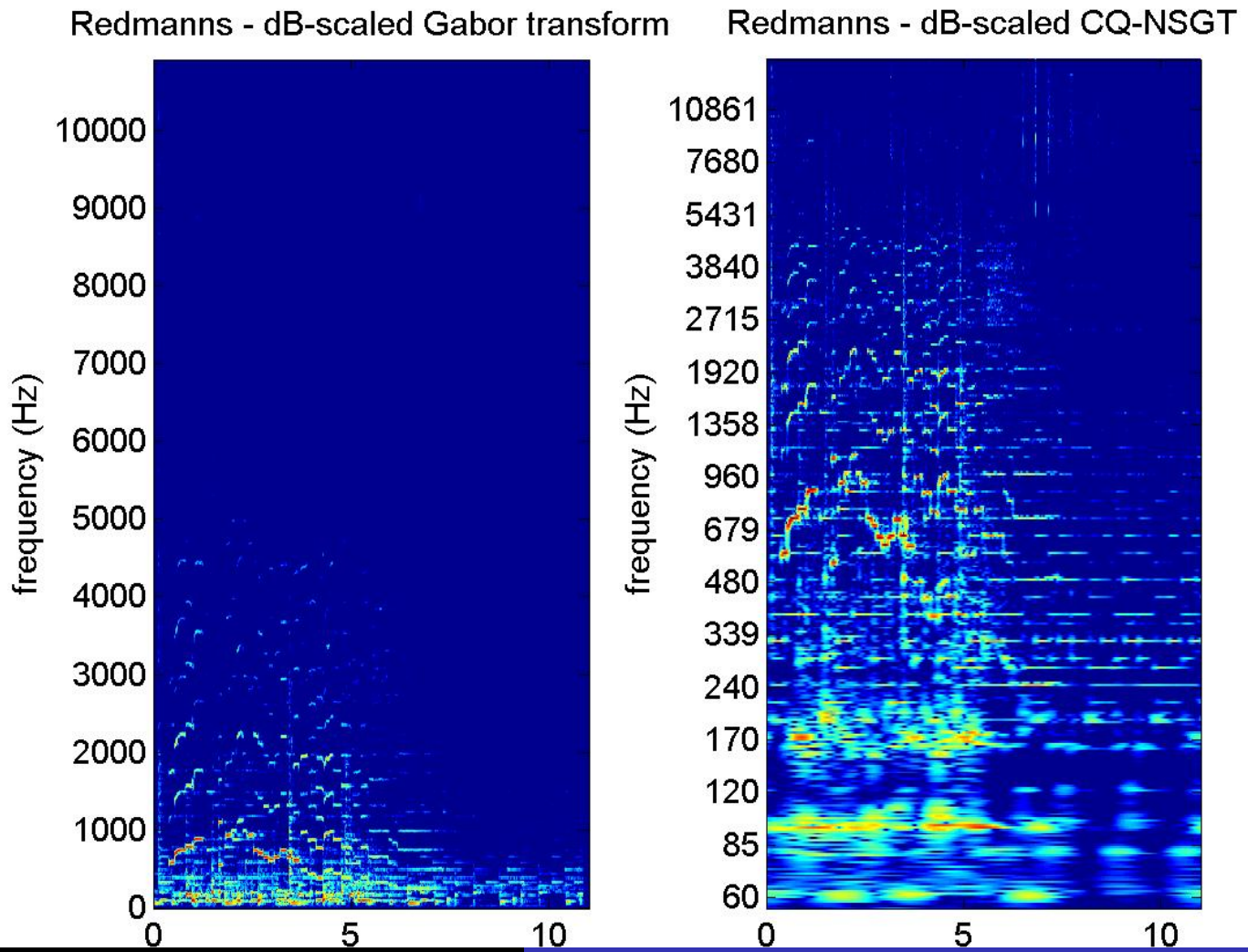

DISCUSSION

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- The meaning of adaptivity: salience of sound objects/Gestalts.

Sparsity and structured representations

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- Systematic formulation of thresholding operators allows for weighting in the time-frequency domain
- Related iterative algorithms are evaluated on synthetic and real-life audio signals in the context of denoising and multi-layer decomposition.
- Shape of the weighting masks influences results

Regression problems with mixed-norm priors

$$\Delta(f) = \| \sum_{n,k} c_{n,k} \varphi^t_{n,k} - \hat{f} \|_2^2 + \mu \| \mathbf{c} \|_{\ell^1}$$

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...becomes...

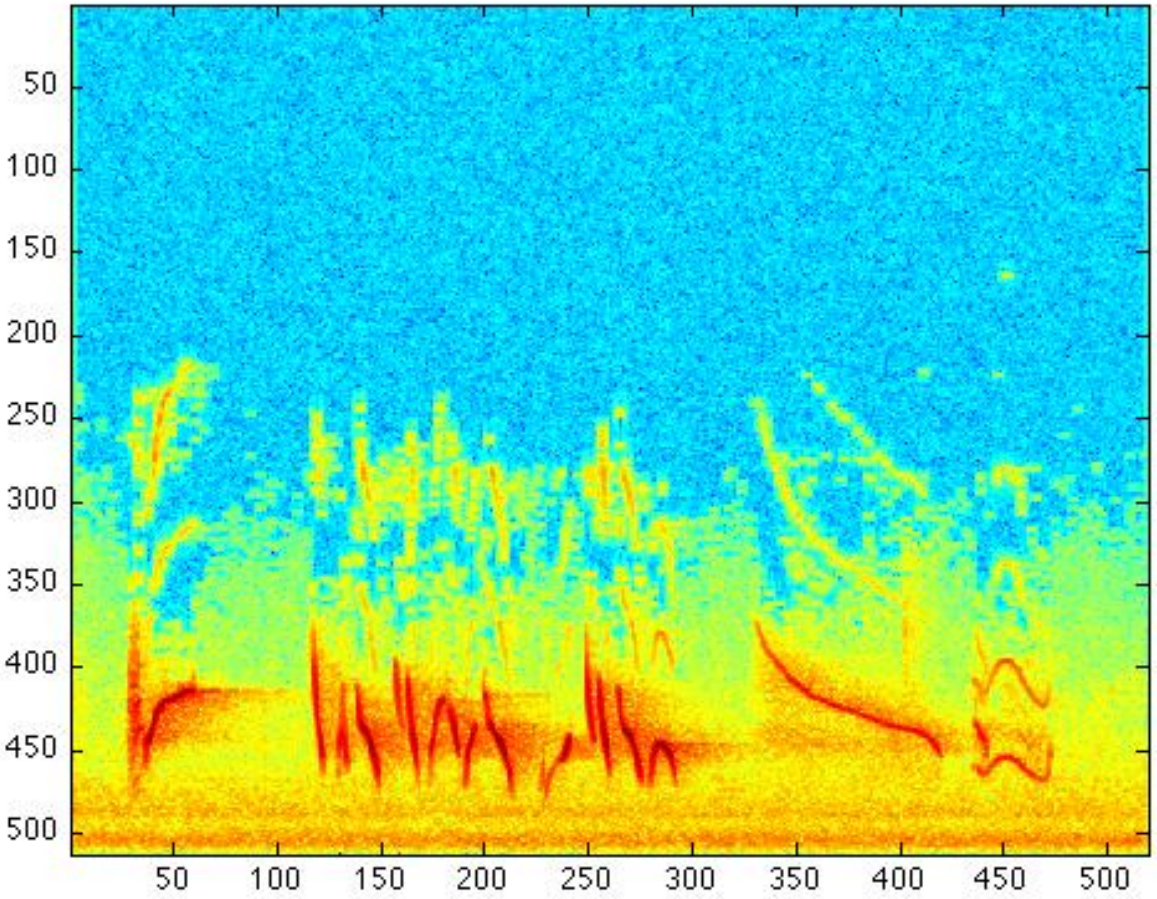
$$\Delta(f) = \| \sum_{n,k} c_{n,k} \varphi^t_{n,k} - \hat{f} \|_2^2 + \mu \|\mathbf{c}\|_{p,q}$$

algorithmic solution is iterative soft thresholding.

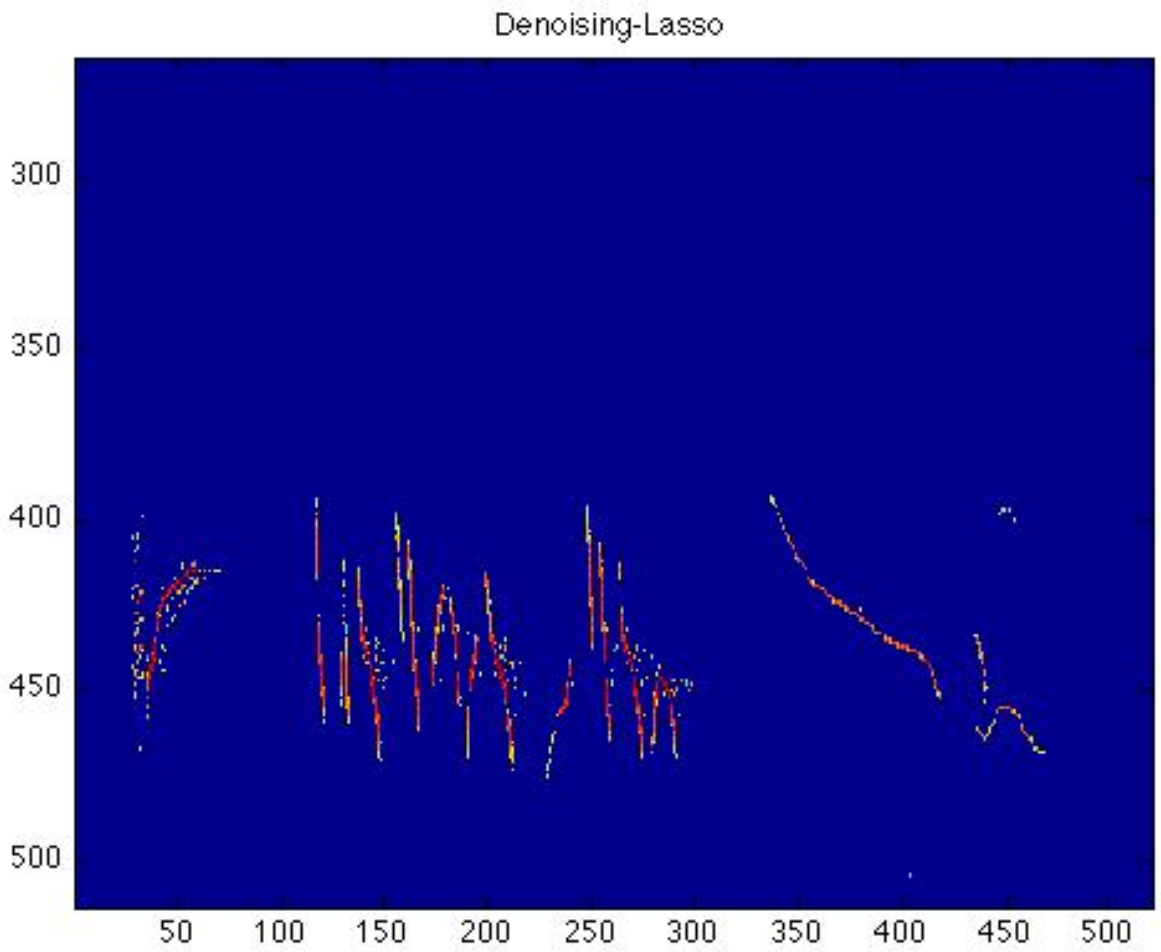
Thresholding operators with weighting in the time-frequency domain

$$\mathbb{S}_\omega(c_\gamma) = c_\gamma\left(1 - \frac{\mu}{\left(\sum_{\gamma' \in U_\gamma} \nu_\gamma(\gamma')|c_{\gamma'}|^2\right)^{1/2}}\right)^+$$

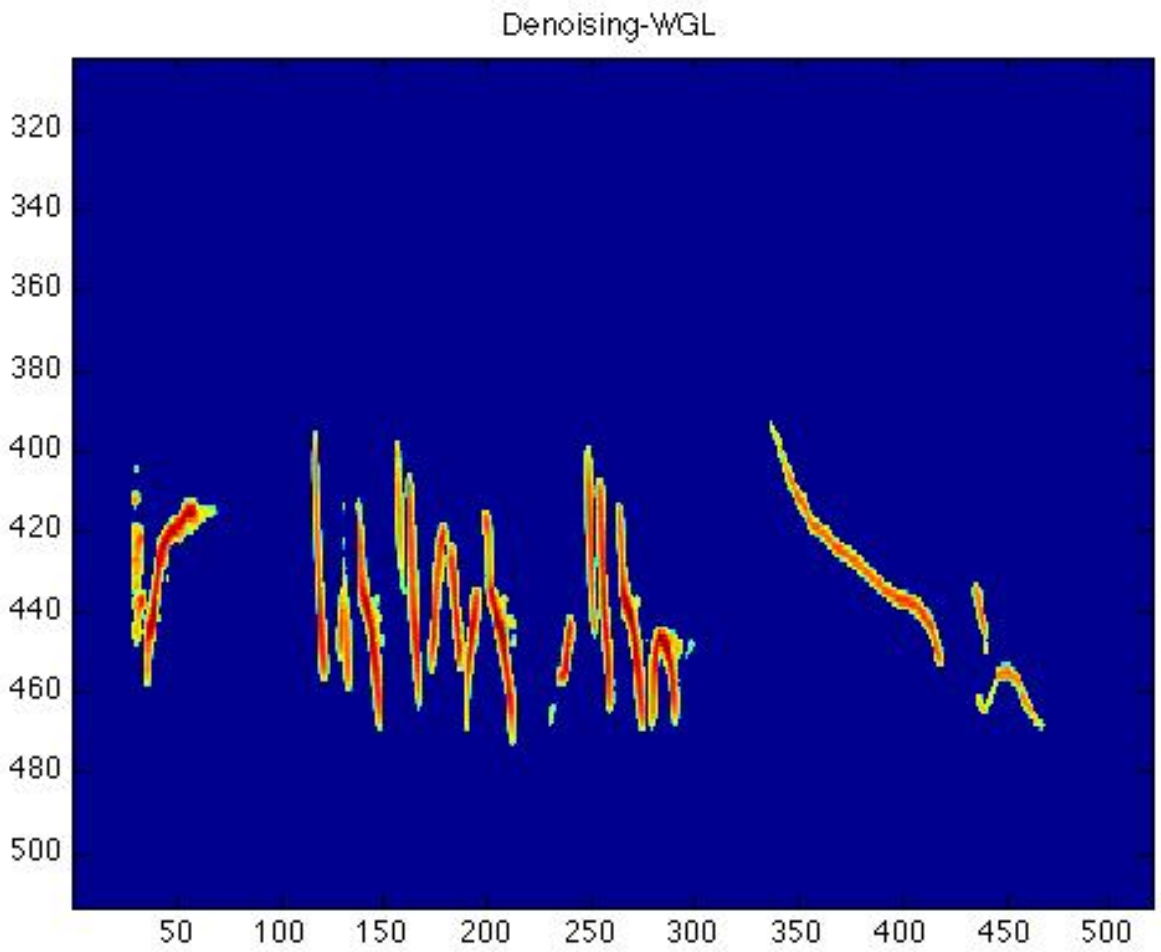
Application to denoising-Bird



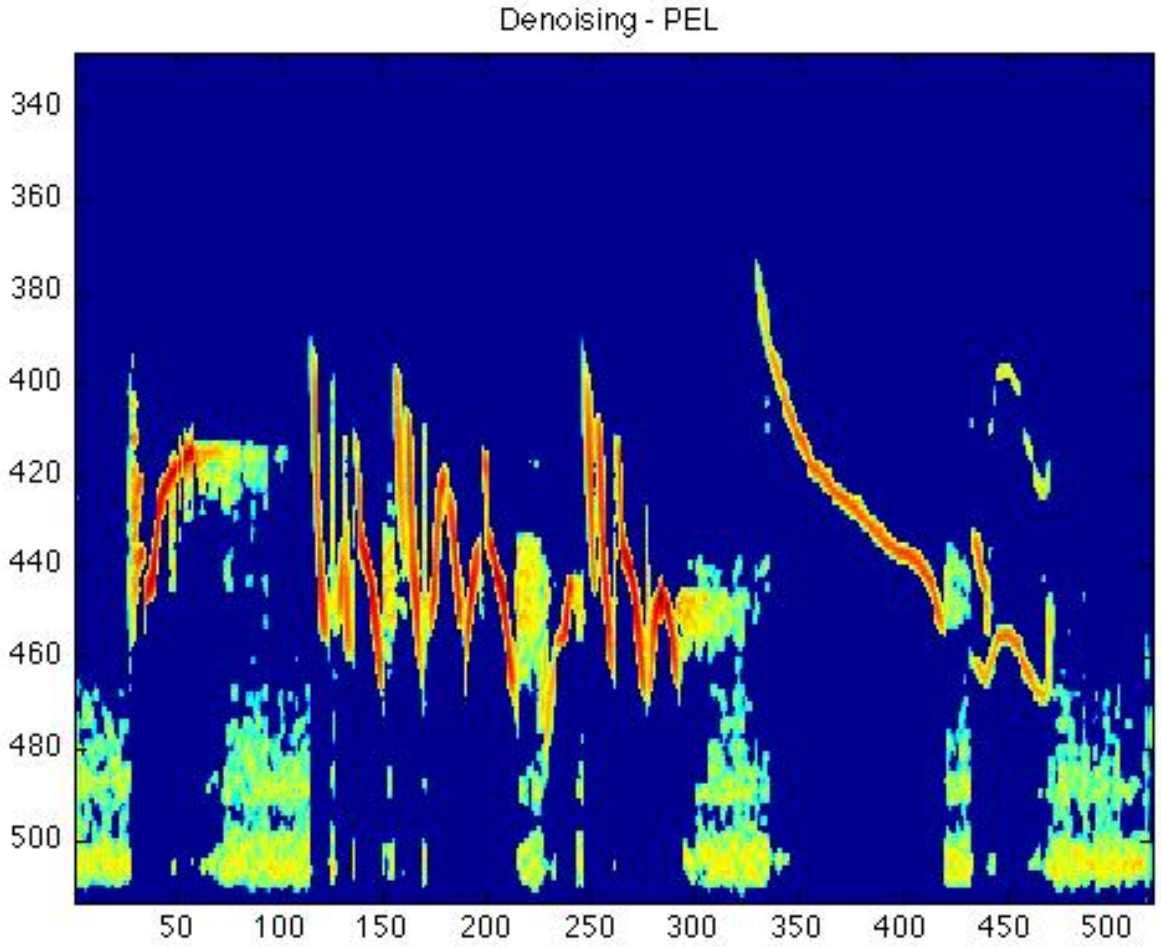
Application to denoising - Lasso, unstructured



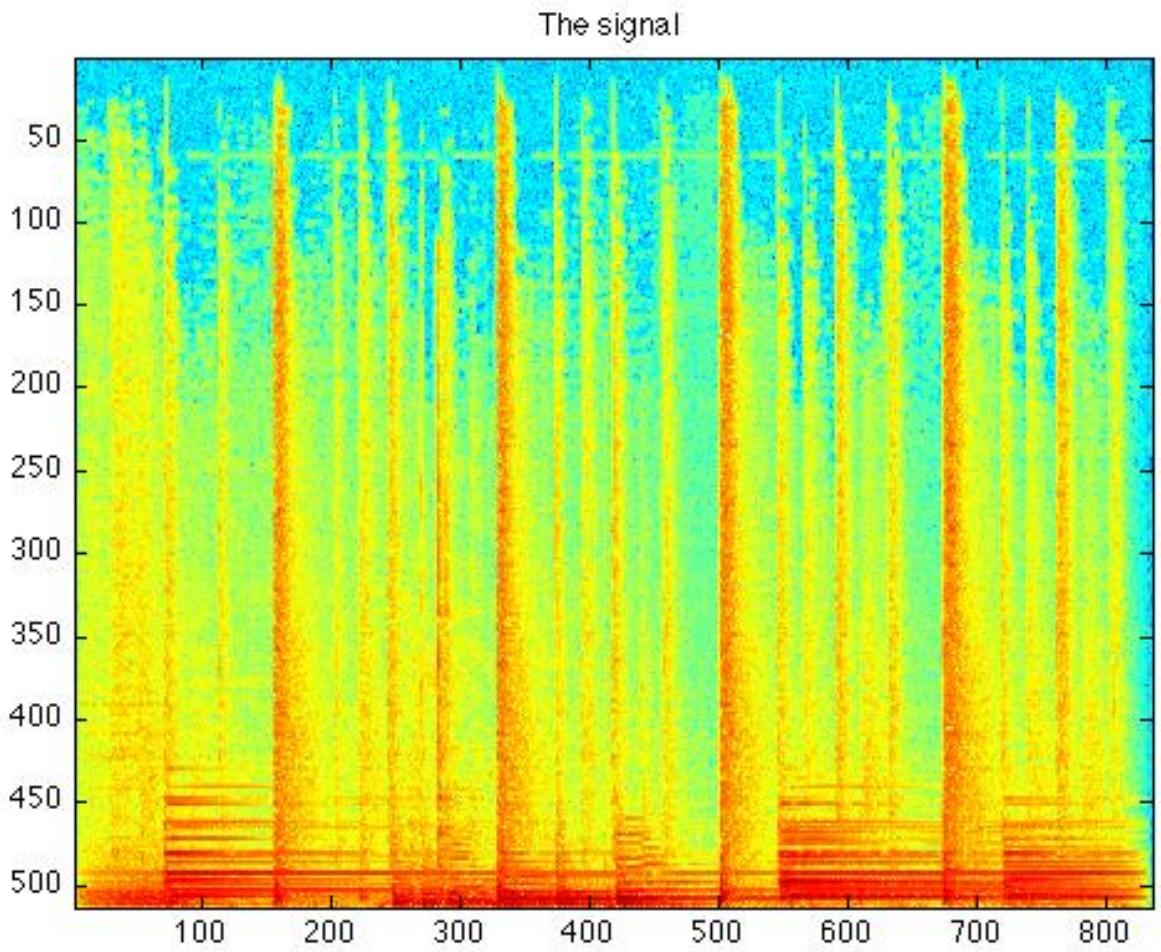
Application to denoising - Windowed Lasso



Application to denoising - Persistent Elitist Lasso



Application to multi-layer decomposition.



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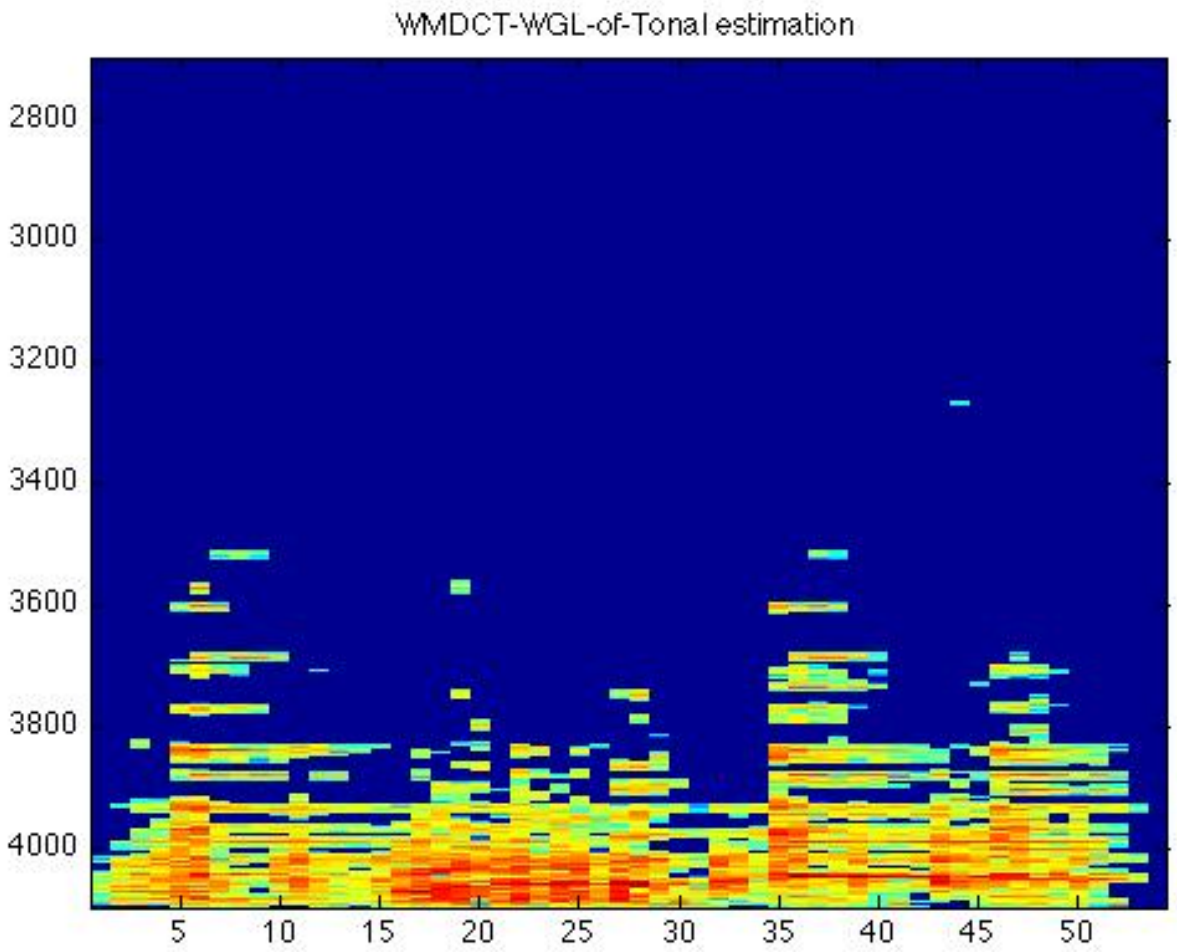

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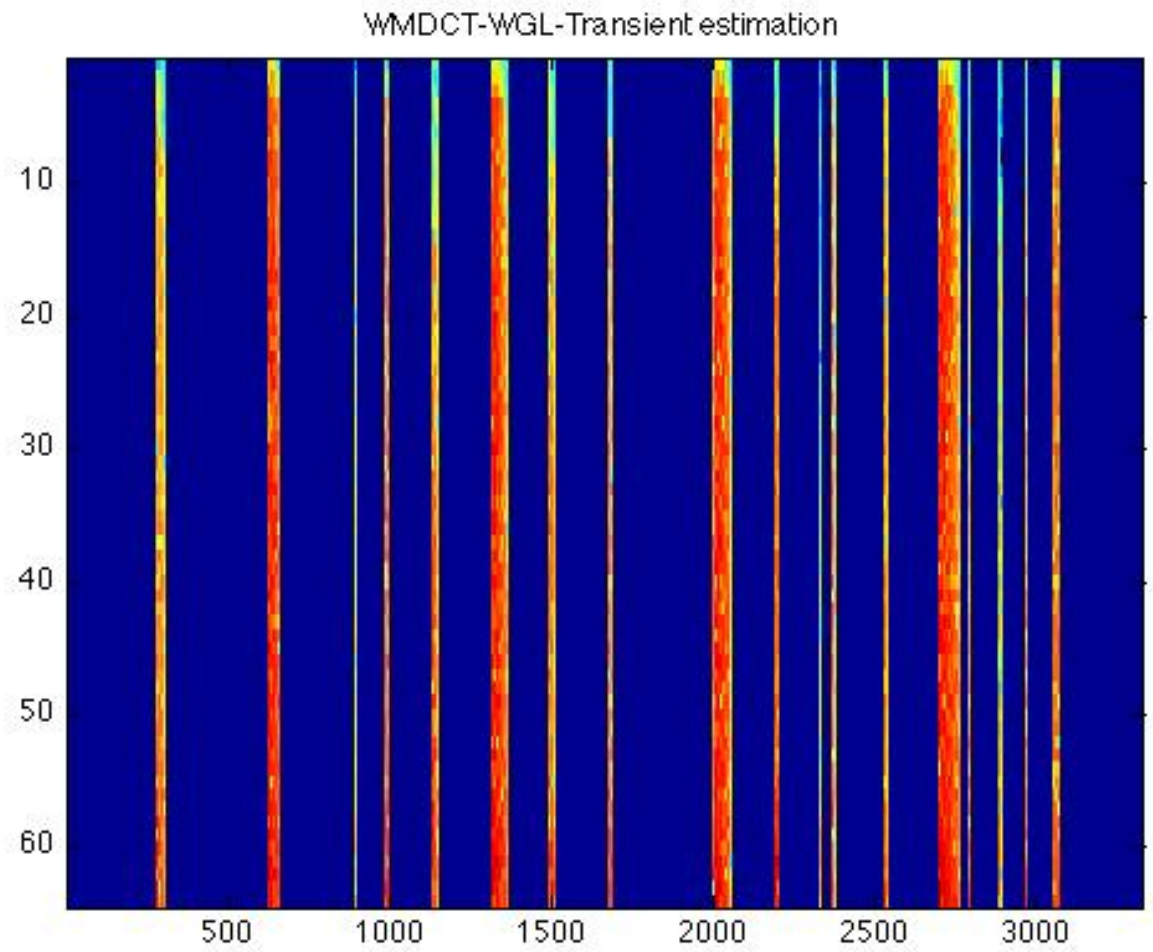
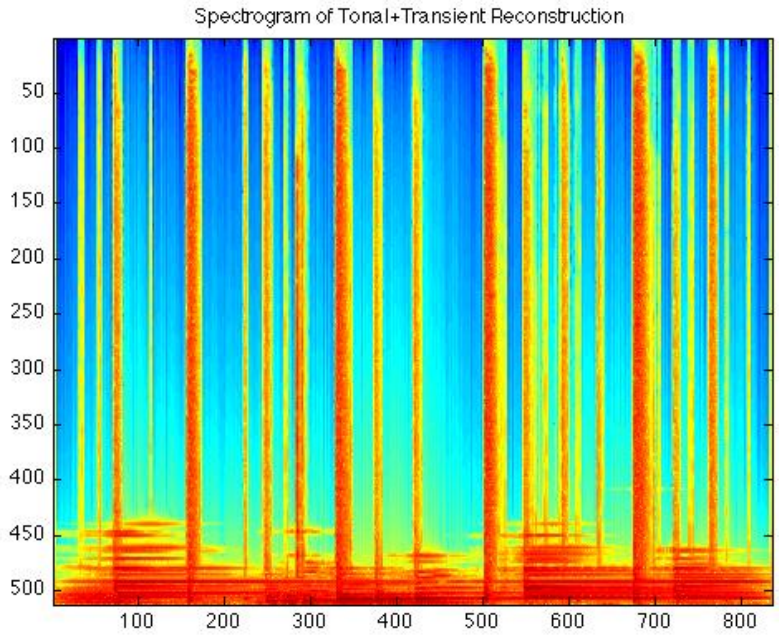


Application to multi-layer decomposition.

- Listen to residual!



(*Reconstruction Ton+Trans+Res*)

Influence of weighting mask shape

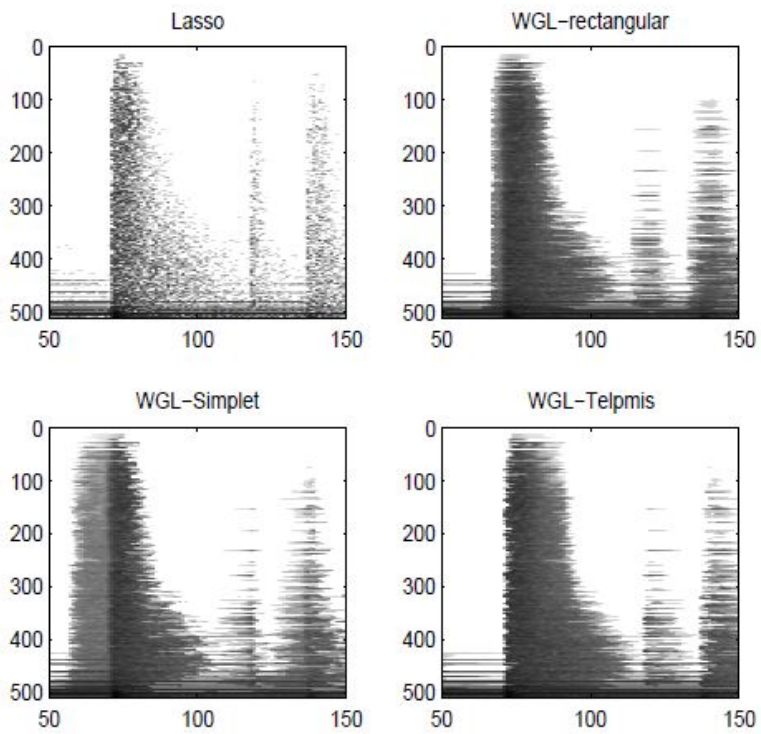


Figure: Iterated WGL shrinkage results for different shapes (i.e. weightings) of the neighborhood on an excerpt including piano, double-bass and drums and on an snare drum hit excerpt. The result of unsmoothed shrinkage, Rectangular, Simplet (= simple tent, starting at 1 and then linearly decaying to zero), Telpmis (= time-reversed simple tent)

Conclusion

- Perception of visual representation is highly dependent on analysis tools
- Also in higher level processing, this influence should be considered
- Prior knowledge can also be used in low level processing to extract meaningful information