Nonnegative Tensor Factorization for Source Separation of Loops in Audio

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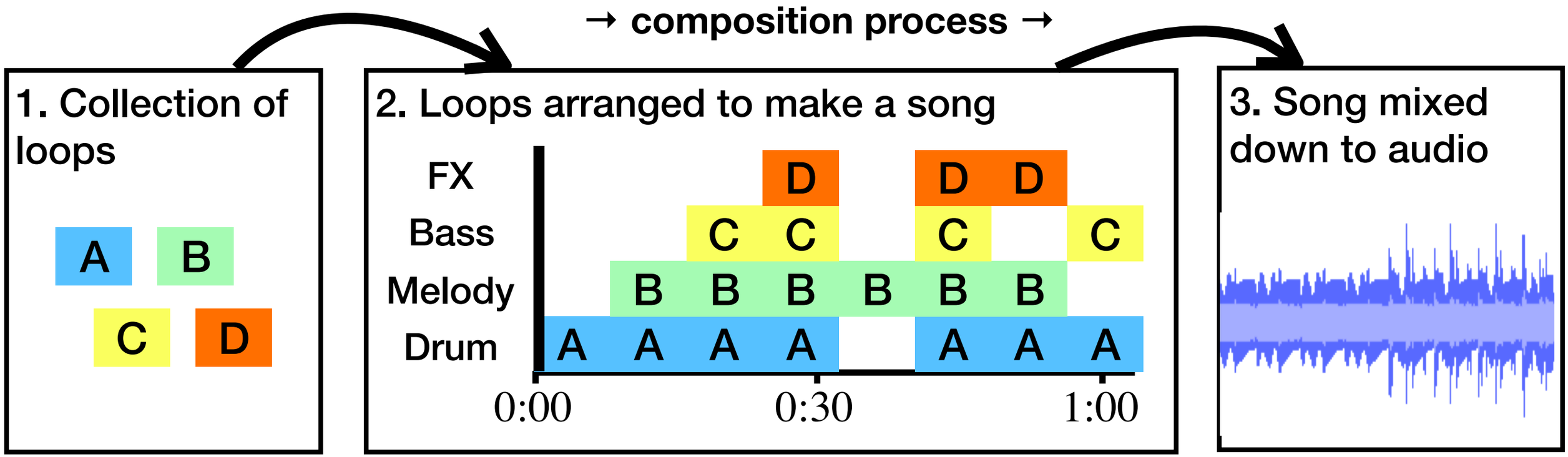
Introduction

Extracting loops from music

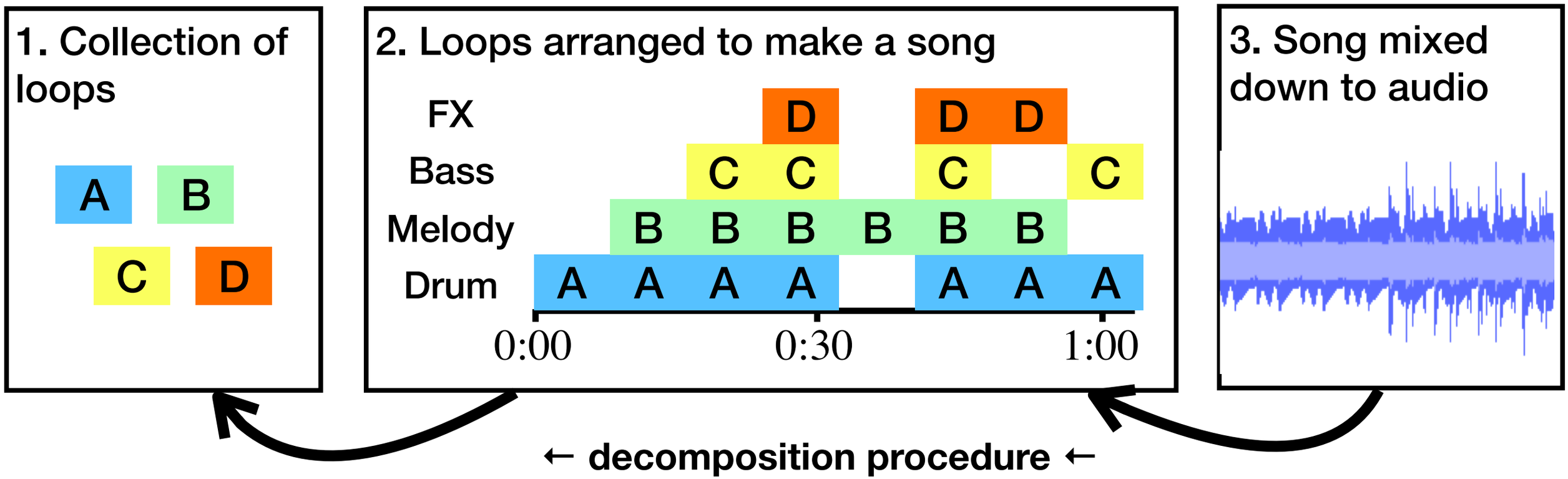
- In some musical styles, songs are built from loops. E.g.:



Audio examples (and test data) all borrowed from [López-Serrano et al. 2016]

Extracting loops from music

- In some musical styles, songs are built from loops. E.g.:

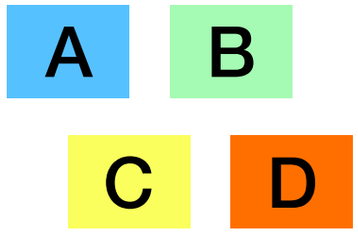


- Goal: decompose the audio signal to recover:
  - the layout of the song
  - the source-separated loops

Extracting loops from music

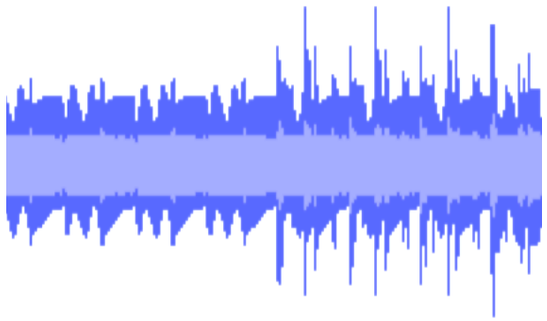
- Two previous approaches that inspired us:
  - Fingerprint-based loop detection [López-Serrano et al. 2016]

Inputs:



Original loops

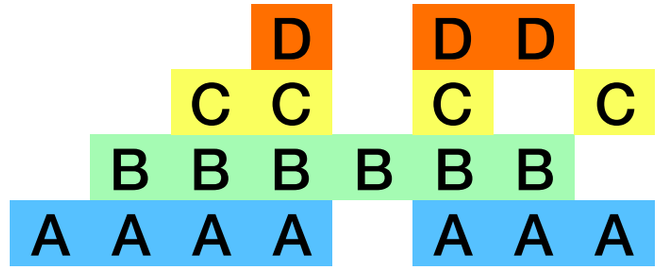
+



Mixed audio

→

Output:



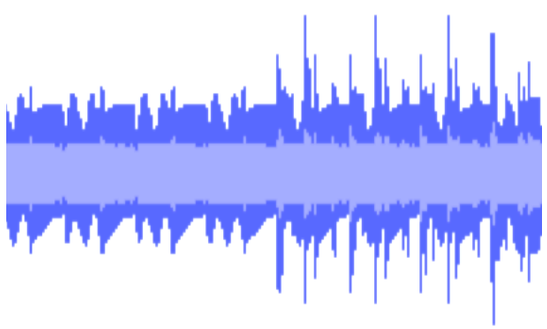
Map of loop activations

- Iterative NMF [Seetharaman & Pardo 2016]

Assumption that loops are introduced additively

Inputs:

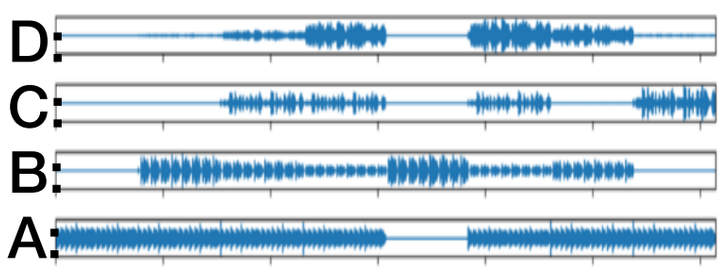
+



Mixed audio

→

Output:

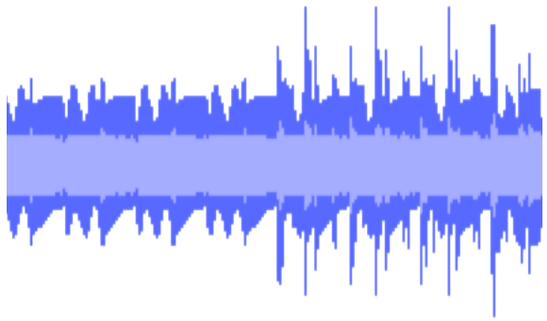


Separated tracks,
one per loop

Extracting loops from music

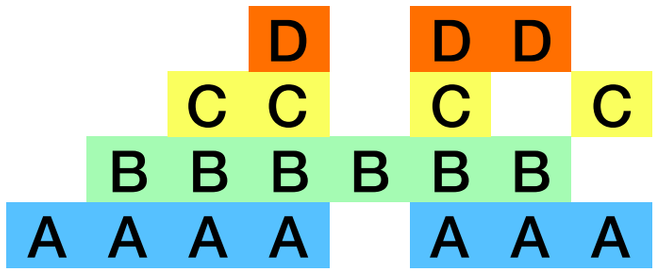
- Our proposed system:

Input:



Mixed audio

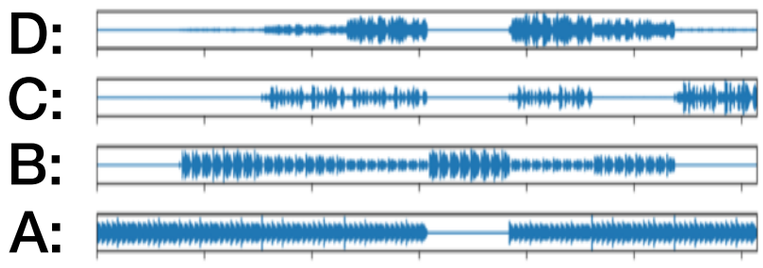
→



Map of loop activations

Outputs:

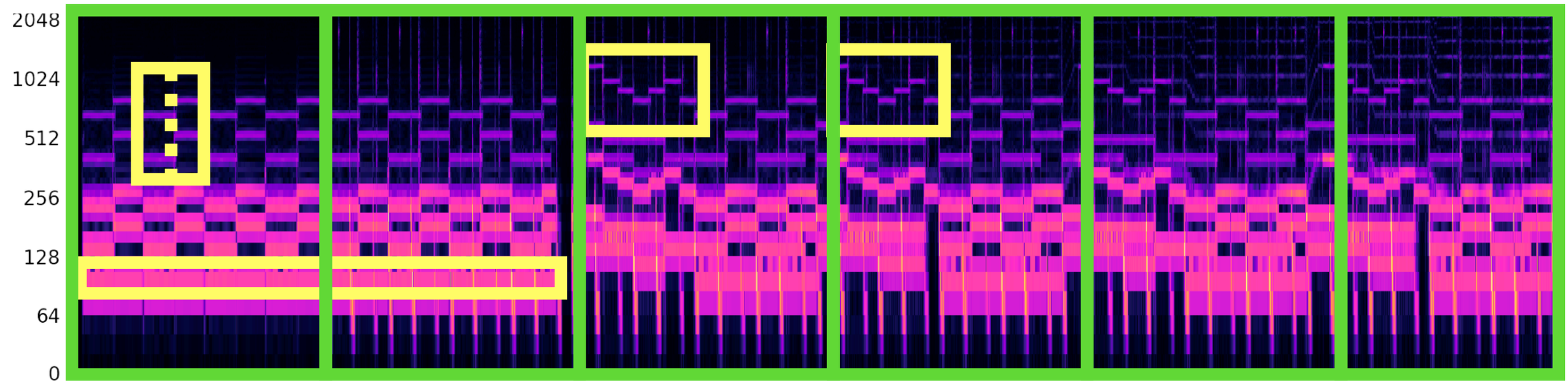
+



Separated tracks, one per loop

- We attempt to solve both problems in one step, without assumption of additive layout
- We do so by extending nonnegative matrix factorization (NMF) to handle periodicity

Source separation using NMF*



NMF can handle many types of repetition:

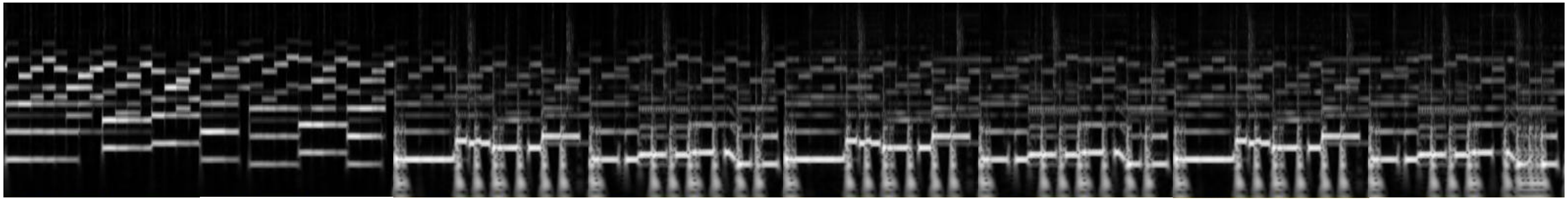
- Steady-state notes
- Note sequences repeated in time
- Transposed notes
- **Periodicity (especially at downbeats)**

- NMF with harmonic templates
- NMFD with time-evolving templates
  [Smaragdis 2004]
- NMF2D with transposed harmonic templates
  [e.g., FitzGerald, Cranitch & Coyle 2008]
- **...no nonnegative approach! NB: REPET, a median-filtering approach**
  [Rafii, Liutkus, & Pardo 2014]

Method

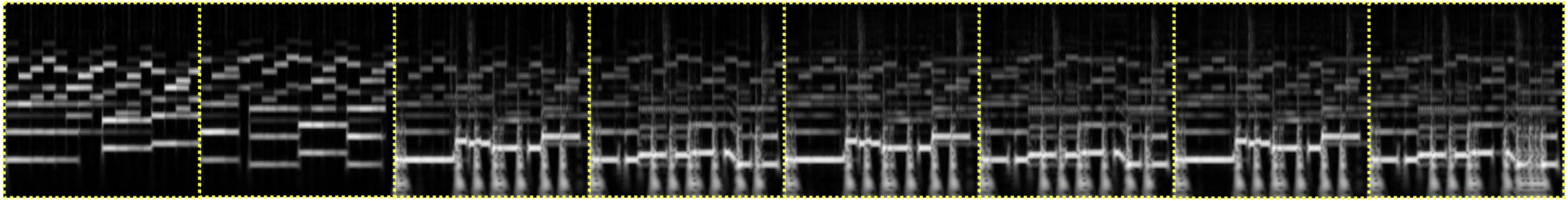
Nonnegative tensor factorization

- Step 1: estimate downbeats [madmom, Böck et al. 2016]



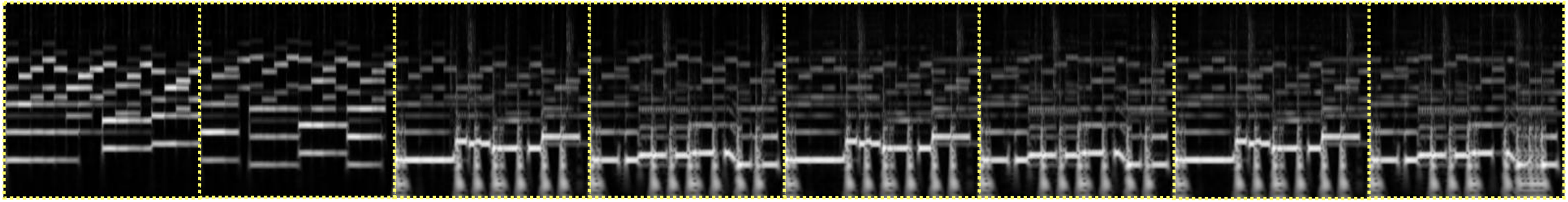
Nonnegative tensor factorization

- Step 1: estimate downbeats [madmom, Böck et al. 2016]



Nonnegative tensor factorization

- Step 1: estimate downbeats
- Step 2: stack the 2D spectrograms into a 3D volume (a “spectral cube”)



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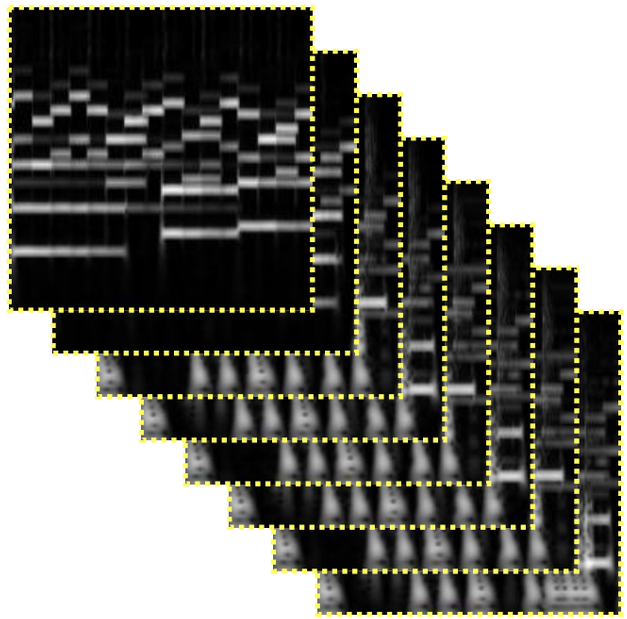

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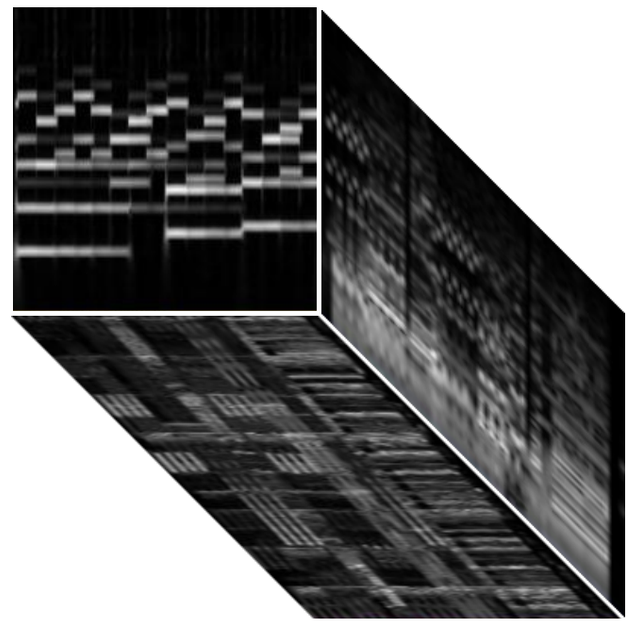
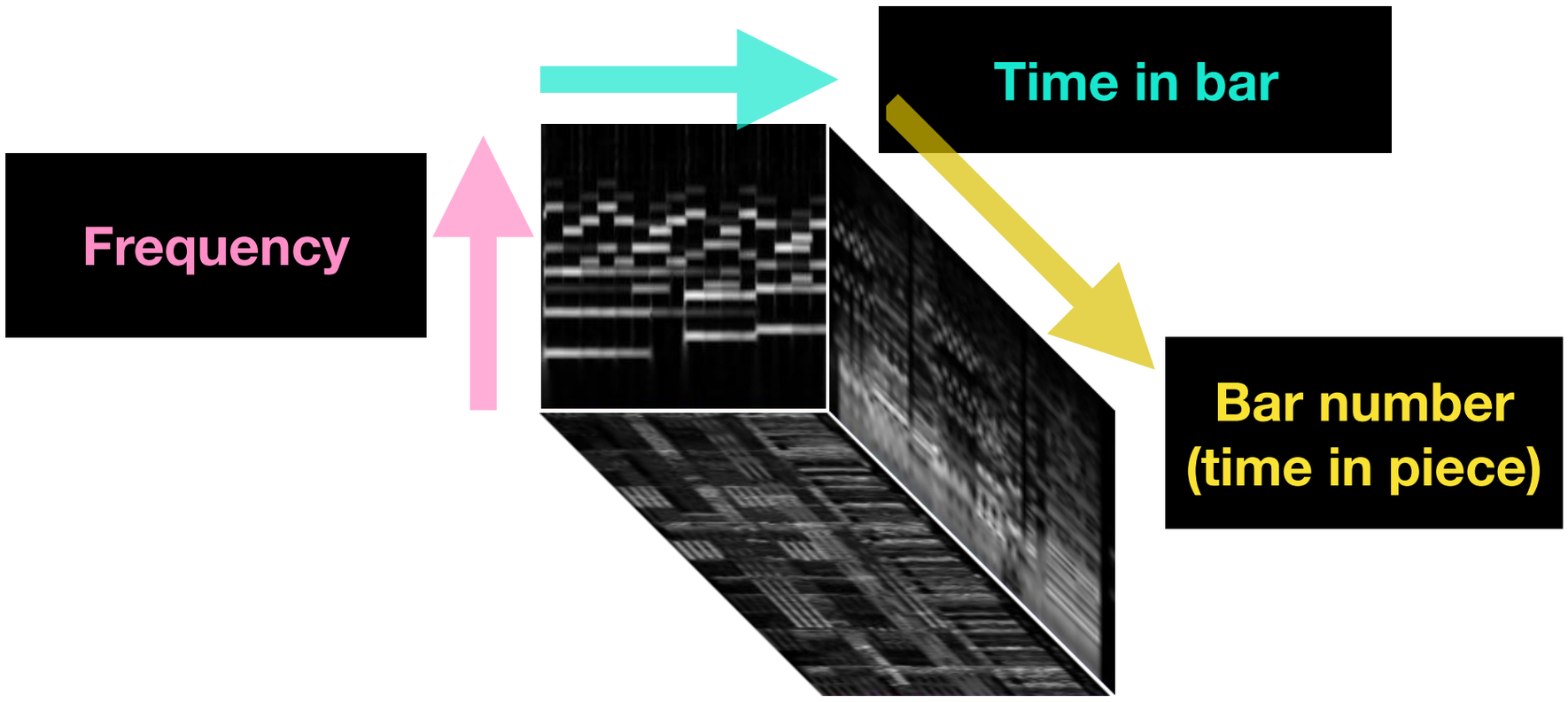
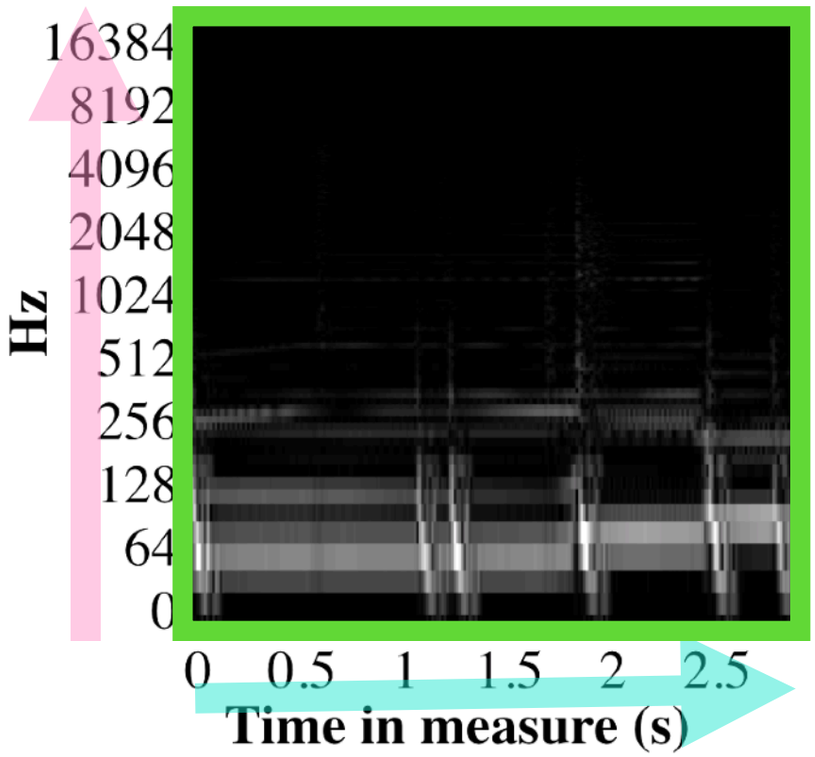
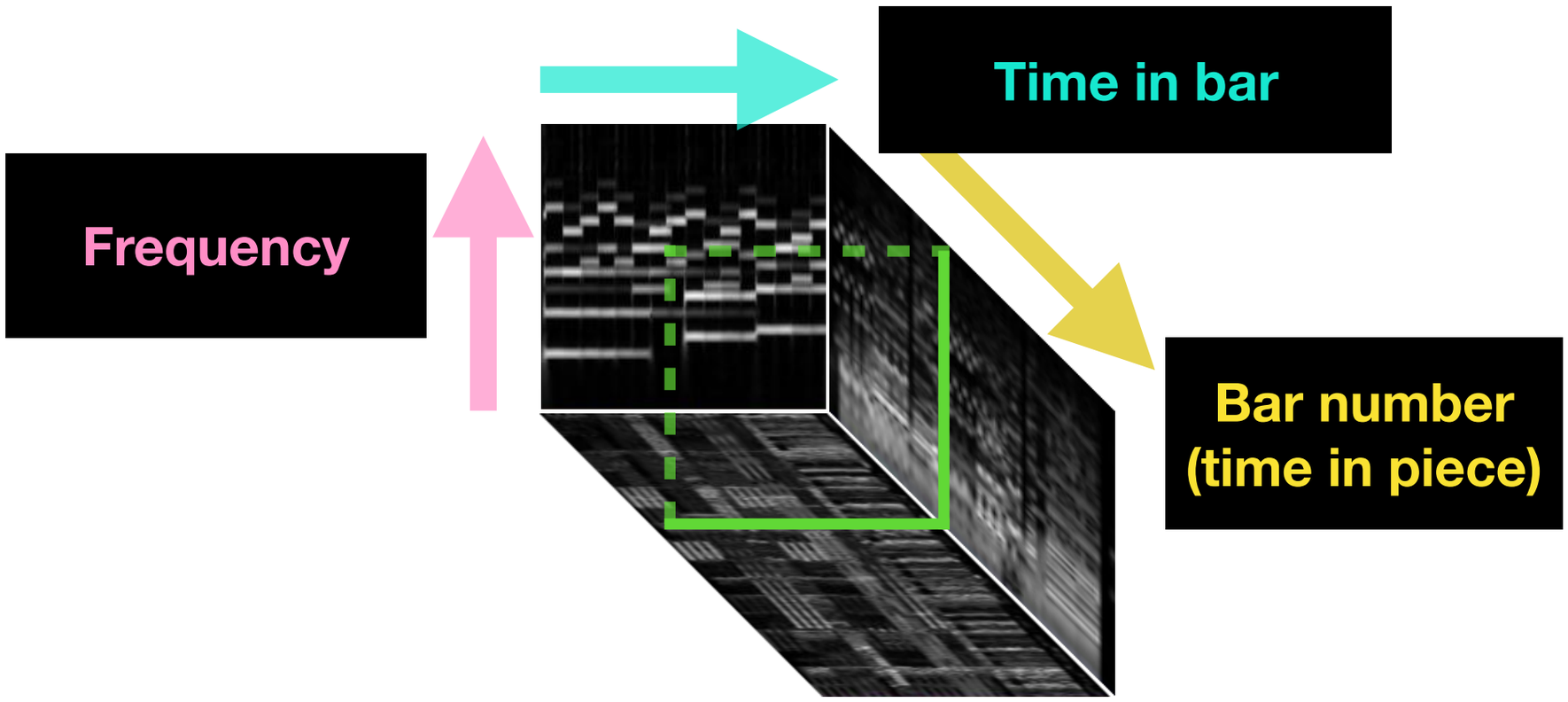


Detour: understanding the spectral cube



Detour: understanding the spectral cube





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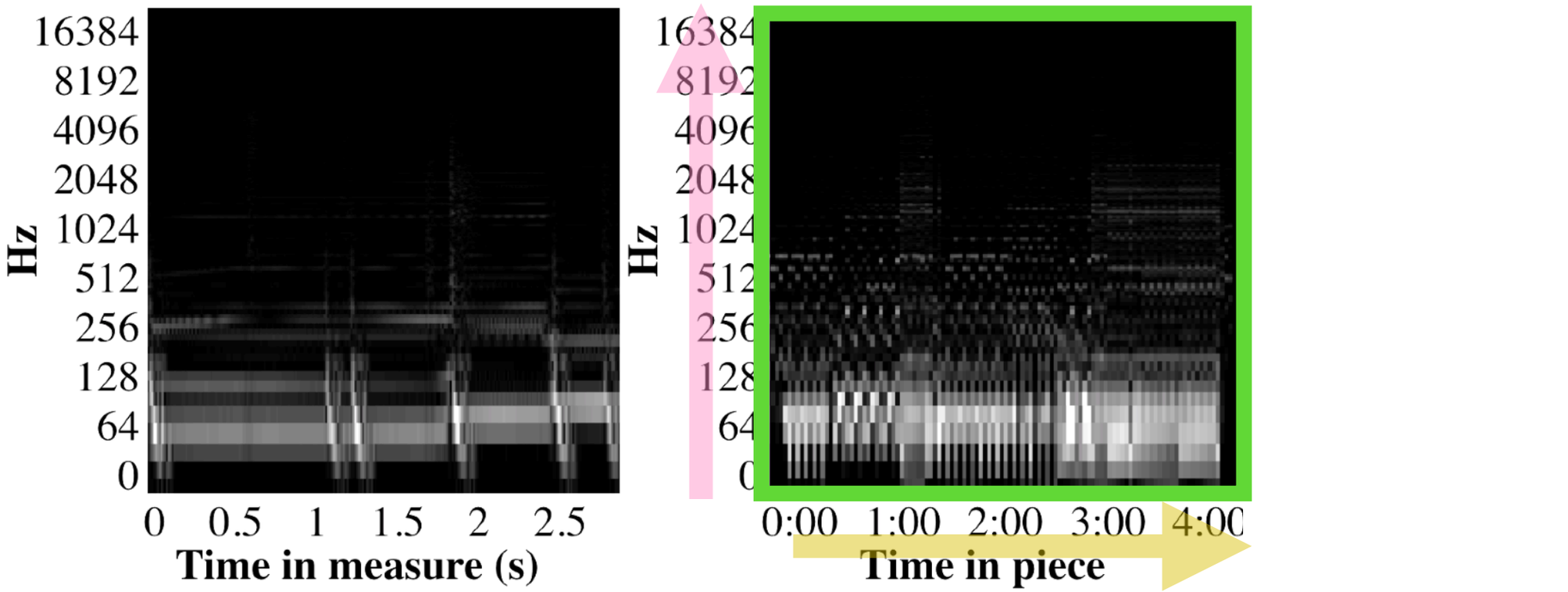

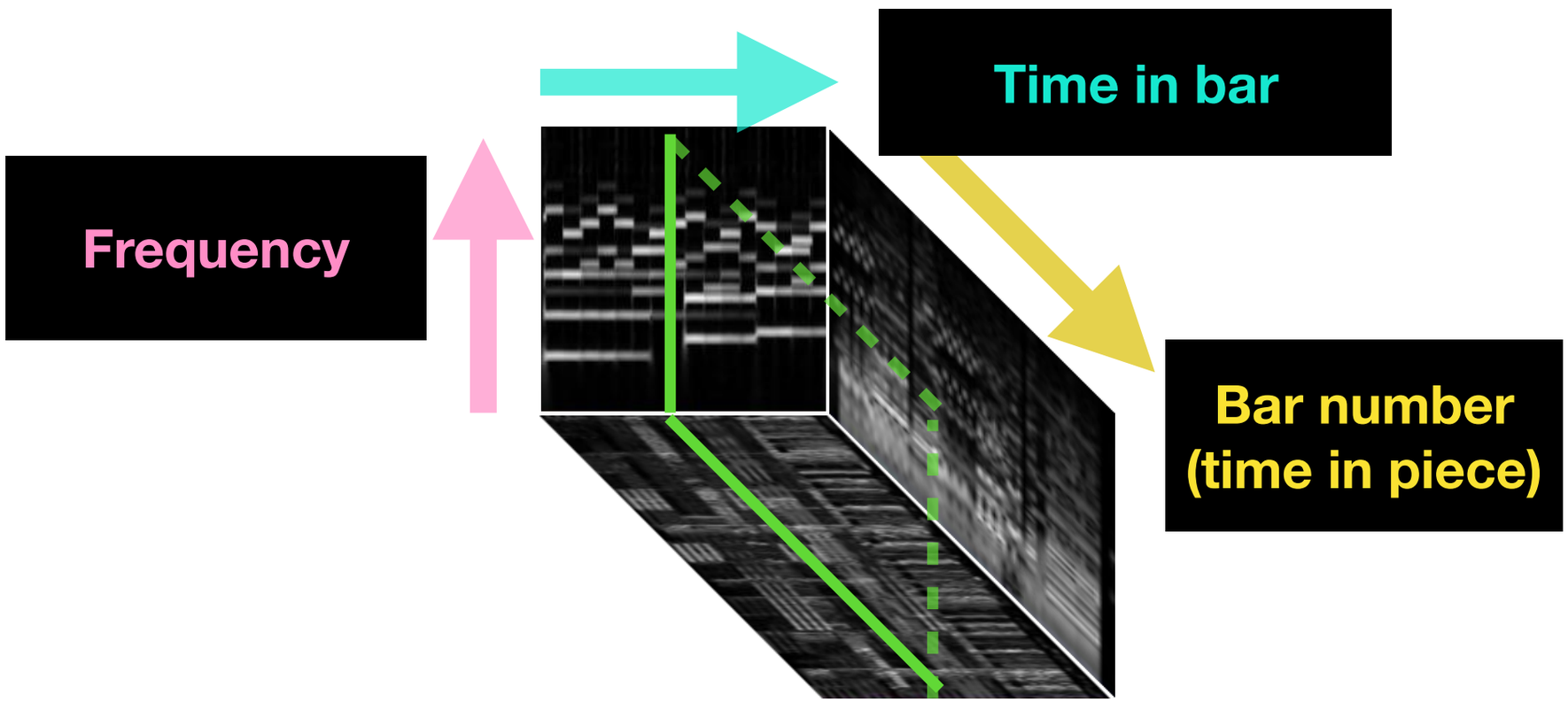

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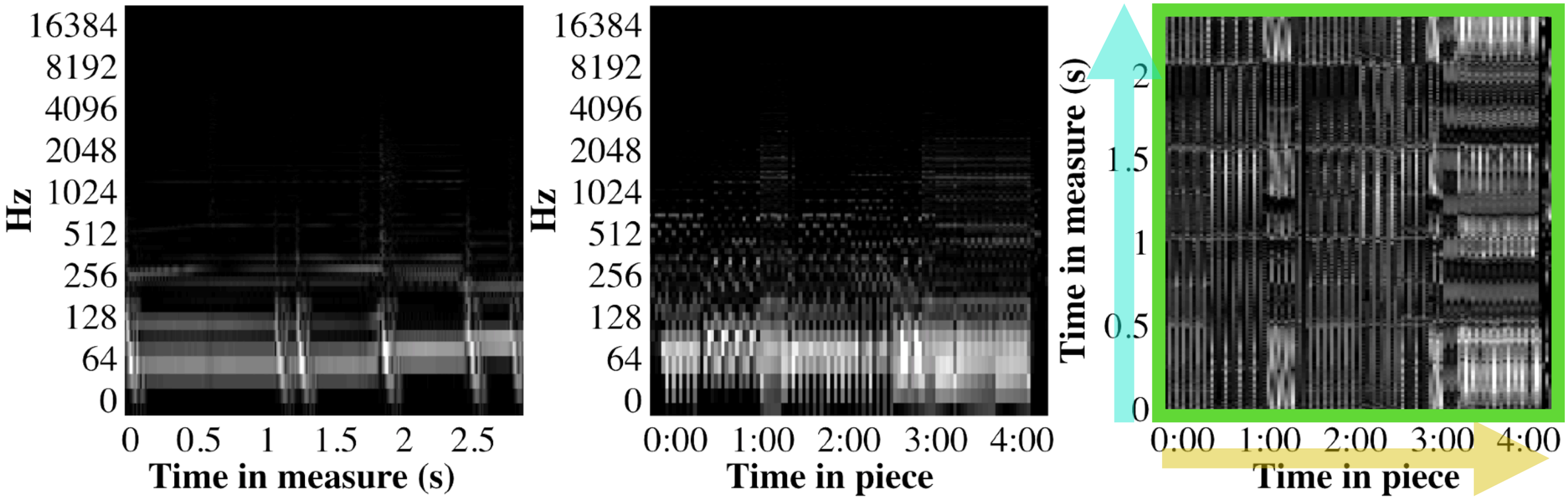
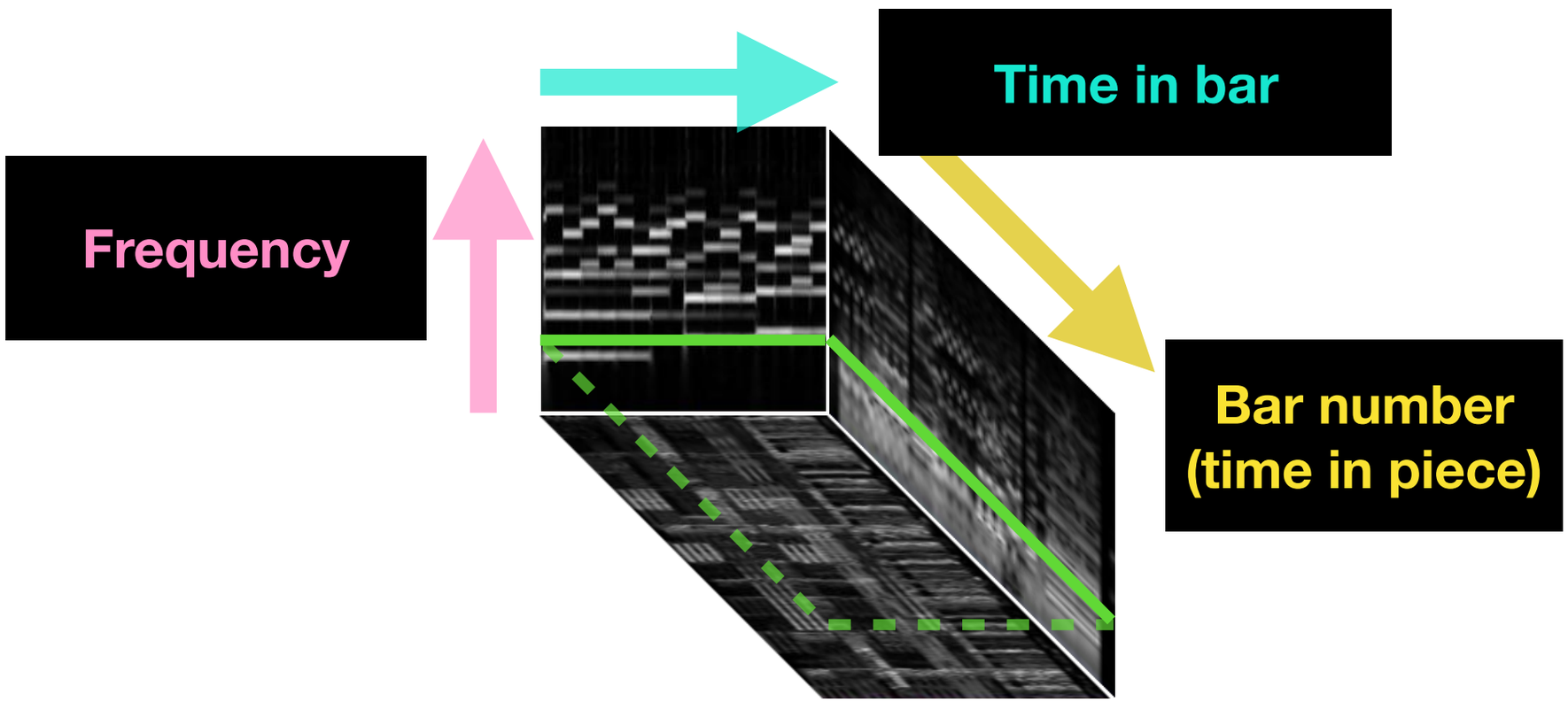
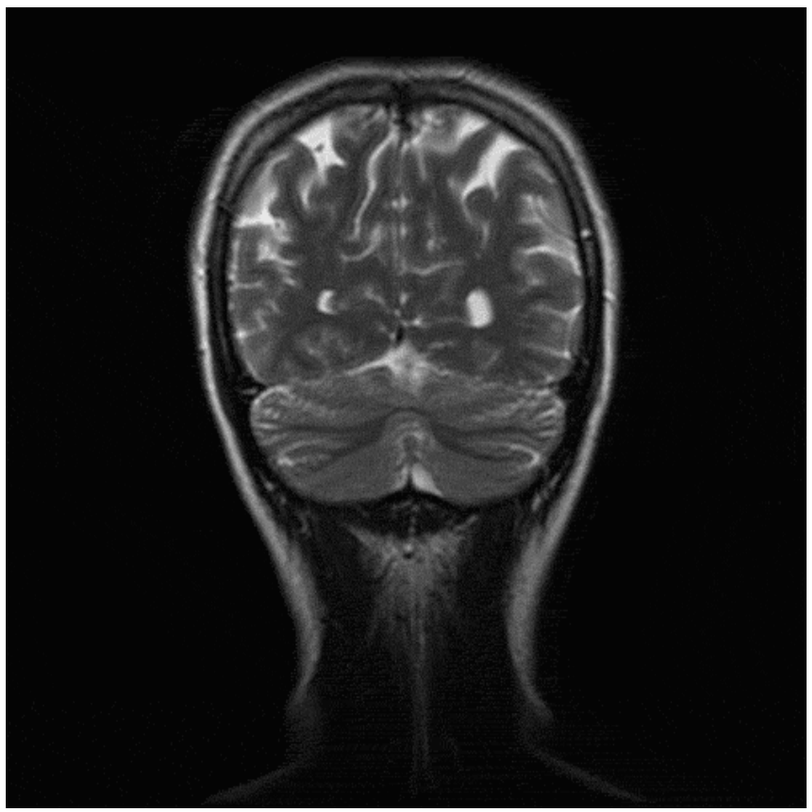
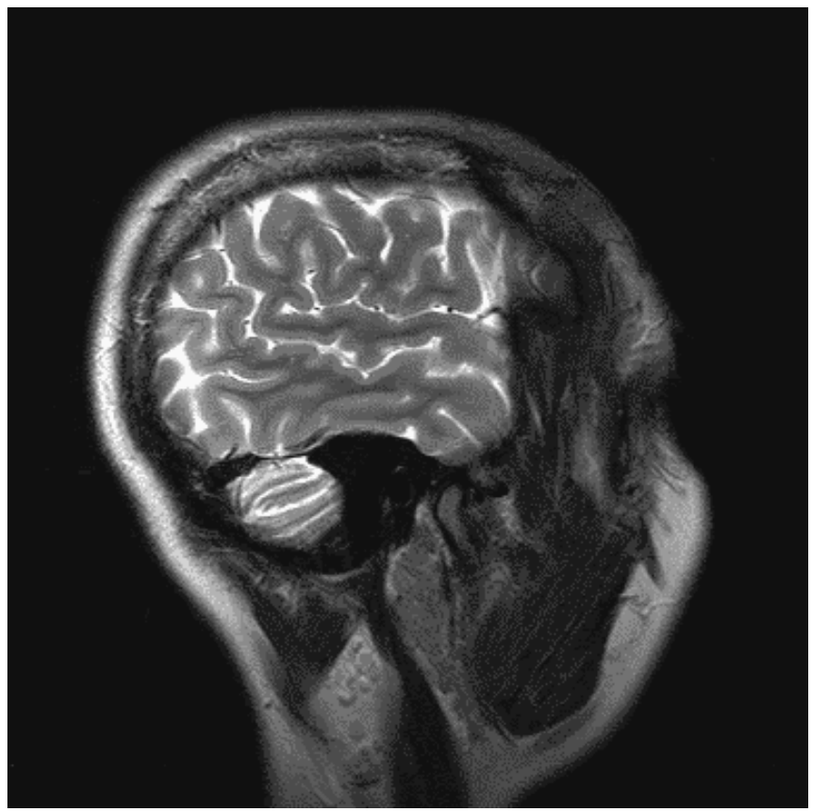




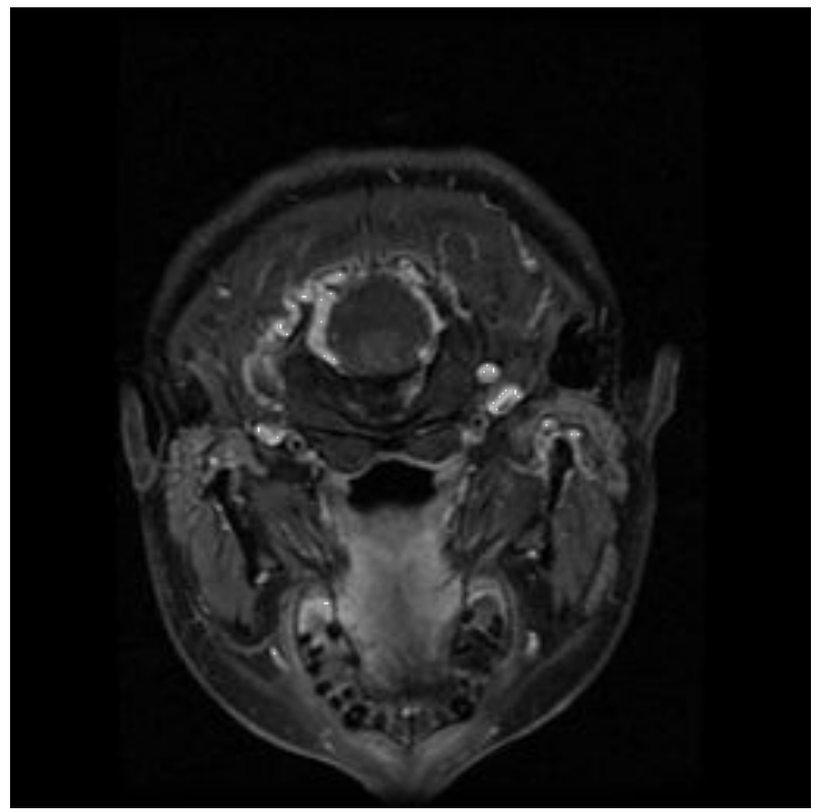
Visualizing a 3D volume: CT scan



Back to front

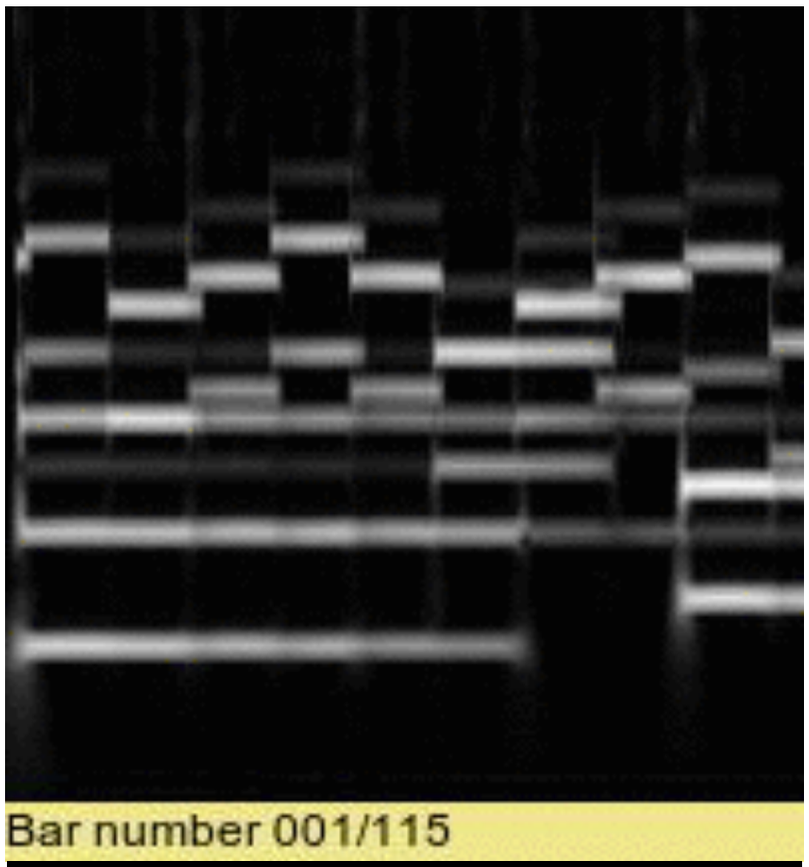


Left to right

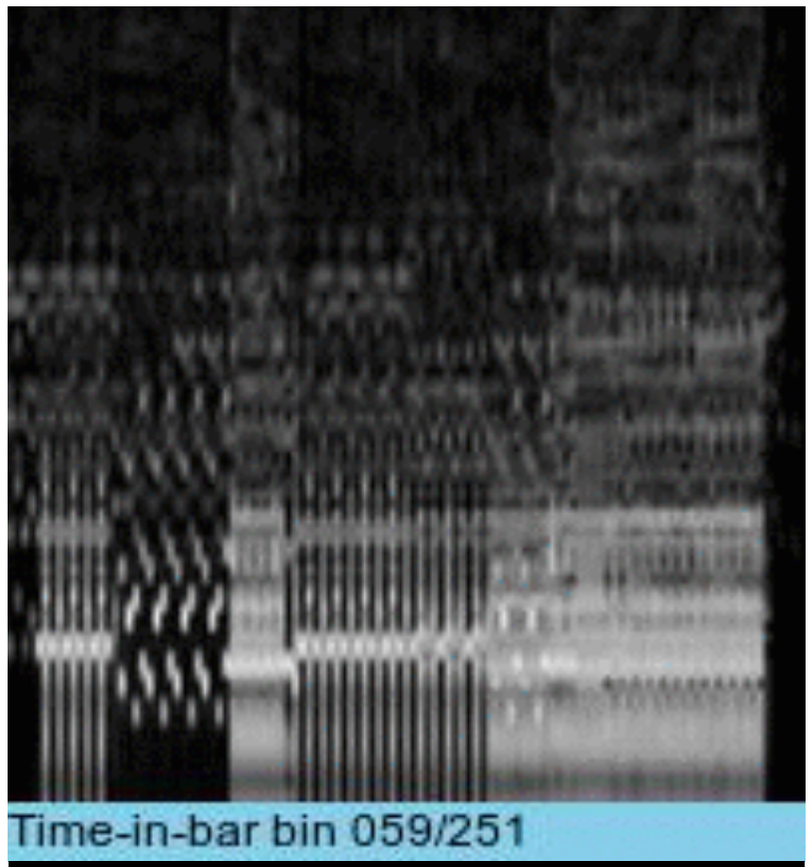


Bottom to top

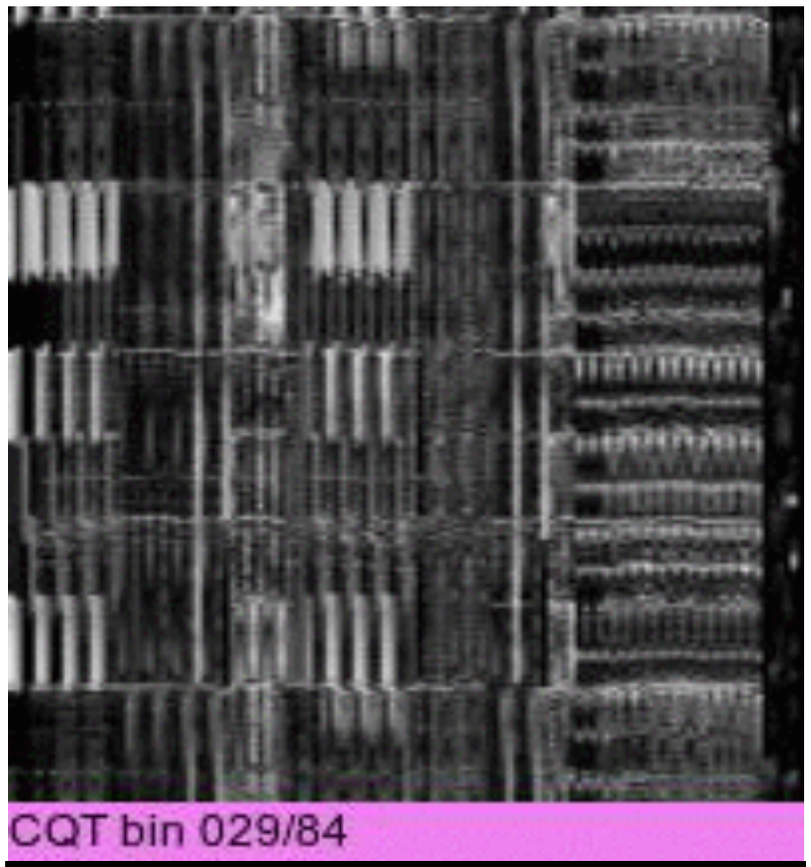
Visualizing a 3D volume: CT scan



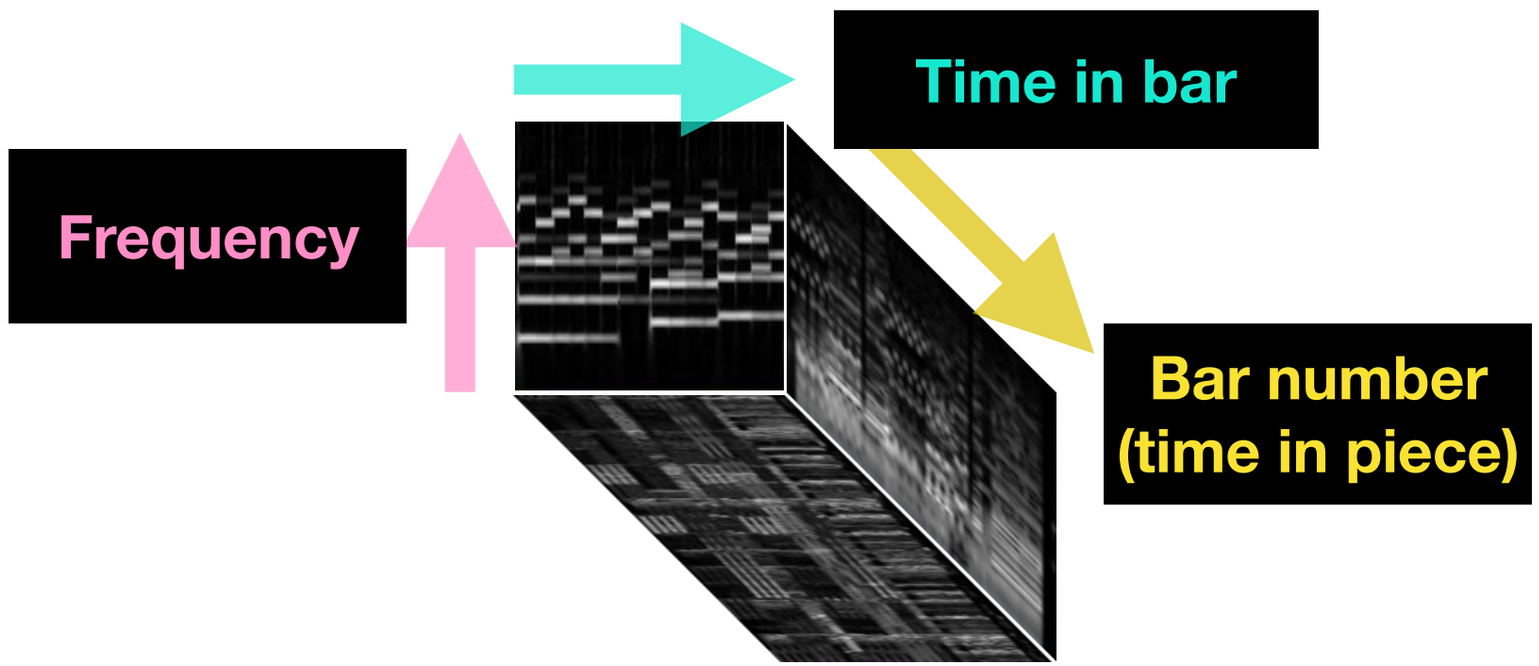
Beginning to end of piece



Beginning to end of a bar



Low frequency to high

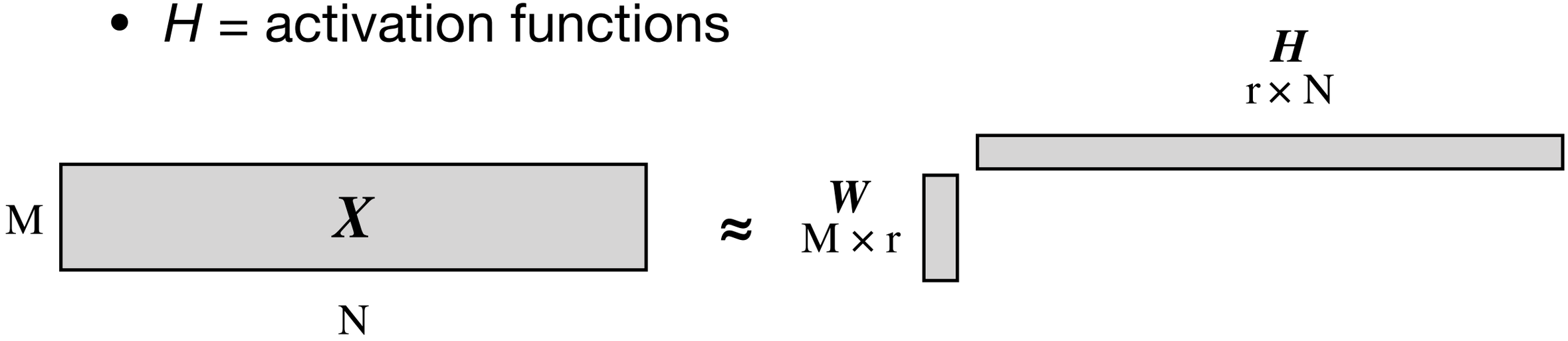


Nonnegative tensor factorization

- Step 1: estimate downbeats
- Step 2: stack the 2D spectrograms into a 3D volume (a “spectral cube”)
- Step 3: use nonnegative tensor factorization (NTF) to model the spectral cube

Nonnegative matrix factorization

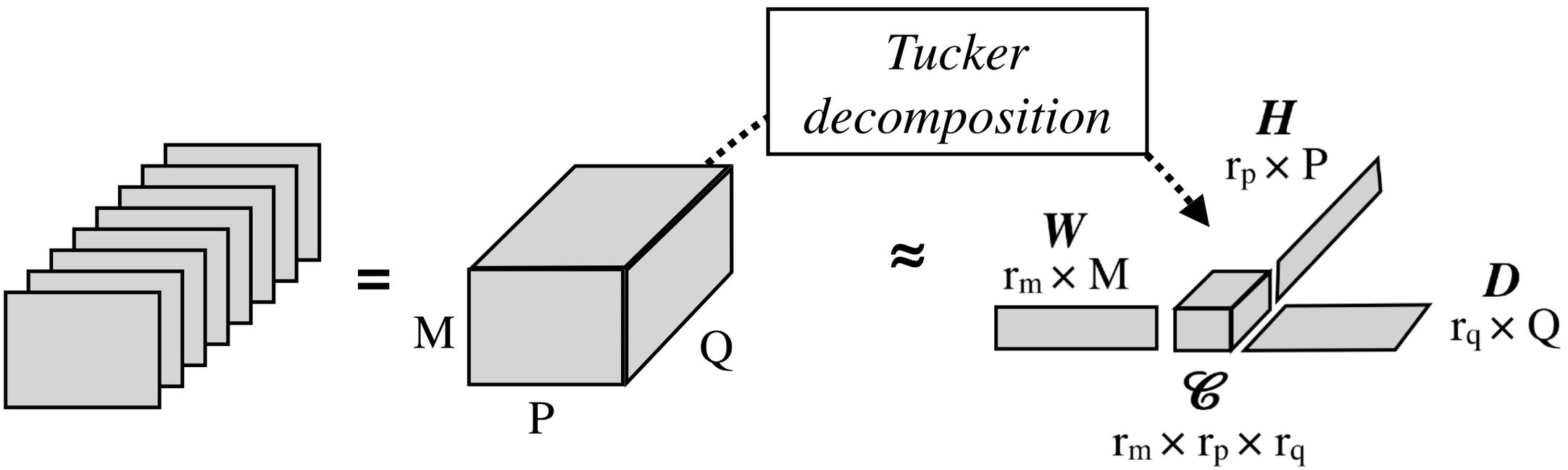
- NMF: $X \approx W \circ H$
  - W = note templates
  - H = activation functions



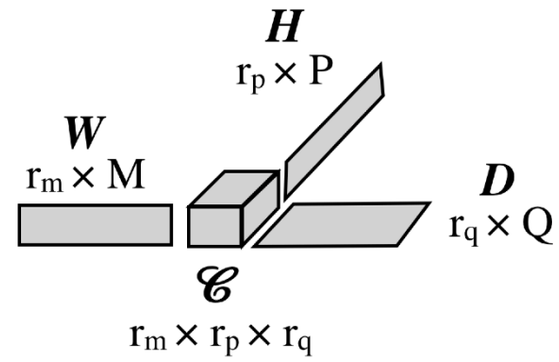
- Needs post-processing to separate sources:
  - which templates in W belong to the same source?
  - different sources could use the same harmonic components!

Nonnegative tensor factorization

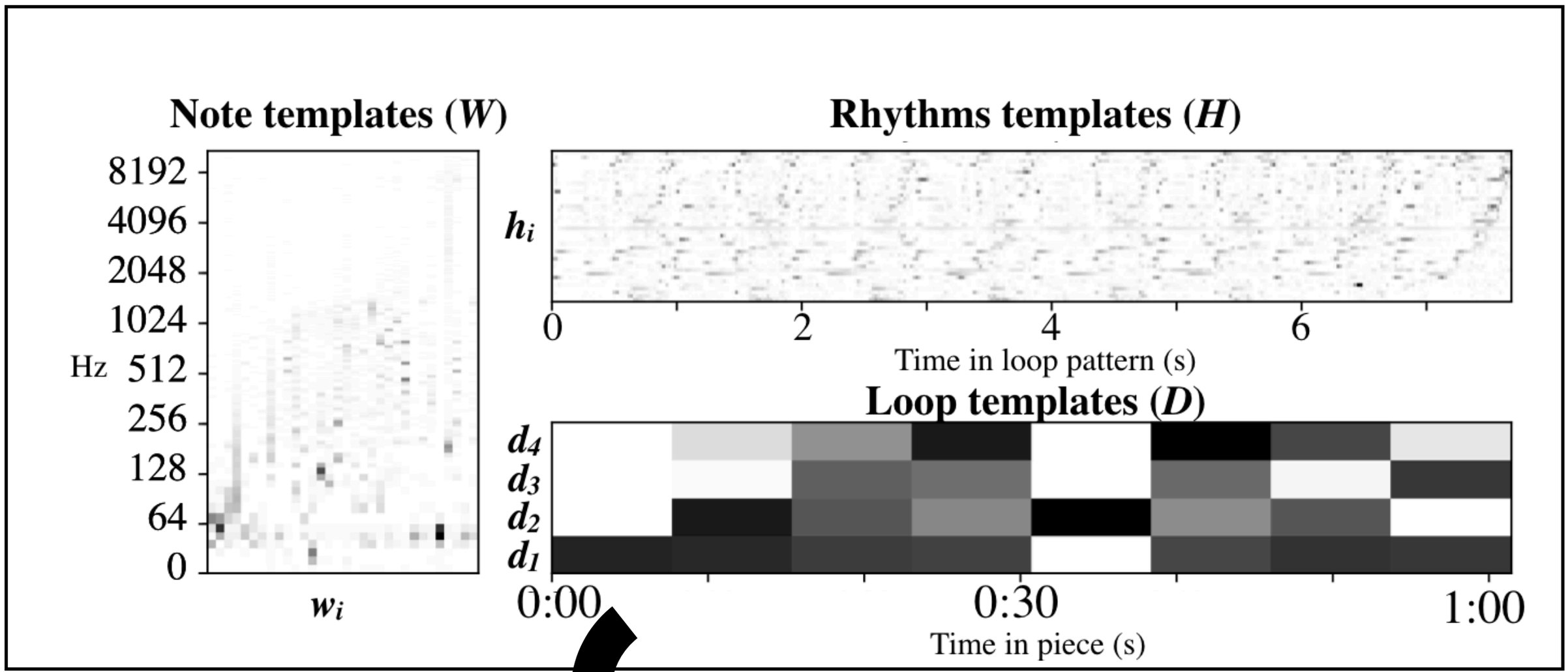
- Tucker Decomposition: $X \approx C \circ (W \circ H \circ D)$
  - W = note templates
  - H = activation functions (time-in-bar)
  - D = loop activation functions (time-in-piece)
  - C = core tensor = recipe for each loop type



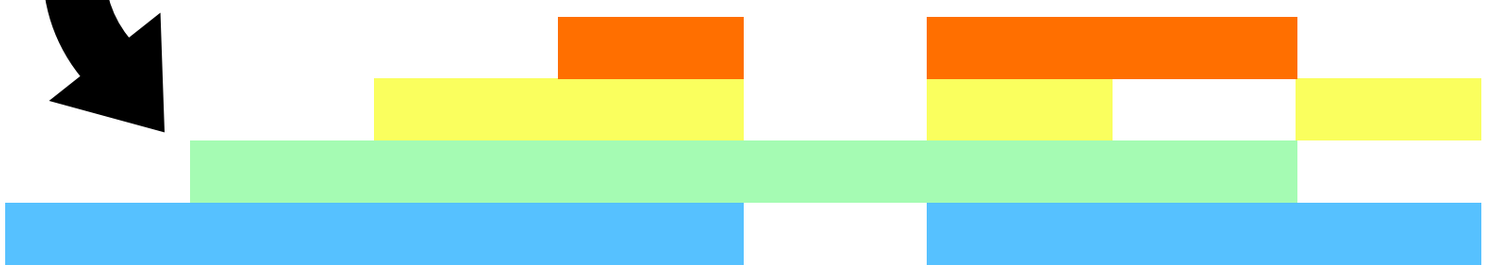
Interpreting the NTF model



- *W, H*, and *D* all musically intuitive:



Loop template activations directly estimate layout of song



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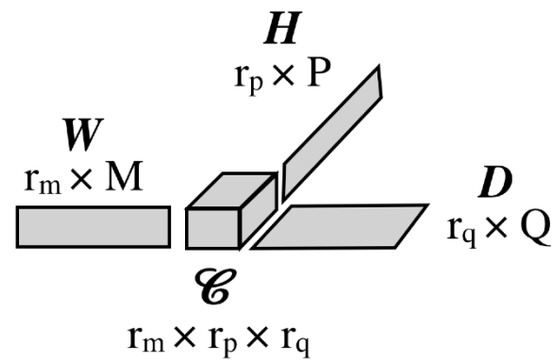
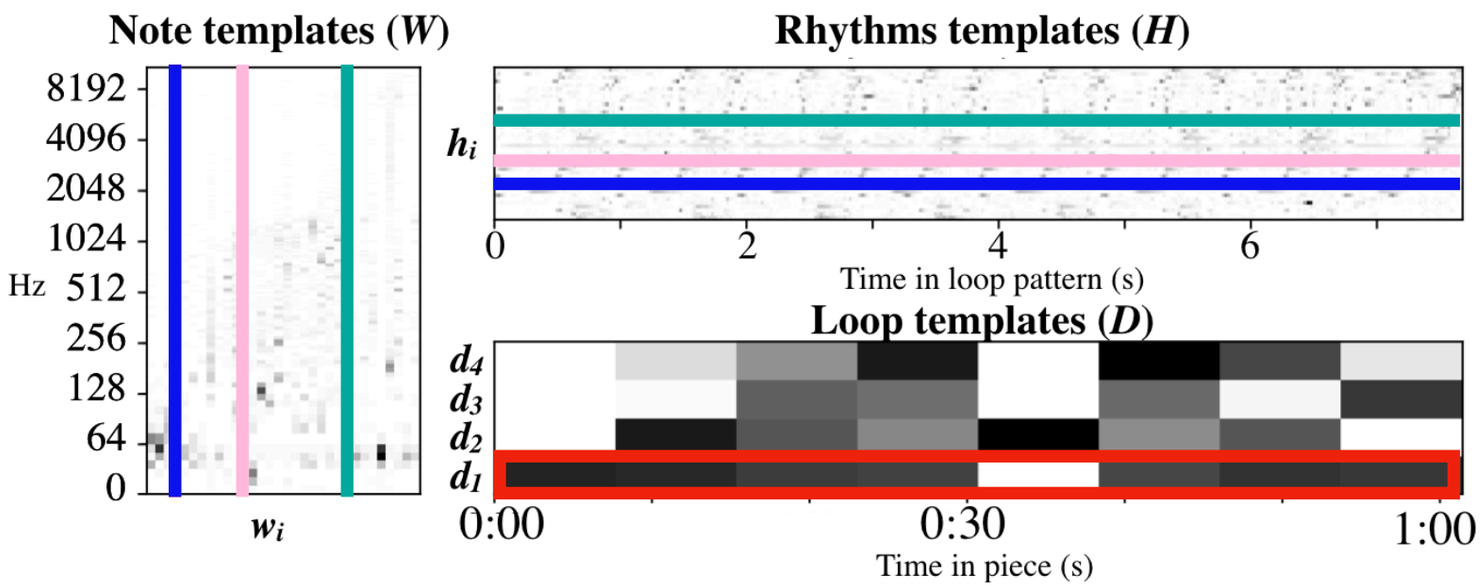
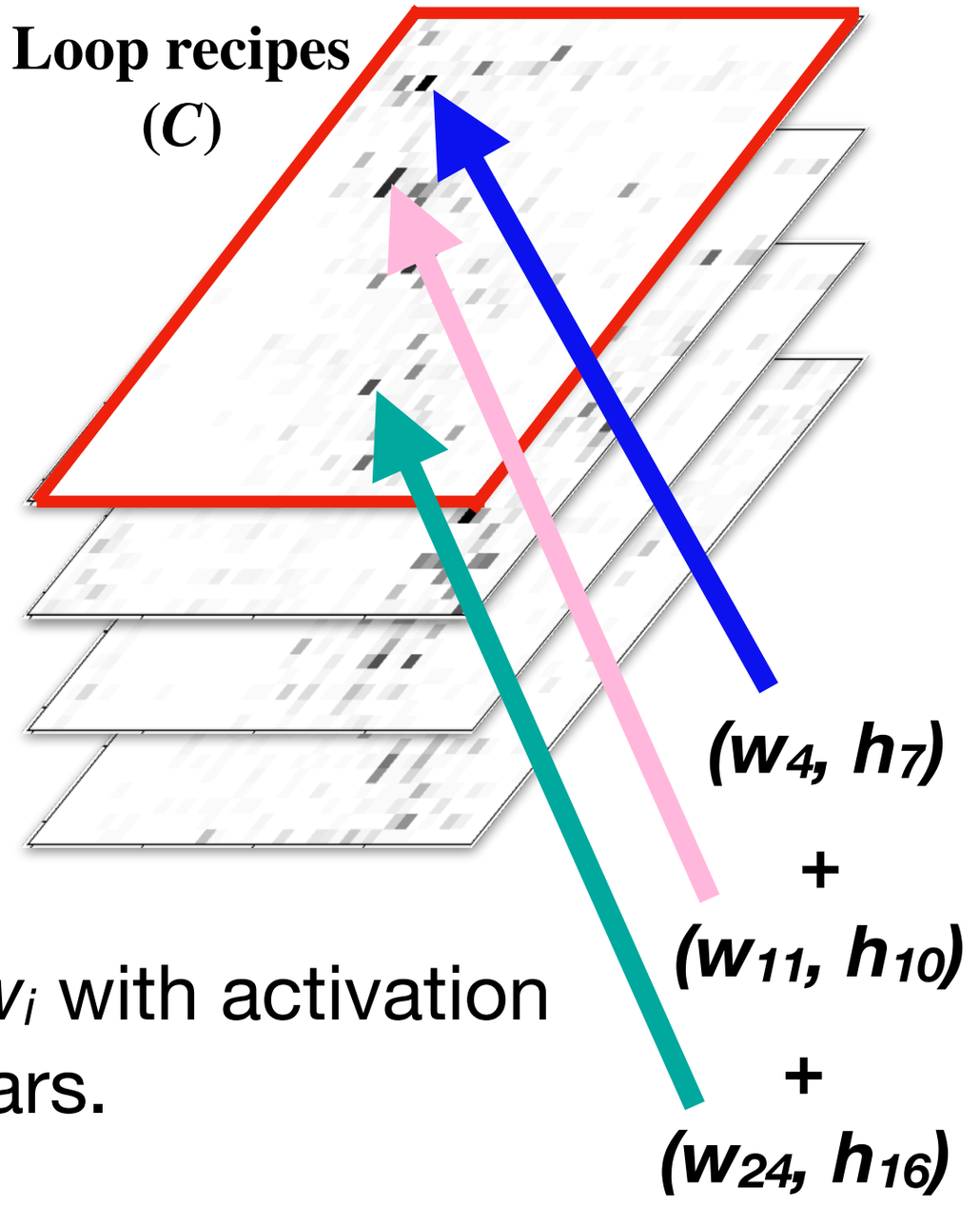


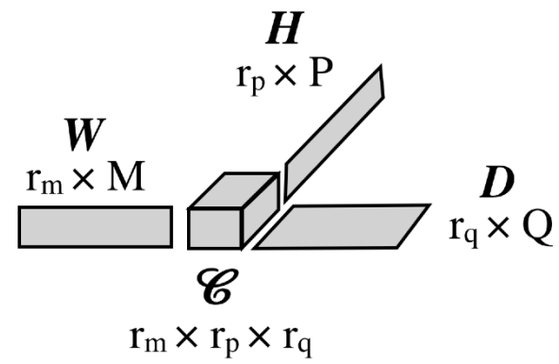
- Core tensor *C* = recipe for each loop type





- Pixel *C(i, j, k)* tells us to play note w_i with activation function h_j whenever loop d_k appears.

Interpreting the NTF model



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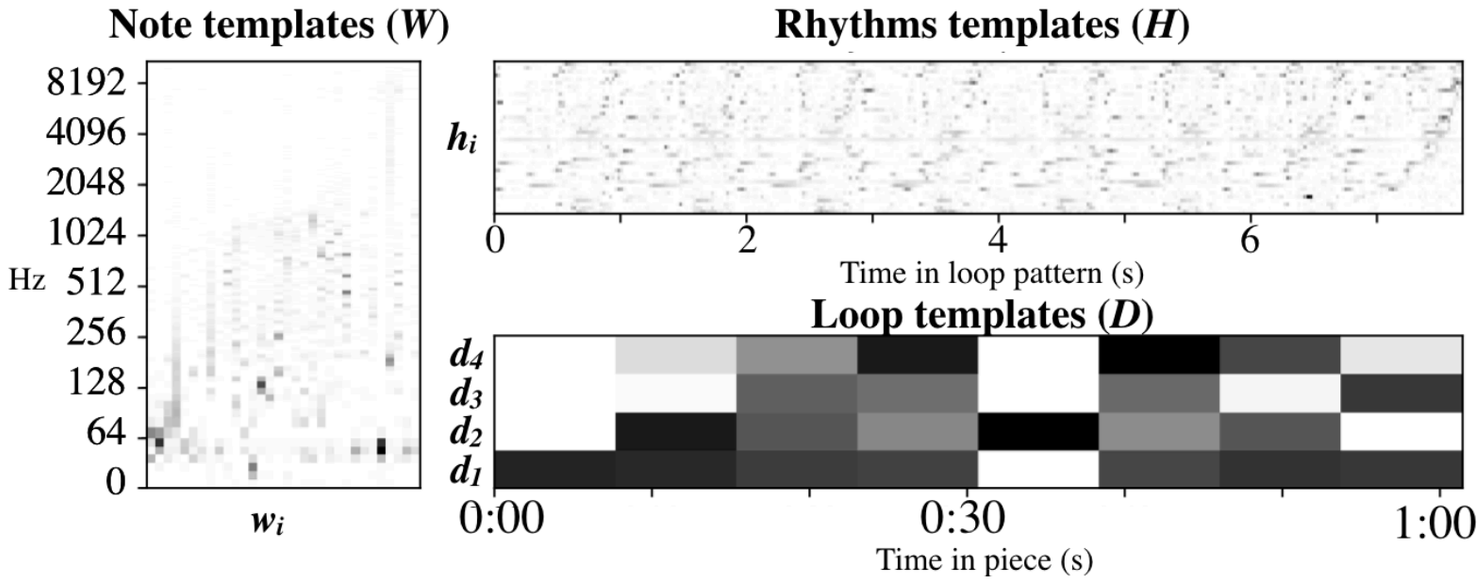
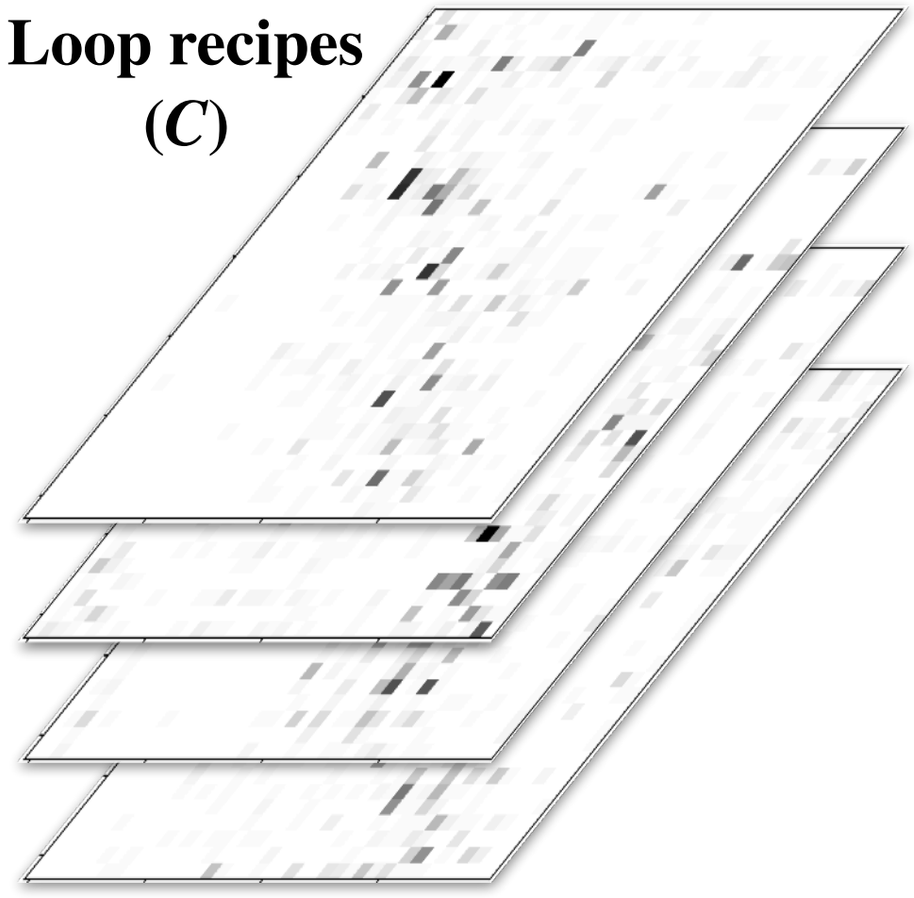




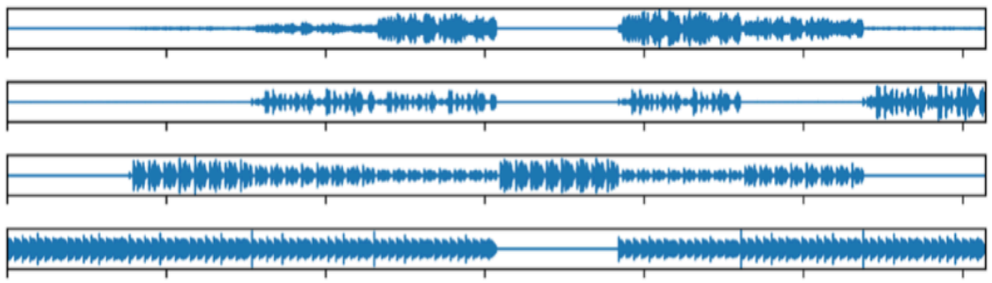
- To recover entire spectrogram: $C \circ (W \circ H \circ D)$
- To recover individual loop source: $C_{[:,:,k]} \circ (W \circ H \circ D_{[k,:]})$

Evaluation

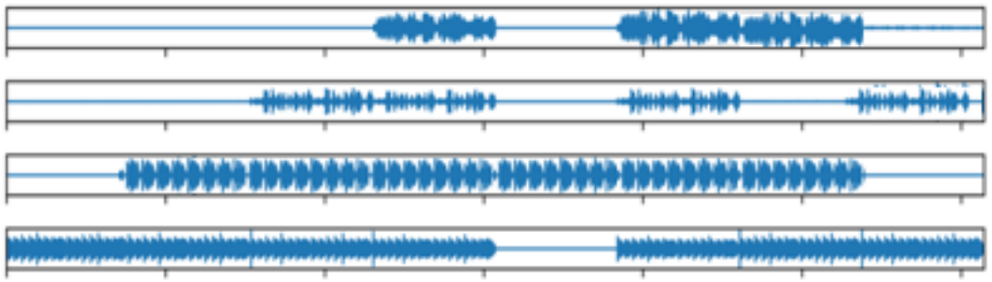
Evaluation

- We used synthetic data [López-Serrano et al. 2016]
  - 7 sets of loops x 3 different layouts (arrangements)
- Algorithm output 1: separated signals
  - Evaluate quality with SDR, SIR, SAR

estimated source tracks

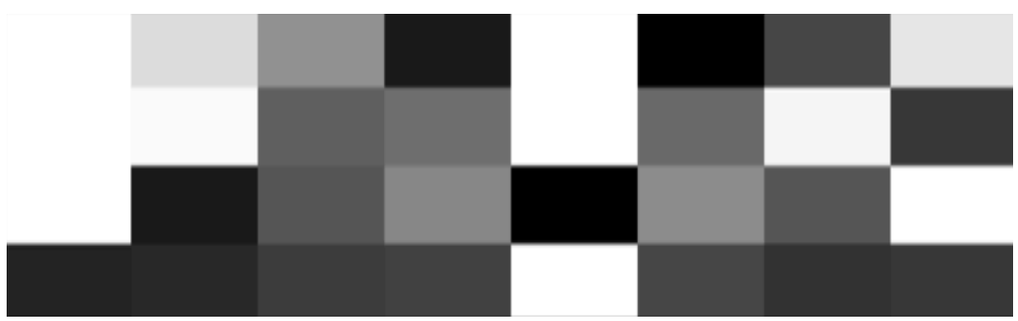


stem tracks

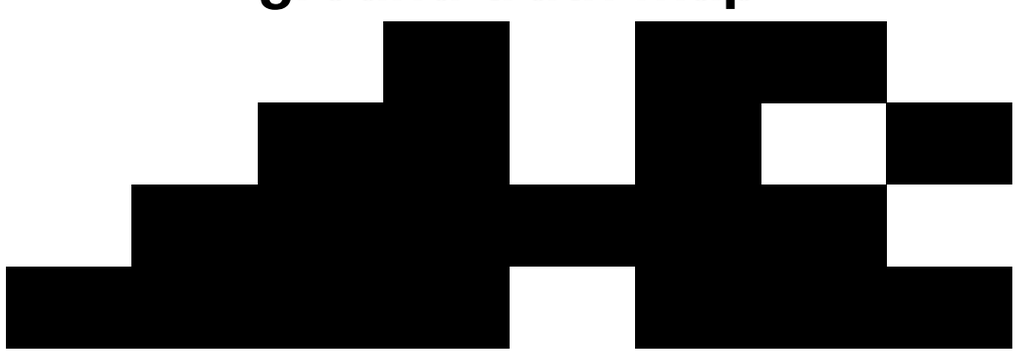


- Algorithm output 2: loop layout
  - Evaluate accuracy with correlation

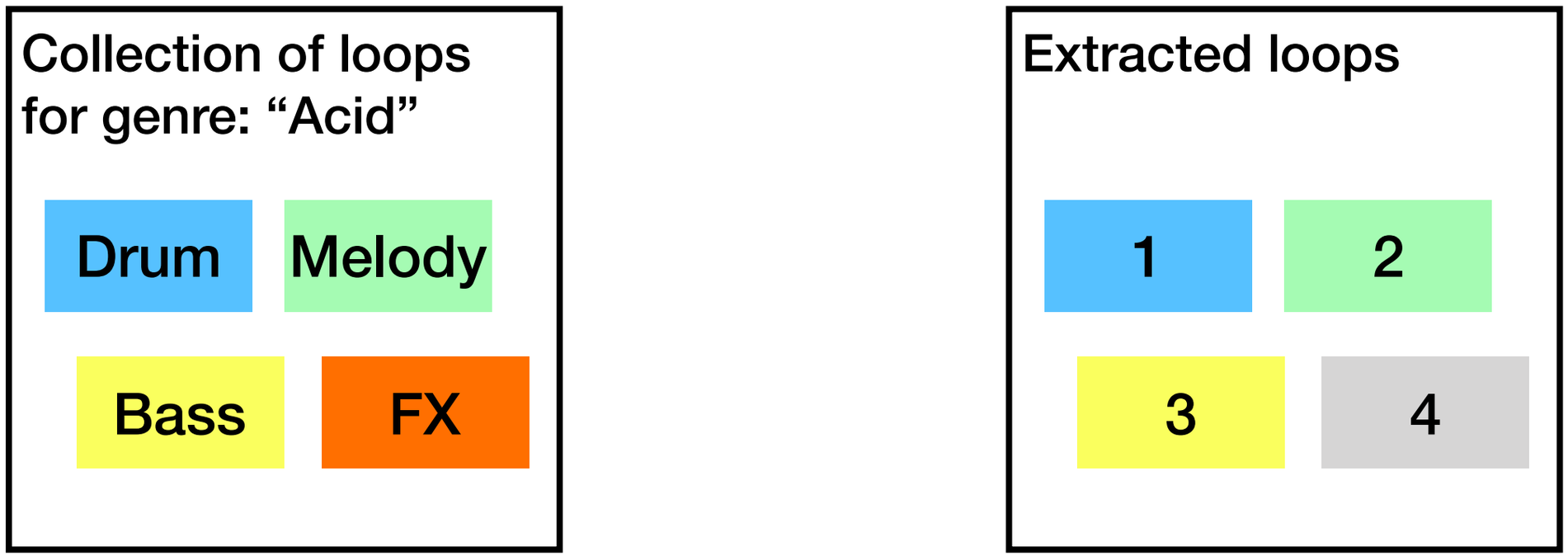
estimated map



ground truth map

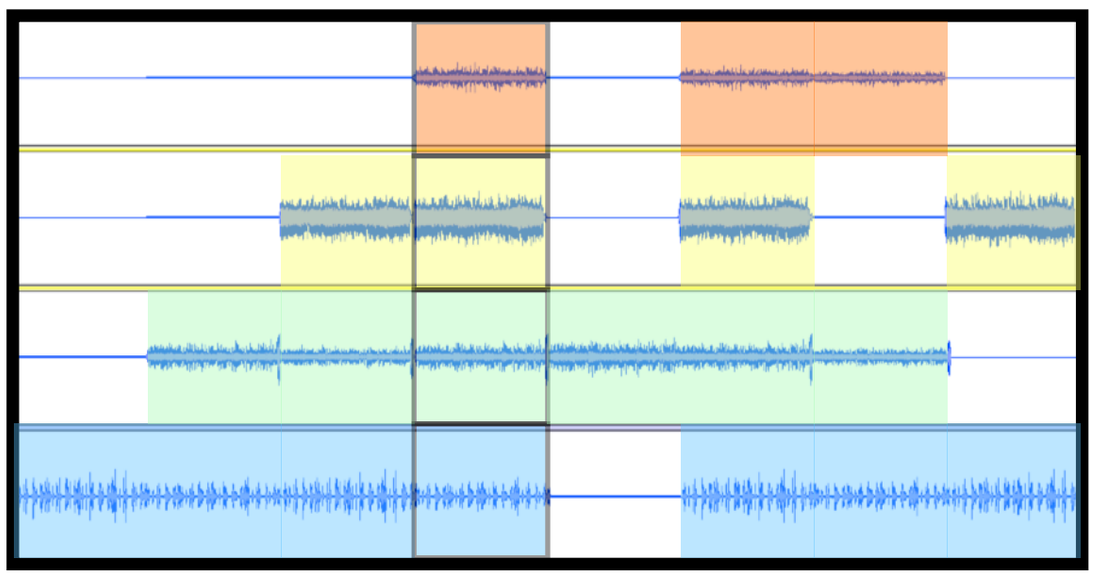


Good separation example

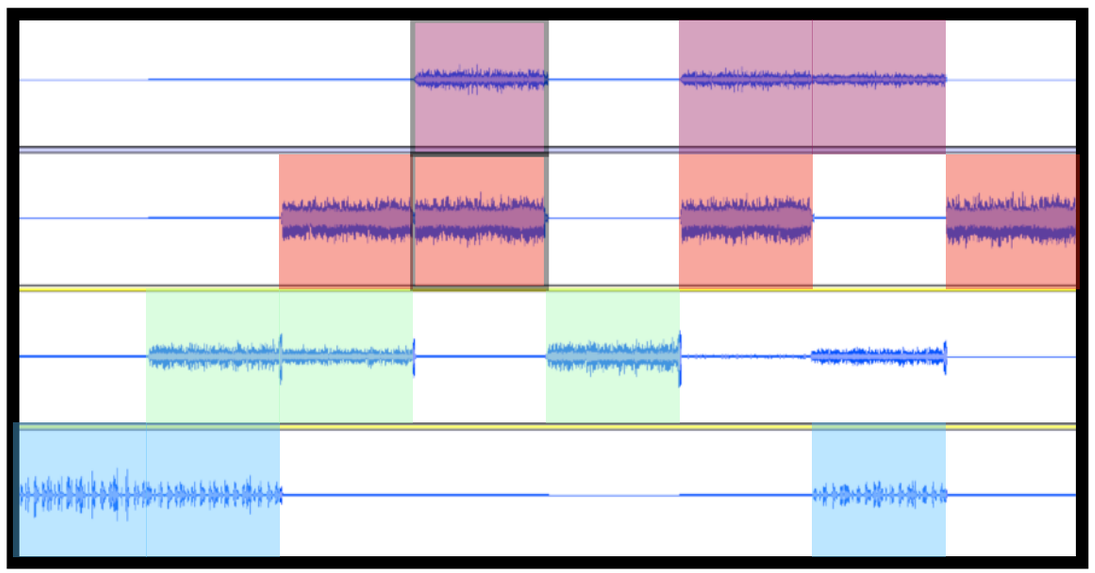


Flawed separation example

Original tracks for genre “Brezo”



Source separated tracks



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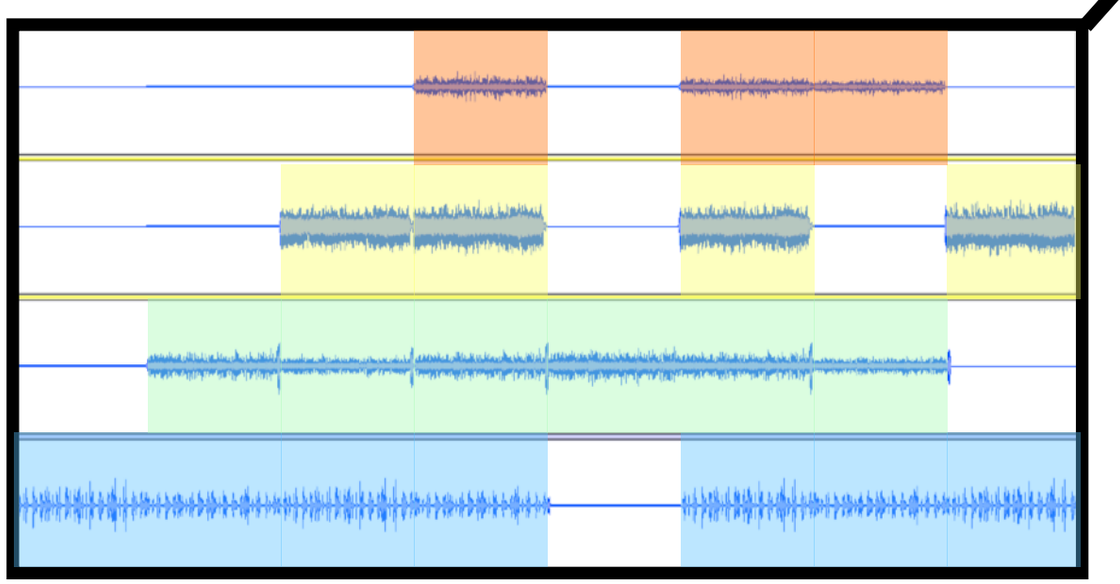
Original tracks for genre “Brezo”



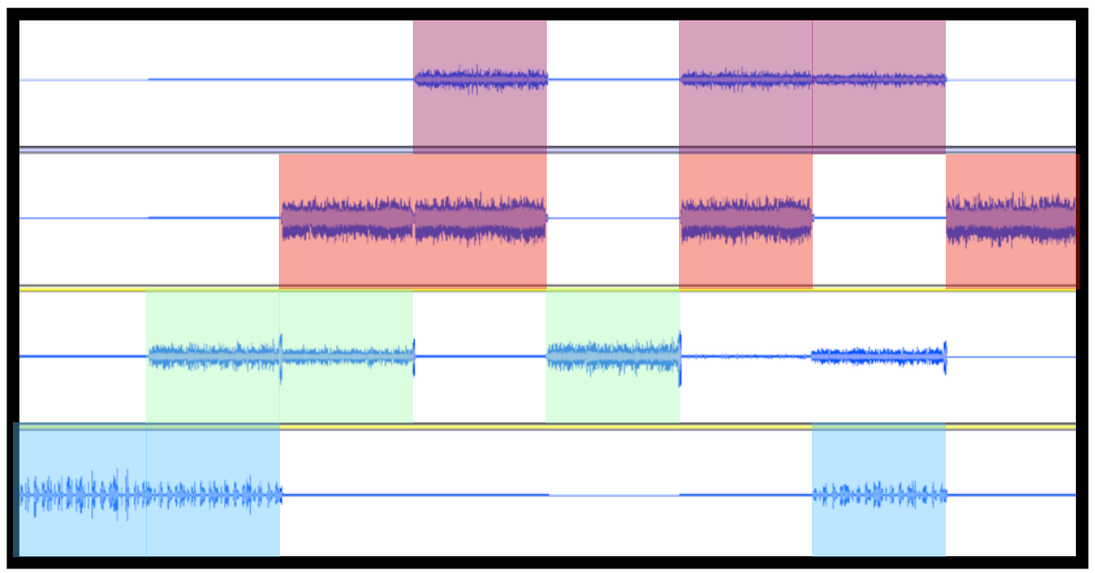
swap rows

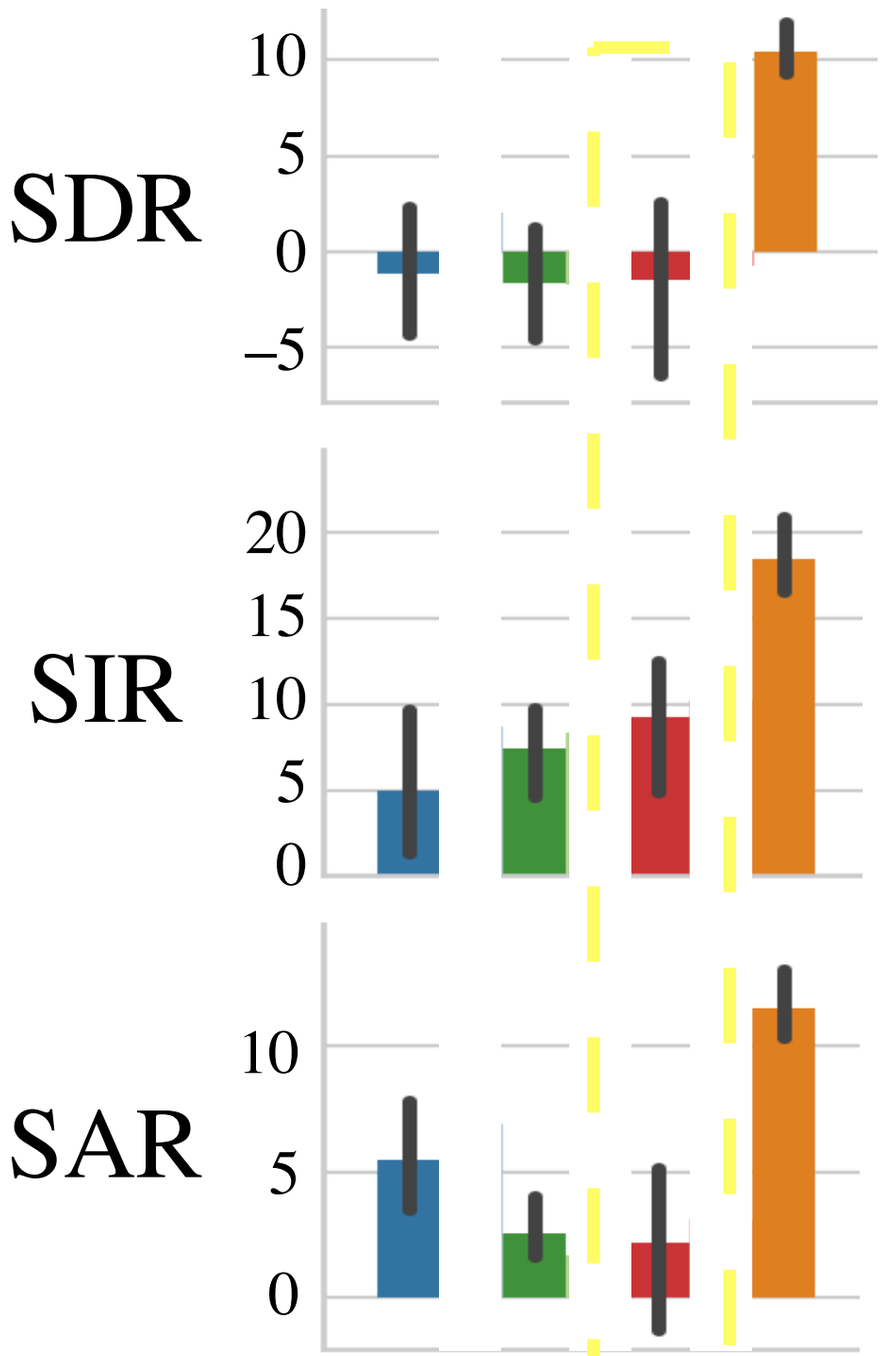
substitute =

substitute =

swap rows

Source separated tracks





Our reconstruction quality is average. :-|

We have less crosstalk than others! :-D

We have more noisy artifacts. :-(

We get very clean layouts! :-D

Algorithm

Iterative NMF

[Seetharaman & Pardo 2016]

NMFD

NTF **(proposed)**

Ideal Mask

(performance ceiling)

Conclusion

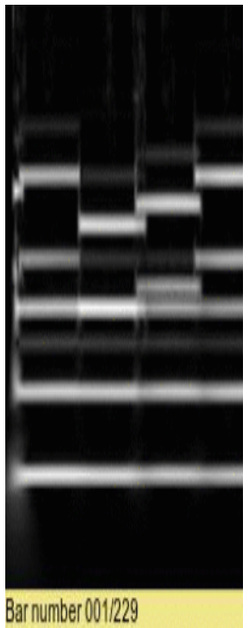
Conclusion

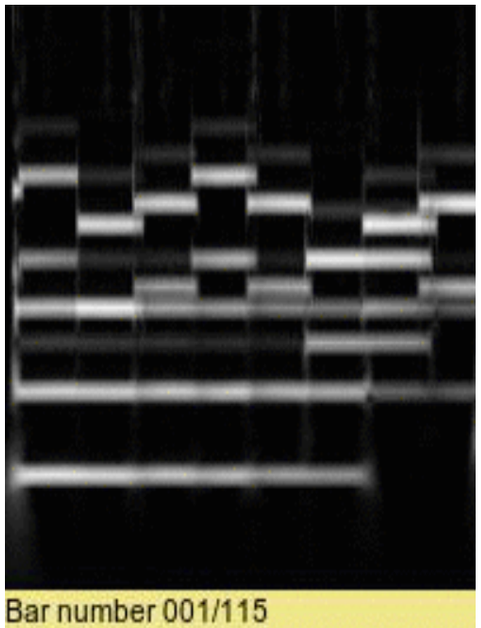
- Proposed method of decomposing audio into loops that:
    - Models periodicity using the spectral cube
    - Models source signals and song composition jointly
    - Tucker decomposition is musically intuitive
- Weaknesses include:
    - Very conservative reconstructions don’t model the whole signal
    - Like NMFD, we cannot distinguish between algebraically equivalent decompositions
- Future work: searching for repetitions at multiple hierarchical time scales

Future work: hierarchical analysis

- Different loops in the song have different lengths and periods

- Spectral cubes with different periods highlight different consistent repetitions



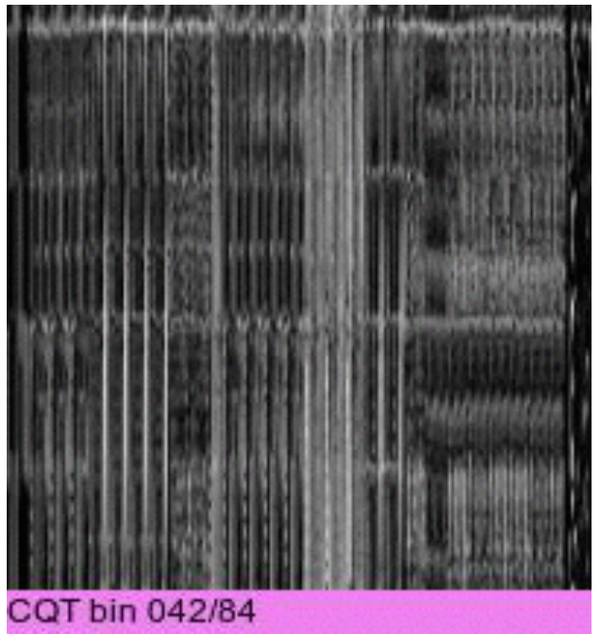


PERIOD: 2 beats 1 downbeat 4 downbeats

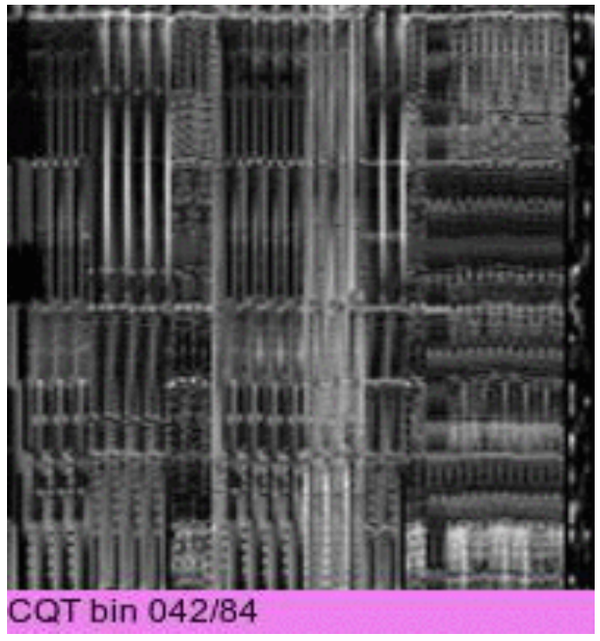
Future work: hierarchical analysis

- Different loops in the song have different lengths and periods

- Spectral cubes with different periods highlight different consistent repetitions

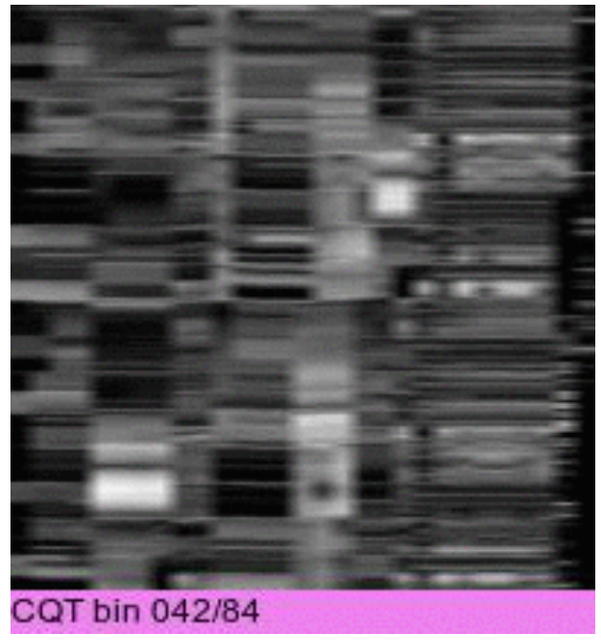


PERIOD: 2 beats



1 downbeat

2 downbeats



4 downbeats

Thank you!

PS. Jordan is now at:

ircam Centre Pompidou + L2S