

DEEP LEARNING FOR MUSIC RECOMMENDATION: Machine Listening & Collaborative Filtering

ORIOL NIETO

ONIETO@PANDORA.COM

SEMINAR ON MUSIC KNOWLEDGE EXTRACTION USING MACHINE LEARNING

POMPEU FABRA UNIVERSITY

BARCELONA

DECEMBER 4, 2016

Outline

- Pandora Overview
- Large Scale Music Recommendation with Deep Learning:
 - Machine Listening
 - Collaborative Filtering

Outline

- **Pandora Overview**
- Large Scale Music Recommendation with Deep Learning:
 - Machine Listening
 - Collaborative Filtering

Now Playing My Stations

Create Station

pandora

Porcupine Tree Radio

Vast Radio

Katatonia Radio

Chaos Chaos Radio

Steven Wilson Radio

See All Stations

The Grudge

Tool

<Q ch=1,3,11,14,18,19,21,23,24,37,71 q=40 p=46.9% s=R1...

Lyrics

Wear the grudge like a crown of negativity.
Calculate what we will or will not tolerate.

3:20 | 8:36

Thumbs down, play, play, thumbs up

This screenshot shows the Pandora mobile app interface. At the top, there are tabs for 'Now Playing' (which is currently selected) and 'My Stations'. A search bar and a 'Create Station' button are also at the top. The main content area displays a radio station titled 'Porcupine Tree Radio'. Below it is a list of other stations: 'Vast Radio', 'Katatonia Radio', 'Chaos Chaos Radio', and 'Steven Wilson Radio'. A 'See All Stations' button is located at the bottom of this list. In the center, there is a large image of the album cover for 'Lateralus' by Tool. Below the album art, the song title 'The Grudge' and the artist 'Tool' are displayed. A lyrics section follows, showing the first two lines of the song. At the bottom, there are playback controls (thumbs down, play, play, thumbs up) and a progress bar indicating the song is at 3:20 of 8:36 minutes.

Search 11:44 AM 100%

My Stations Browse

Browse Genres View all >

Motown

6.6M listeners

Classic Metal

1.3M listeners

Disco

3.2M listeners

Smooth Jazz

10M listeners

Selenium Forest

Plini

pandora®

This screenshot shows the Pandora mobile app interface. At the top, there is a search bar, the current time (11:44 AM), battery level (100%), and signal strength. Below the search bar are buttons for 'My Stations' and 'Browse'. The main content area is titled 'Browse Genres' with a 'View all >' link. It features four genre cards: 'Motown' (6.6M listeners), 'Classic Metal' (1.3M listeners), 'Disco' (3.2M listeners), and 'Smooth Jazz' (10M listeners). Each card includes an album cover thumbnail and the genre name. At the bottom, there is a partial view of another station, 'Selenium Forest' by Plini, with its album cover and title visible.

TODAY



78 M
Monthly Listeners



10 B
Stations



22 H
Average Listening per Month



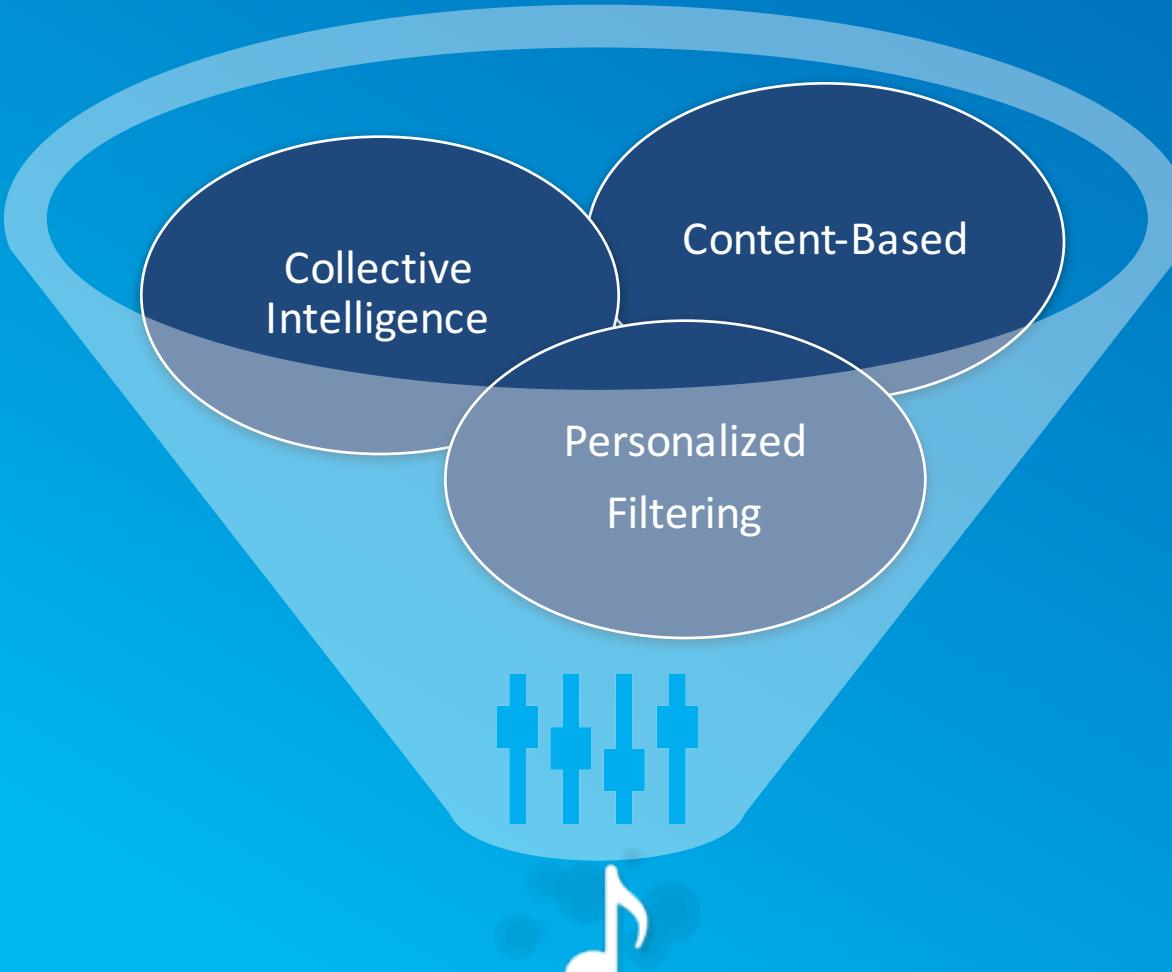
180 K
Artists Spinning per Month



75 B +
Thumbs



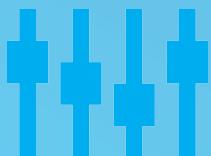
55 %
of all Music Streaming in USA



Collective
Intelligence

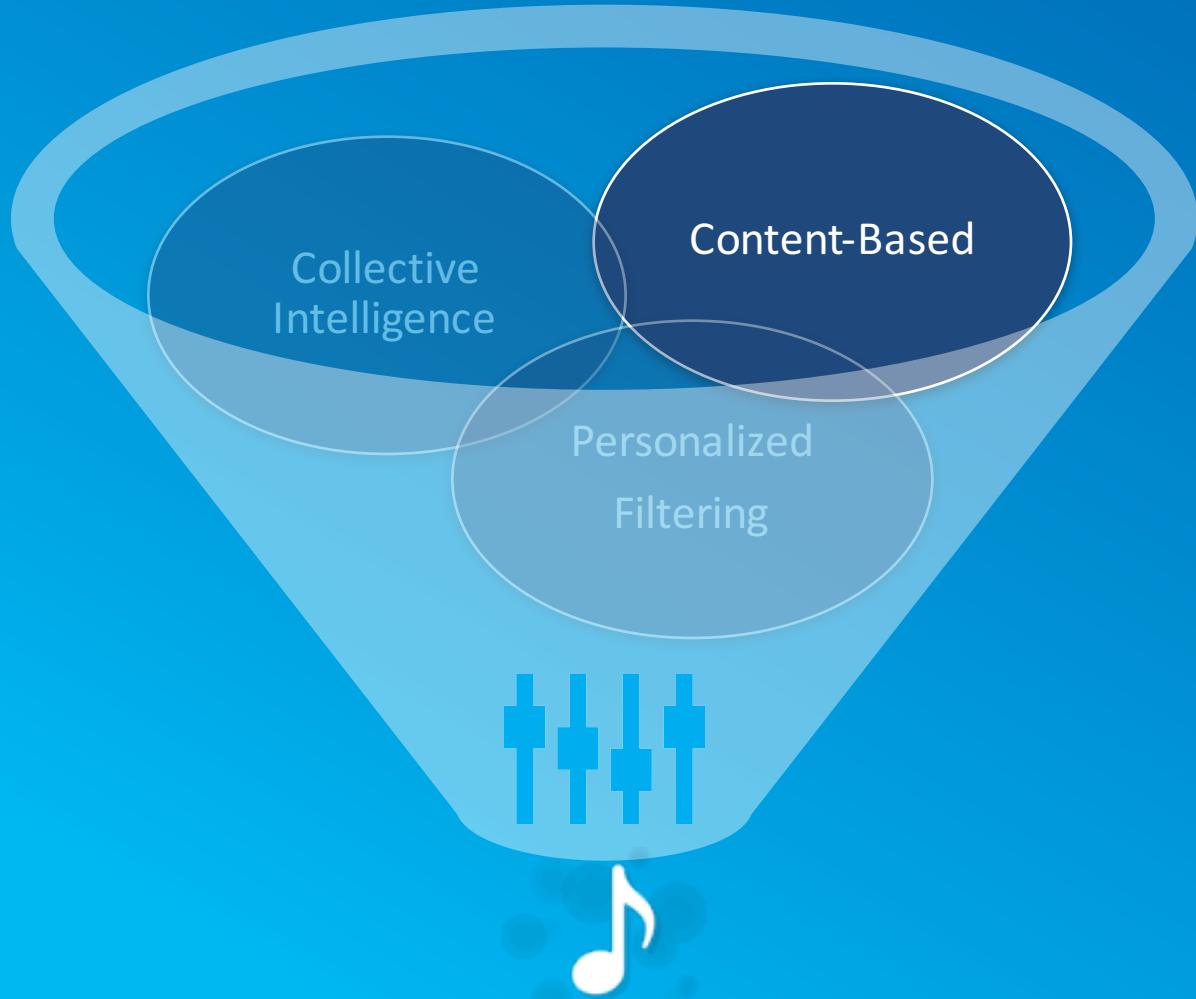
Content-Based

Personalized
Filtering



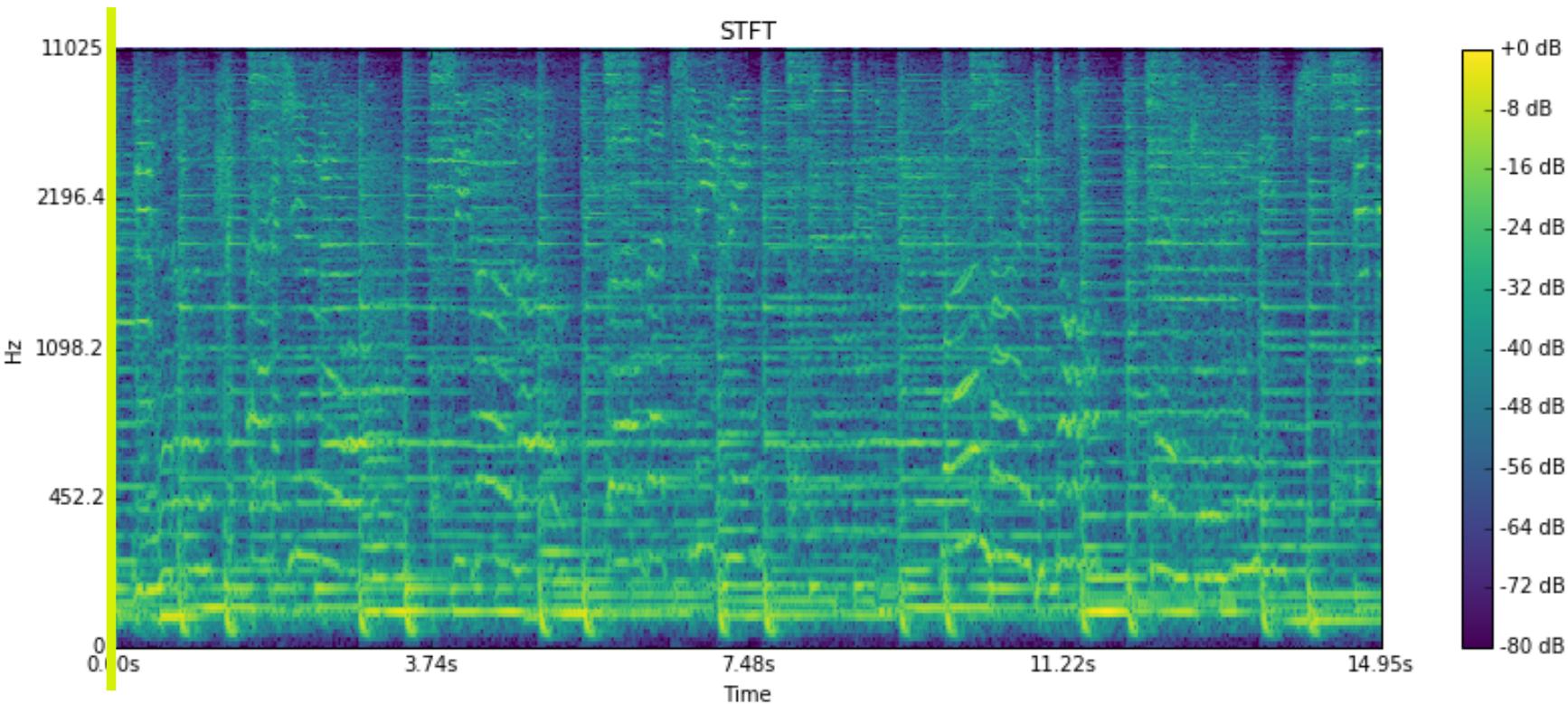
Outline

- Pandora Overview
- Large Scale Music Recommendation with Deep Learning:
 - Machine Listening
 - Collaborative Filtering

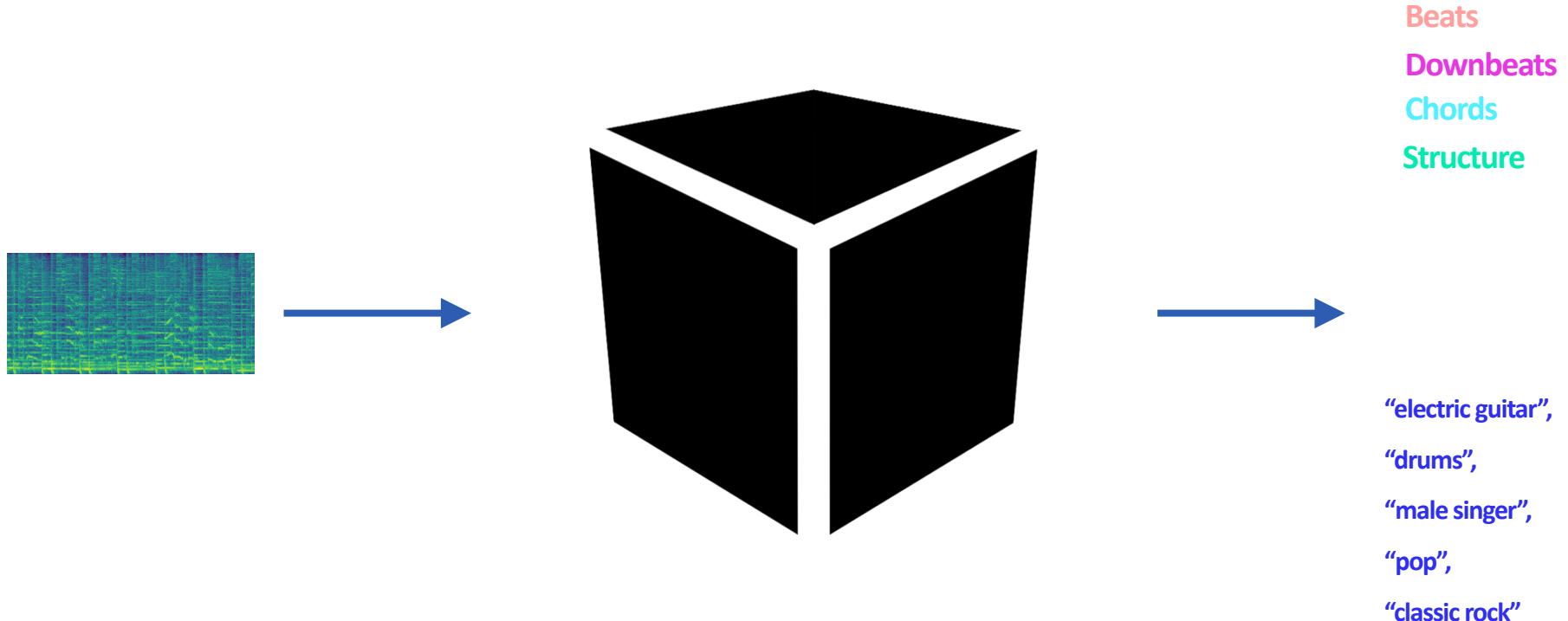


Short Time Fourier Transform

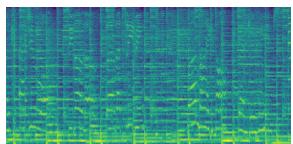
MY GUITAR GENTLY WEEPS - THE BEATLES



Extracting Information



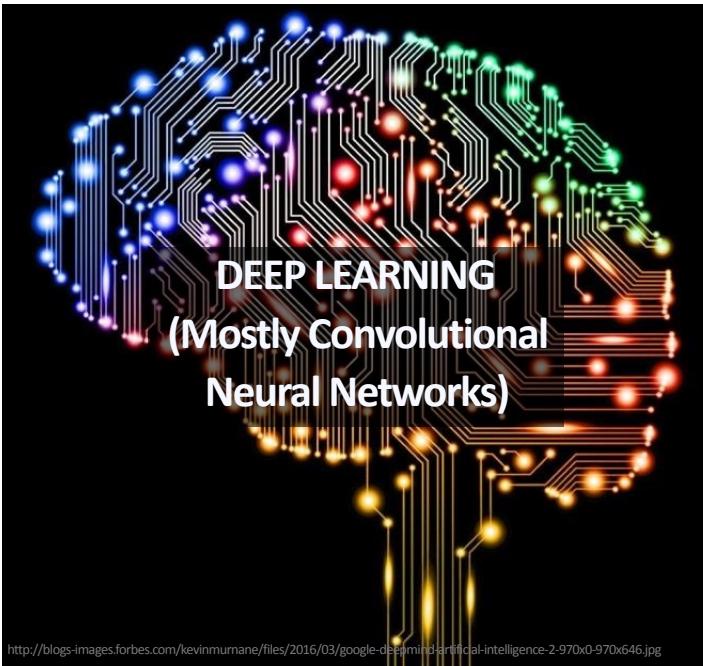
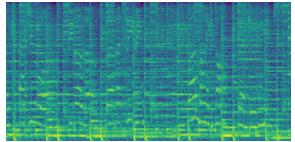
Hand Crafted Features



Beats
Downbeats
Chords
Structure

“electric guitar”,
“drums”,
“male singer”,
“pop”,
“classic rock”

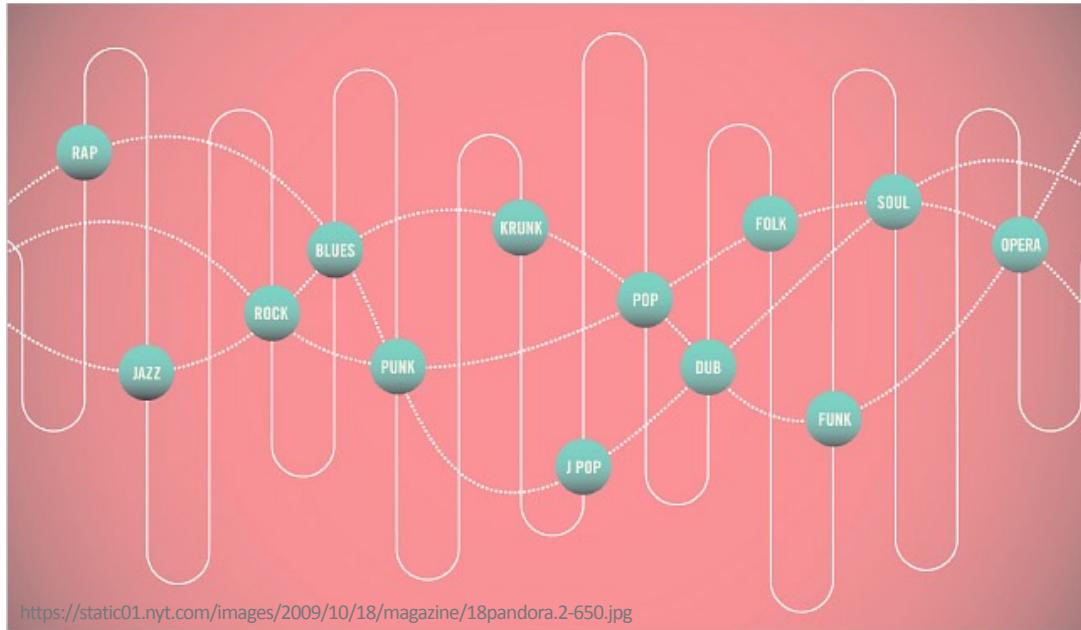
Learned Features



Beats
Downbeats
Chords
Structure

“electric guitar”,
“drums”,
“male singer”,
“pop”,
“classic rock”

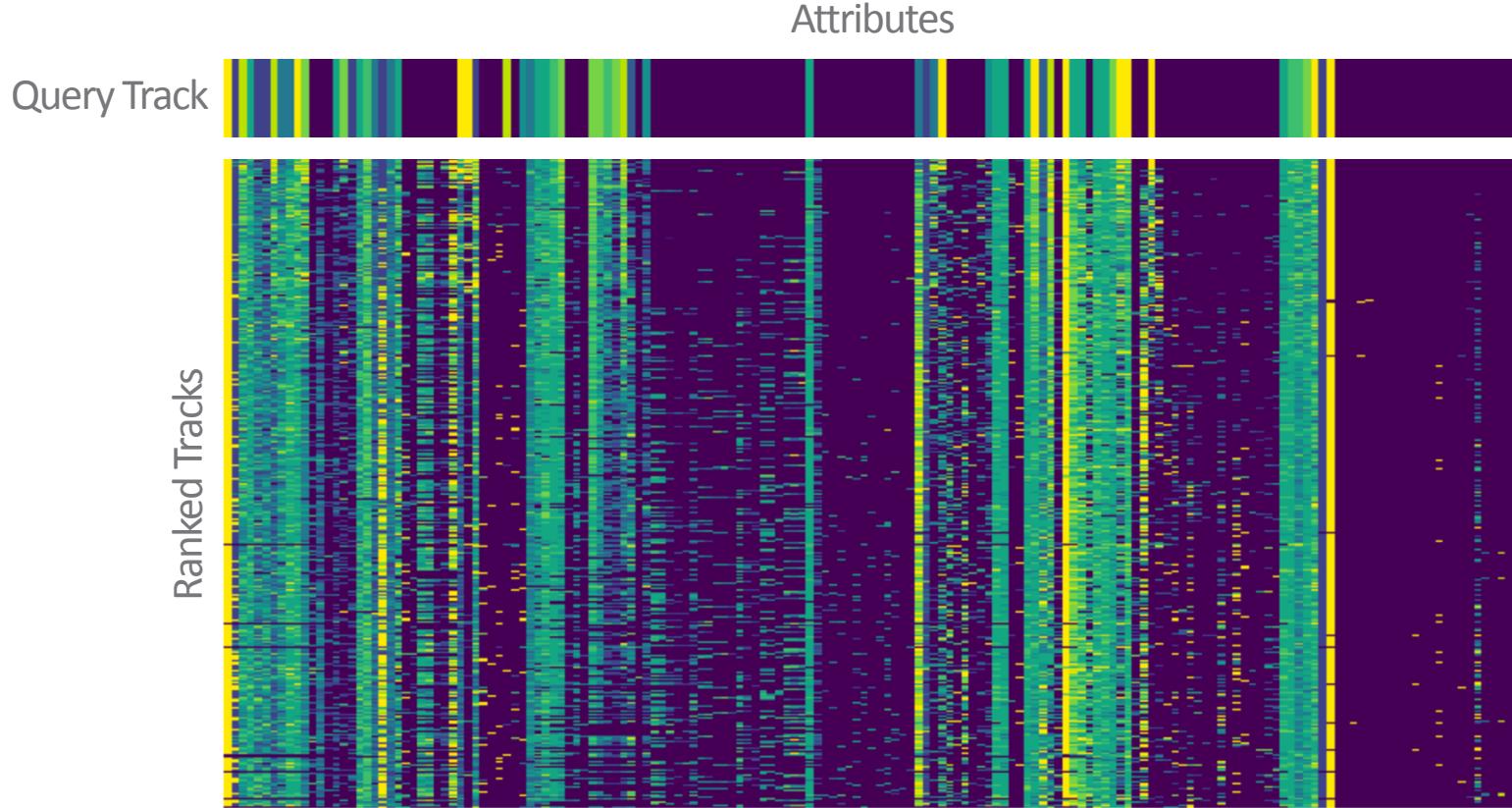
The Music *Genome* Project



>1.5 Million tracks manually analyzed

~400 attributes per track

Recommending Music using the MGP



Recommending Music using the MGP

EXAMPLE

	Artist	Title
Query Track	The Beatles	While My Guitar Gently Weeps
Ranked 1	Paul McCartney	Freedom
Ranked 2	Badly Drawn Boy	What Is It Now
Ranked 3	Jefferson Starship	Fading Lady Light

Recommending Music using the MGP

EXAMPLE

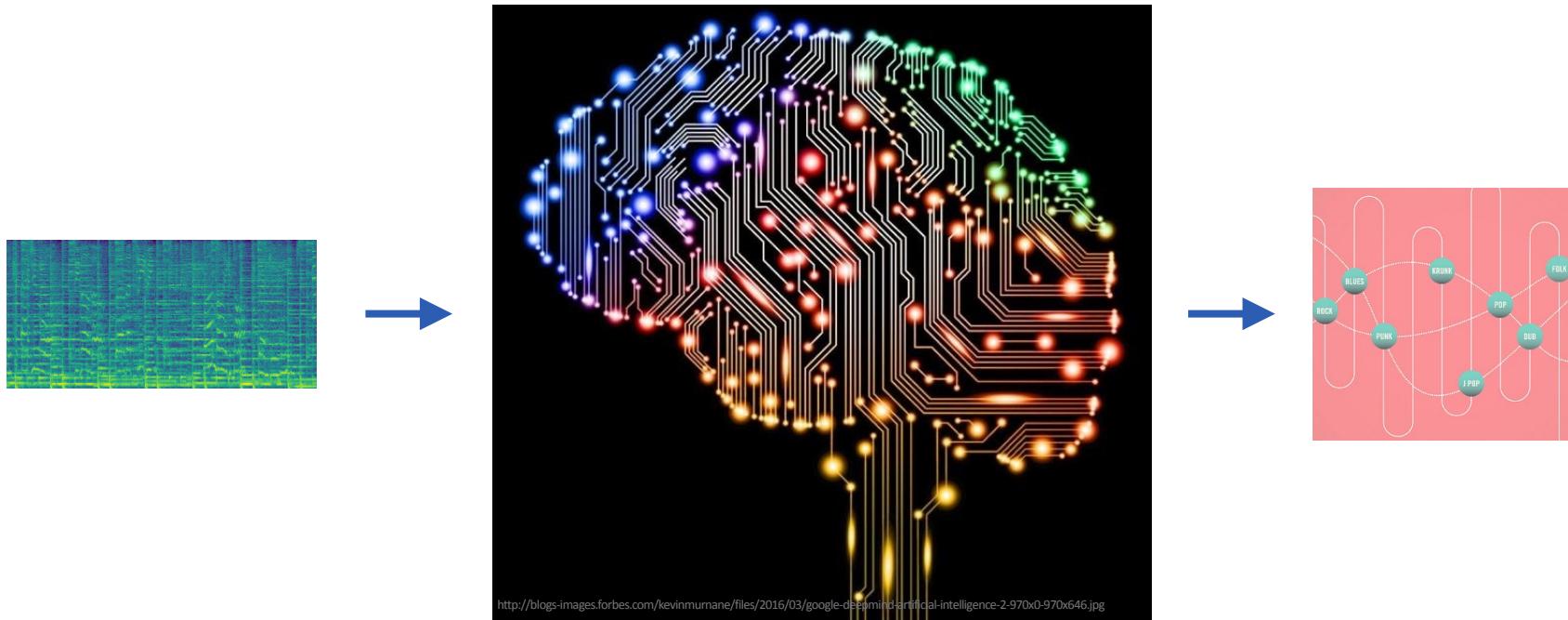
	Artist	Title
Query Track	The Beatles	While My Guitar Gently Weeps
Ranked 1	Paul McCartney	Freedom
Ranked 2	Badly Drawn Boy	What Is It Now
Ranked 3	Jefferson Starship	Fading Lady Light

Recommending Music using the MGP

EXAMPLE

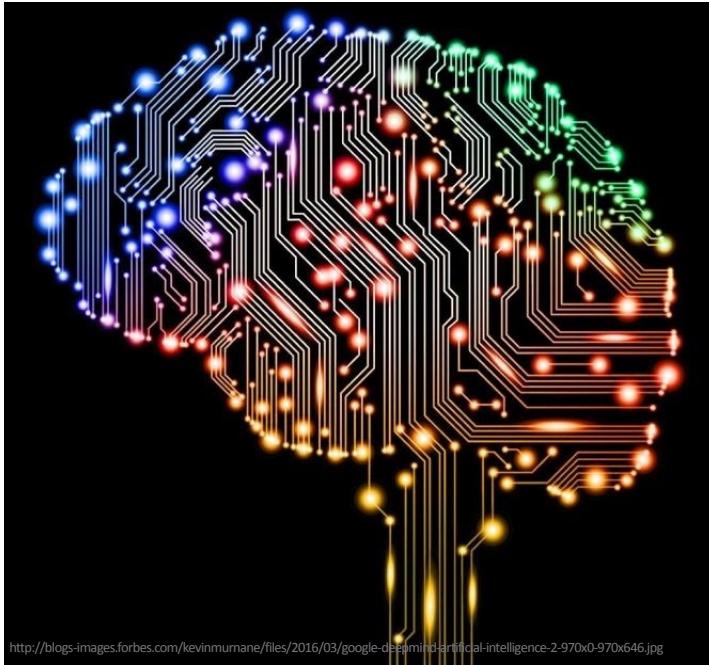
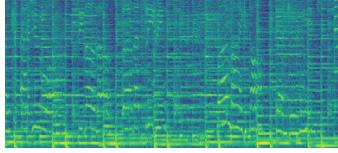
	Artist	Title
Query Track	The Beatles	While My Guitar Gently Weeps
Ranked 1	Paul McCartney	Freedom
Ranked 2	Badly Drawn Boy	What Is It Now
Ranked 3	Jefferson Starship	Fading Lady Light

Estimating MGP Attributes USING DEEP LEARNING



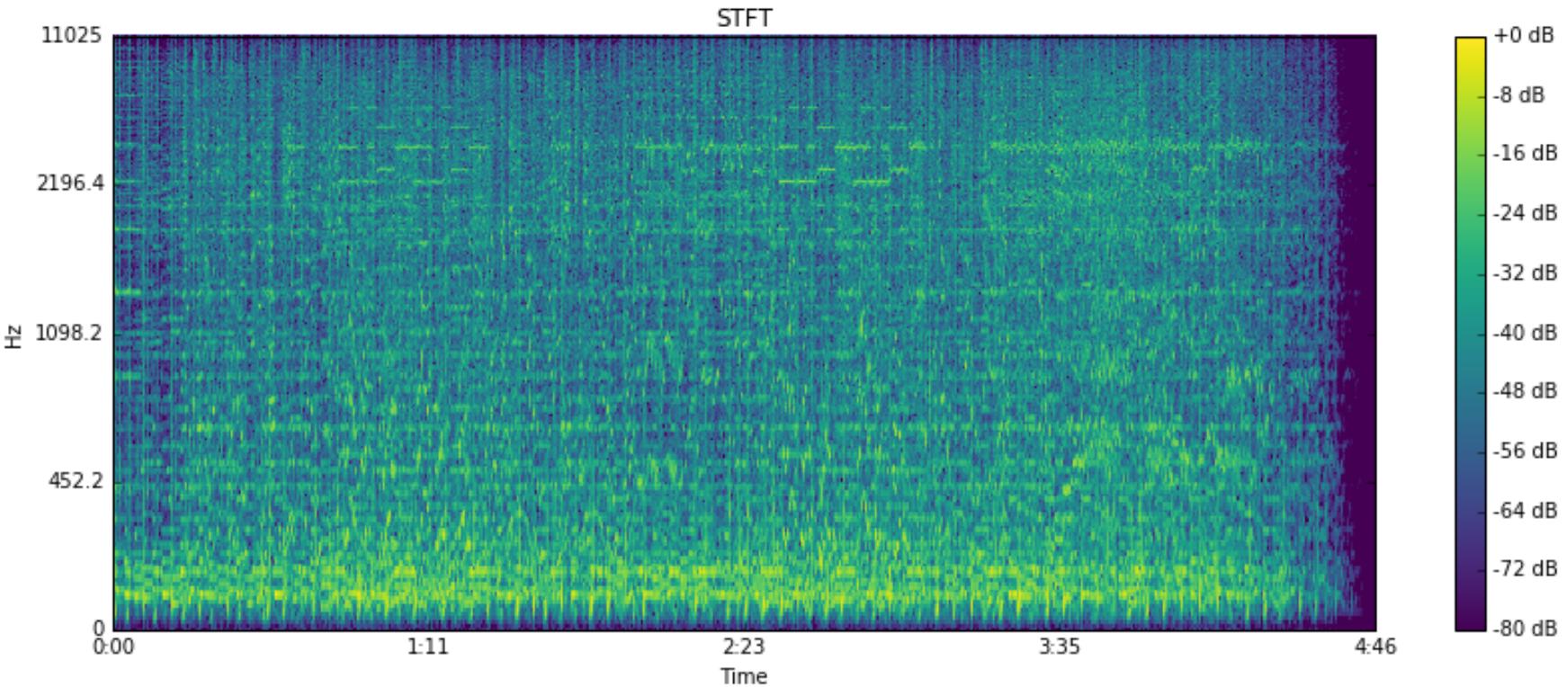
Estimating MGP Piano Attribute

USING DEEP LEARNING



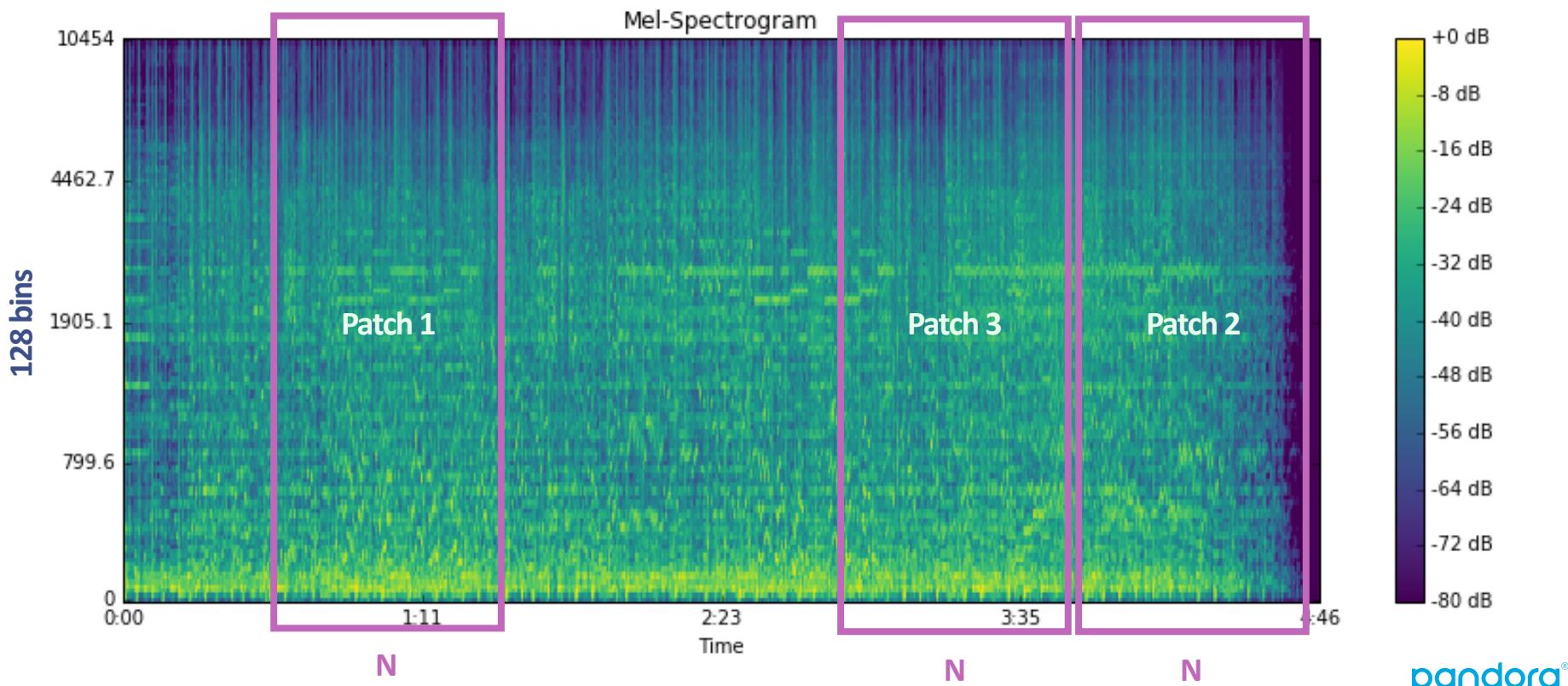
Piano Detector

USING DEEP LEARNING



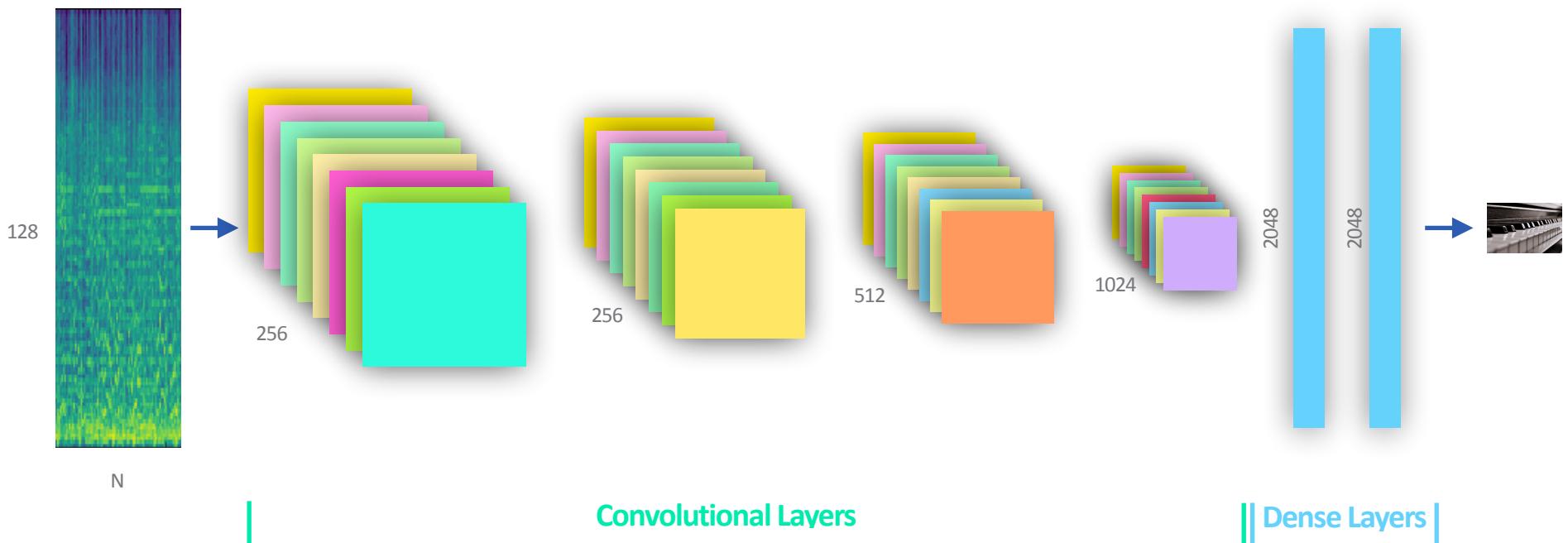
Piano Detector

USING DEEP LEARNING



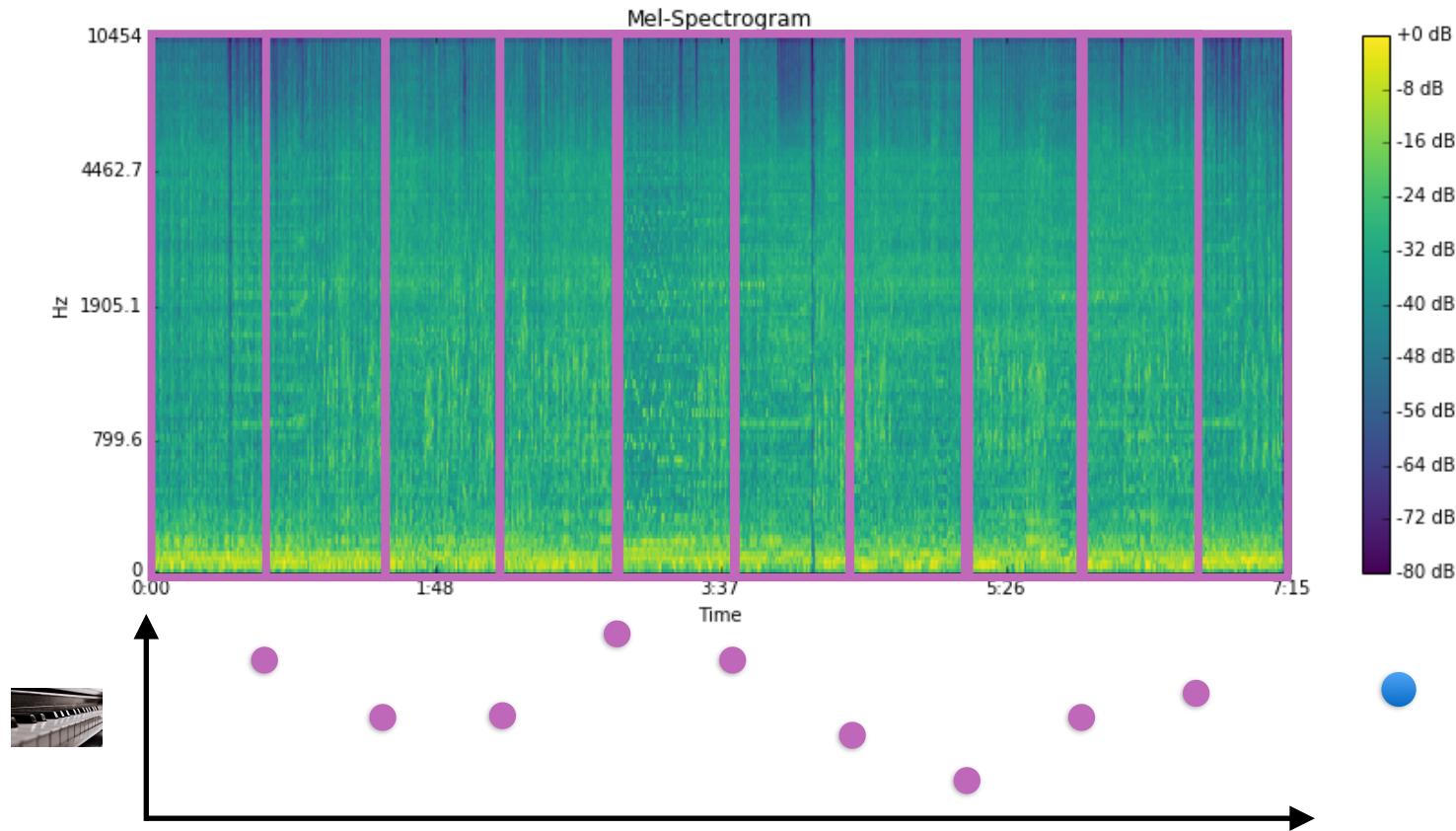
Piano Detector

DEEP ARCHITECTURE



Piano Detector

ESTIMATING FULL TRACKS



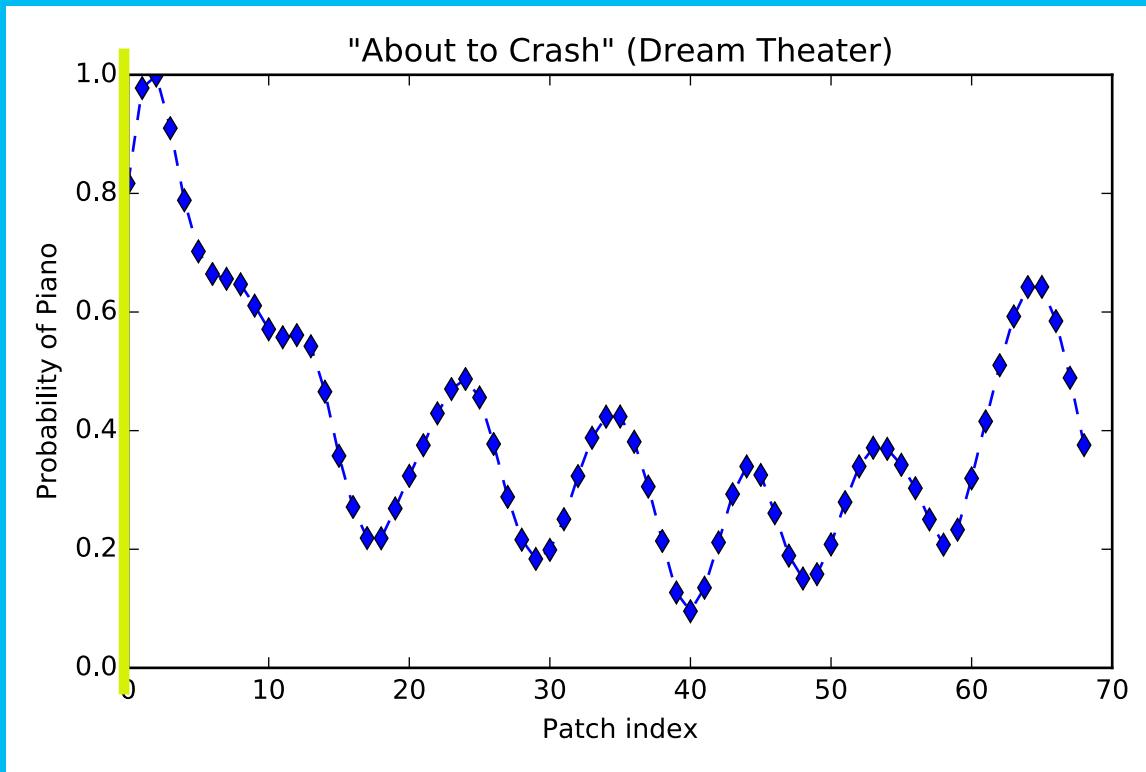
Piano Detector

RESULTS

Method	AUC ROC	
Logistic Regression	~85%	
Gradient Boosted Trees	~87.5%	
Deep Learning	91.1%	

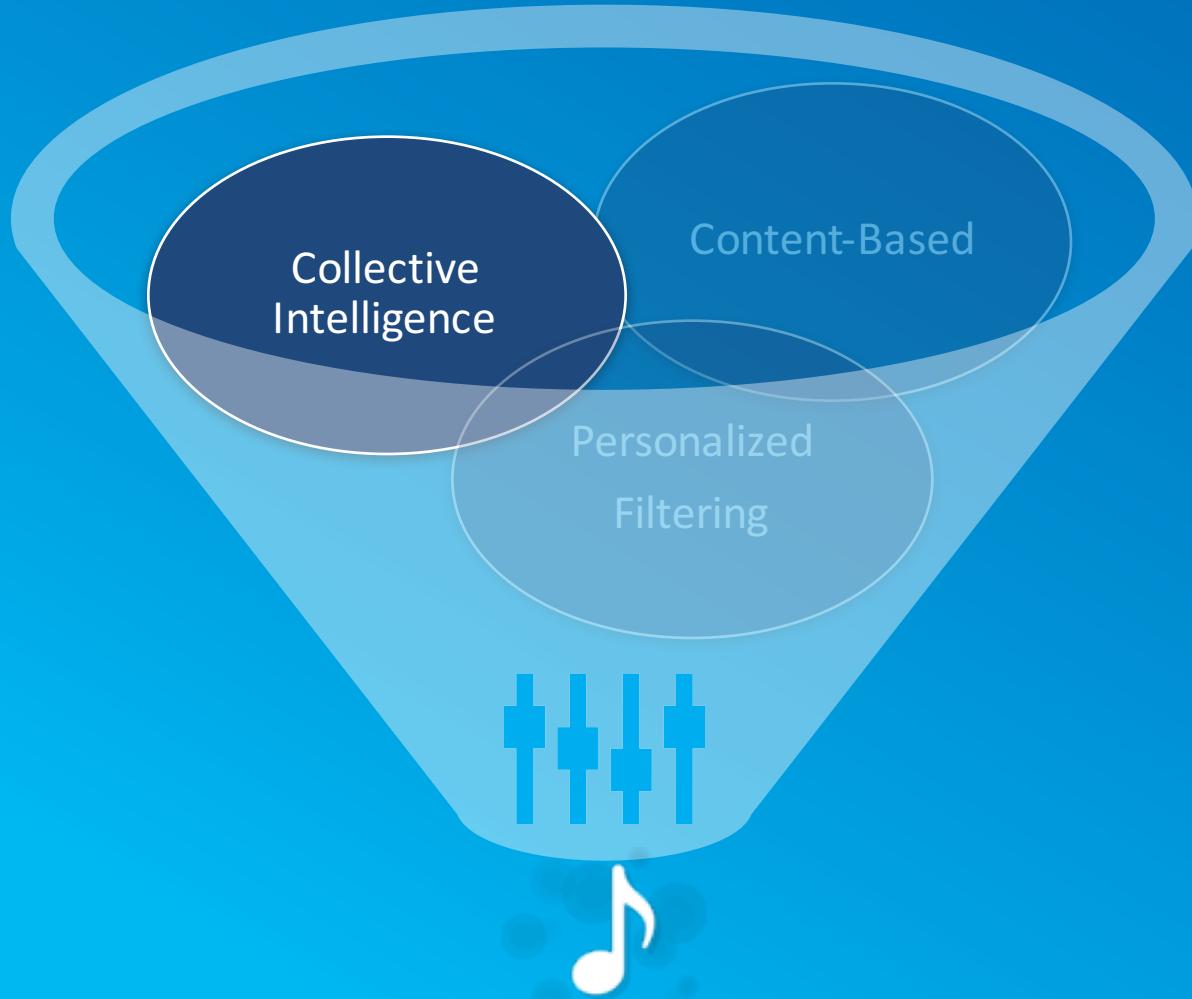
Piano Detector

OUTPUT EXAMPLE



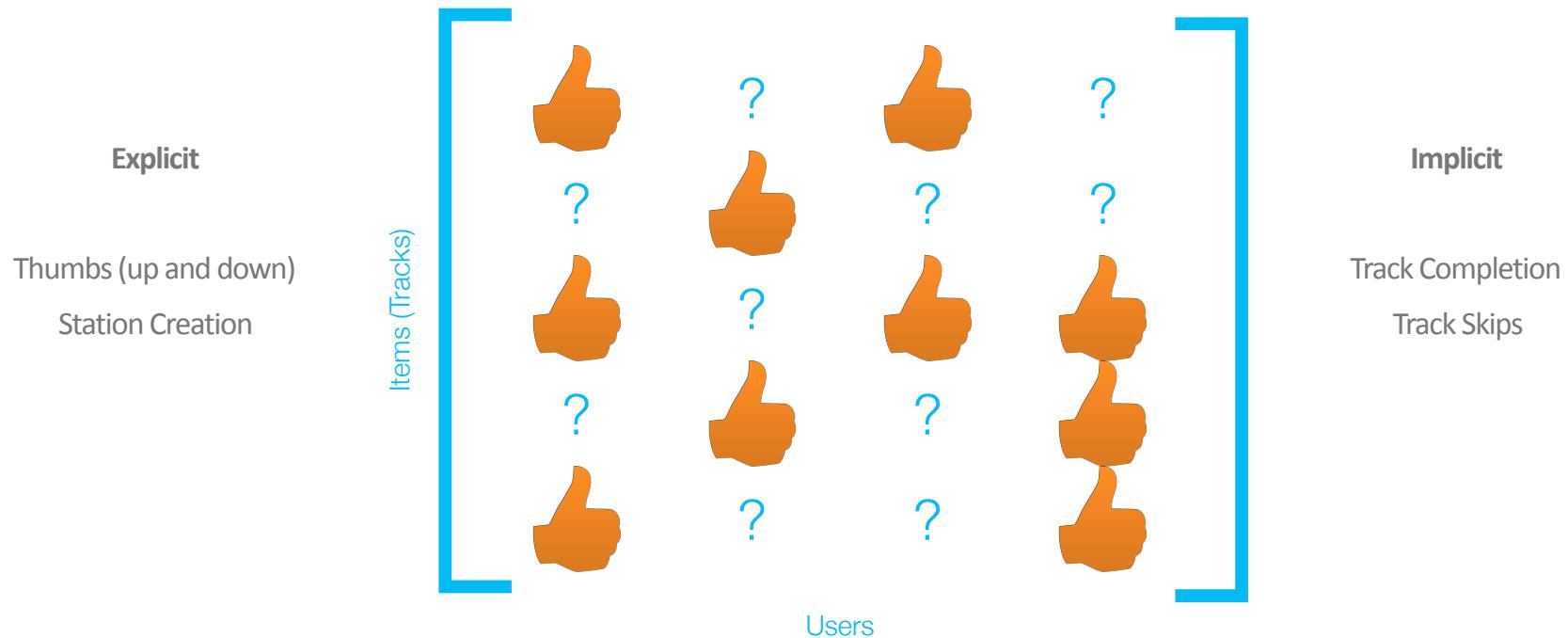
Outline

- Pandora Overview
- Large Scale Music Recommendation with Deep Learning:
 - Machine Listening
 - **Collaborative Filtering**



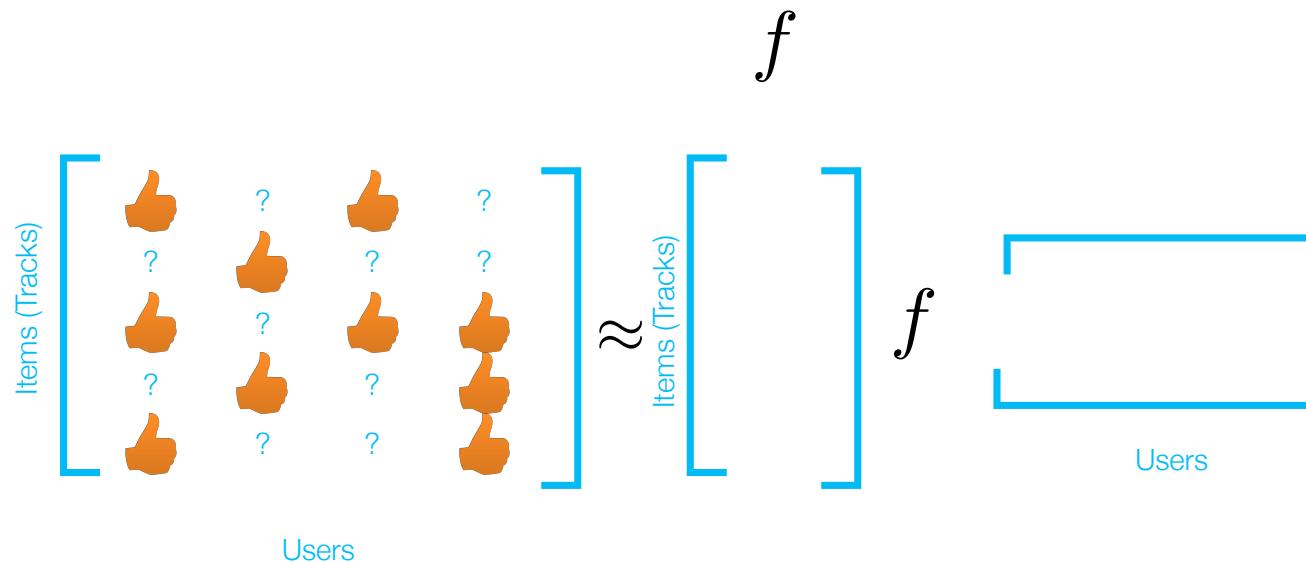
Collaborative Filtering

PROBLEM OVERVIEW



Collaborative Filtering

MATRIX FACTORIZATION



(Koren et al., 2009)

pandora®

Collaborative Filtering

EXAMPLE

	Artist	Title
Query Track	The Beatles	While My Guitar Gently Weeps
Ranked 1	The Beatles	A Day In The Life
Ranked 2	The Beatles	A Day In The Life (Love Version)
Ranked 3	The Beatles	While My Guitar Gently Weeps (Love Version)

Collaborative Filtering

THE GOOD AND THE BAD

Rich preference-driven similarity space

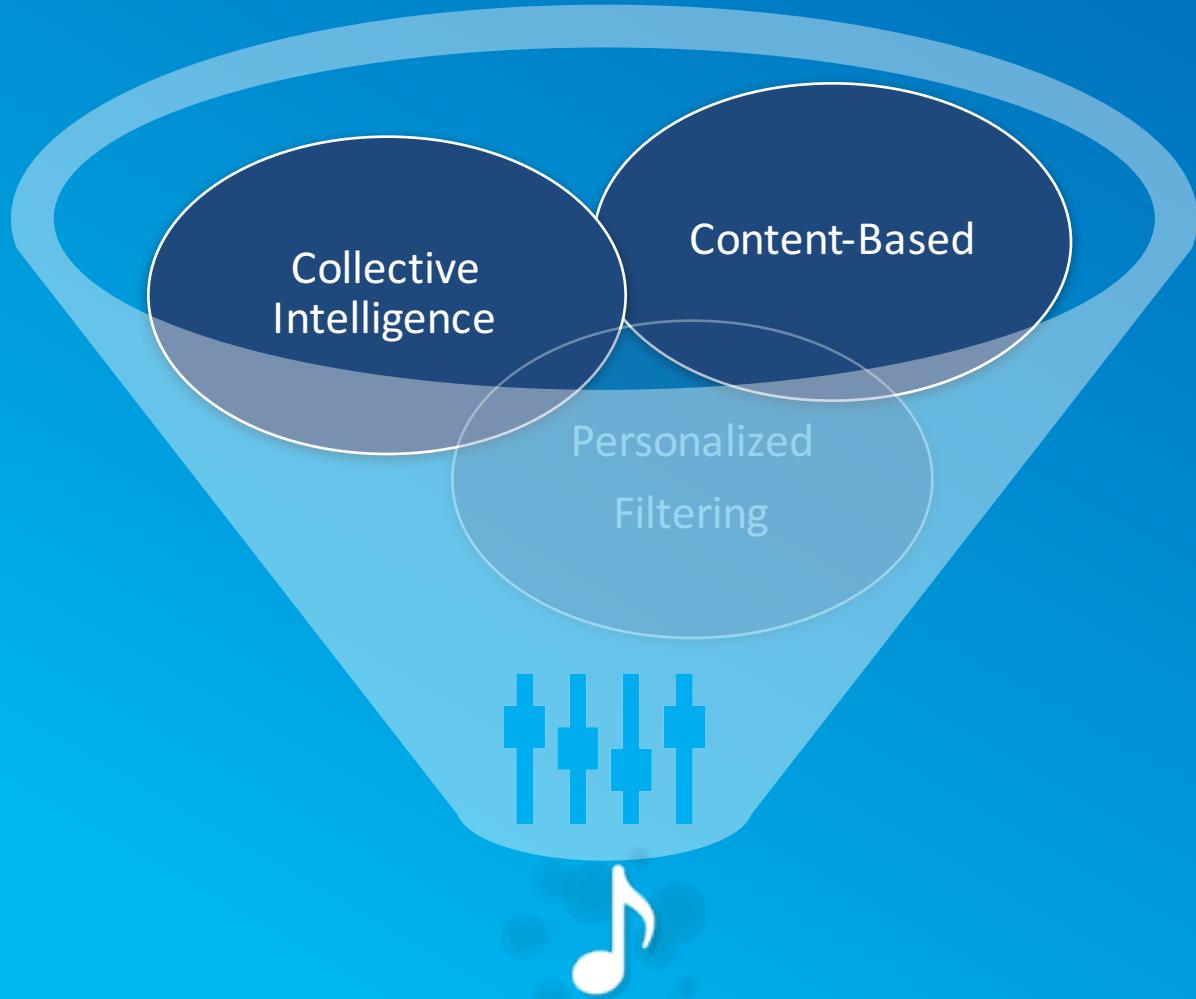
Powerful at matching the right song
with the right listener



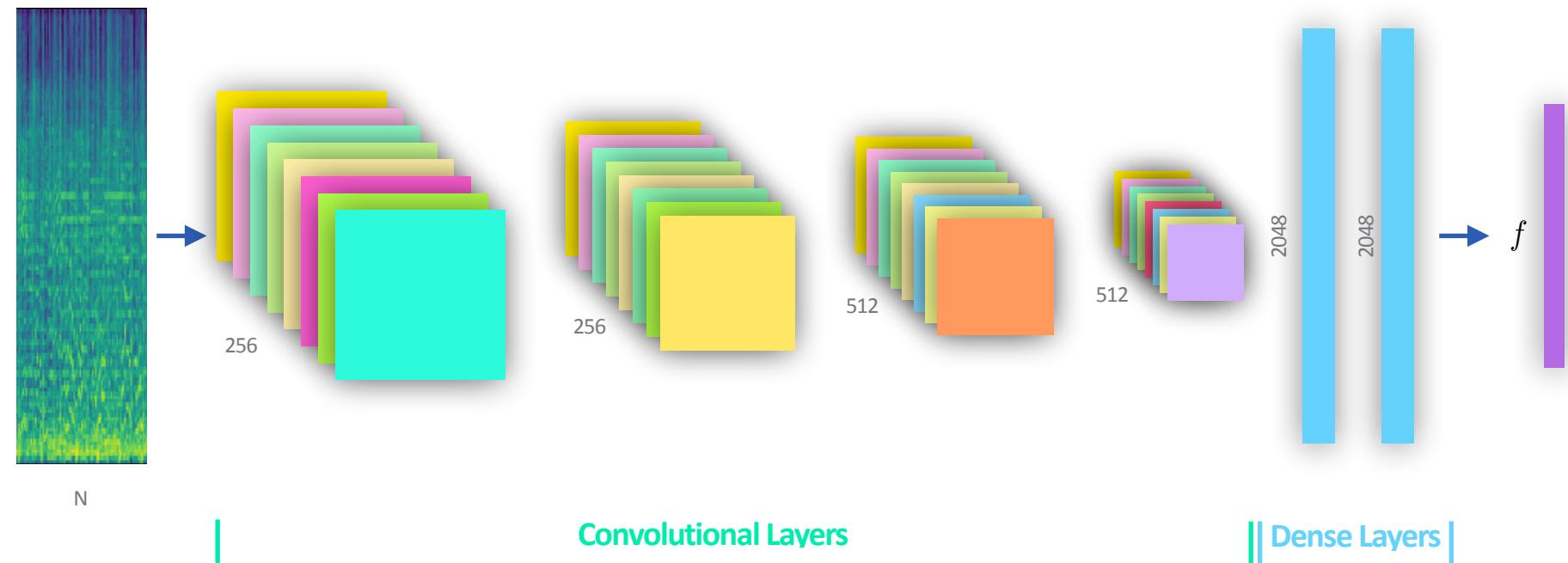
Latent space is generally not interpretable

Can only recommend items that
have already been rated





Approximating Item Factors WITH DEEP LEARNING

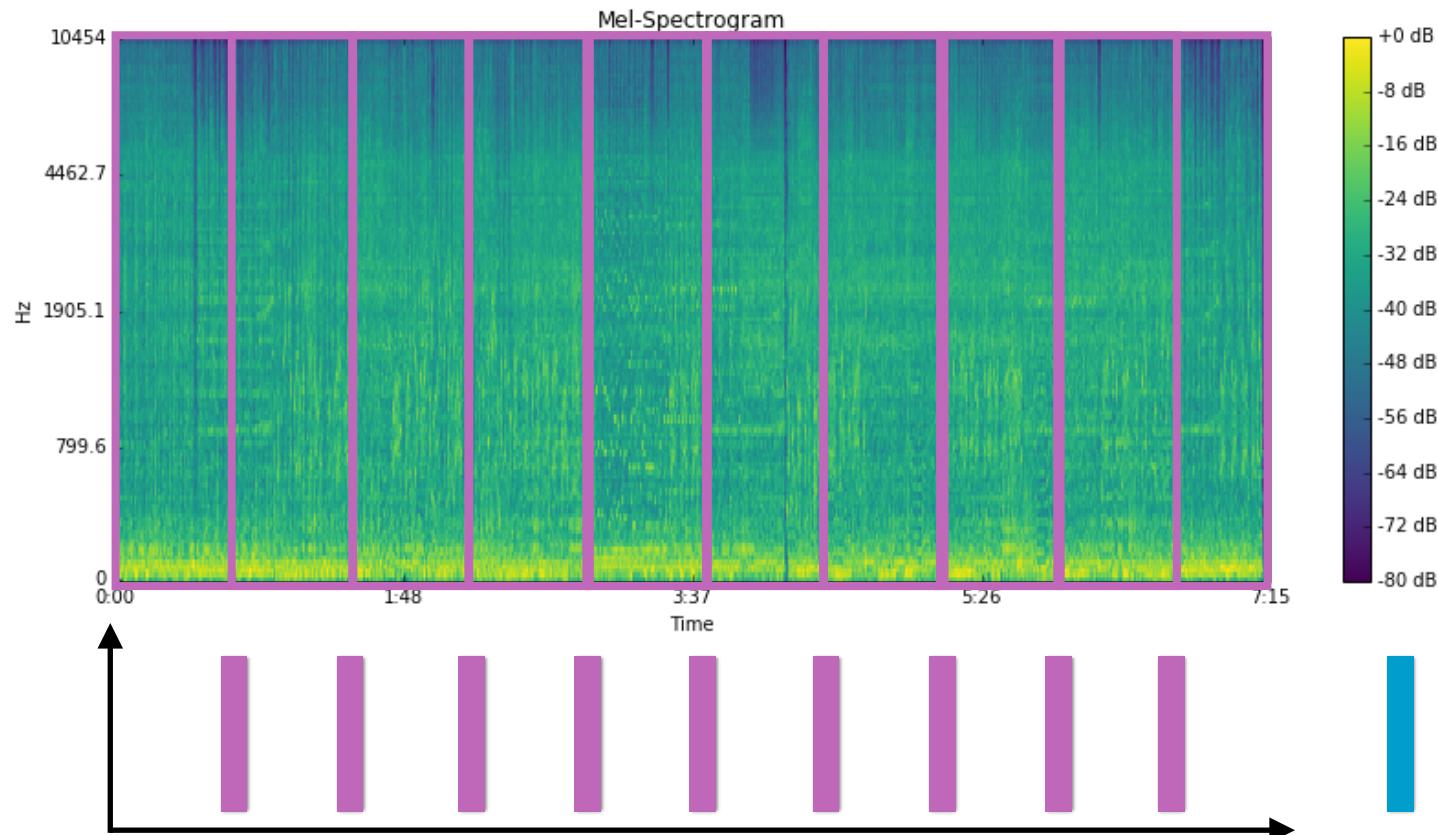


(van den Oord et al., 2013)

pandora®

Approximating Item Factors

ESTIMATING FULL TRACKS



Recommending from Learned Factors

EXAMPLE

	Artist	Title
Query Track	La Bossa d'Urina	Mama i Papa
Ranked 1	Johnny Cash	I'm Going To Memphis
Ranked 2	Merle Haggard	The Woman Made A Fool Out Of Me
Ranked 3	Waylon Jennings	Lonesome On'ry And Mean



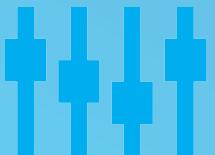
Collective
Intelligence



Content-Based



Personalized
Filtering





ENSEMBLE OF RECOMMENDERS MAY PRODUCE OPTIMAL RECOMMENDATIONS



MAN vs MACHINE?



MAN + MACHINE



MAN + MACHINE

“Mix of Art and Science”

THANKS!

ONIETO@PANDORA.COM

WE'RE
HIRING!

pandora®

References

- Van Den Oord, A., Dieleman, S., Zen, H., Simonyan, K., Vinyals, O., Graves, A., Kavukcuoglu, K. (2016). Wavenet: A Generative Model for Raw Audio, 846–849.
- Simonyan, K., & Zisserman, A. (2015). Very Deep Convolutional Networks for Large-Scale Image Recognition. International Conference on Learning Representations, 1–14. <http://doi.org/10.1101/10.1016/j.infsof.2008.09.005>
- Mcfee, B., Humphrey, E. J., & Bello, J. P. (2015). A Software Framework For Musical Data Augmentation. In Proc. of the 16th International Society for Music Information Retrieval Conference (pp. 248–254). Málaga, Spain.
- Koren, Y., Bell, R., & Volinsky, C. (2009). Matrix Factorization Techniques for Recommender Systems. Computer, 42(8), 42–49. <http://doi.org/10.1109/MC.2009.263>
- Oord, A. Van Den, Dieleman, S., & Schrauwen, B. (2013). Deep Content-based Music Recommendation. Advances in Neural Information Processing Systems, 2643–2651. Retrieved from <http://papers.nips.cc/paper/5004-deep-content-based-music-recommendation>