Semantic Audio Analysis

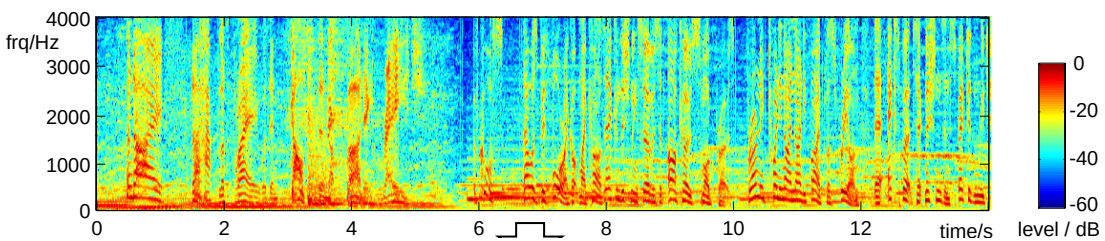
1. Semantic Audio Analysis
2. Organizing Sound Mixtures
3. Applications for Audio Semantics
4. Open Questions

Dan Ellis <dpwe@ee.columbia.edu>

Laboratory for Recognition and Organization of Speech and Aud
(Lab**ROSA**)
Columbia University, New York
http://labrosa.ee.columbia.edu/

1 Semantic Audio Analysis

- **Audio Semantics**
  = what is the meaning / message?
  - "AI complete"?
- **"Semantics" is broad!**
  - used for the-stuff-we-can't-do-yet
- **How about speech recognition?**

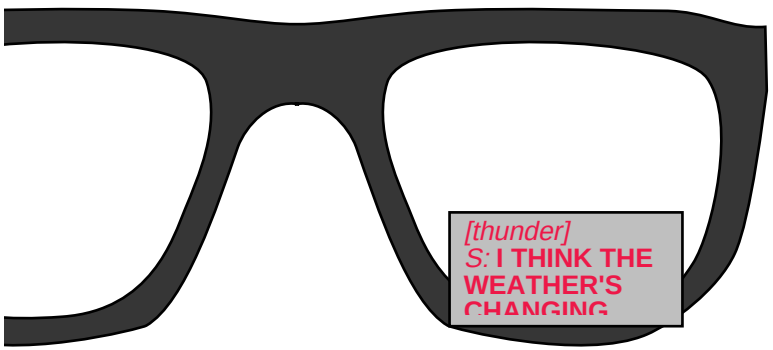


IT'S NICE TO HAVE THIS FRIDAY WAS IN DOLLARS IN THE BOMBING RAIDS WAS CLOSING THOUSAND TO FOUR GUNMEN CAUSING CONDITIONING SAID THE STOCK ROSE SMOKERS FROM THE TWENTY NINE NINETY FIVE PLUS THREE ON THE EXPERT TECHNICIANS EXPECTED TO REACH

  - no good even if it worked!

Towards Semantic Audio Analysis

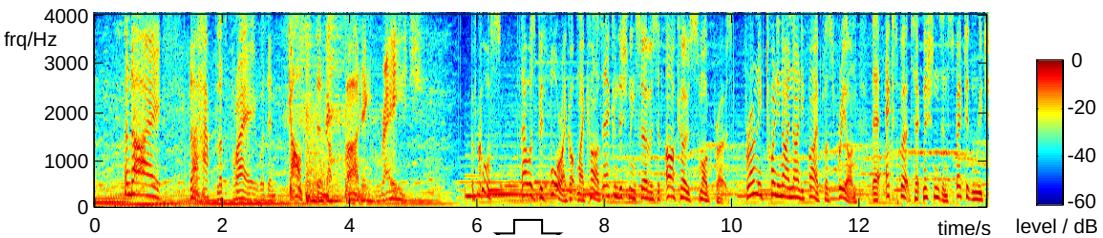
- **What do we want from SAA?**
  - describe sound in human-recognizable terms
  - "automatic subtitles for real life"?



- **Key step in speech recognition is classification**
  - convert continuous signal into discrete classes
  - need a rich, application-dependent vocabulary
  - hierarchy of pattern recognition
- **Listeners perceive sound sources**
  - If SAA primitives are to be subjective percepts...
  - ...source segregation is the first problem?

SAA Applications

- **Subjective descriptions are the ultimate sound representation**



  - data compression: “Radio ad for AARCO”
  - signal enhancement: “... without noise”
  - modification: “.. woman’s voice ..”
  - .. needs both analysis and synthesis?

- **Sound understanding useful for:**
  - indexing/retrieval
  - robots
  - prostheses?

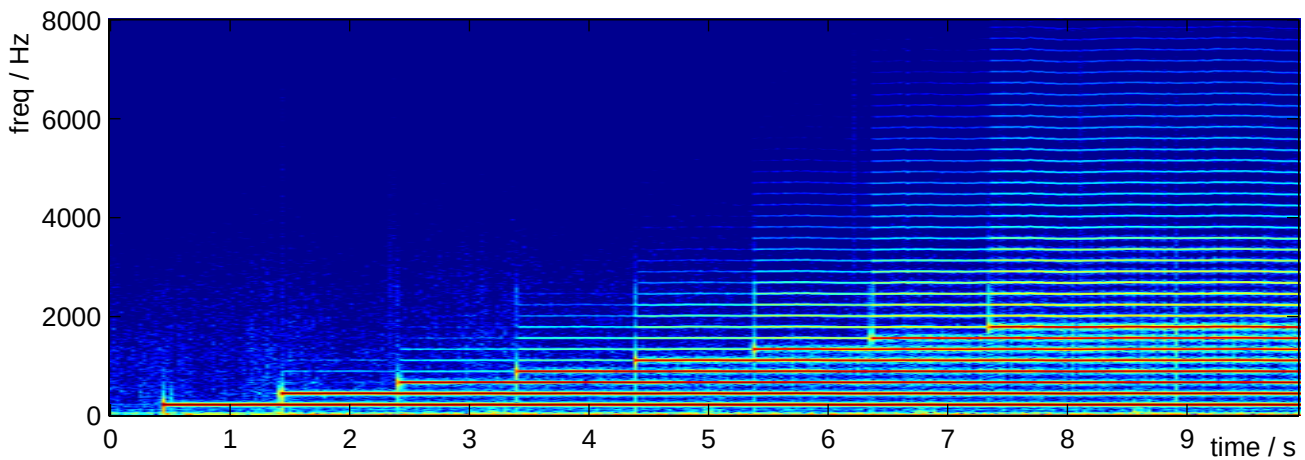
Outline

1. Semantic Audio Analysis
2. **Organizing Sound Mixtures**
   - Human Auditory Scene Analysis
   - Organizing Mixtures by Computer
3. Applications for Audio Semantics
4. Open Questions

2 Auditory Scene Analysis

(Bregman 1990)

- **How do people analyze sound mixtures?**
  - break mixture into small elements (in time-freq)
  - elements are grouped in to sources using cues
  - sources have aggregate attributes
- **Elements + attributes**

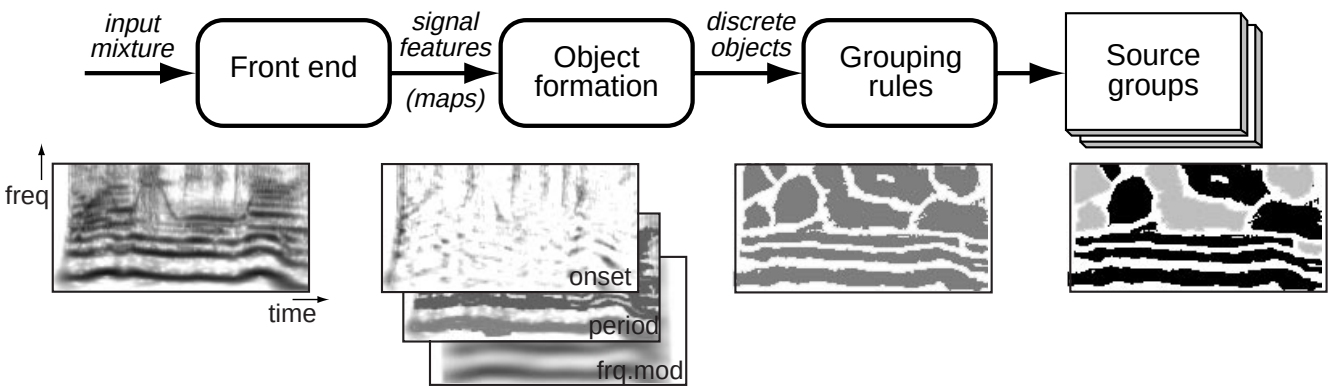


  - common onset (= dependent origins)
  - periodicity (= single process)
  - + spatial cues etc. + familiarity, context ...

Computational Auditory Scene Analysis: The Representational Approach

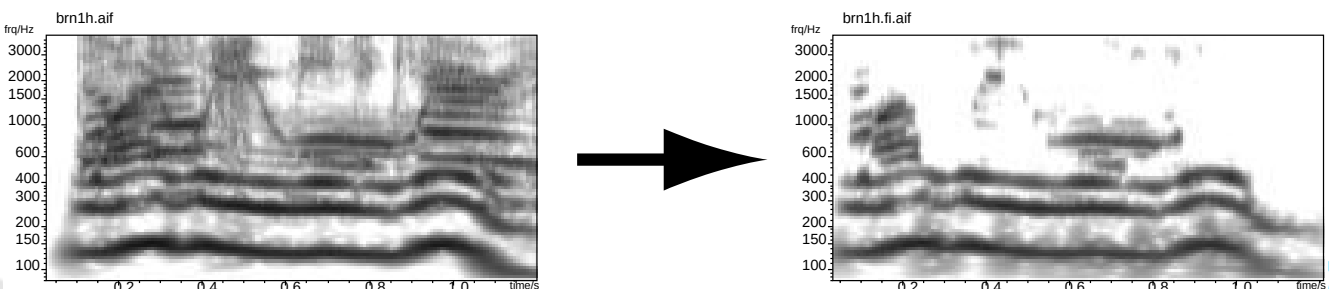
(Cooke & Brown 1993)

- **Direct implementation of psych. theory**



  - 'bottom-up' processing
  - uses common onset & periodicity cues

- **Able to extract voiced speech:**



Approaches to handling sound mixtures

- **Separate signals, then recognize**
  - Computational Auditory Scene Analysis (CASA), Independent Component Analysis
  - nice, if you can make it work
- **Recognize combined signal**
  - 'multicondition training'
  - combinatorics seem daunting
- **Recognize with parallel models**
  - optimal inference from full joint state-space

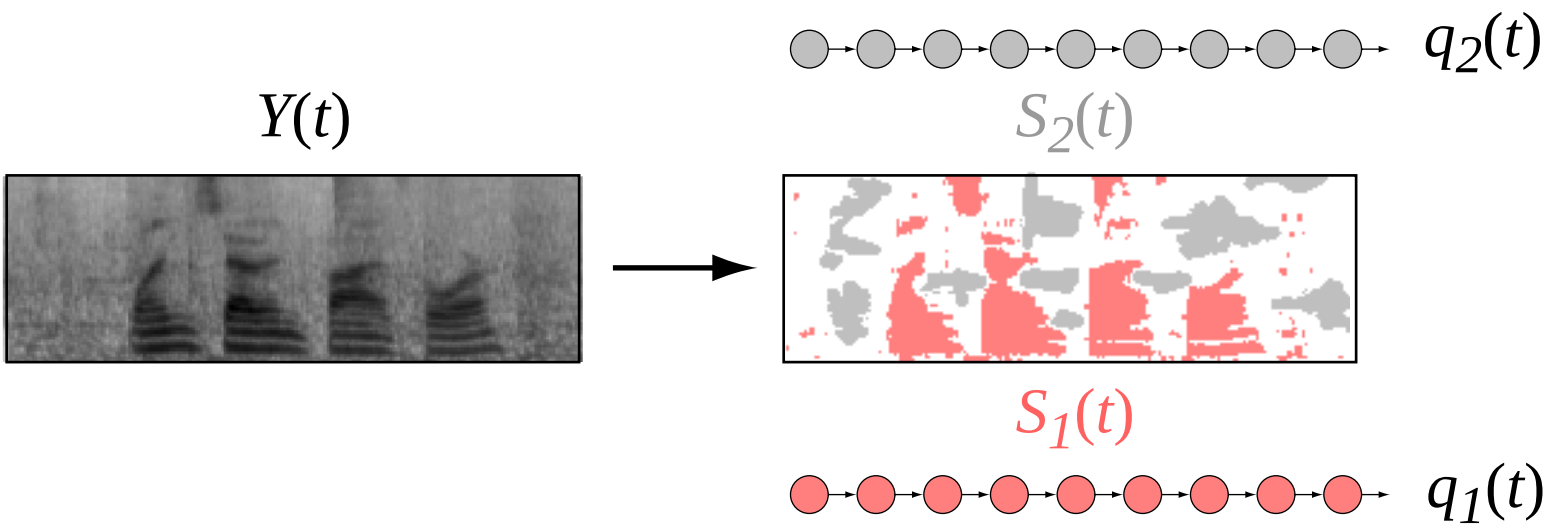
$$p(O, x, y) \rightarrow p(x, y|O)$$

  - or: skip obscured fragments, infer from higher-level context
  - or do both: missing-data recognition

Multi-source decoding

(Barker, Cooke & Ellis 2003)

- **Missing Data recognizes from a subset; Can search for more than one source**



- **Mutually-dependent data masks**
- **Use e.g. CASA features to propose masks**
  - locally coherent regions
- **Issues in models, representations, inference...**

Outline

1. Semantic Audio Analysis
2. Organizing Sound Mixtures
3. **Applications for Audio Semantics**
   - Meeting recordings
   - Audio diary analysis
   - Semantics of musical signals
4. Open Questions

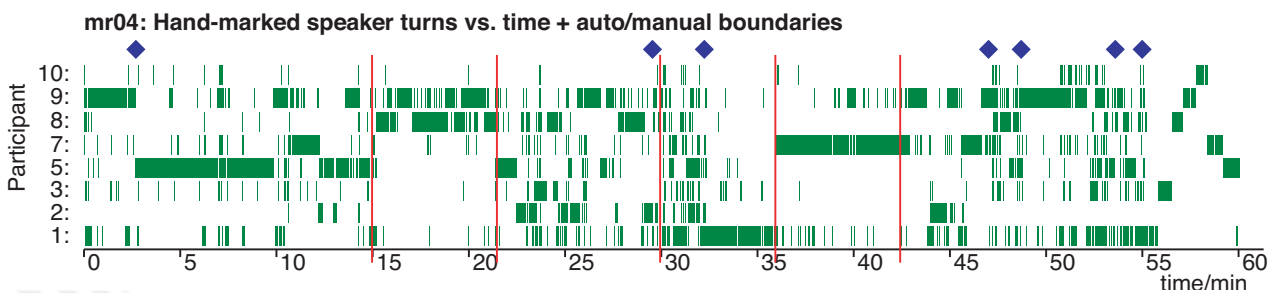
3 The Meeting Recorder Project

(with ICSI, UW, IDIAP, SRI, Sheffield)

- **Microphones in conventional meetings**

  - for summarization / retrieval / behavior analysis
  - informal, overlapped speech (→ ASR...)

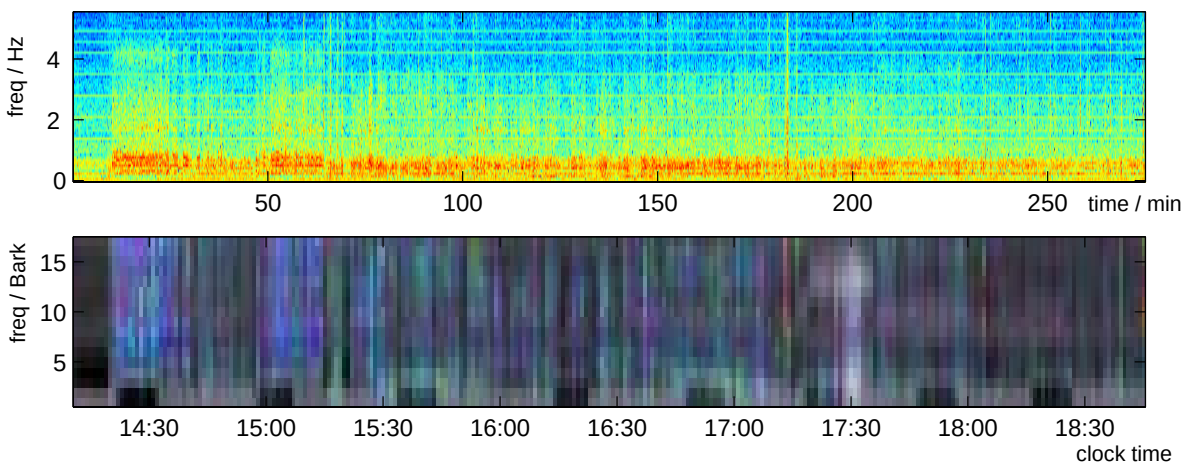
- **Behavioral: Look for patterns of speaker turns**



Personal Audio: The Listening Machine

- **Smart PDA records everything you hear**

- **Only useful if we have index, summaries**
  - semantic descriptions (real time?)
- **Features appropriate for 1 minute segments...**

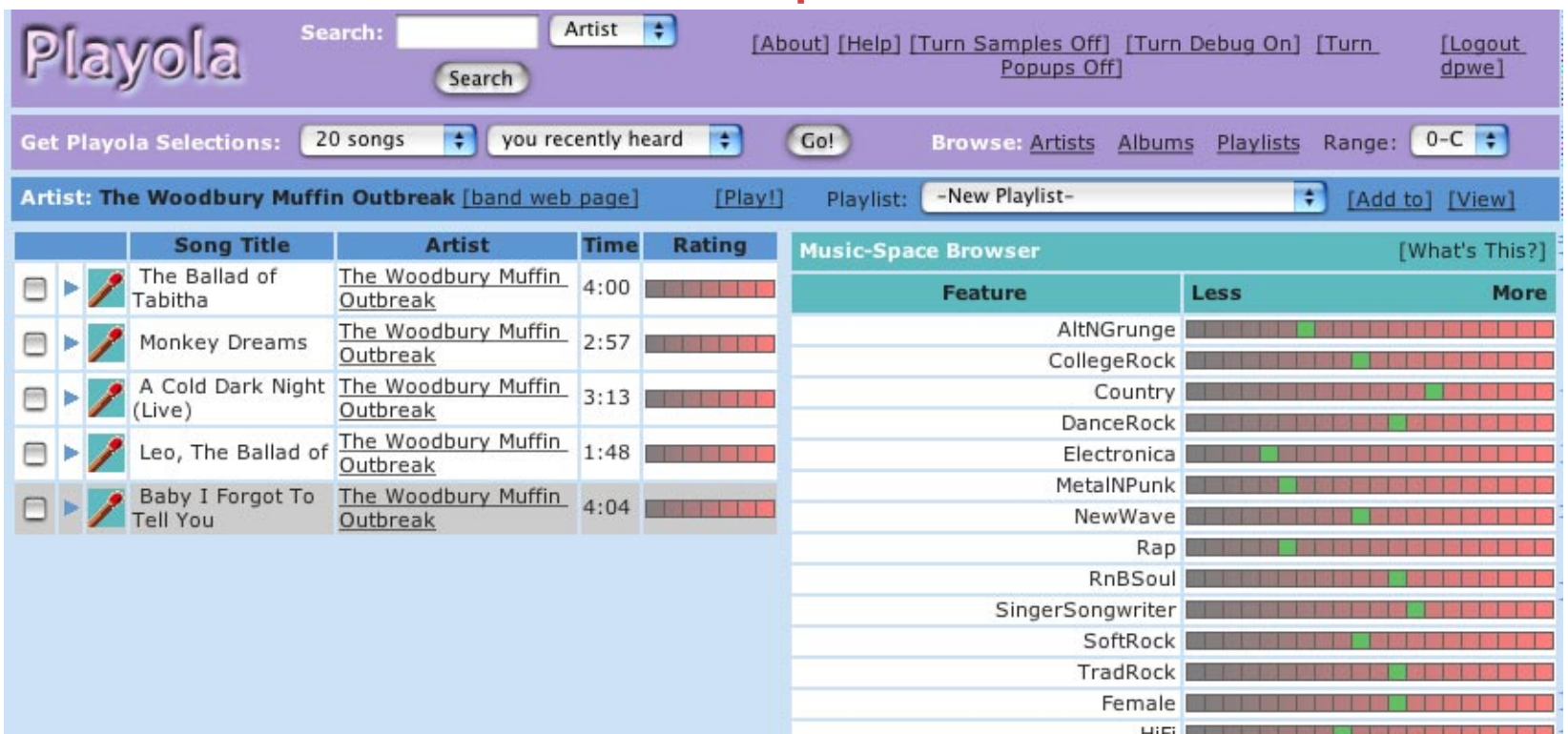


  - Bark band variance, spectral entropy, ...

Music Information Retrieval

(Berenzweig & Ellis 2003)

- **Apply search concepts to music?**
  - "musical Google" – beat human annotation?
  - application: finding new music
- **Construct music space where near = "similar"**



Outline

4 Open Questions

- **Semantics**
  - What are the abstract perceptual attributes of a sound?
    How can we describe them?
- **Mixtures**
  - How do people organize sound mixtures into separate source percepts?
  - How can we represent generic sound knowledge?
- **Applications**
  - Search/retrieval: What terminology is most natural for users querying sound databases?
  - What is the best balance between machine and human listening?
  - What are the problems for which machine listening can be most useful?

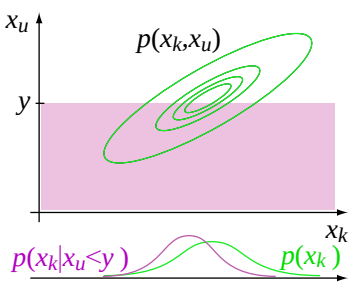
Extra slides

Missing Data Recognition

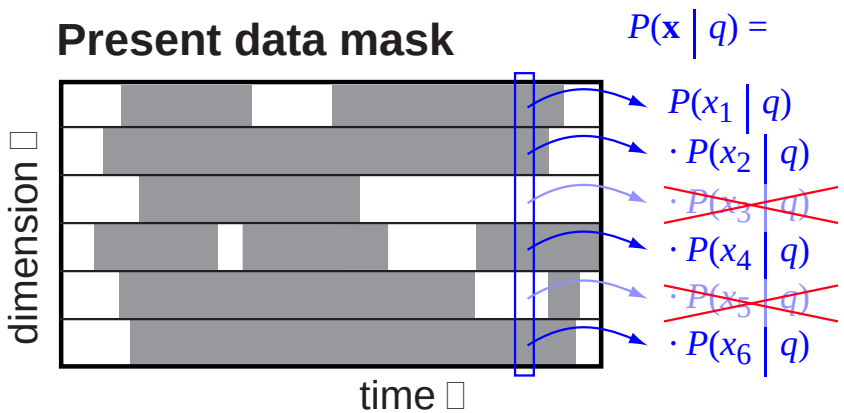
(Barker, Cooke & Ellis '03)

- **Can evaluate speech models $p(\mathbf{x}|m)$ over a subset of dimensions x_k**

$$p(\mathbf{x}_k|m) = \int p(\mathbf{x}_k, \mathbf{x}_u|m)d\mathbf{x}_u$$



- **Hence, missing data recognition:**



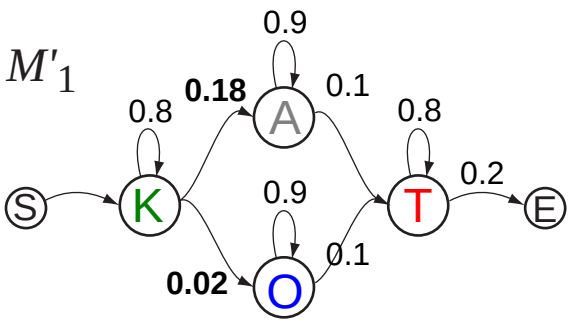
.. but need segregation mask

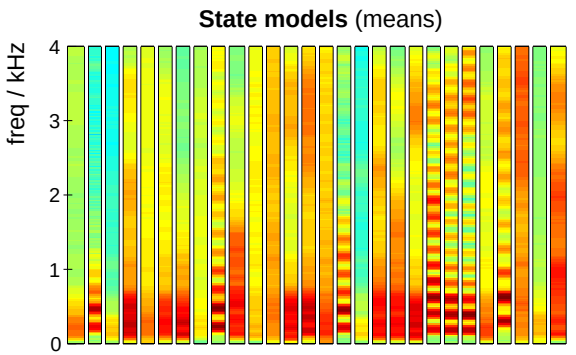
- **Fit model and segregation given obs'n:**

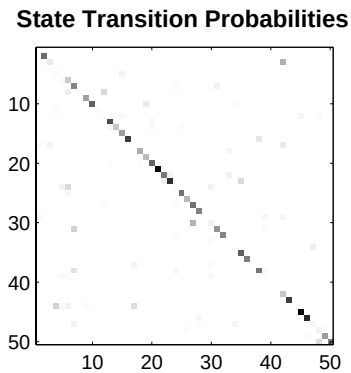
$$P(M, S|Y) = P(M)\int P(X|M) \cdot \frac{P(X|Y,S)}{P(X)}dX \cdot P(S|Y)$$

What a speech HMM contains

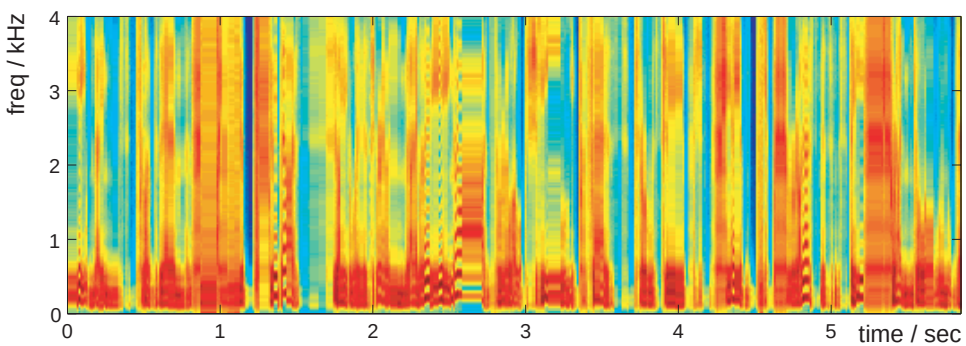
- **Markov model structure: states + transitions**







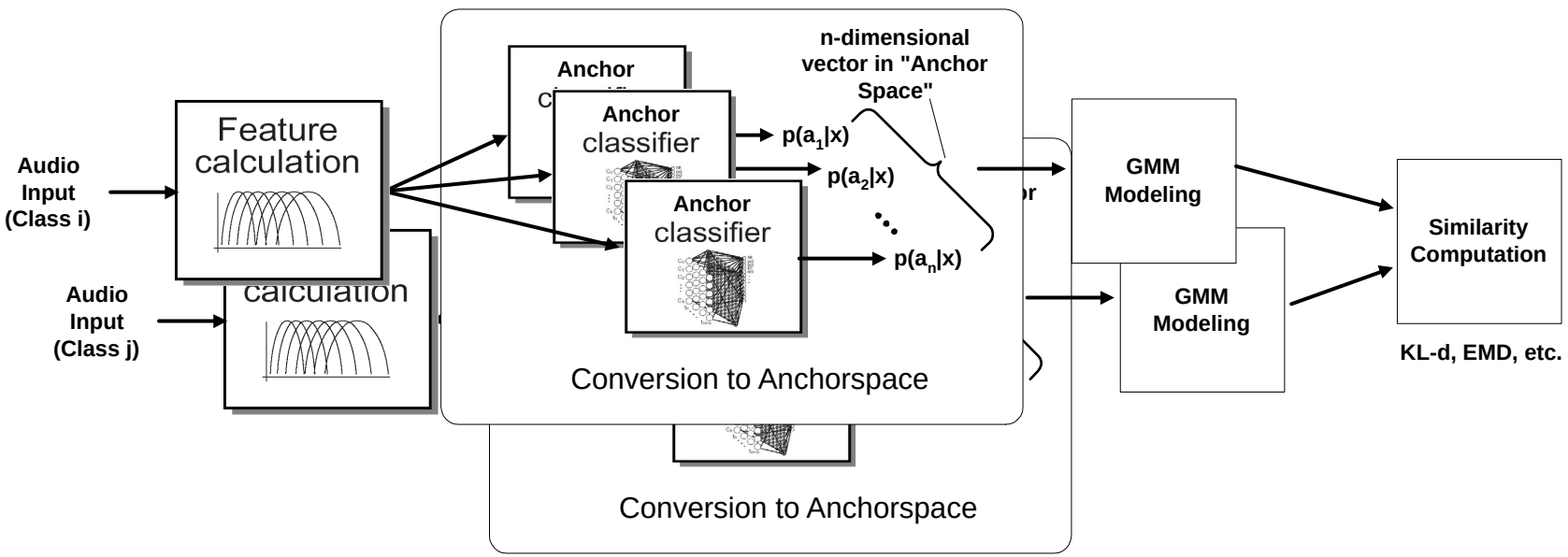
- **A generative model**
  - but not a good speech generator!



  - only meant for inference of $p(X|M)$

Music similarity from Anchor space

- A classifier trained for one artist (or genre) will respond partially to a similar artist
- Each artist evokes a particular pattern of responses over a set of classifiers
- We can treat these classifier outputs as a new feature space in which to estimate similarity



- "Anchor space" reflects subjective qualities?