Computational Auditory Scene Analysis

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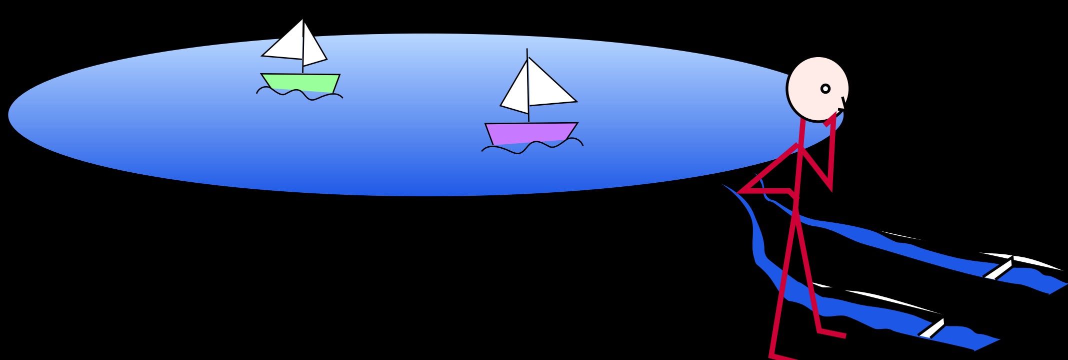
1. ASA and CASA
2. The Development of CASA
3. The Prospects for Computational Audition

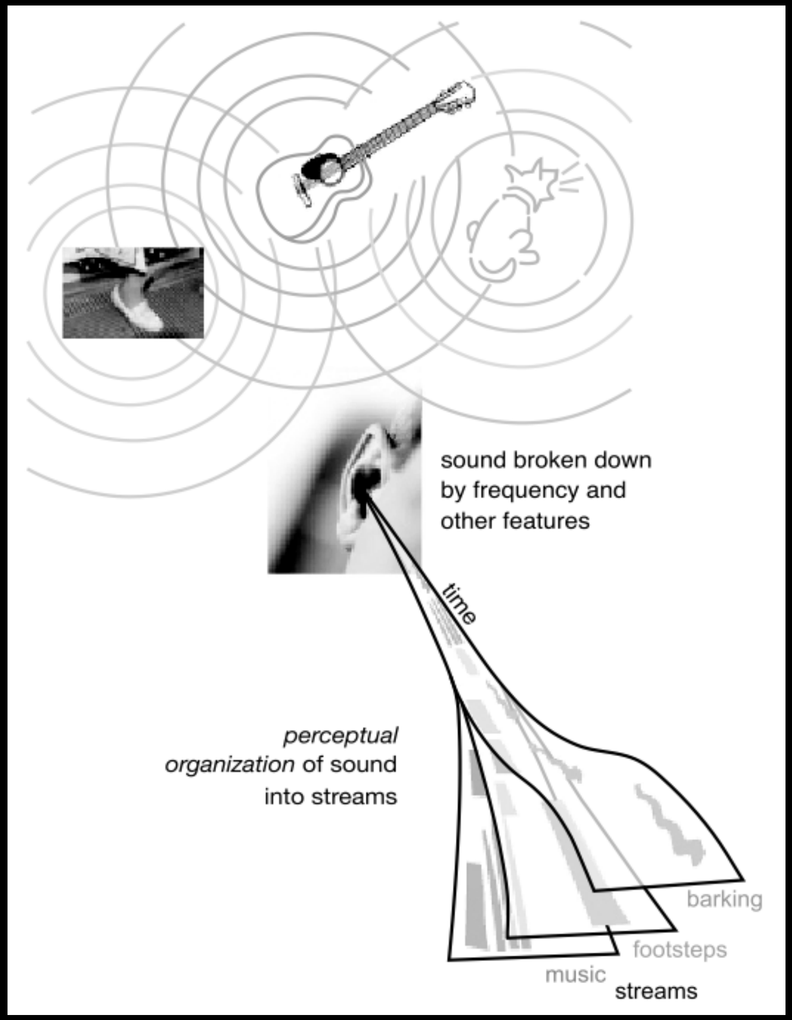
Laboratory for the Recognition and Organization of Speech and Audio

Columbia University in the City of New York

1. Auditory Scene Analysis (ASA)

"To recognize the component sounds that have been added together to form the mixture that reaches our ears, the auditory system must somehow create individual descriptions that are based only on those components of the sound that have arisen from the same environmental event."

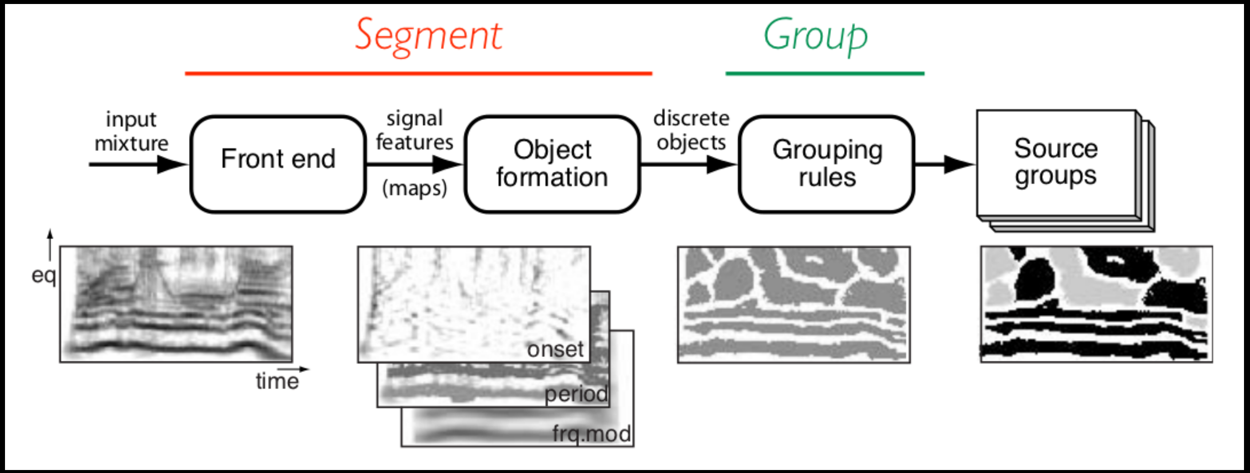




Cusack & Carlyon 2004

What is CASA?

- **Computer systems for separating sounds**
  - based on biological "inspiration" (ASA)
  - based on a source / stream formation paradigm
  - frequently using pitch information (less binaural)
  - frequently involving time-frequency masking

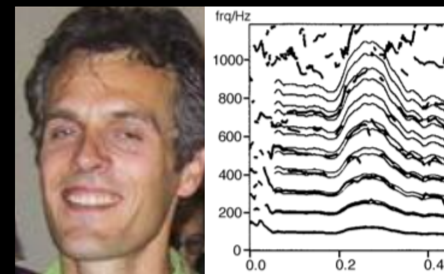


after Brown 1992

"If the study of human audition were able to lay bare the principles that govern the human skill, there is some hope that a computer could be designed to mimic it."

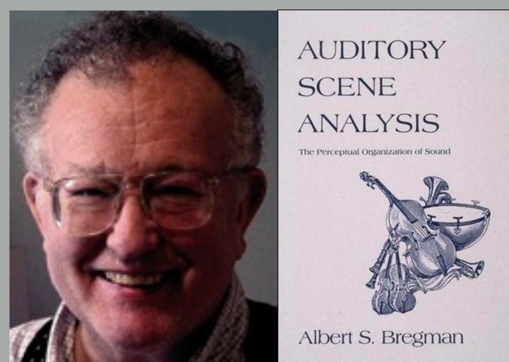
CASA History

Lyon 1984

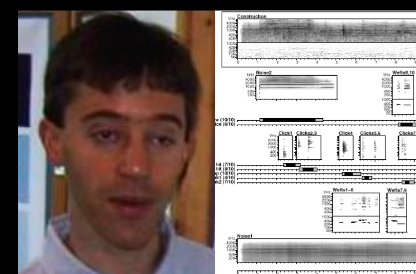


Cooke 1991

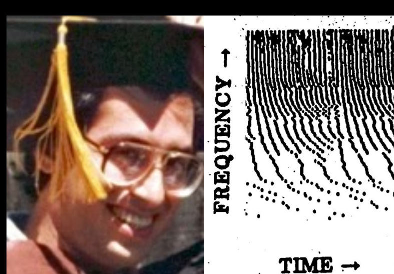
Wang & Brown 2006



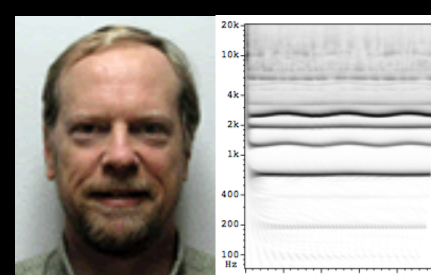
Bregman 1990



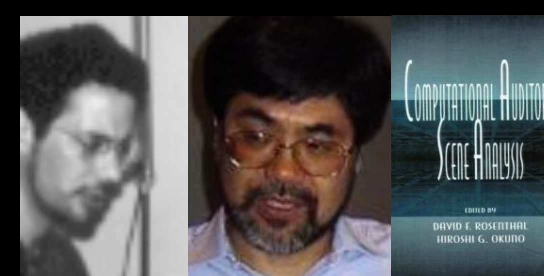
Ellis 1996



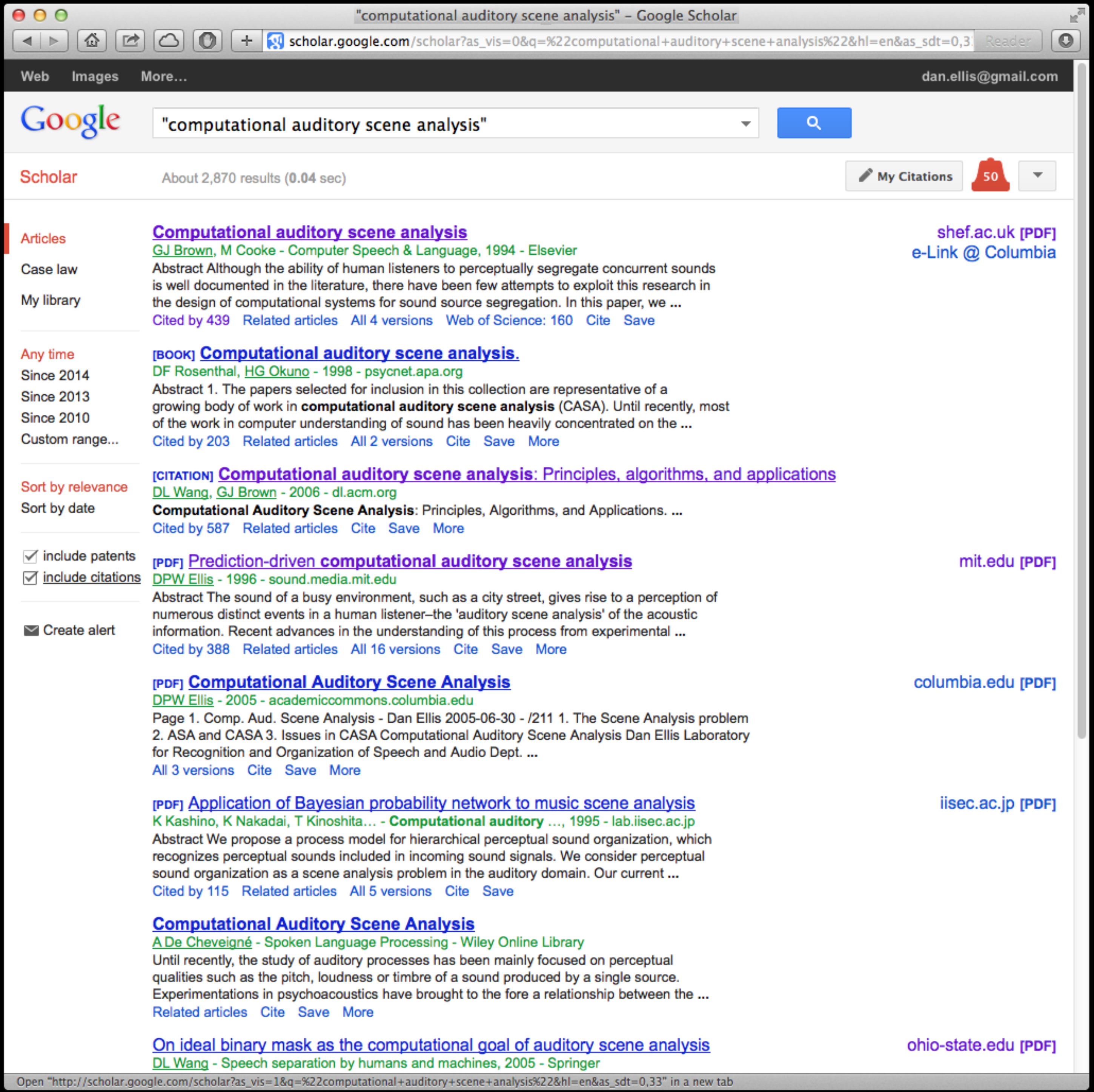
Weintraub 1985



Mellinger 1991



Rosenthal & Okuno 1998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Computational auditory scene analysis
GJ Brown, M Cooke - Computer Speech & Language, 1994 - Elsevier
Abstract Although the ability of human listeners to perceptually segregate concurrent sounds is well documented in the literature, there have been few attempts to exploit this research in the design of computational systems for sound source segregation. In this paper, we ...
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[BOOK] Computational auditory scene analysis.
DF Rosenthal, HG Okuno - 1998 - psycnet.apa.org
Abstract 1. The papers selected for inclusion in this collection are representative of a growing body of work in computational auditory scene analysis (CASA). Until recently, most of the work in computer understanding of sound has been heavily concentrated on the ...
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[CITATION] Computational auditory scene analysis: Principles, algorithms, and applications
DL Wang, GJ Brown - 2006 - dl.acm.org
Computational Auditory Scene Analysis: Principles, Algorithms, and Applications. ...
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[PDF] Prediction-driven computational auditory scene analysis
DPW Ellis - 1996 - sound.media.mit.edu
Abstract The sound of a busy environment, such as a city street, gives rise to a perception of numerous distinct events in a human listener–the 'auditory scene analysis' of the acoustic information. Recent advances in the understanding of this process from experimental ...
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[PDF] Application of Bayesian probability network to music scene analysis
K Kashino, K Nakadai, T Kinoshita... - Computational auditory ..., 1995 - lab.iisec.ac.jp
Abstract We propose a process model for hierarchical perceptual sound organization, which recognizes perceptual sounds included in incoming sound signals. We consider perceptual sound organization as a scene analysis problem in the auditory domain. Our current ...
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Computational Auditory Scene Analysis
A De Cheveigné - Spoken Language Processing - Wiley Online Library
Until recently, the study of auditory processes has been mainly focused on perceptual qualities such as the pitch, loudness or timbre of a sound produced by a single source. Experimentations in psychoacoustics have brought to the fore a relationship between the ...
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On ideal binary mask as the computational goal of auditory scene analysis
DL Wang - Speech separation by humans and machines, 2005 - Springer
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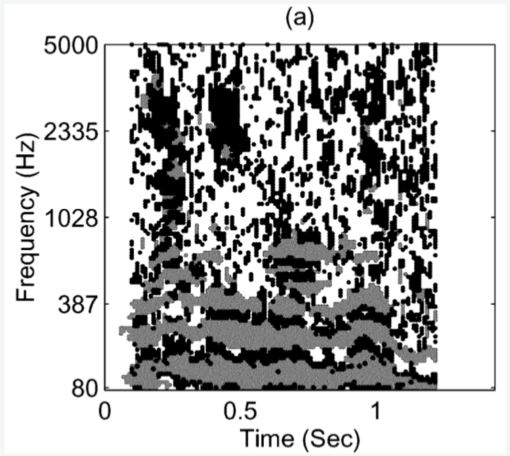
2. CASA Systems

- Literal implementations of the process described in Bregman 1990:
  - compute "regularity" cues:
    - common onset
    - gradual change
    - harmonic patterns
    - common fate

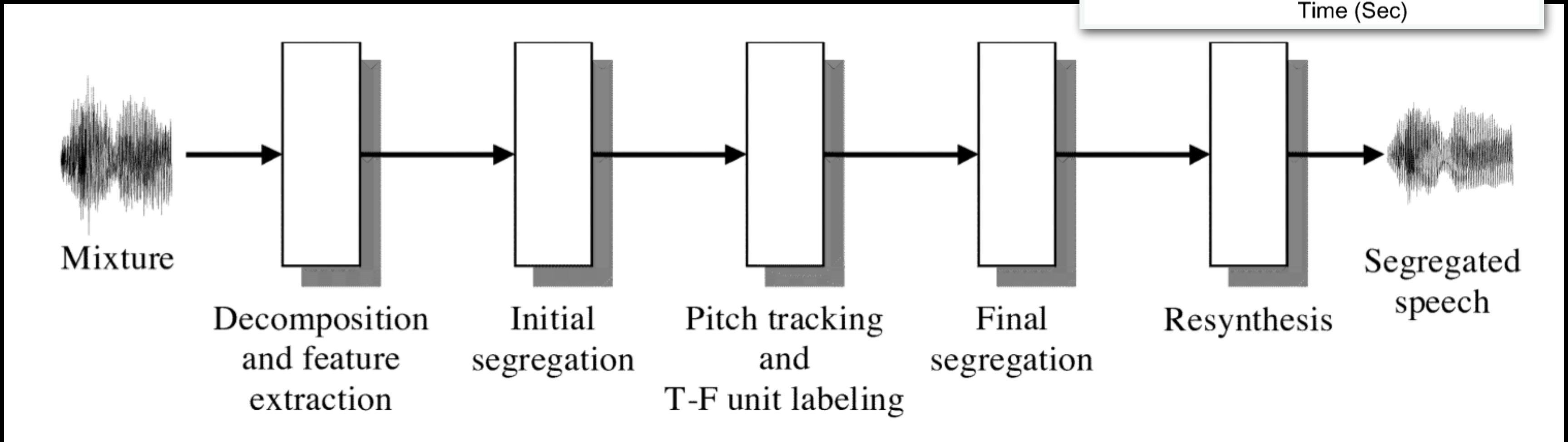


Original v3n7

Brown 1992

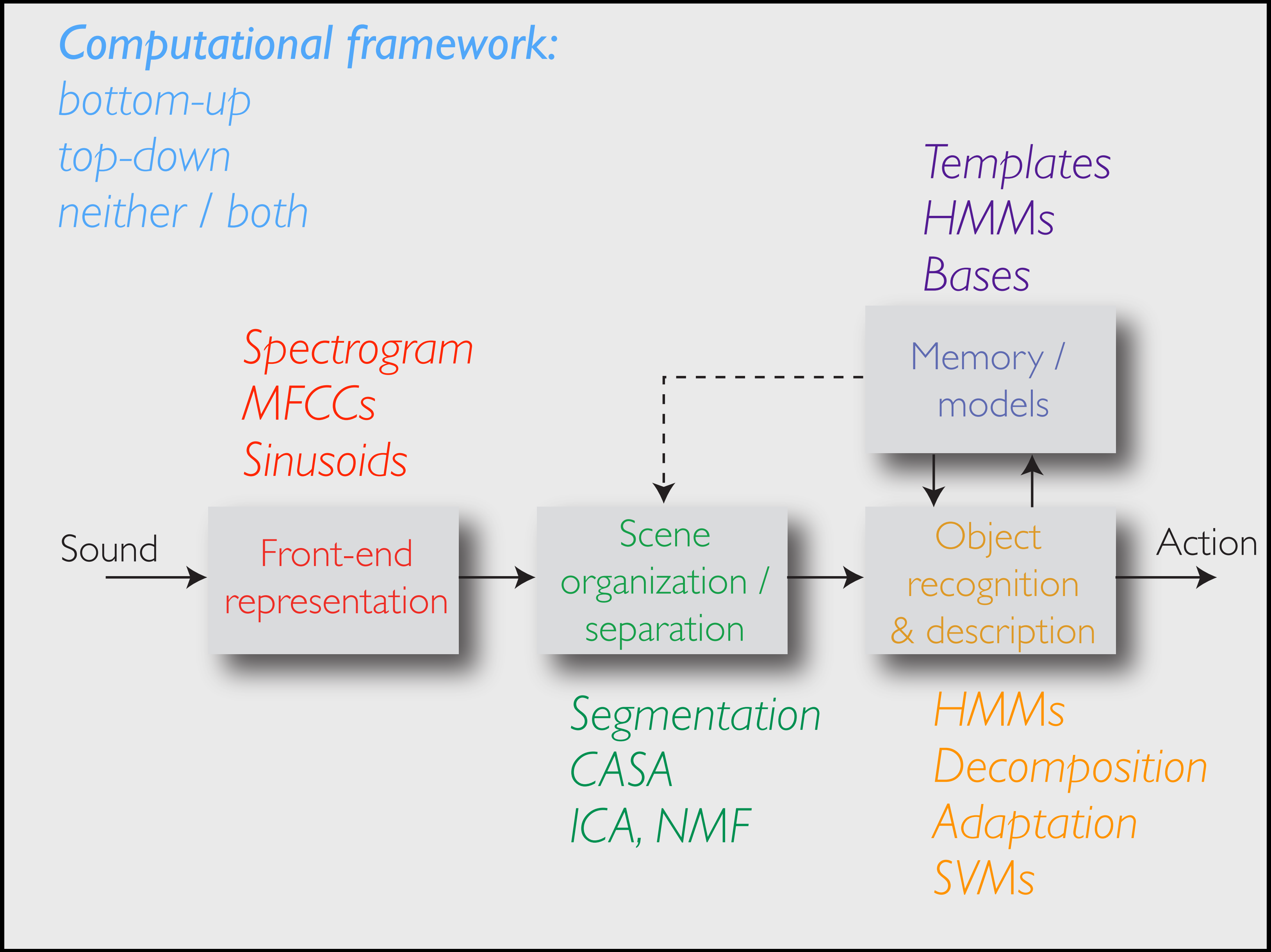
Ellis 1996

Hu & Wang 2004



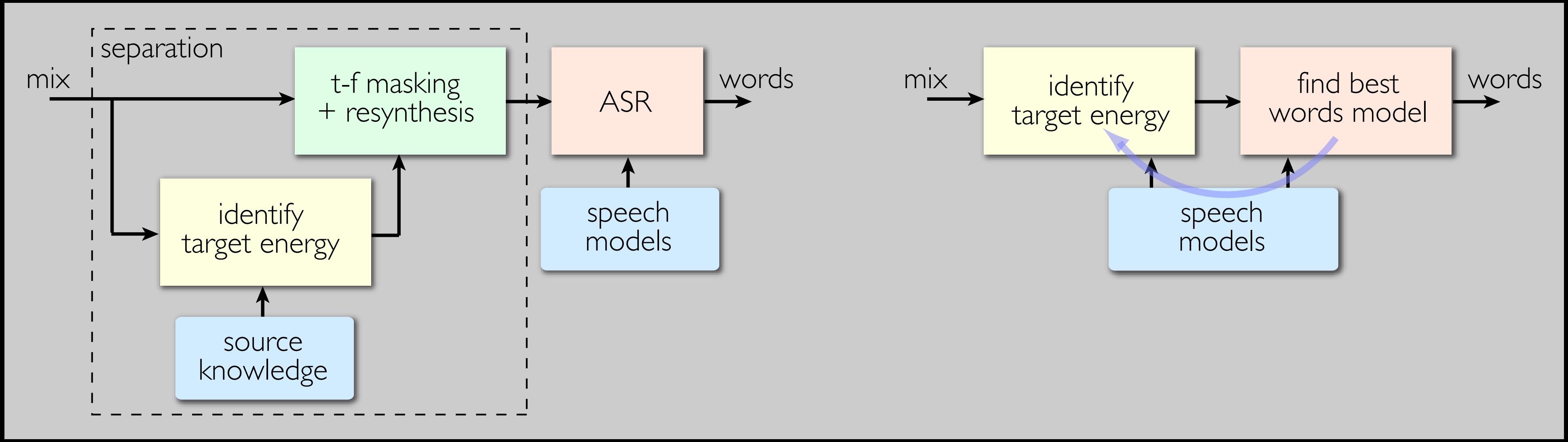
Hu & Wang 2004

Key CASA Components



How Important is Separation?

- **Separation systems often evaluated by SNR**
  - i.e., comparison to pre-mix components
  - is this relevant?
- **Best systems use resynthesis**
  - e.g. IBM's Superhuman Speech Recognizer
    - "separate then recognize"



- **Separating original signals is not necessary**

Machine Listening Tasks

- What is the goal? How to evaluate?

Task	Environmental Sound	Speech	Music
Describe	Automatic Narration	Emotion	Music Recommendation
Classify	Environment Awareness	ASR	Music Transcription
Dectect	"Sound Intelligence"	VAD	Speech/Music

Domain

Sound Separation Techniques

- Marr (1982): Levels of a perceptual problem:

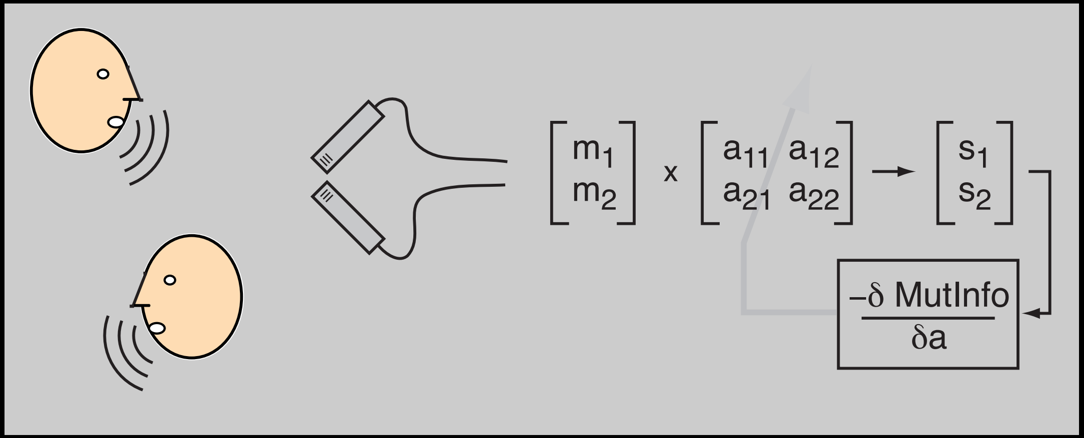
Computational Theory	Properties of the world that make the problem solvable
Algorithm	Specific calculations & operations
Implementation	Details of how it's done

- What is ASA's "computational theory"?
  - Environmental regularities → CASA
  - Independence → ICA
  - Efficient / sparse description → NMF
  - Underlying explanation → MaxVQ, Factorial HMM

Independent Component Analysis

Bell & Sejnowski '95
Smaragdis '98

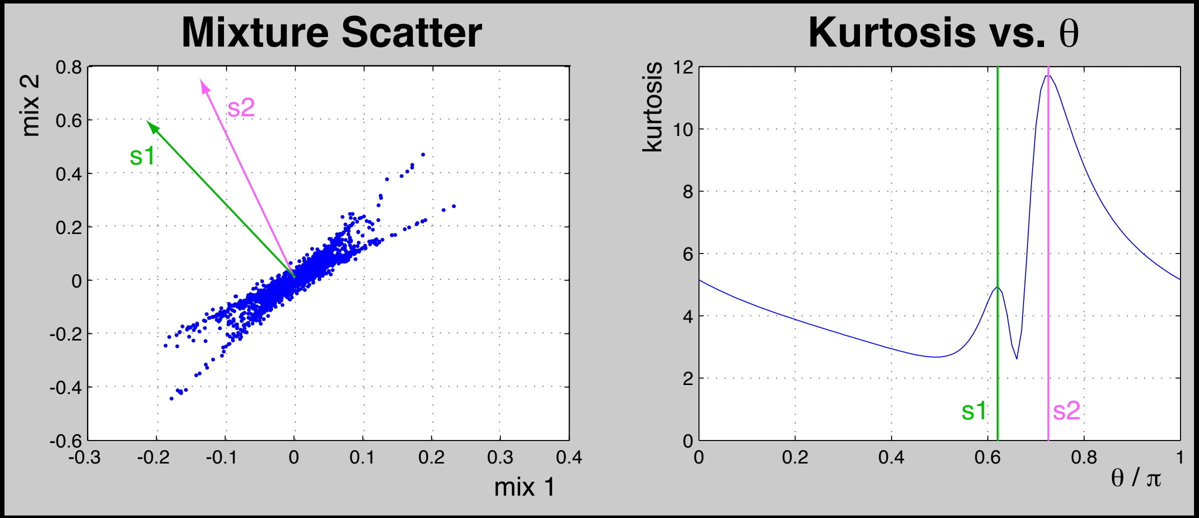
- Separate "blind" combinations by maximizing independence of outputs:



- e.g. Kurtosis

$$\mathrm{kurt}(y) = E\left[\left(\frac{y-\mu}{\sigma}\right)^4\right] - 3$$

as a measure of independence



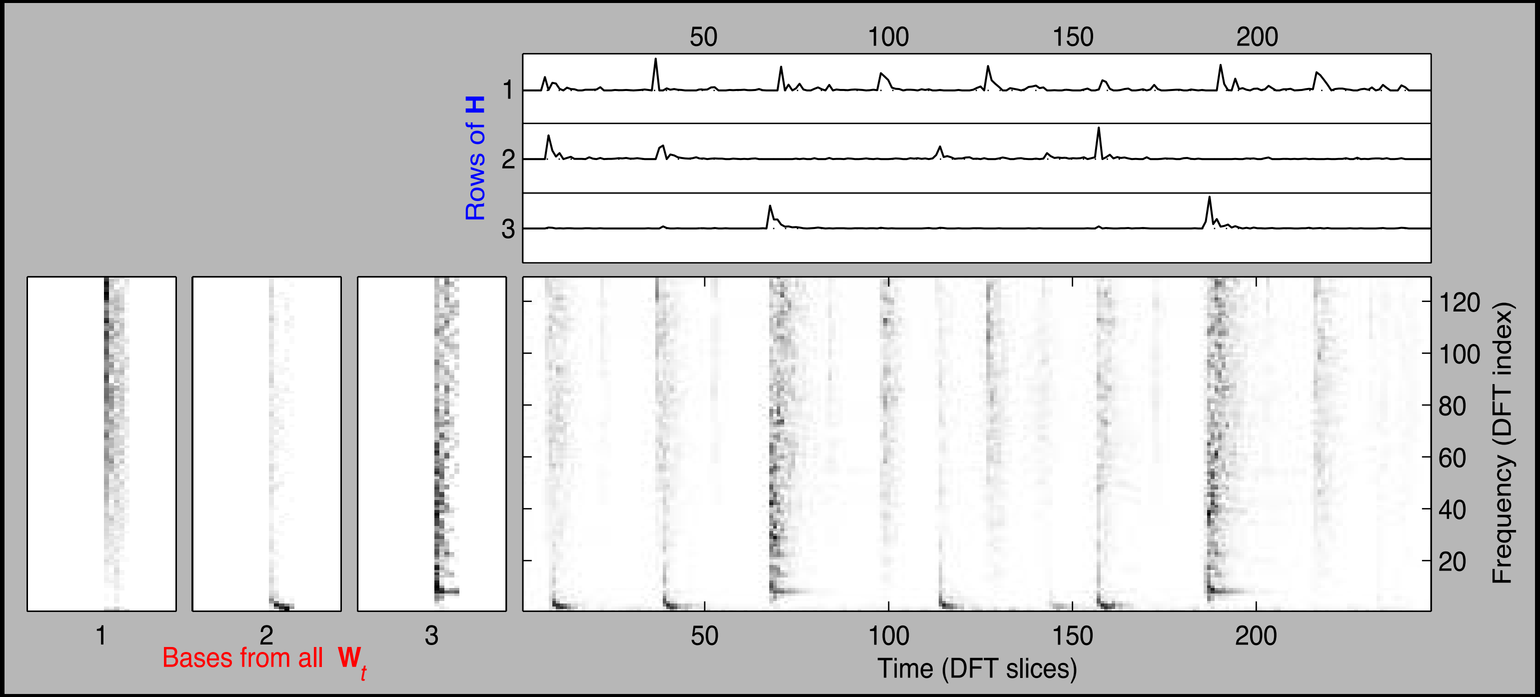
Nonnegative Matrix Factorization

Lee & Seung '99
Smaragdis & Brown '03
Abdallah & Plumbley '04
Virtanen '07

- Decomposition of spectrograms into templates + activation

$$X = W \cdot H$$

  - fits neatly with time-frequency masking
  - useful for repeated events e.g. music

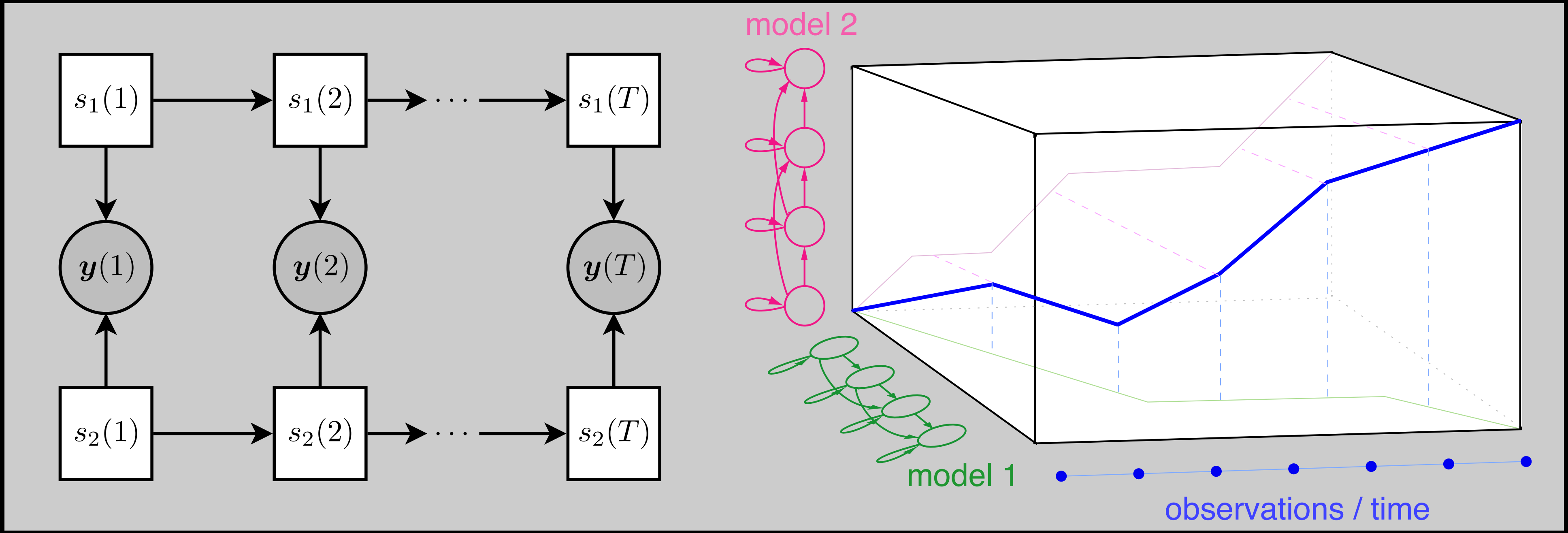


Model-Based Explanation

- Probabilistic approach:
  Find most likely parameters
  of some model

Varga & Moore '90
Gales & Young '95
Ghahramani & Jordan '97
Roweis '01
Kristjansson et al '06
Hershey et al '10

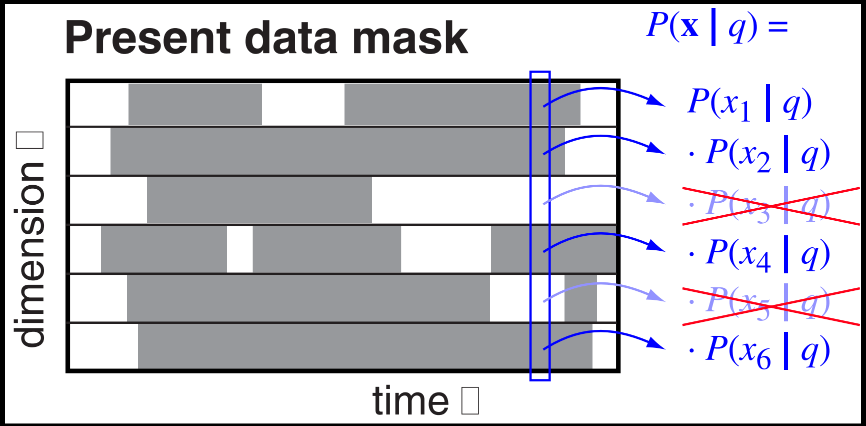
$$\{s_i(t)\}^* = \arg\max_{\{s_i(t)\}} \Pr(y(t)|\{s_i(t)\}) \cdot \Pr(\{s_i(t)\})$$



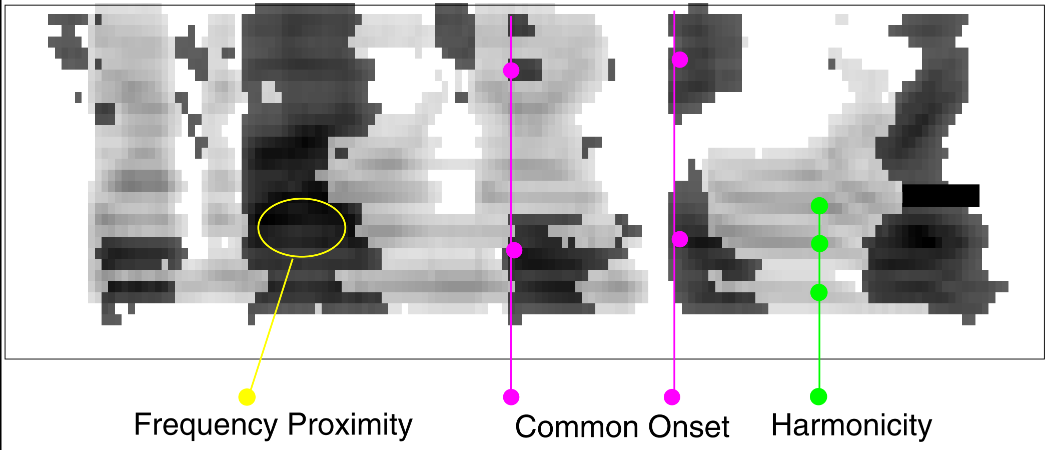
Missing Data Recognition

Cooke et al. '01
Barker et al. '05

- Integrate out missing information needed to recognizing a source…
  - no need to estimate missing/masked values



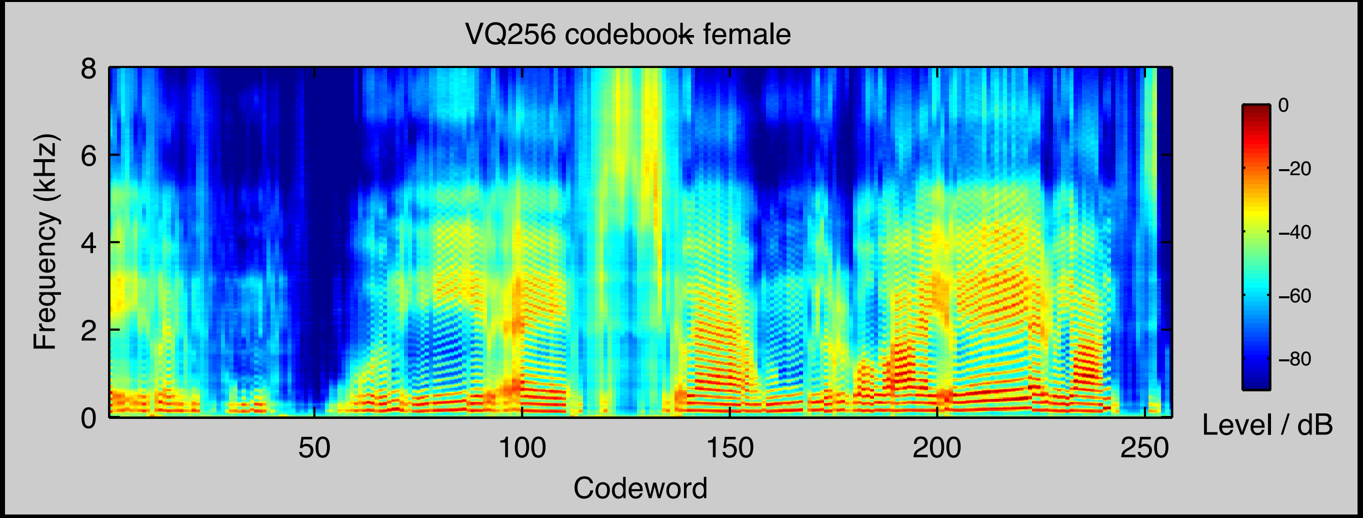
- Joint search for model M and segregation S
  - use CASA as prior on segregations



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

3. Whither ASA?

- Dictionary models can learn harmonicity, onset, etc.

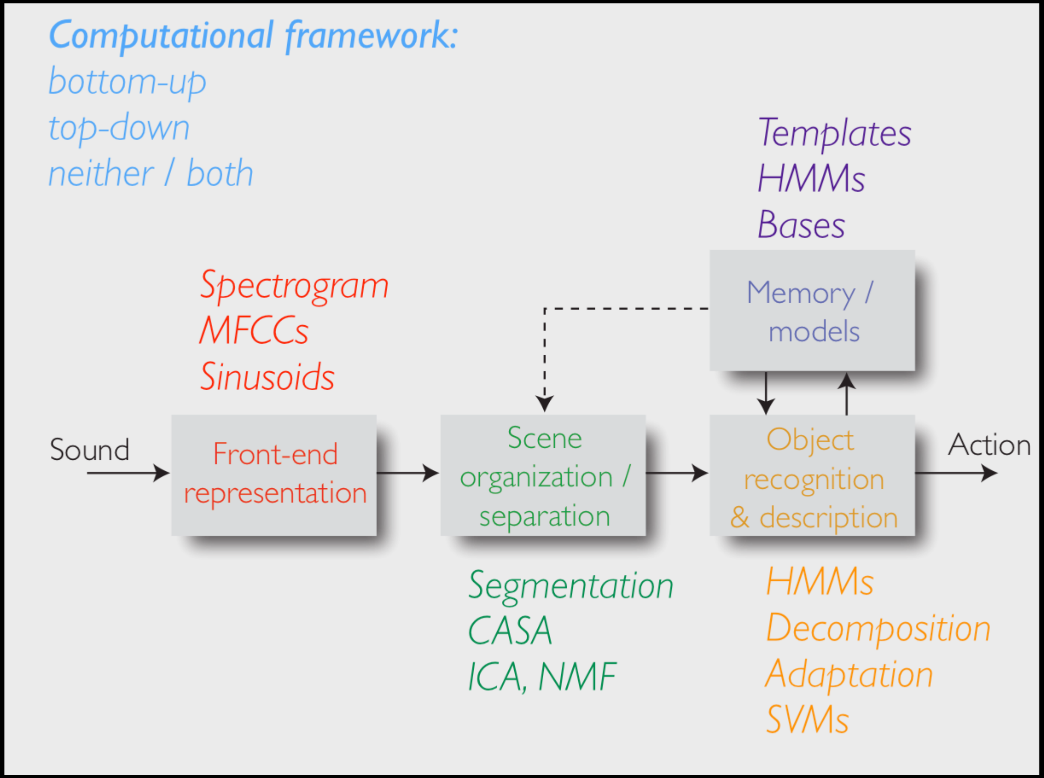


- secondary effects (harmony)
- subsume the ideas of CASA?

- Can also capture sequential structure
  - e.g., consonants follow vowels ("schema")
  - use overlapping patches?
- Computational theory or implementation?

Future CASA Systems

- **Representation**
  - still missing the key basis of fusion?
- **Models, Separation**
  - learn from examples
- **Object description**
  - what is salient to listeners? what is attention?
- **Computational framework**
  - pragmatic search for solution (illusions)



Summary

- Auditory Scene Analysis
  - the functional problem of hearing
- Computational Auditory Scene Analysis
  - computer implementations
- Automatic Sound Source Separation
  - different problems, different solutions

"We have reached the point where we have a good appreciation of many of the kinds of evidence that the human brain uses for partitioning sound, and it seems appropriate to begin to explore the formal patterns of computation by which the process could be accomplished." Bregman, 1990

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