Recognition & Organization of Speech and Audio

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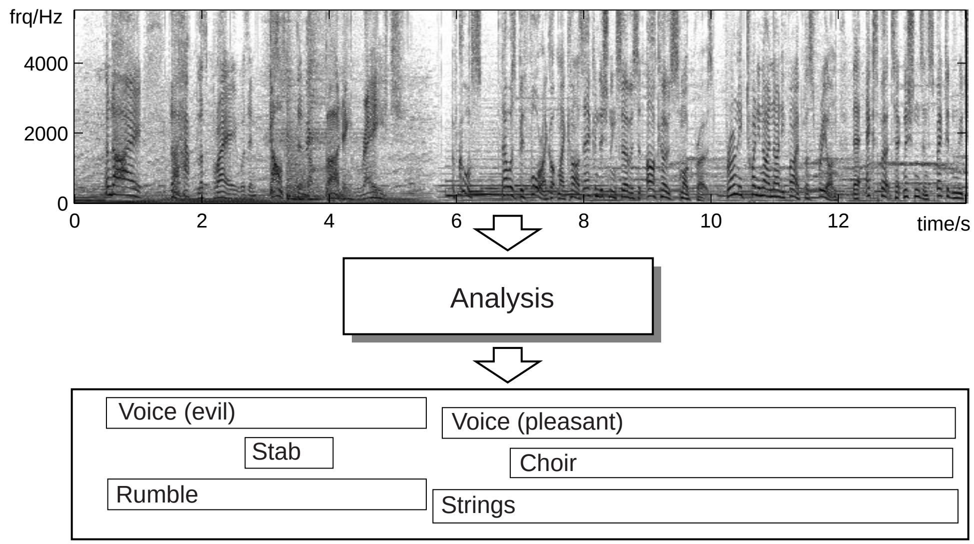
Outline

1. Introducing LabROSA
2. Tandem modeling for robust ASR
3. Other current projects
4. Future projects
5. Summary & conclusions

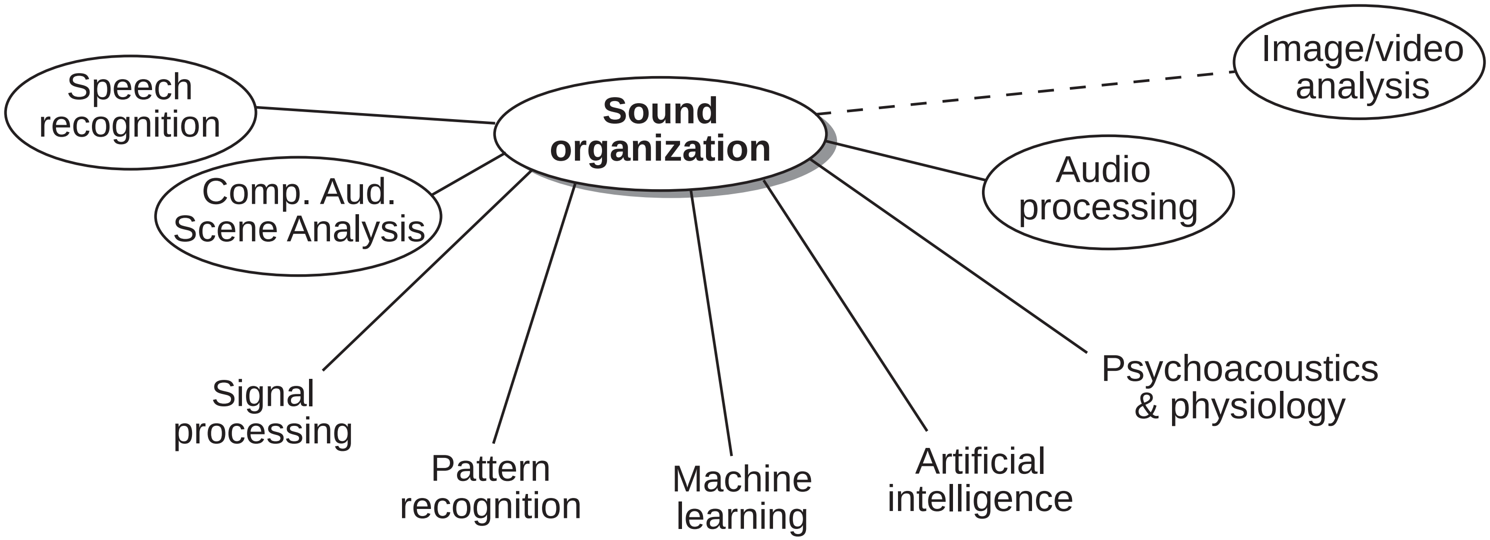
1 Organization of sound mixtures



- **Core operation:**

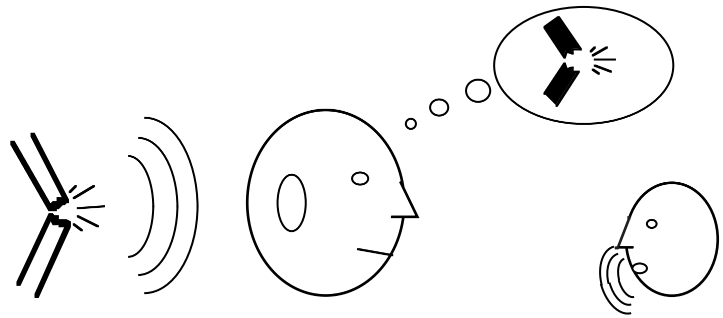
  Converting continuous, scalar signal into discrete, symbolic representation

Positioning sound organization



- **Draws on many techniques**
- **Abuts/overlaps various areas**

About auditory perception



- **Received waveform is a mixture**
  - two sensors, N signals ...
  - need knowledge-based constraints
- **Psychoacoustics:**
  the study of human sound organization
  - 'auditory scene analysis' (Bregman'90)
- **Auditory perception is ecologically grounded**
  - scene analysis is preconscious ($\rightarrow$ illusions)
  - perceived organization:
    real-world objects + events (transient)
  - subjective *not* canonical (ambiguity)

Key themes for LabROSA

http://www.ee.columbia.edu/~dpwe/LabROSA/

- **Sound organization: construct hierarchy**
  - at an instant (sources)
  - along time (segmentation)
- **Scene analysis**
  - find attributes according to objects
  - use attributes to form objects
  - ... plus constraints of knowledge
- **Exploiting large data sets (the ASR lesson)**
  - supervised/labeled: pattern recognition
  - unsupervised: structure discovery, clustering
- **Special cases:**
  - speech recognition
  - other source-specific recognizers
- **... within a 'complete explanation'**

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1. **Introducing LabROSA**
2. **Tandem modeling for robust ASR**
   - ASR overview
   - Tandem modeling
   - Investigating the benefits
3. **Other current projects**
4. **Future projects**
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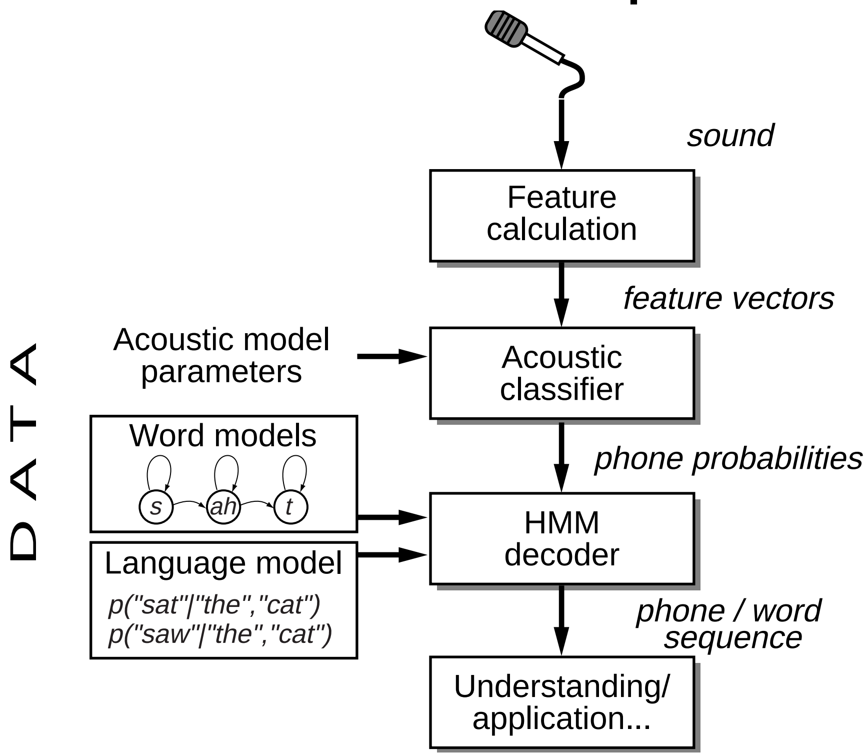
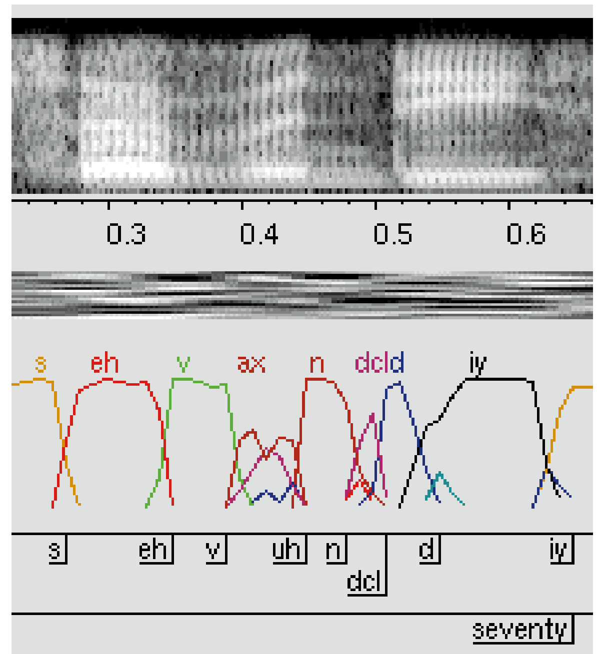
Lab ROSA

Automatic Speech Recognition (ASR)

- **Standard speech recognition structure:**





- **'State of the art' word-error rates (WERs):**
  - 2% (dictation) - 30% (telephone conversations)

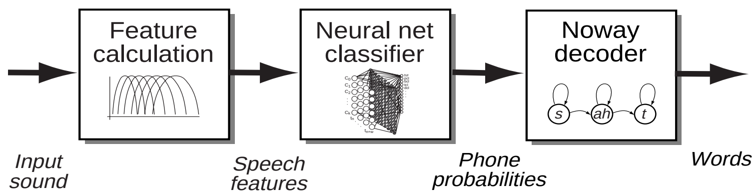
- **Can use multiple streams...**

Tandem speech recognition

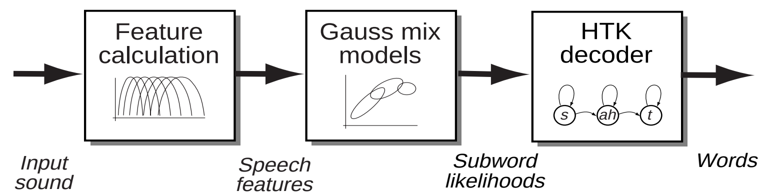
(with Hermansky, Sharma & Sivadas/OGI, Singh/CMU)

- **Neural net estimates phone posteriors; but Gaussian mixtures model finer detail**
- **Combine them!**

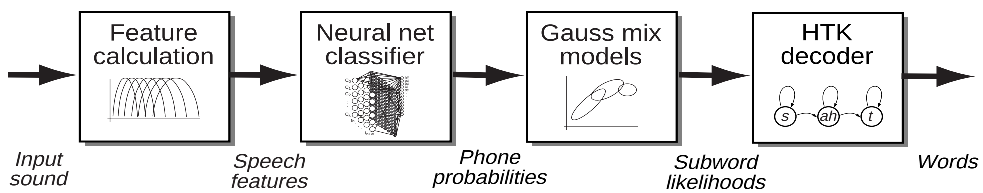
Hybrid Connectionist-HMM ASR



Conventional ASR (HTK)



Tandem modeling

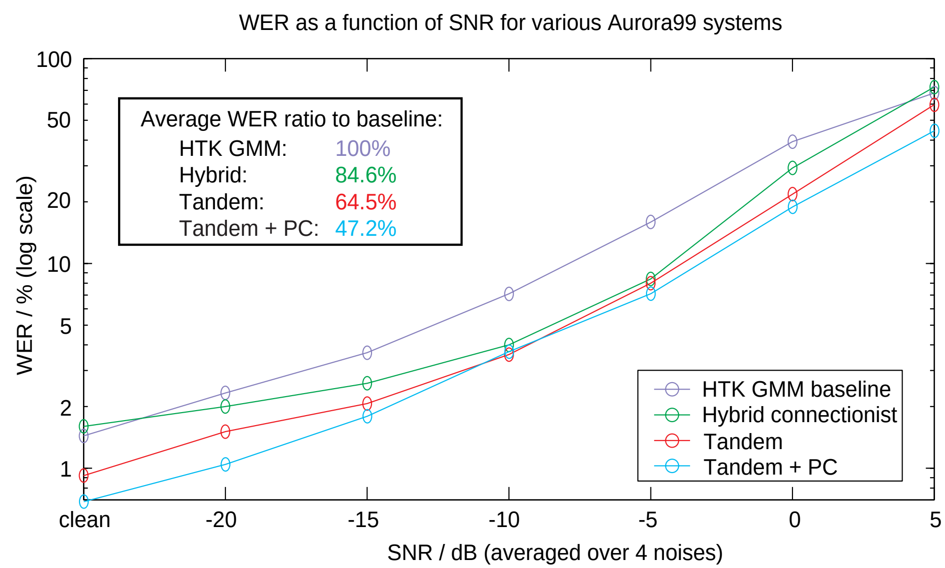


- **Train net, then train GMM on net output**
  - GMM is ignorant of net output 'meaning'

Lab ROSA

Tandem system results

- **It works very well ('Aurora' noisy digits):**



System-features	*Avg. WER 20-0 dB*	*Baseline WER ratio*
HTK-mfcc	13.7%	100%
Neural net-mfcc	9.3%	84.5%
Tandem-mfcc	7.4%	64.5%
Tandem-msg+plp	**6.4%**	**47.2%**

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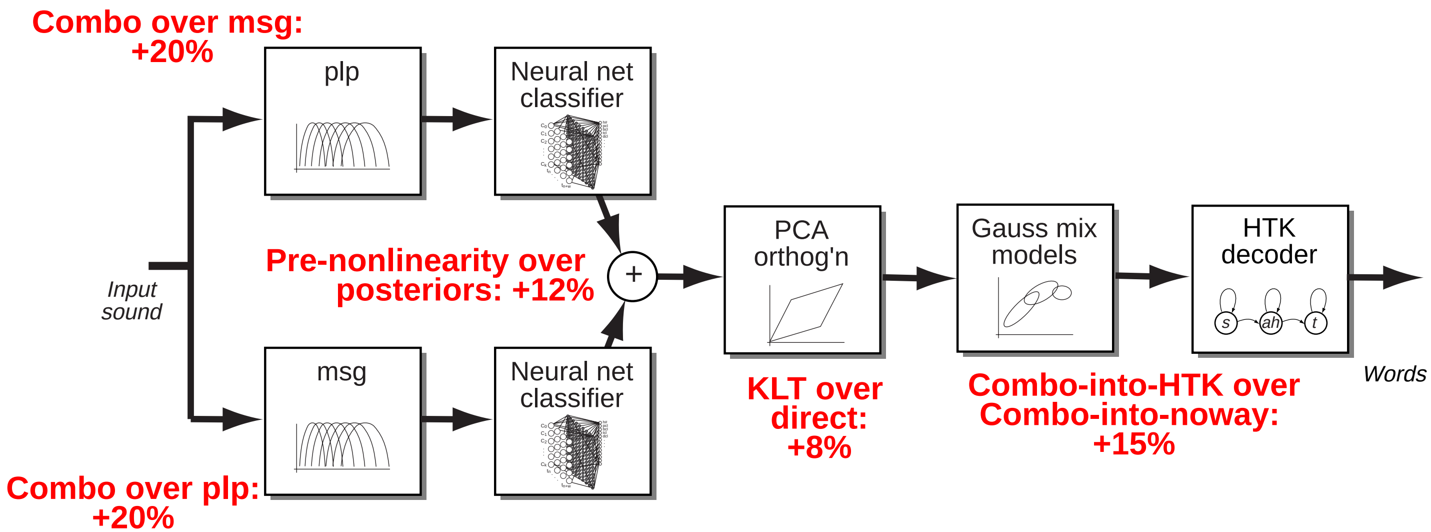
Relative contributions

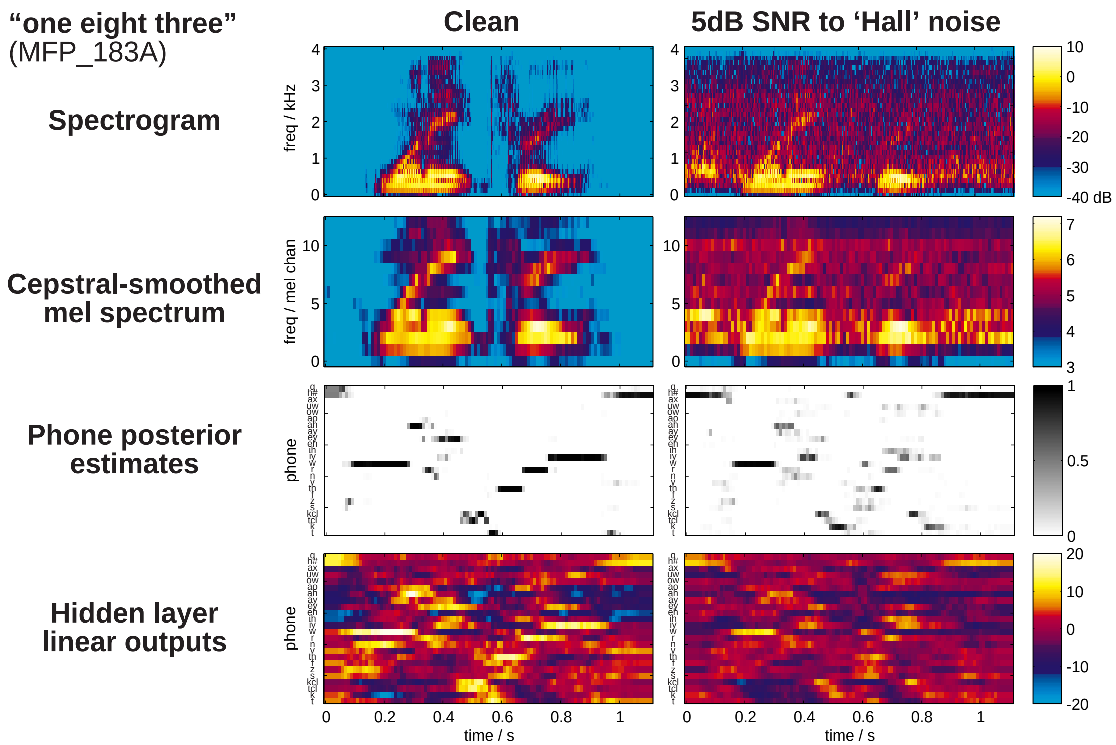
- **Approx relative impact on baseline WER ratio for different component:**



Tandem combo over HTK mfcc baseline: +53%

Inside Tandem systems: What's going on?

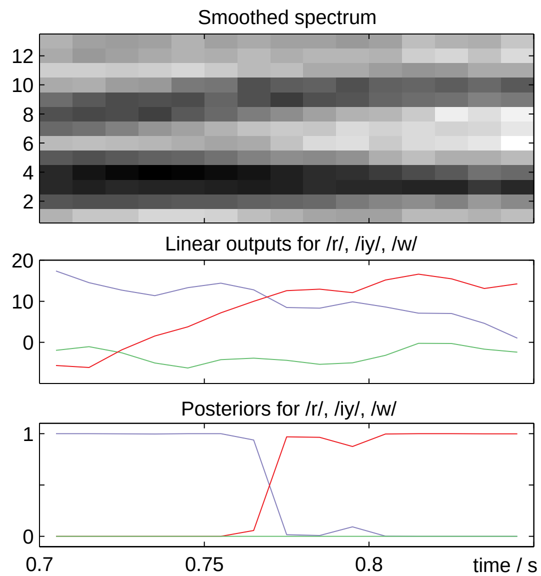
- **Visualizations of the net outputs**



- **Neural net normalizes away noise**

Tandem feature space ‘magnification’

- **Neural net performs a nonlinear remapping of the feature space**



- small changes across critical boundaries result in large output changes

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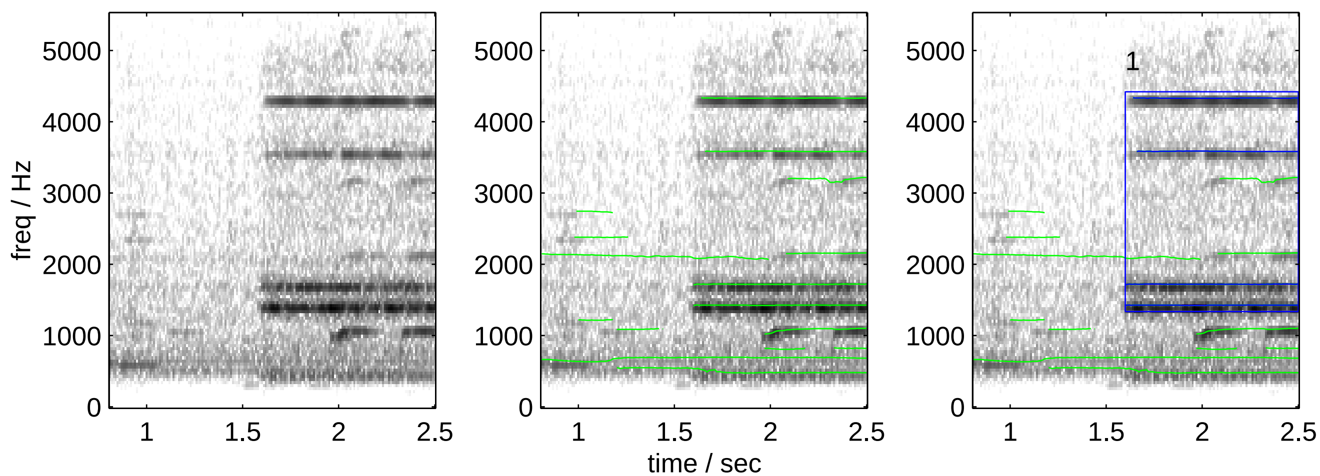
2. **Tandem modeling for robust ASR**
3. **Other current projects**
   - Alarm sound detection
   - Computational Auditory Scene Analysis
   - Multi-source and missing-data recognition
   - The Meeting Recorder project
4. **Future projects**
5. **Summary & conclusions**

Alarm sound detection

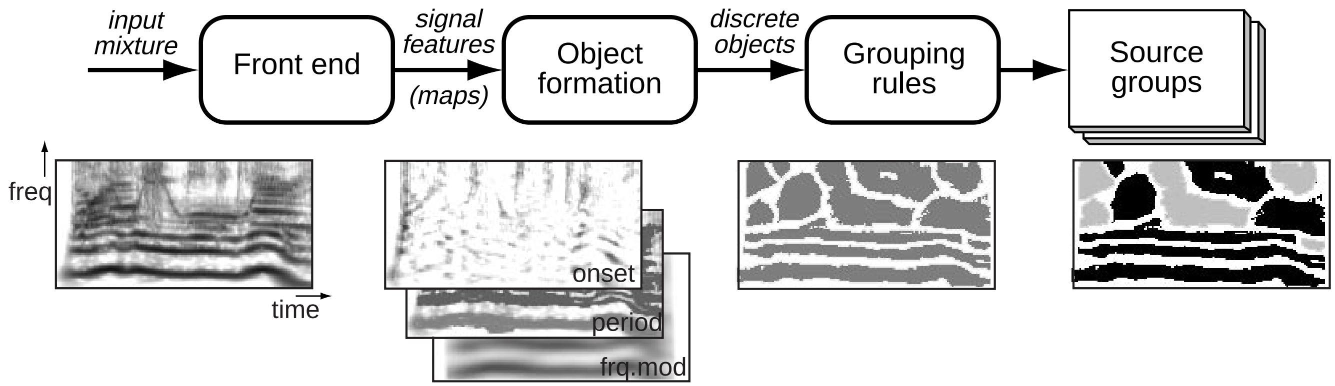
- **Alarm sounds have particular structure**
  - people ‘know them when they hear them’
  - build a generic detector?
- **Isolate alarms in sound mixtures**



  - representation of energy in time-frequency
  - formation of atomic elements
  - grouping by common properties (onset &c.)
  - classify by attributes...

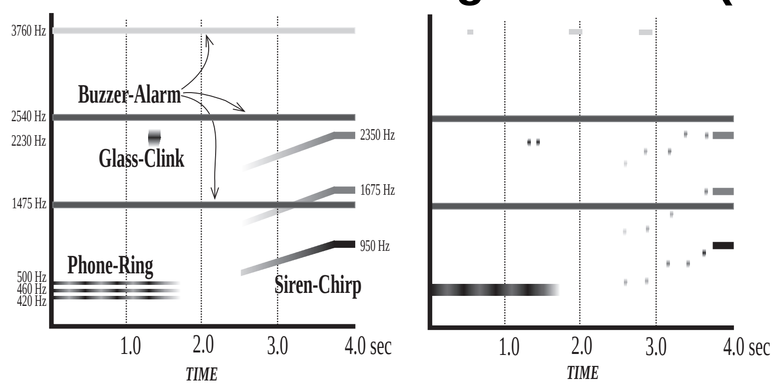
Computational Auditory Scene Analysis (CASA)

- **Implement psychoacoustic theory? (Brown'92)**



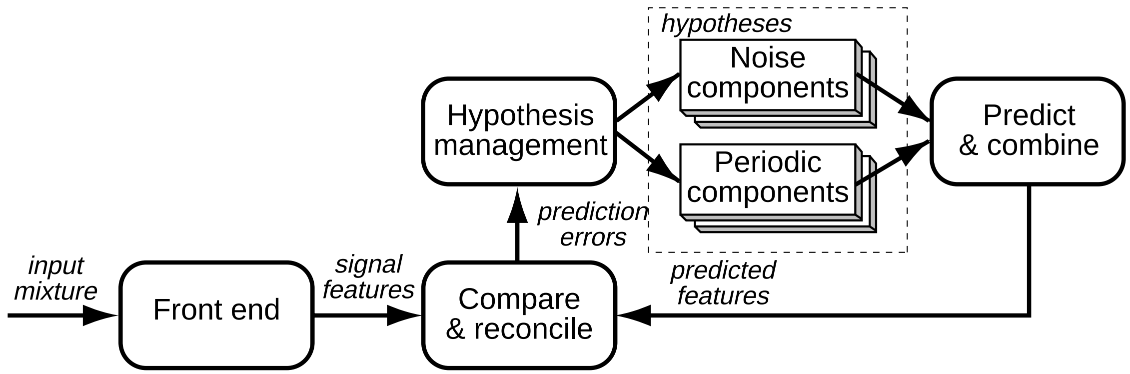
  - what are the features? how are they used?

- **Additional 'knowledge' needed (Klassner'96)**



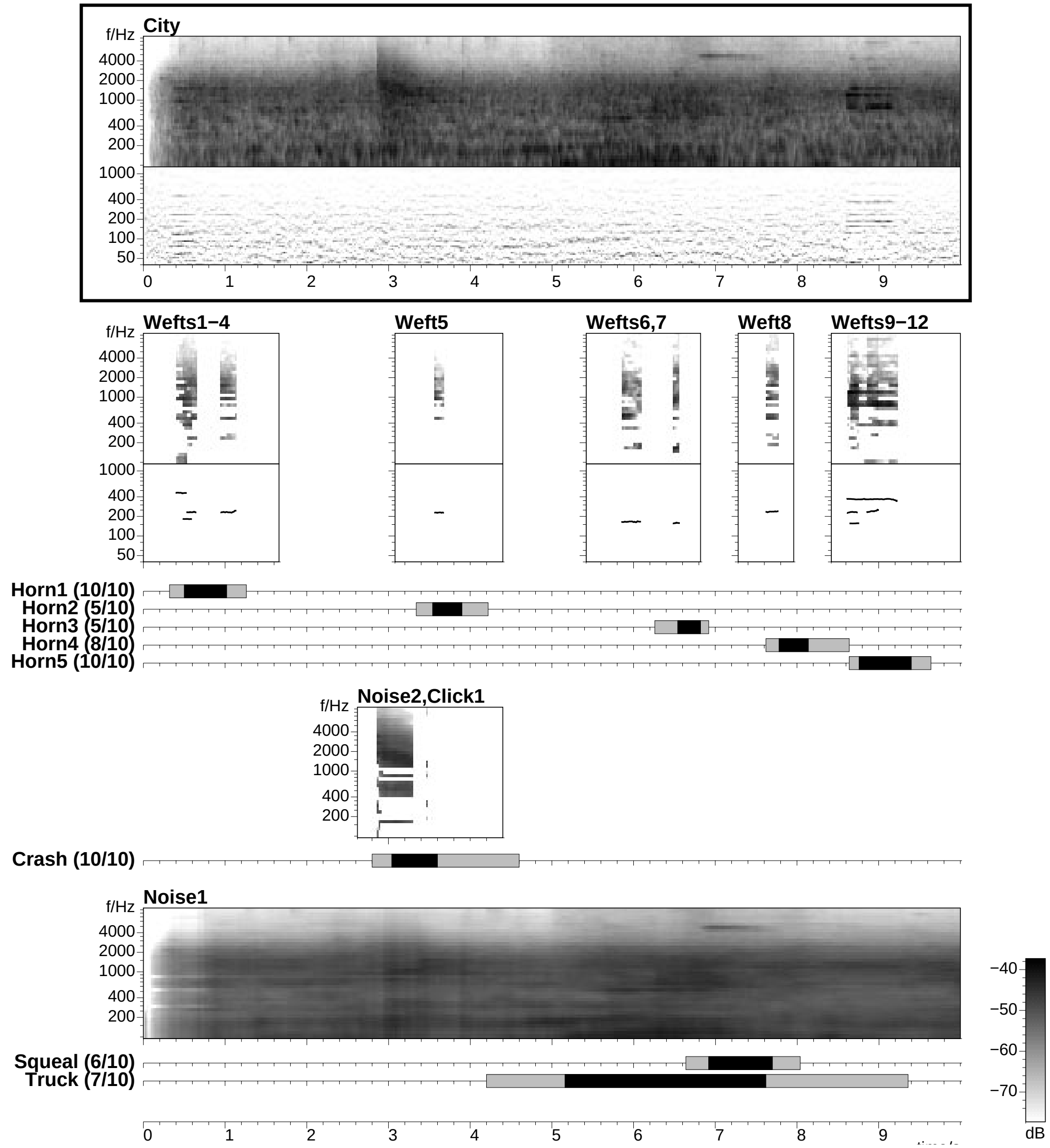
Prediction-driven CASA

- **Data-driven (bottom-up) fails for noisy, ambiguous sounds (most mixtures!)**
- **Need top-down constraints:**



  - fit vocabulary of generic elements to sound ... bottom of a hierarchy?
  - account for entire scene
  - driven by prediction failures
  - pursue alternative hypotheses

PDCASA example

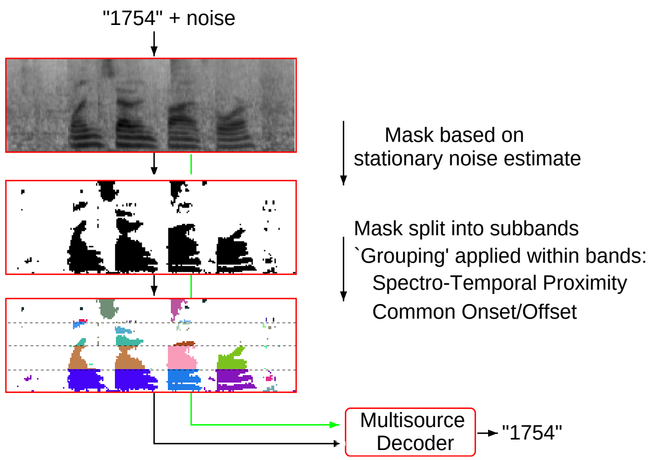


Lab ROSA

Missing data recognition & CASA

(with Barker, Cooke, Green/Sheffield)

- **Missing-data recognition**
  - integrate across ‘don’t-know’ values
  - ‘perfect’ mask $\rightarrow$ excellent performance in noise
- **Multi-source decoder**
  - Viterbi search of sound-fragment interpretations



- **CASA for masks/fragments**
  - larger fragments $\rightarrow$ quicker search

Meeting recorder

(with ICSI, UW, SRI, IBM)

- **Microphones in conventional meetings**
  - for transcription/summarization/retrieval
  - informal, overlapped speech
- **Data collection (ICSI and ...):**

  - 10s of hours collected, ongoing
  - now being transcribed

Meeting recorder: Research issues

- **Preliminary analysis**
  - transcription & forced alignment
  - ground truth in turns/overlaps
  - preliminary distant-mic recordings
- **Research areas**
  - meeting dialog: overlaps, turns etc.
  - language modeling for meetings
  - feature design for distant acoustics
- **Applications**
  - information retrieval from meetings
  - ‘mapping’ meeting content
  - sociological analysis of meeting behavior

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    - Audio Content-Based Retrieval
    - A ‘machine listener’
    - Audio-video-text content analysis
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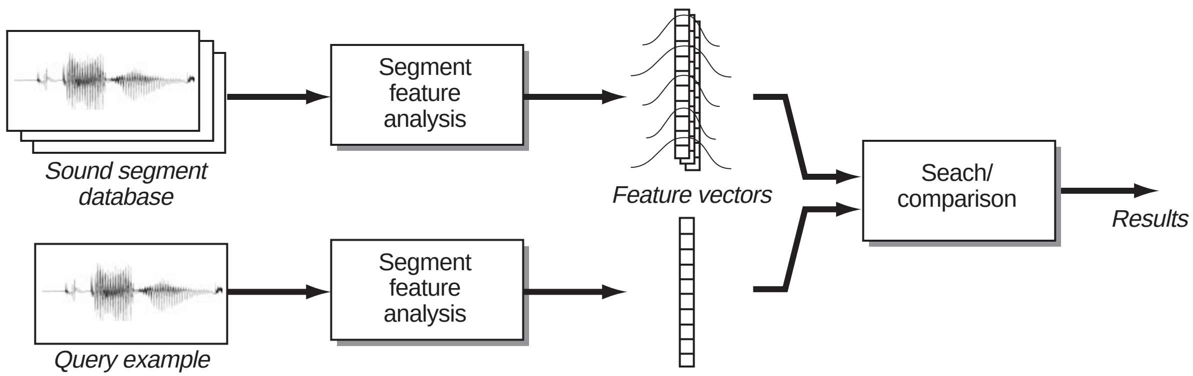
Audio Information Retrieval

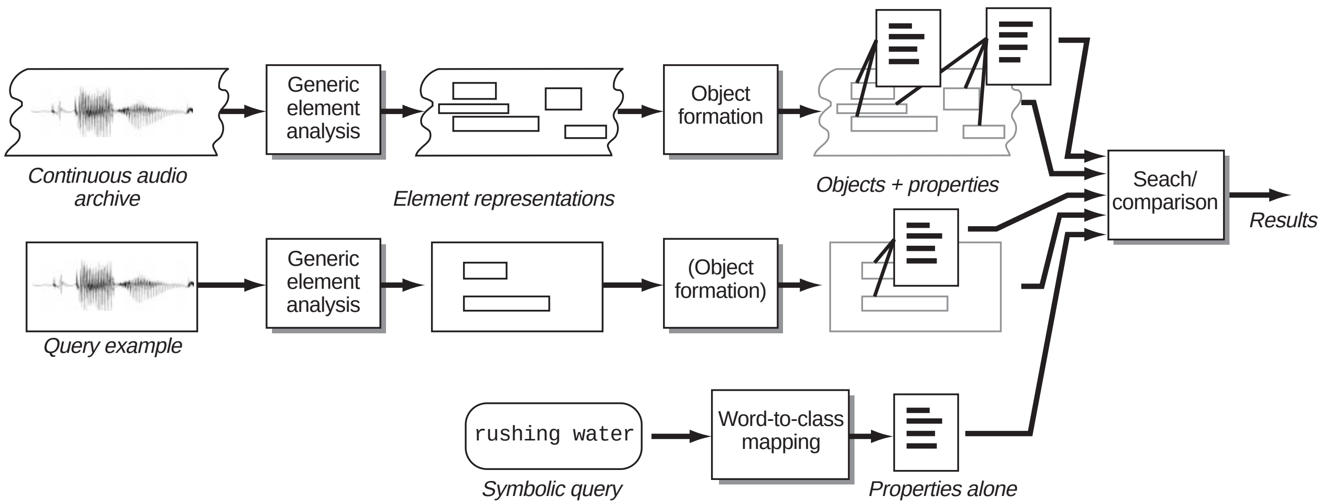
- **Searching in a database of audio**
  - speech .. use ASR
  - text annotations .. search them
  - sound effects library?
- **e.g. Muscle Fish “SoundFisher” browser**
  - define multiple ‘perceptual’ feature dimensions
  - search by proximity in (weighted) feature space



  - features are ‘global’ for each soundfile, no attempt to separate mixtures

CASA for audio retrieval

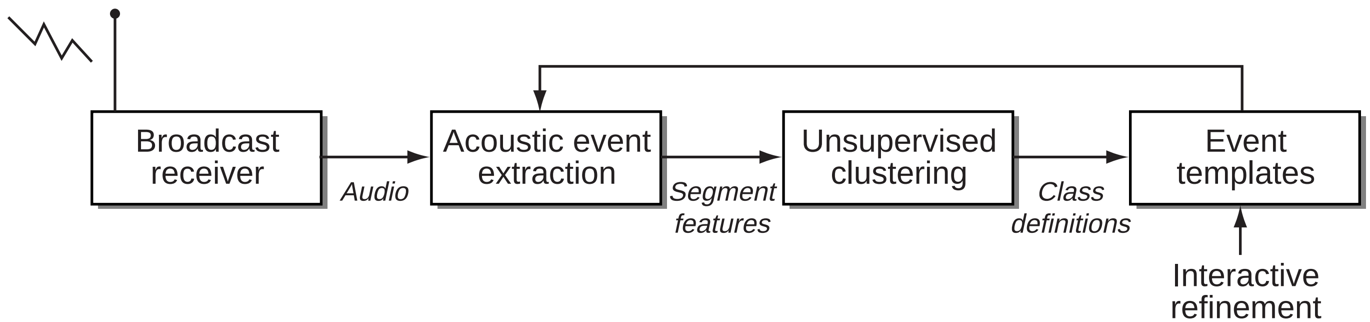
- **When audio material contains mixtures, global features are insufficient**
- **Retrieval based on element/object analysis:**



- features are calculated over grouped subsets

A ‘machine listener’

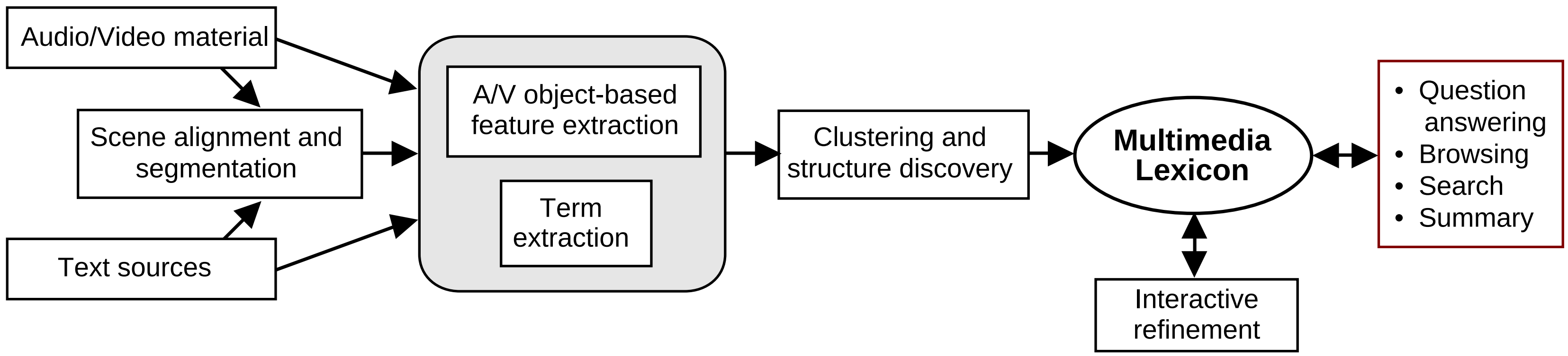
- **Goal: Unsupervised structure discovery**



- **What can you do with a large unlabeled training set (e.g. broadcast)?**
  - bootstrap learning: look for common patterns
  - have to learn generalizations in parallel: e.g. self-organizing maps, EM HMMs
  - post-filtering by humans may find ‘meaning’ in clusters

Audio-video-text content analysis

(with Shih-Fu Chang, Kathleen McKeown)



- **Audio and video provide complementary info**
  - correlate object features to define templates?
- **Associated text annotations provide a very small amount of labeling**
  - .. but for a very large number of examples – sufficient to obtain purchase?
  - build a 'multimedia lexicon' for question-answering

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Applications for sound organization

What do people do with their ears?

- **Human-computer interface**
  - .. includes knowing when (& why) you've failed
- **Robots**
  - intelligence requires perceptual awareness
  - Sony's AIBO: dog-hearing
- **Archive indexing & retrieval**
  - pure audio archives
  - true multimedia content analysis
- **Content 'understanding'**
  - intelligent classification & summarization
- **Autonomous monitoring**
- **Broader 'structure discovery' algorithms**

Summary

DOMAINS

- Broadcast
- Movies
- Lectures
- Meetings
- Personal recordings
- Location monitoring

ROSA

- Object-based structure discovery & learning

- Speech recognition
- Speech characterization
- Nonspeech recognition
- Scene analysis
- Audio-visual integration
- Music analysis

APPLICATIONS

- Structuring
- Search
- Summarization
- Awareness
- Understanding

Conclusions

- **New classification schemes for ASR**
  - ... combining multiple approaches/sources
- **But sound is more than just speech!**
  - speech is a special case
  - need to deal with the ‘other stuff’
- **Object-based analysis**
  - it’s what people do
  - the world presents acoustic mixtures
- **Whole-scene representation**
  - it’s what people do
  - provides mutual constraints of overlap
- **Broad range of approaches for a broad range of phenomena**