Overview of the PASCAL CHiME Speech Separation and Recognition Challenge

Jon Barker[1], Emmanuel Vincent[2], Ning Ma[1], Heidi Christensen[1], and Phil Green[1]

[1]Department of Computer Science, University of Sheffield, UK
[2]INRIA Rennes - Bretagne Atlantique, France

1st September, 2011

The University Of Sheffield. informatics mathematics PASCAL Pattern Analysis Statistical Modelling and Computational Learning EPSRC Pioneering research and skills

Outline

Previous speech separation challenges

PASCAL single-channel separation challenge, Interspeech 2006

- Instantaneous speech + speech mixtures from the Grid corpus.
- Not multisource in the sense that the number of sources is know a priori
- Best solutions built models of each speaker and combined the models to explicitly model the mixture
- ‘super human’ results. Too artificial?

PASCAL microphone array separation challenge, MLMI 2007

- Simultaneous live readings of WSJ recorded by microphone array.
- Small number of competitors.
- Very poor results. Too challenging?

Previous speech separation challenges

SiSEC evaluation campaign, ICA 2009 and LVA/ICA 2010

- 2- to 5-channel datasets, where the number of sources is generally known a priori.
- One exception: denoising dataset including real multisource outdoor noise (subway, cafeteria, town square).
- Performance evaluated in terms of source separation quality only.

The PASCAL CHiME challenge

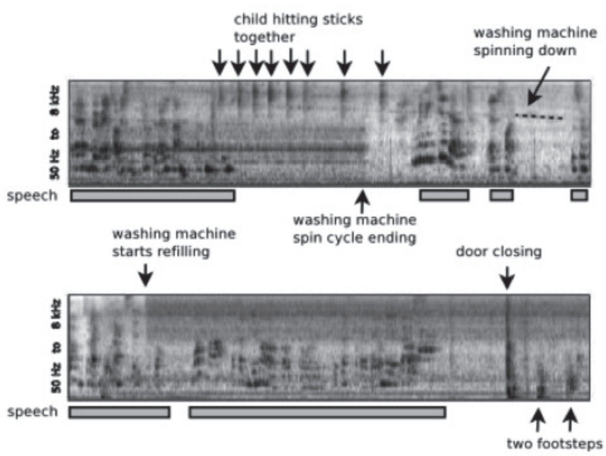
PASCAL CHiME challenge, 2011

- Using Grid corpus - small vocabulary and fixed grammar; continuity with 1st PASCAL challenge
- Real multisource environment – a domestic living room.
- Convolutive mixtures using impulse responses recorded in the room.
- Binaural recording – to provide link to hearing research and comparisons with human performance

The CHiME noise background

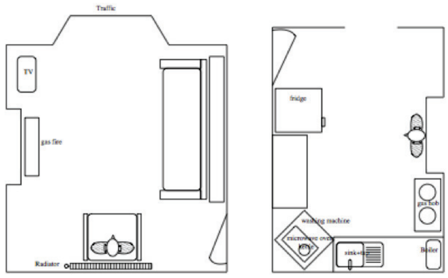
Noise backgrounds collected from a family home,

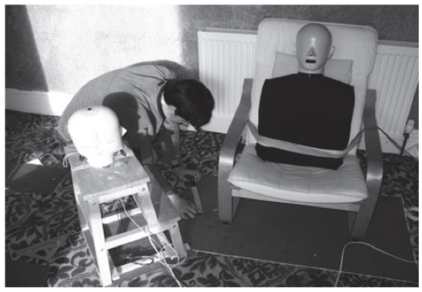
- it's noisy ... plenty of sources and potential for low SNRs
- it's easy to collect,
- potential application interest,
- well defined 'domain' with a learnable noise 'vocabulary' and 'grammar'.



Recording Details

- Recordings made in the main living room.
- Recorded using a B&K 'head and torso' simulator.
- Total of 50 hours of stereo audio at 96 kHz, 24bit.
- Morning and evening sessions over course of several weeks.
- Set of binaural room impulse responses recorded.





The target speech data

Target utterances come from the Grid corpus.

VERB	COLOUR	PREP.	LETTER	DIGIT	ADV.
bin lay place set	blue green red white	at by in with	a-z (no 'w')	1-9 + zero	again now please soon

- Small vocabulary so easy to build recognisers and computationally cheap.
- Still represents significant challenge for its size – letter set highly confusable.
- Small number of speakers (34) but a lot of data from each (1000 utterances). So can focus on speaker dependent models.
- Provides continuity with 1st PASCAL separation challenge.

Preparing the mixed data

The aim was to simulate the effect of Grid utterances being spoken from a fixed position within the room.

- A single room location was chosen: 2 metres in front of the binaural manikin.
- Some Grid utterances were recorded from this position to establish a reference speaking level.
- Grid corpus utterances convolved with room impulse responses, inverse filter applied to remove recording coloration, and a testset-wide gain set to match reference level.
- Utterances added to CHiME background recordings at positions chosen so as to match a set of target SNRs.
- Possible to generate SNRs down to -6 dB.

Original

Convolved

Mixed

Comparison

Preparing the mixed data

Some points worth noting,

- SNR calculation a little unconventional
  - Two channels, so channels were averaged before SNR computation.
  - Rumble in some CHiME recordings was leading to very low SNRs for perceptually low-noise mixtures...
  - ... so SNR calculation performed after applying a high pass filter with a 80 Hz cut off.
  - SNR was measured over the duration of the entire Grid utterance.
- After mixing the Grid utterances are not evenly spread through the CHiME data
  - The average interval between utterances is about 10 seconds,
  - but asymmetric distribution: 23% < 1 second, 50% < 5 seconds and 70% < 10 seconds.
- Characteristic of noise background highly SNR dependent,
  - 9 dB backgrounds tend to be fairly stationary ambient noise,
  - -6 dB backgrounds highly non-stationary energetic events.

The recognition task

Test data

- 600 test utterances at each of 6 SNRs: -6, -3, 0, 3, 6, 9 dB
- All utterances embedded in 20 hours of CHiME audio.

Task

- Task is to report the 'letter' and the 'digit' spoken by the Grid talker.
- Competition assumes the speaker identity and the temporal location of each utterance are known, but not the SNR.

Human listening tests

- Listening tests have been performed to allow human machine comparison.
- The 1st PASCAL challenge saw 'super human' performance ...
  - ... but the comparison was arguably unfair in favour of the machines.

Unfairness in previous comparison

- Task: recognising two simultaneous speakers over a single channel is not a natural task.
- Training: the machines had been trained on Grid corpus, humans were given no specific training.

Human listening tests

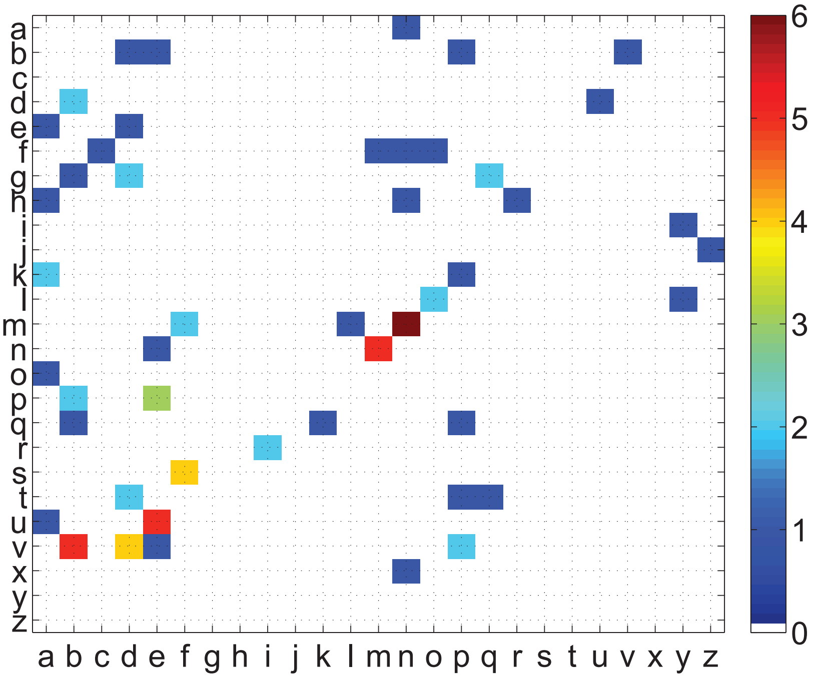
This time around we hope that the comparison is a little fairer...

Reasons that the current comparison is fairer

- The task is more natural - binaural listening in an everyday environment.
- Tests have used one highly motivated listener who is very familiar with the specific CHiME domestic audio environment
- Grid talkers were played in order (i.e. not randomised)
- Reverberant noise free training examples played prior to the test
- Two second of audio context played leading in to each utterance.

Example 6 dB | Example -3 dB

Listening test confusions: Letters



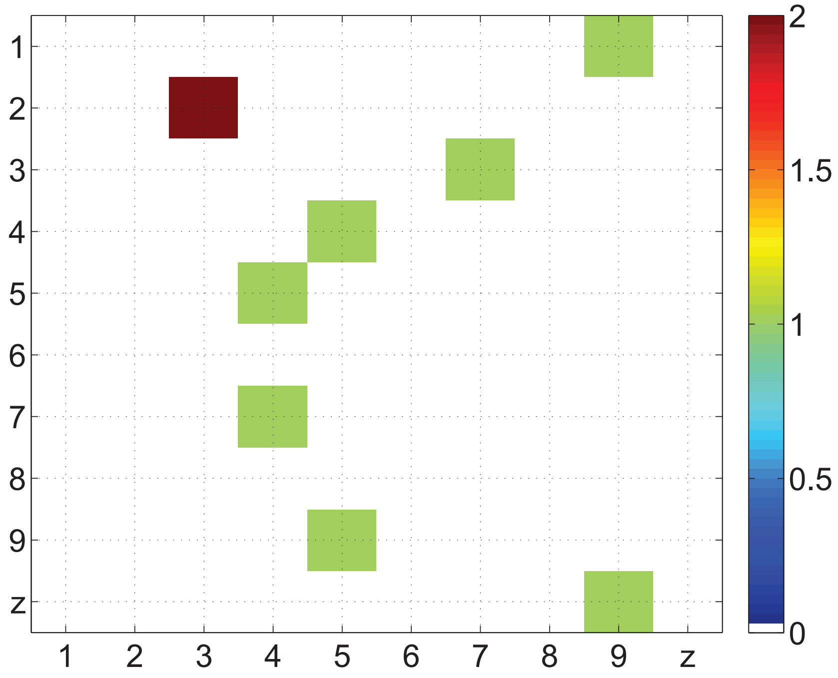
Confusions...

- m → n, n → m
- v → b, v → d, p → e
- s → f
- u → e

also,

- d → b, g → d, v → p, p → b, t →d
- k → a
- m → f
- r → i
- l → o, g → q ??

Listening test confusions: Digits



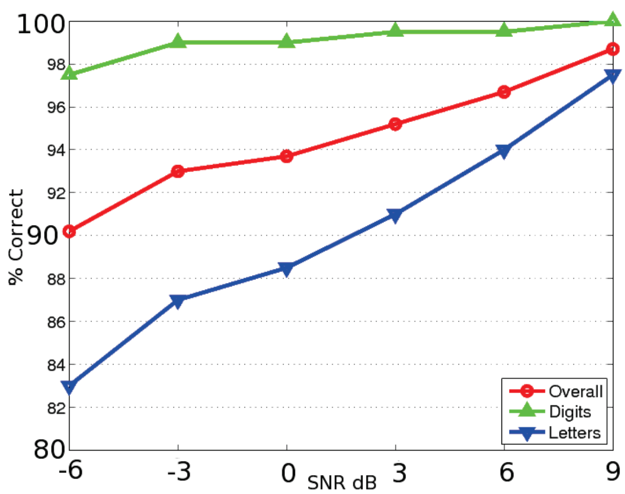
Confusions . . .

Very few.

- one → nine
- four → five, five → four
- nine → five
- zero → nine ?
- seven → four ?
- three → seven ?
- two → three ?

Listening test results

Percentage digits and letters recognised correctly versus SNR.



- Digit recognition highly reliable: 99% correct down to -3 dB.
- Letter recognition falls steadily with increasing noise level at about 1% per dB: 97% at 9 dB down to 83 % at -6 dB.

CHiME Challenge Systems

Training data

- Reverberated noise-free Grid utterances provided for training speaker-dependent speech models. 500 utterances per speaker.
- Access to 6 hours of speech-free background also provided for training noise models.

Development data

- 600 Grid utterances @ 6 SNRs provided for adapting the speech models to noisy speech.

Test data

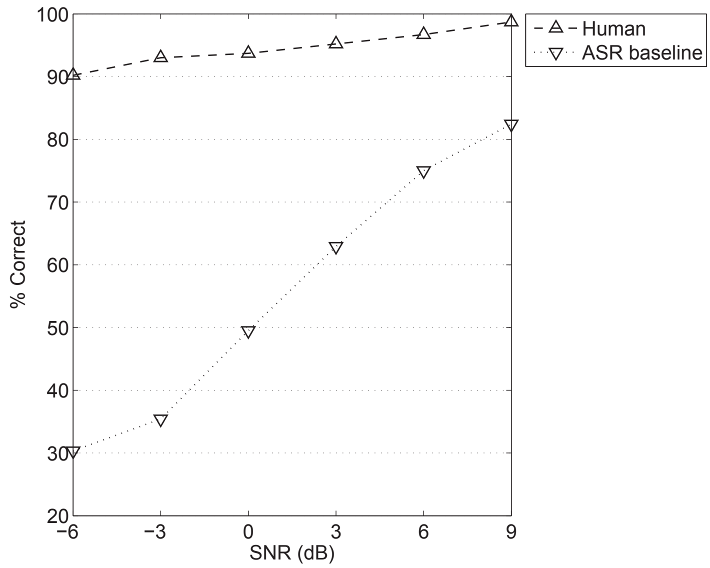
- 600 Grid utterances @ 6 SNRs released shortly before submission deadline.

Baseline system

Baseline system configuration

- Target signal enhancement: none
- Features: MFCC with deltas and delta-deltas computed from magnitude spectra with Cepstral Mean Subtraction (CMS)
- Decoder:
  - Word level HMMs - 2 states per phoneme
  - States modelled with GMMs, 7 components with diagonal covariance.
  - Viterbi decoding using Grid grammar, no pruning.
- Training:
  - Flat start training.
  - Initial models trained using 34x500 utterance training set.
  - 34 sets of Spkr. Dep. model reestimated using 500 utterances.

Baseline system



As expected, non-robust baseline system performs fairly well on matched clean data (94%) but it is not robust to additive noise.

Overview of the 13 accepted entries

	Enhanced target signal	Modified features	Modified decoder	Trained noise model
U. Aalto	X	X	X	
U. Bochum	X	X	X	
U. Erlangen	X		X	
ETRI	X	X	X	
EURECOM	X		X	X
FBK-IRST	X	X	X	
INRIA	X		X	X
K.U. Leuven	X		X	X
T.U. Liberec	X			
T.U. München	X	X	X	X
NTT	X		X	X
U. Sheffield	X	X	X	
T.U. Tampere		X	X	X

Target signal enhancement strategies

A wide variety of filters. . .

- Different domains:
  - STFT
  - mel spectrum
  - gammatone spectrum
- Different families of filters:
  - highpass/lowpass
  - beamforming
  - single-/multichannel Wiener filtering
  - binary/soft TF masking
- Tuned implementations:
  - oversubtraction
  - spectral floor/offset
  - temporal smoothing
  - exponentiation
- More fundamental issue: which cues are exploited to discriminate the target speaker from the background?

CHiME Challenge motivation and design | Human listening test results | Overview of CHiME Challenge entrants

Target signal enhancement strategies

. . . but few discrimination cues

- Spatial diversity = spatial location (5 entries)
  - beamforming,
  - geometrically constrained Independent Component Analysis (ICA),
  - clustering of Interaural Time/Level Differences (ITD/ILD).
- Spectral diversity = pitch and/or timbre (4 entries)
  - multiple pitch tracking,
  - Gaussian Mixture Model (GMM),
  - Nonnegative Matrix Factorization (NMF),
  - exemplar-based enhancement.
- Combined spatial and spectral diversity (3 entries)
  - chained design, *e.g.* ITD clustering followed by exemplar-based enhancement,
  - joint design: joint probabilistic frameworks for ITD and GMM/NMF.

Feature extraction strategies

Robust features and robustifying transformations

- Robust features (5 entries)
  - Gammatone Frequency Cepstral Coefficients (GFCC): improve robustness to spectrum underestimation thanks to wider filters.
  - Mel spectra: concentrate noise in fewer coefficients.
  - Parallel stream of phoneme predictions generated by a recurrent neural net: model the long-range context.
- Robustifying feature transformations (2 entries)
  - Maximum Likelihood Linear Transformation (MLLT).
  - Linear Discriminant Analysis (LDA).

Decoding strategies

Four complementary decoding strategies...

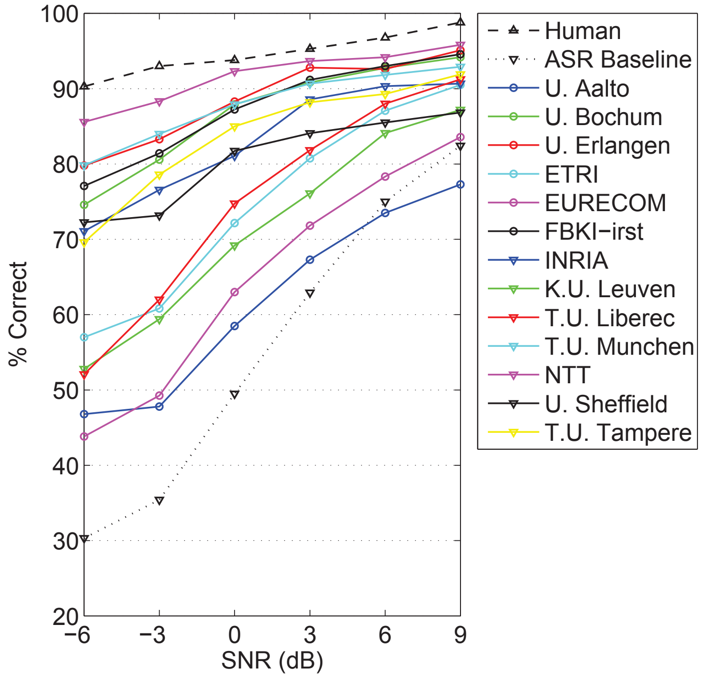
- Multi-condition training/adaptation (8 entries)
  - train/adapt the decoder over unprocessed noisy speech,
  - train/adapt the decoder over noisy speech processed by the target enhancement front-end.
- Robust training (6 entries)
  - manual setting of the number of Gaussians per mixture,
  - MLLR/MAP/mean-only speaker adaptation,
  - discriminative training.
- Noise-aware decoding (5 entries)
  - missing data: fragment decoding, channel-attentive decoding,
  - uncertain data: modified imputation, uncertainty decoding, Dynamic Variance Adaptation (DVA), location-informed decoding.
- System combination (4 entries)
  - Recogniser Output Voting Error Reduction (ROVER),
  - multistream decoding.

Decoding strategies

. . . and one singular strategy

- Model combination (1 entry)
  - no target enhancement front-end,
  - jointly decode speech and noise via an exemplar-based model,
  - train the mapping between exemplar activations and likelihoods.

Overview of ASR results



Overview of ASR results

What we can tell...

- Human performance is roughly twice that of the best entry.
- Strategies often present in the top-performing entries include:
  - multi-condition training,
  - robust training,
  - spatial diversity-based enhancement.
- More complex strategies (including trained noise models) seem to bring smaller additional improvement.

...and what we cannot tell

- The exact impact of each strategy is unknown, since they have not always been separately evaluated nor combined together.
- This impact may depend a lot on the data and the task.

Editorial choice

- Five entries chosen for oral presentation at the workshop.
- Not necessarily highest performing: selection bias towards novelty.

Main questions to think about

- Was this challenge sufficiently realistic? If not, in which direction should it evolve?
- How could the scientific insight gained from the challenge be increased?
- Is there a way to facilitate combination of the best strategies?
- What would be the best business model for a regular challenge?

These (and other) issues will be debated during the panel session.
Please fill the questionnaire and return it to us before 4pm!