SCAN - Speech Content Based Audio Navigator: A Systems Overview

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ABSTRACT

SCAN (Speech Content based Audio Navigator) is a spoken document retrieval system integrating speaker-independent, large-vocabulary speech recognition with information-retrieval to support query-based retrieval of information from speech archives. Initial development focused on the application of SCAN to the broadcast news domain. This paper provides an overview of this system, including a description of its graphical user interface which incorporates machine-generated speech transcripts to provide local contextual navigation and random access for browsing large speech databases.

1. INTRODUCTION

We present an overview of SCAN (Speech Content based Audio Navigator), a system developed at AT&T Labs-Research which supports the retrieval, browsing and navigation of speech archives. The system consists of three components: (i) a speaker-independent large-vocabulary speech recognition engine which segments the speech archive and generates transcripts, (ii) an information-retrieval engine which indexes the transcriptions and formulates hypotheses regarding document relevance to user-submitted queries and (iii) a graphical-user-interface which supports search and local contextual navigation based on the machine-generated transcripts and graphical representations of query-keyword distribution in the retrieved speech transcripts. An overview of the system architecture is provided in Figure 1.

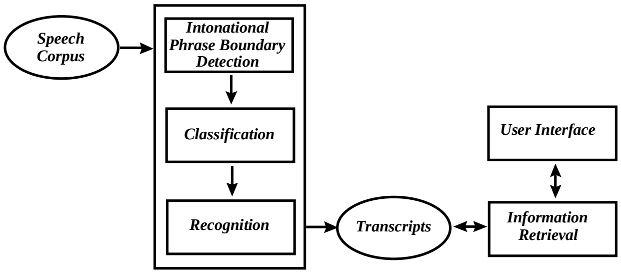


Figure 1: Overview of the spoken document system architecture

Previous work on information retrieval from speech databases include a system for Swiss radio news [14], a system for a digital video library [15], radio news broadcast retrieval using subword units [9], a Video Mail Retrieval system [4,5] and a number of systems developed for the Text Retrieval Conference Spoken Document Retrieval track [13], *inter alia*.

2. SPEECH RECOGNITION

The speech recognition component of SCAN includes an intonational phrase boundary detection module and a classification module. These subcomponents preprocess the speech data before passing the speech to the recognizer itself.

2.1. Intonational Phrase Boundary Detection

The intonational phrase boundary detection module analyzes and classifies the incoming speech stream every 20 msec as either occurring within an intonational phrase or within a break between intonational phrases [3]. This classification is driven by a regression tree model [1] which take as observation vectors values for fundamental frequency, RMS energy and autocorrelation-peaks.

The resulting intonational phrases serve as recognition units by breaking up the incoming speech stream into smaller segments for decoding. In addition, the phrases serve as prosodically well-formed browsing and play-back units in the user-interface. This is arguably preferable to using fixed-size segments, which might begin and terminate within words and otherwise form prosodically ill-formed segments for play-back.

2.2. Channel Condition Classifier

The intonational phrases are subsequently passed to a classifier designed to detect one of four different channel conditions: (i) wideband (0-8kHz) speech recorded in a studio environment with no background noise; (ii) wideband (0-8kHz) speech recorded in non-studio environments, including field conditions, with no background noise; (iii) narrowband (0-4kHz) speech recorded from telephone interviews and (iv) speech with background noise and/or music. The training data come from the 1996 broadcast news corpus distributed by the Linguistic Data Consortium and that comprised the HUB4 continuous speech recognition task for that year. The decision to apply one of potentially several acoustic models is based on this classification.

The classifier itself is based on full covariance Gaussian mixture models, initialized using vector quantization and trained using the Expectation-Maximization algorithm [7]. Input consists of 31-dimensional vectors of filter-bank coefficients in dB units, derived from Hamming windowed frames of 20 msec with a frame advance rate of 10 msec. The filter-bank coefficients are computed by taking the base 10 logarithm from short term power spectra in the 0-8kHz band from a mel-scaled bank of filters.

2.3. Recognizer

The core speech recognizer is based on a standard time-synchronous beam search algorithm and continuous-density, left-to-right, three-state, context-dependent HMM phone models. The transduction from phone HMMs to word sequences is implemented in the general framework of weighted finite-state transducers [14,17]. The decoder supports multiple recognition hypotheses in the form of word lattices, derived from model lattices by transducer composition.

Acoustic observations serving as input to the HMMs consist of 39-dimensional vectors taken from 20 msec analysis frames with 10 msec overlap. Each acoustic vector contains the first 13 normalized mel-frequency cepstral coefficients, along with their first and second time derivatives.

We have experimented with several acoustic models trained on broadcast news data, partitioning the training data in terms of differing channel conditions. Training iterations for all the acoustic models consist of eigenvector rotations to decorrelate the training data, k-means clustering, normalization of means and variances based on maximum-likelihood, and Viterbi alignment to resegment the data. The output probability distributions in the HMMs consist of a weighted mixture of Gaussians with diagonal covariance. The number of components per mixture varies from model to model, but ranges between 4 and 12.

We have also experimented with several language models, varying in vocabulary size from 20k to 237k. Standard Katz backoff trigram models [6] are constructed from appropriate training corpora. Trigrams and bigrams are then discarded from the model in cases where the difference between the model prediction and backed-off prediction is less than a threshold T:

$$f * (P_o * P_b) < T$$

where f is the observed n-gram frequency, P_o is the n-gram prediction and P_b is the backed-off (n-1)-gram prediction.

3. INFORMATION RETRIEVAL

The information-retrieval engine used in the system is based on a vector space model which generates weighted term (word) vectors for a given transcript and is known as SMART in the information retrieval community [2,11]. SMART initially preprocesses the transcripts by (i) tokenizing the text into individual words, (ii) removing common functions words and (iii) running morphological stemming. The term vectors are then weighted using the *lnu* term weighting scheme [12]:

$$\frac{(\,1 + \mathit{ln}\,(\,\mathit{tf}\,)\,)\,/\,(\,1 + \mathit{ln}\,(\,\mathit{average\ tf}\,)\,)}{0.8 * \mathit{pivot} + 0.2 * (\,\#\ \mathit{of\ unique\ terms}\,)}$$

where term frequency *tf* is the number of times a term occurs in the text, *average tf* is the average of the *tf*s of all the terms in a document, *ln* is a length normalization factor, and *pivot* is the average number of unique terms in a document, computed across the entire collection.

The user-queries are also preprocessed in the manner described above and indexed using *ltn* weights [12]:

$$(\,1 + \mathit{ln}\,(\,\mathit{tf}\,)\,) * \mathit{idf}$$

where inter document frequency *idf* is defined as the ratio of the total number of documents in the collection *N* and the number of documents *df* that contain the word, scaled again by a length normalization factor *ln*:

$$\mathit{ln}\,(\,N\,/\,\mathit{df}\,)$$

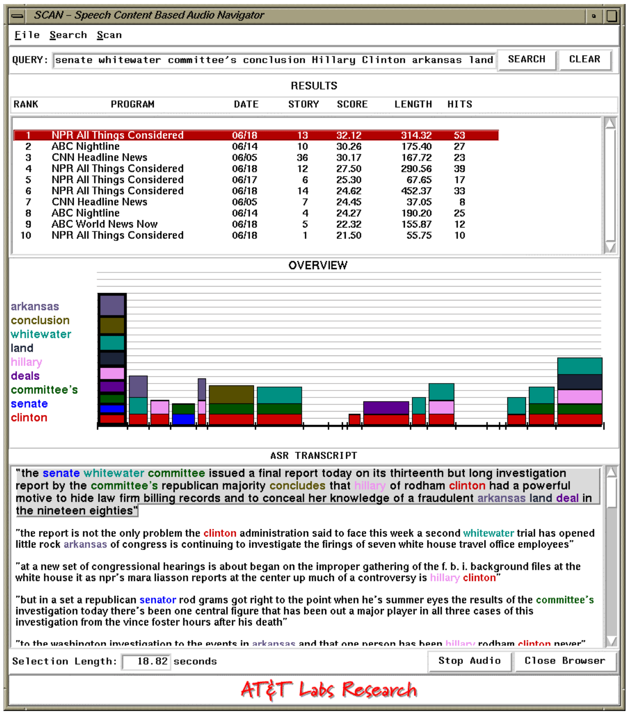
An inner-product similarity measure is used to assess the relevance of a document vector D_i and a query vector Q

$$\mathit{Sim}\,(\,Q,D_i\,) \;=\; \sum_{\text{common terms } t_j} q_j * d_{ij}$$

where t_j is a term present in both the query and the document, q_j is the weight of term t_j in the query, and d_{ij} is its weight in document i. The transcripts are ranked by their decreasing similarity to the query and presented to the user in this order.

4. USER INTERFACE

The graphical-user-interface is built on the principle of "what you see is almost what you hear" (WYSIAWYH) and uses the ASR transcripts extensively. The term "almost" is included because the machine-generated transcripts are errorful.



QUERY: senate whitewater committee's conclusion Hillary Clinton arkansas land

RANK	PROGRAM	DATE	STORY	SCORE	LENGTH	HITS
1	NPR All Things Considered	06/18	13	32.12	314.32	53
2	ABC Nightline	06/14	10	30.26	175.40	27
3	CNN Headline News	06/05	36	30.17	167.72	23
4	NPR All Things Considered	06/18	12	27.50	290.56	39
5	NPR All Things Considered	06/17	6	25.30	67.65	17
6	NPR All Things Considered	06/18	14	24.62	452.37	33
7	CNN Headline News	06/05	7	24.45	37.05	8
8	ABC Nightline	06/14	4	24.27	190.20	25
9	ABC World News Now	06/18	5	22.32	155.87	12
10	NPR All Things Considered	06/18	1	21.50	55.75	10

"the senate whitewater committee issued a final report today on its thirteenth but long investigation report by the committee's republican majority concludes that hillary of rodham clinton had a powerful motive to hide law firm billing records and to conceal her knowledge of a fraudulent arkansas land deal in the nineteen eighties"

"the report is not the only problem the clinton administration said to face this week a second whitewater trial has opened little rock arkansas of congress is continuing to investigate the firings of seven white house travel office employees"

"at a new set of congressional hearings is about began on the improper gathering of the f. b. i. background files at the white house it as npr's mara liasson reports at the center up much of a controversy is hillary clinton"

"but in a set a republican senator rod grams got right to the point when he's summer eyes the results of the committee's investigation today there's been one central figure that has been out a major player in all three cases of this investigation from the vince foster hours after his death"

"to the washington investigation to the events in arkansas and that one person has been hillary rodham clinton never"

Selection Length: 18.82 seconds

Figure 2: The SCAN graphical user interface.

The interface, presented in Figure 2, consists of three components: (i) Search, (ii) Overview and (iii) Transcripts. The Search component (top of Figure 2) accommodates user submitted queries. The information returned by the information-retrieval engine is displayed as a ranked list of (potentially) relevant documents. Each of the items displayed in the ranked list provide links to the corresponding documents.

Associated with each document in the ranked list is an Overview display and a Transcript display. The Overview display (middle of Figure 2) provides the user with information about the distribution of query-keywords within the transcripts associated with the selected document. A graphical rendering of this information allows the user to quickly assess regions within the transcripts that are "hotspots" insofar as they exhibit high query-keyword density or occurrences of a certain word or word combinations. This information is rendered as a histogram in Figure 2. The x-axis represents the length of the selected audio document, with the bin-boundaries corresponding to the intonational phrase boundaries detected at recognition time. Within each intonational phrase, we denote the occurrence of a query-keyword in the phrase by adding a color-coded block. The height of the block is determined by the term weight computed by the information-retrieval engine for the specific query-keyword. The query-keywords themselves are displayed to the left of the histogram, again color-coded for easy identification with the blocks in the histogram. Each bin in the histogram is linked to the audio associated with the intonational phrase; simply clicking on a bar in the histogram, or on the baseline in cases of an empty bin, will trigger audio play-back of the corresponding intonational phrase.

The final component of our interface consists of a display of the ASR transcripts (bottom of Figure 2) associated with the document that the user has selected. Within the transcripts, words matching the keywords from the query are color-hilighted to facilitate quick visual scanning. The transcripts are also formatted so that the text associated with separate intonational phrases are delimited in paragraph type breaks. Again, each paragraph is linked to the audio associated with the intonational phrase; simply clicking on a paragraph will trigger audio play-back of the corresponding intonational phrase.

Both the Overview and Transcript components are designed to provide the user with information about the internal structure and content of the selected transcript. The aim of this design is to afford the user quick access to the underlying speech at any point in the speech document. By visually rendering the underlying speech in terms of keyword distribution and machine-generated transcripts, the interface allows the user to fully exploit the human ability to rapidly scan and browse complex visual data to identify the relevant portions of the lengthy audio material that they wish to listen to. Each transcript can be viewed as a visual analogue to the speech story, and it can be used as a partial index to access relevant speech information. The visual analogue also allows us to exploit existing textual layout conventions, to provide some structure to the underlying speech. Furthermore, the Transcript component allows the played speech to be interpreted in context: i.e., users can scan the transcript to see what was said before and after the soundbite they are currently playing. They no longer hear an isolated soundbite with no idea of where the played speech occurs in relation to the whole document. Finally, providing the transcript enables users to exercise "checks" to determine the relevance of a given document: by quickly scanning it they can determine whether problems in either speech recognition or information retrieval led to the selection of an irrelevant document.

5. SYSTEM ASSESSMENT

To provide an assessment of the effectiveness of information-retrieval, we present results from two tasks. The first is the TREC-6 SDR task [13] which involves 49 known-item user-queries where each query has associated with it a unique document in a collection of 1452 documents. Performance on the task can be measured by simply counting the number of queries for which the target document is ranked within some K ranks. Figure 3 presents these counts for K=1, i.e., when the correct document was ranked #1 by the information-retrieval engine, and for K=5, i.e., when the correct document was ranked within the top 5 ranked documents. Results are presented for retrieval based on both machine-generated transcripts and human-generated transcripts.

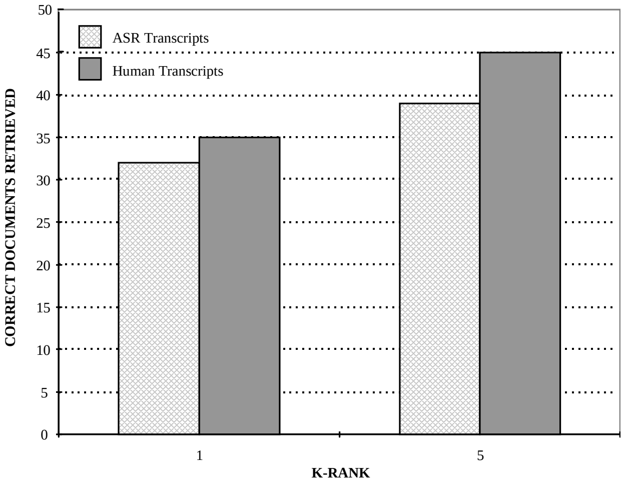


Figure 3: Information retrieval accuracy on a known-item task based on ASR transcripts and human transcripts.

While the TREC-6 SDR task affords us a benchmark with which to compare our system performance against other systems on the same task, it is widely held that the task is too restricted in its scope, due primarily to the small size of the corpus over which retrieval is being conducted, to be a robust measure of spoken document retrieval performance. To compensate for this, we exercised the system further, devising another task in which we selected 94 AP Newswire headlines from the same period that the broadcast news archives were collected. These headlines were then used as user queries. In lieu of relevance assessments for these headlines, which were not available, we simply compared the retrieval results from the machine-generated transcripts with those from the human-generated transcripts. In doing so, we assume that retrieval from human-generated transcripts serves as an upper-bound on our retrieval performance; i.e., average precision is 100%. Having made this assumption, we can calculate average precision based on retrieval from the machine-generated transcripts and compare this to the upper-bound.

The results from the AP headlines task is illustrated in Figure 4, where average precision based on the machine-generated transcripts is plotted as a function of K ranks, where K={1, 5, 10, 20, 30, 50, 100}. The top curve represents average precision when the word-error-rate is 30.0%. For comparison, another curve is plotted which represents average precision when the word-error-rate is 42.7%. This test shows that with a word-error-rate of 30.0%, we perform approximately 81% as well as we would if the transcripts were perfect. This test also shows that better recognition results in higher precision retrieval.

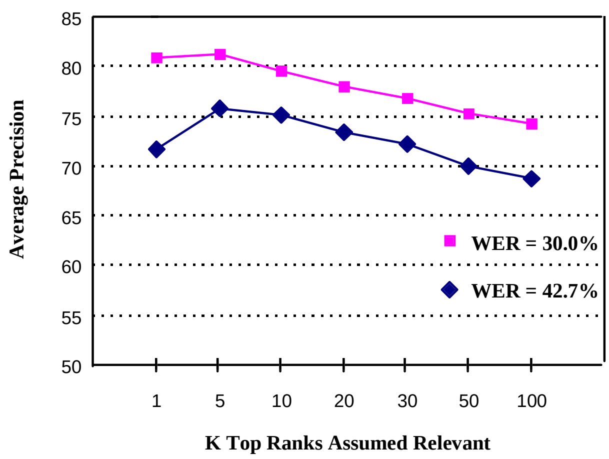


Figure 4: Average precision based on ASR transcripts at different word-error-rates for the AP headlines task.

6. CONCLUSION

We have described a system for querying and retrieving information from speech databases which integrates speech recognition and information retrieval technologies. Preliminary assessments conducted on tasks in the broadcast news domain are encouraging and we continue to explore techniques for improving information retrieval precision through the use of word lattices. We have also described an interface which allows users to identify relevant regions of the underlying speech without having to listen to the entire speech document and are conducting usability tests on this interface.

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