CSE6328.3
Speech & Language Processing

YORK UNIVERSITÉ UNIVERSITY redefine THE POSSIBLE.

No.1

Introduction

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CSE6328 Course Outline: *"Speech & Language Processing"*

- Part I: Introduction (2 weeks)
  - Overview of speech and language technologies
  - Basic Knowledge of speech and spoken language
  - Math foundation: review
- Part II: Basic theory of pattern classification/verification (4—5 weeks)
  - Bayesian decision rule; Model estimation methods
  - Generative models: Gaussian, GMM, Markov Chain, HMM, Graphical models
  - Discriminative models: SVM, Neural networks (NN) and beyond
- Part III: Case studies (3—4 weeks)
  - Automatic speech recognition
  - Spoken language processing
- Part IV: Advanced topics – YOUR PARTICIPATION !! (1—2 weeks)
  - Choose an advanced topic in machine learning
  - Choose a journal article in speech/language or other applications
  - Self-study and oral presentation in class

Course Info

- **Course Web site:** *http://www.cs.yorku.ca/course/6328/*
- **Course Format:**
  - **Lectures (10 weeks):**
    - **Covers basic data modeling, pattern classification theory;**
    - **Introduces some selected applications in speech recognition and spoken language processing.**
  - **Students' in-class presentations (2 weeks): based on basic theories in class, self-study recently published technical article and orally present it in class.**
    - **Choose an advanced topic in machine learning**
    - **Choose an application in speech/language or other domains**
- **Evaluation:**
  - **One assignment (10%) (roughly first 1/3 of the course)**
  - **Two lab projects (50%): report + oral presentation(?)**
  - **Advanced topic self-study and in-class presentation (30%)**
  - **Class Participation (10%)**

Reference Materials

- **Lecture notes**
- **Assigned reading materials through the course**
- **Reference books:**

[1] Pattern Recognition and Machine Learning by C. M. Bishop. (Springer, ISBN 0-387-31073-8)

[2] *Pattern Classification* (2nd Edition) by R. O. Duda, P. Hart and D. Stork. (John Wiley & Sons, Inc., ISBN 0-471-05669-3)

[3] *Spoken Language Processing: a guide to theory, algorithm, and system development* by X.D. Huang, A. Acero, H.W. Hon. (Prentice Hall PTR, ISBN 0-13-022616-5)

[4] *Foundations of Statistical Natural Language Processing* by C. D. Manning and H. Schutze. (The MIT Press, ISBN 0-262-13360-1

- **Prerequisite:**
  - First course in probability or statistics
  - First course in linear algebra or matrix theory
  - C/C++/Java and perl/shell programming skill (for project)

Speech Research and Technology

- Speech Communication
- Speech Production and Perception
- Speech Analysis and Synthesis
- Speech and Audio Coding & Compression
- Speech Recognition and Understanding
- Speaker Identification and Verification
- Speech Enhancement
- Language Identification
- Dialogue Processing

Language Research and Technology

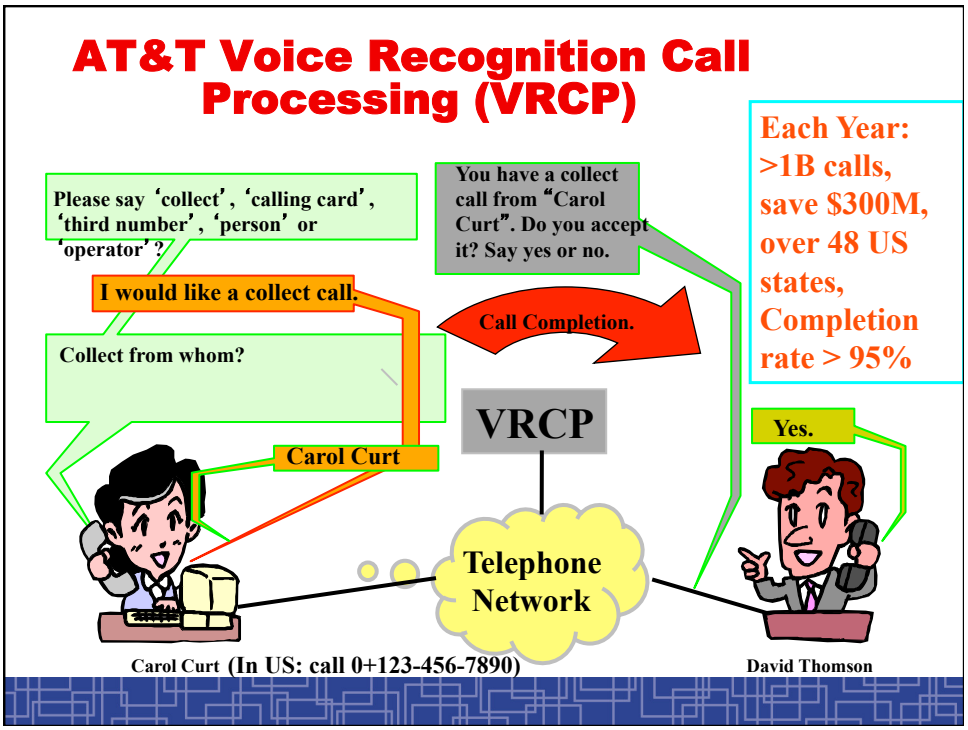
- Written vs. Spoken Languages
- Computational Linguistics
- Corpus-Based Language Technologies
- Statistical Language Modeling
- Language Analysis and Generation
- Statistical Part-of-Speech Tagging
- Modeling Syntax and Semantics
- Statistical Text Understanding / Text Mining
- Probabilistic Parsing
- Text Categorization
- Statistical Machine Translation
- Information Retrieval

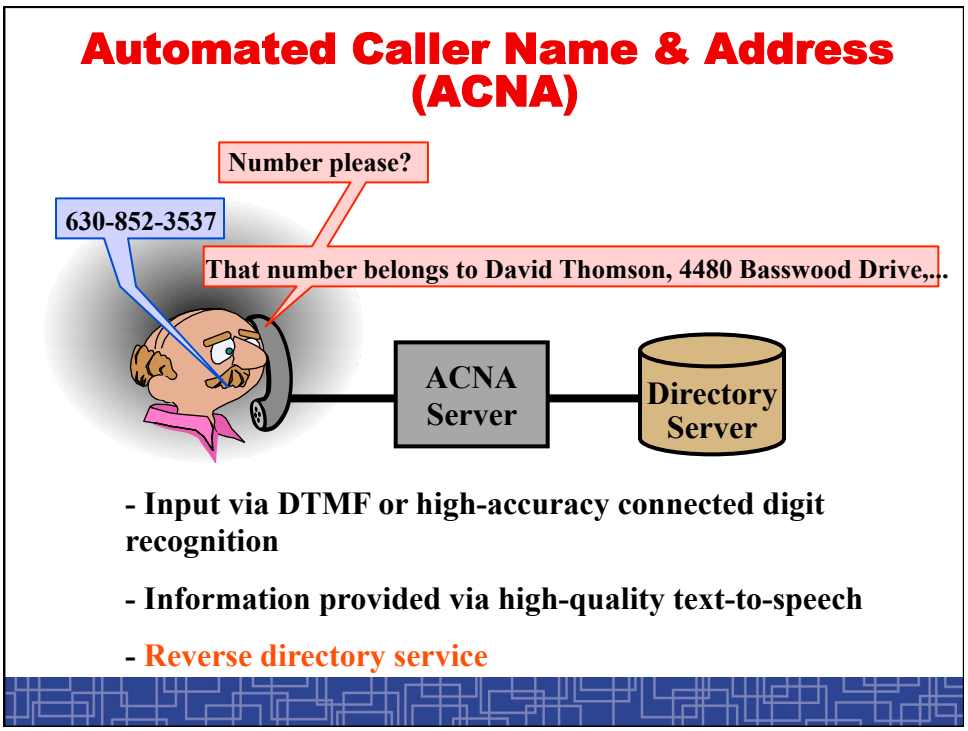
Applications of Speech and Language Technologies

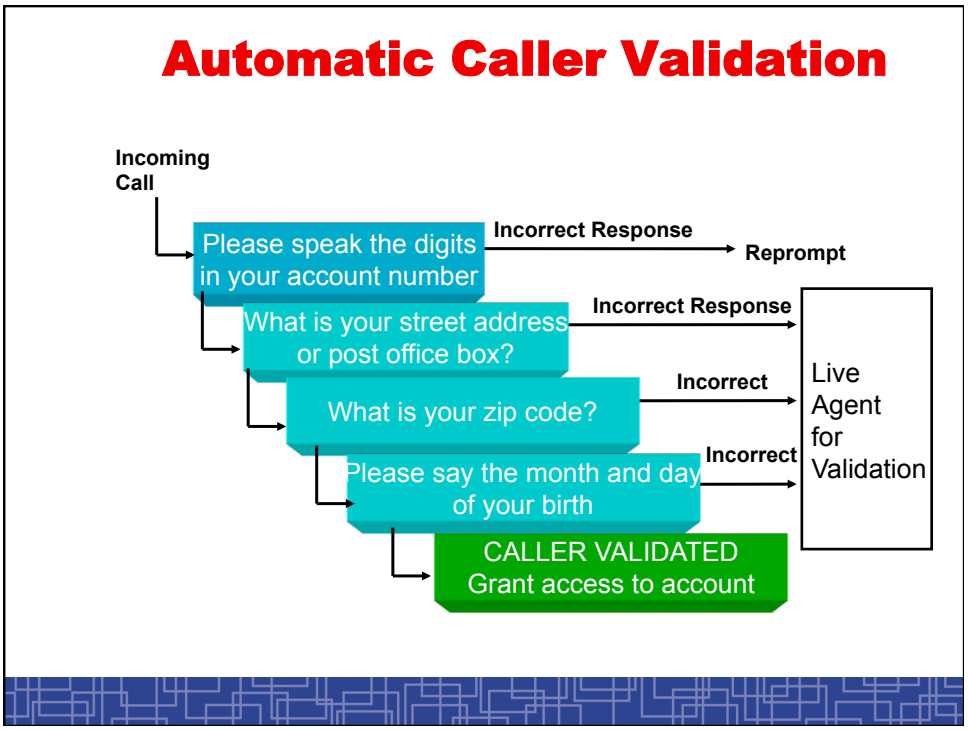
- Voice typewriter – dictation systems for PC:
  - IBM, Microsoft, Nuance, etc.
- Applications in telecommunications:
  - AT&T, Lucent Bell Labs, Nuance, Philips, Motorola, etc.
  - Automatic Call Centers.
  - Google 411, Microsoft Tellme, Free 411.
- Applications related to the Internet:
  - Google's voice search
  - Apple's Siri (voice assistant)
  - SMS Input system in smart phone (Nuance, iFlytek, etc)
  - More and more to emerge

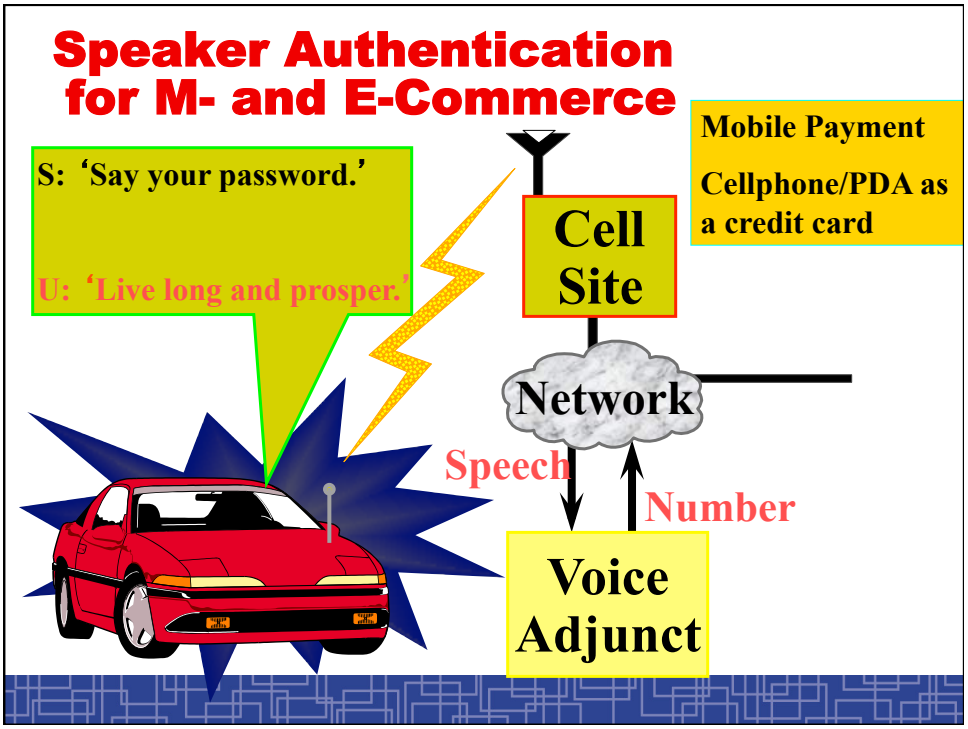
Voice Typewriter (Dictation system)

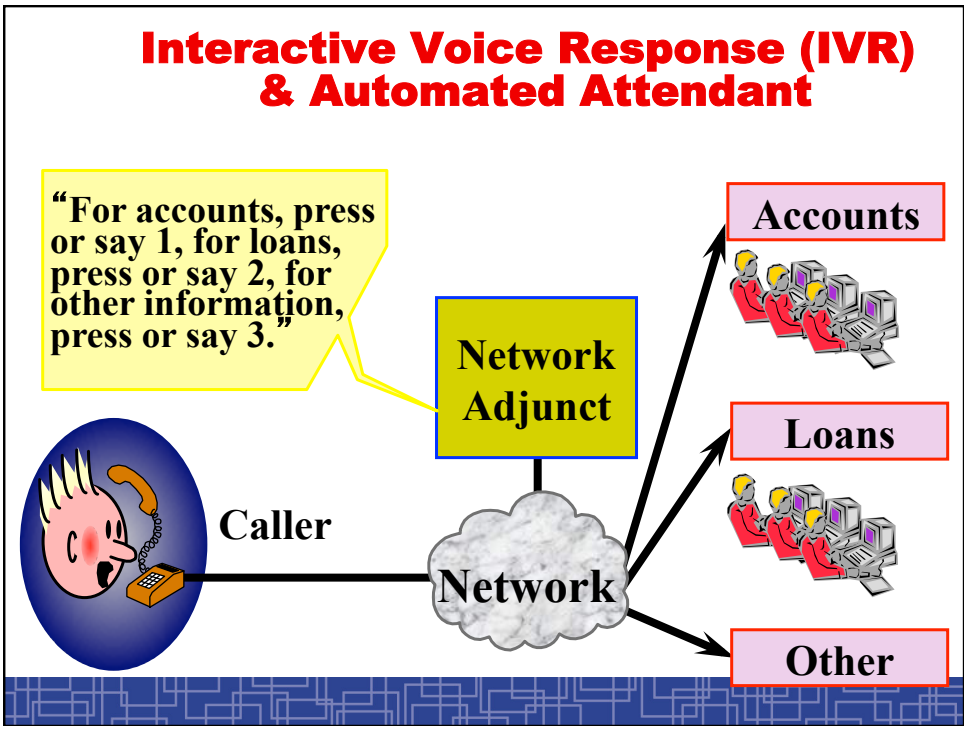
- IBM ViaVoice® System
  http://www.ibm.com/software/voice/viavoice/
- Microsoft Speech SDK and Whisper® System
  http://www.microsoft.com/speech/
- Nuance's Naturally Speaking System
  http://www.dragontalk.com/NATURAL.htm *http://www.scansoft.com/naturallyspeaking/*

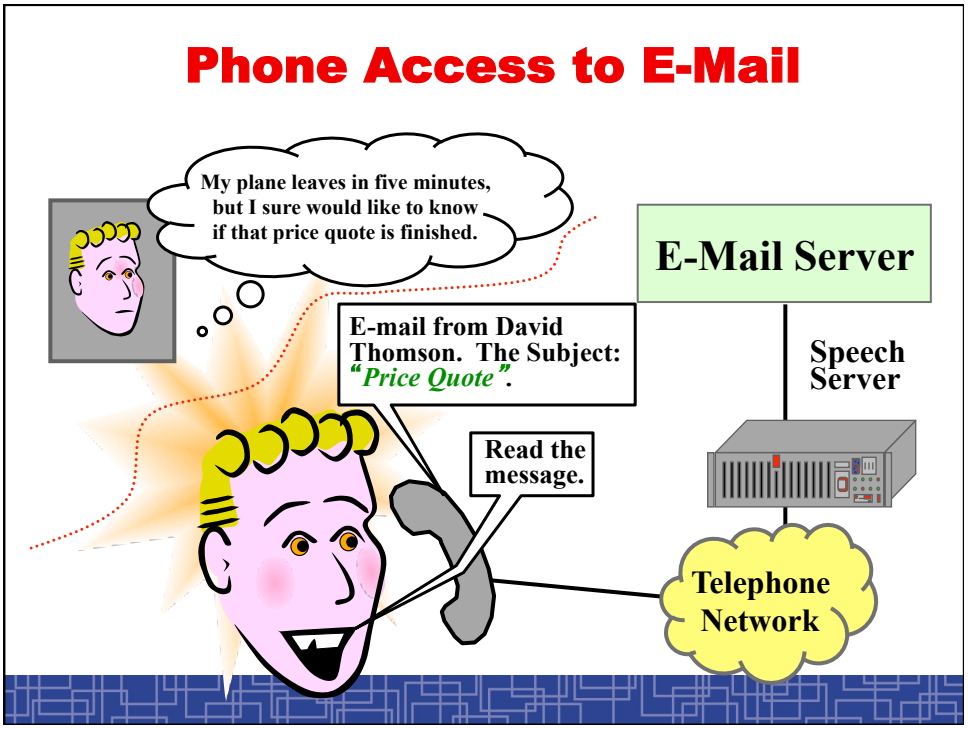

AT&T Voice Recognition Call Processing (VRCP)
Each Year: >1B calls, save $300M, over 48 US states, Completion rate > 95%
Please say 'collect', 'calling card', 'third number', 'person' or 'operator'?
You have a collect call from "Carol Curt". Do you accept it? Say yes or no.
I would like a collect call.
Call Completion.
Collect from whom?
VRCP
Yes.
Carol Curt
Telephone Network
Carol Curt (In US: call 0+123-456-7890)
David Thomson


Automated Caller Name & Address (ACNA)
Number please?
630-852-3537
That number belongs to David Thomson, 4480 Basswood Drive,...
ACNA Server
Directory Server
- Input via DTMF or high-accuracy connected digit recognition
- Information provided via high-quality text-to-speech
- Reverse directory service


Automatic Caller Validation
Incoming Call
Please speak the digits in your account number
Incorrect Response
Reprompt
What is your street address or post office box?
Incorrect Response
What is your zip code?
Incorrect
Please say the month and day of your birth
Incorrect
Live Agent for Validation
CALLER VALIDATED
Grant access to account


Speaker Authentication for M- and E-Commerce
S: 'Say your password.'
U: 'Live long and prosper.'
Mobile Payment
Cellphone/PDA as a credit card
Cell Site
Network
Speech
Number
Voice Adjunct


Interactive Voice Response (IVR)
& Automated Attendant
"For accounts, press or say 1, for loans, press or say 2, for other information, press or say 3."
Network Adjunct
Accounts
Loans
Other
Caller
Network


Phone Access to E-Mail
My plane leaves in five minutes, but I sure would like to know if that price quote is finished.
E-Mail Server
E-mail from David Thomson. The Subject: "Price Quote".
Speech Server
Read the message.
Telephone Network

Natural Language Example: Movie Locator

Moviefone (777-film)

Other applications:

- "This is the operator, how can I help you?"
- "Hi, I'd like a large pizza with pepperoni with mushrooms toppings."
- "Play all messages from Tom Smith."
- Business (restaurant) locator, yellow pages
- Travel information systems (train/flight)
- TellMe, UA FlightInfo, Google-411
- L&H, Nuance, SpeechWorks, Philips, etc.

The Bell Labs "Natural Language Call Router"

- Input: user request (in speech or text)
- Output: desired destination related to the request (in a call center)
- Data Preparation: user (request, destination) pairs are grouped to train routing matrix using a data-driven approach
- Technologies: speech recognition, language modeling, call routing, dialogue generation

The United Airlines Flight Information System

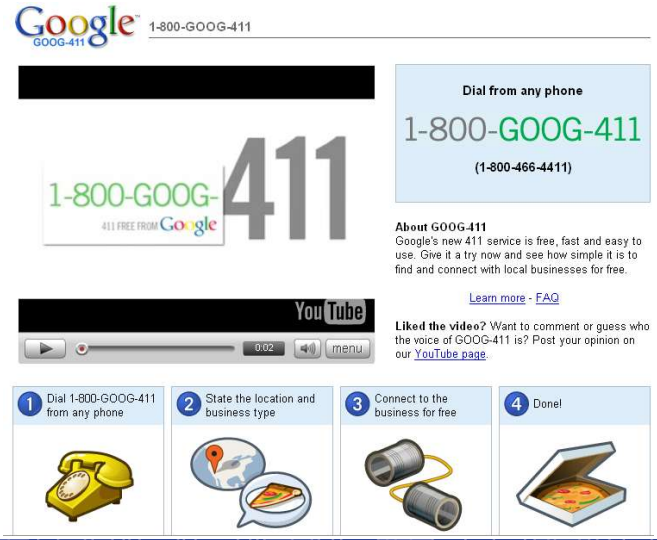
- Input: user request (in speech)
- Output: desired flight information
- Data Preparation: flight schedule info is converted into groups of finite state grammars, prompts are used to guide users
- Technologies: speech recognition, language modeling, user modeling

The Stock Information System

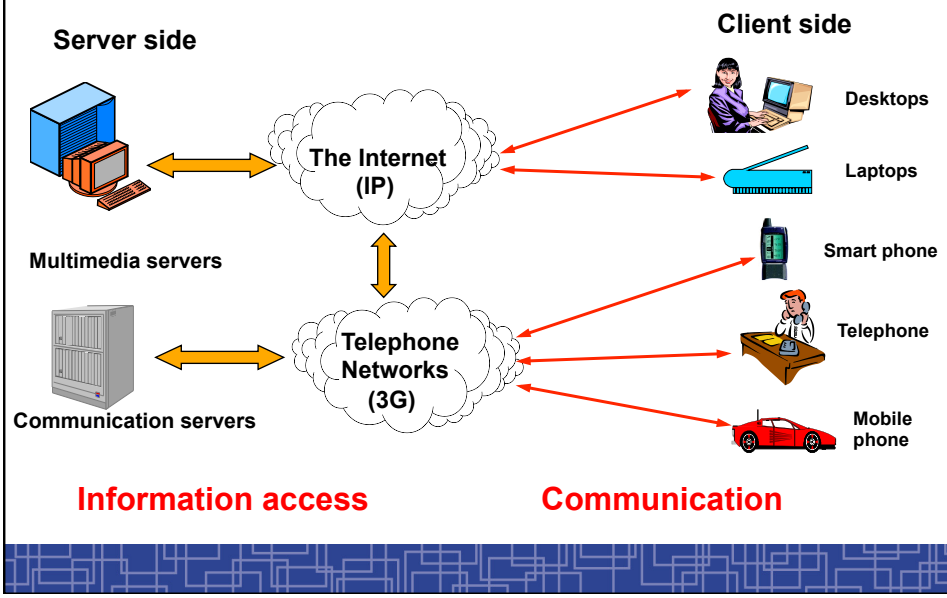
- Input: user request (in speech)
- Output: desired update stock info
- Data Preparation: convert stock names into pronunciation entries
- Technologies: speech recognition, pronunciation modeling, database, text-to-speech synthesis

The Google 411 Service

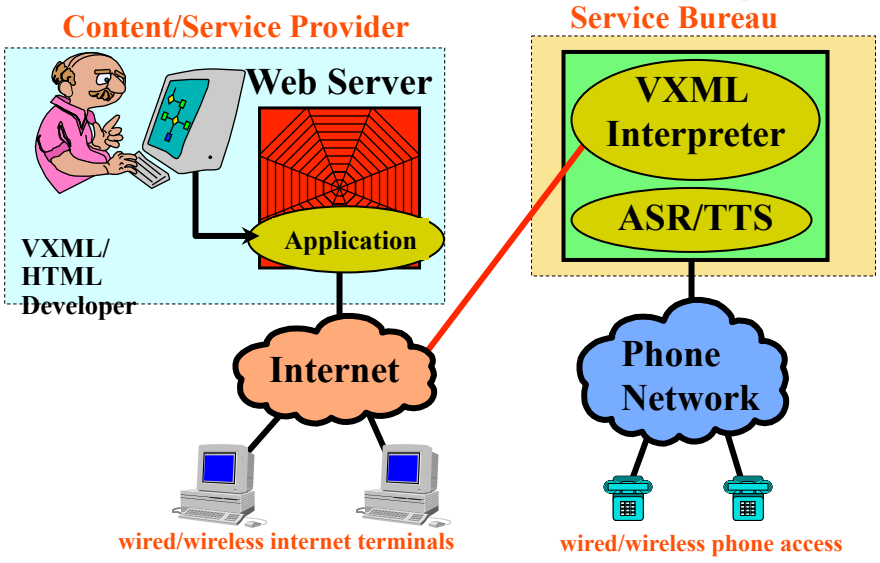
- http://www.google.com/goog411/



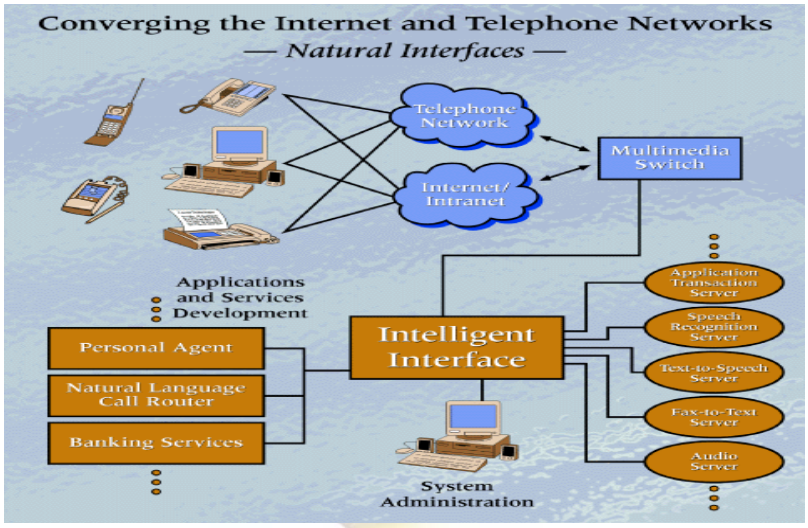
The Internet Era



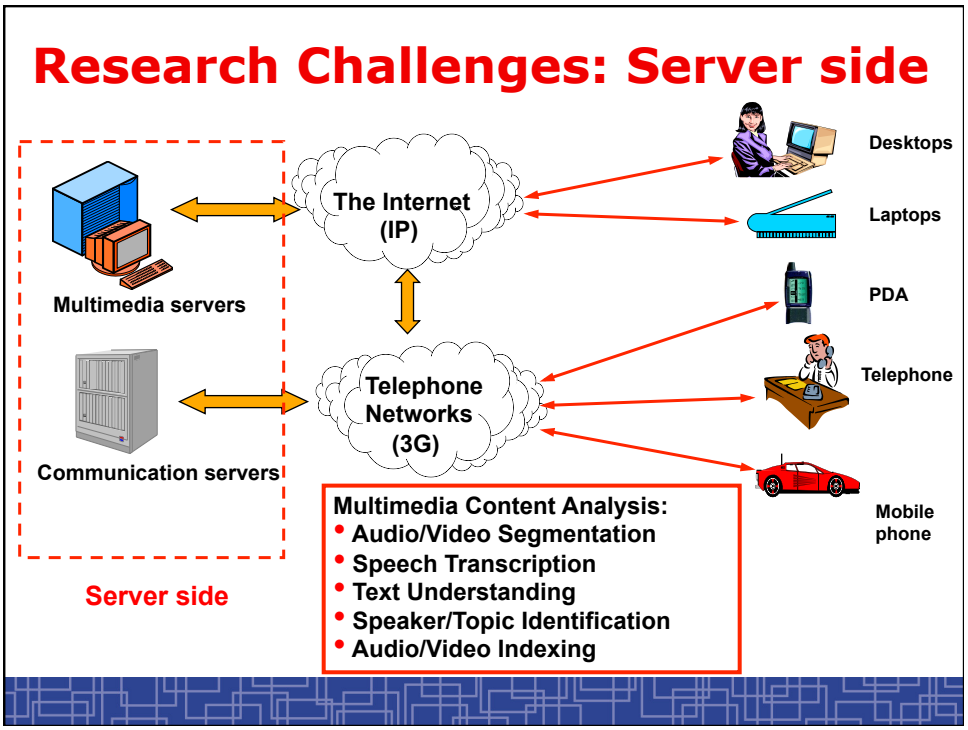
Web and Phone Integration (Voice Portal vs. Web Portals)

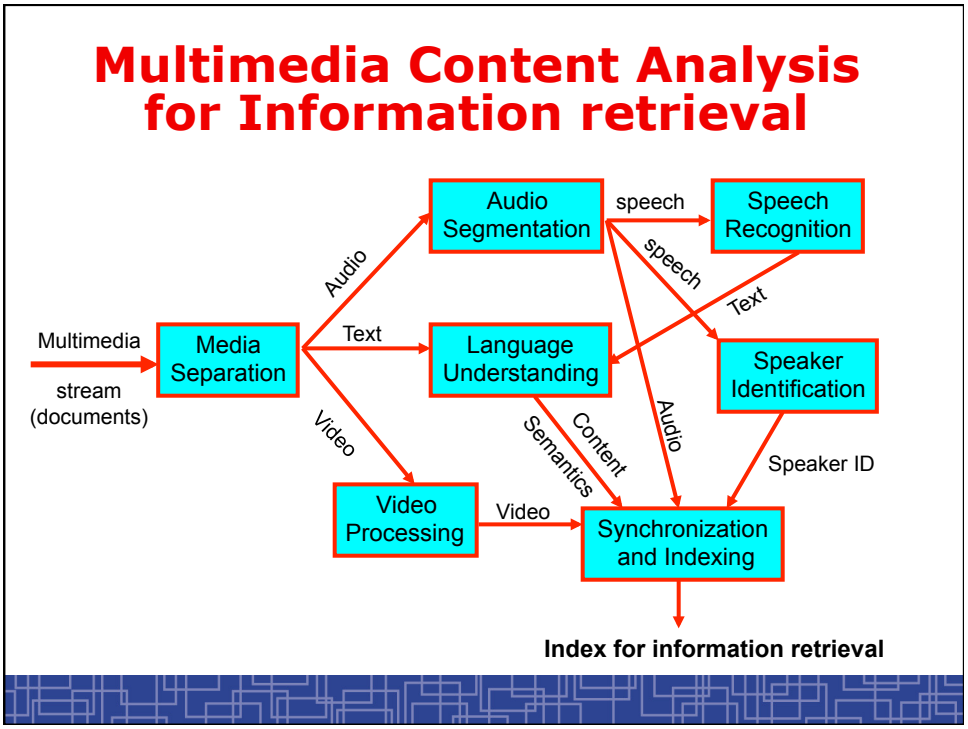


Universal Human-Machine Interface



- Anytime, Any place, Any Device, Any Platform, Any form
- Multimedia & Multi-modality Access


Research Challenges: Server side
Desktops
Laptops
PDA
Telephone
Mobile phone
The Internet (IP)
Telephone Networks (3G)
Multimedia servers
Communication servers
Server side
Multimedia Content Analysis:
• Audio/Video Segmentation
• Speech Transcription
• Text Understanding
• Speaker/Topic Identification
• Audio/Video Indexing


Multimedia Content Analysis for Information retrieval
Multimedia stream (documents)
Media Separation
Audio
Text
Video
Audio Segmentation
Language Understanding
Video Processing
speech
Speech Recognition
speech
Text
Speaker Identification
Audio
Semantics
Content
Video
Synchronization and Indexing
Speaker ID
Index for information retrieval

Video and Audio Segmentation

Archiving & Browsing Multimedia Data

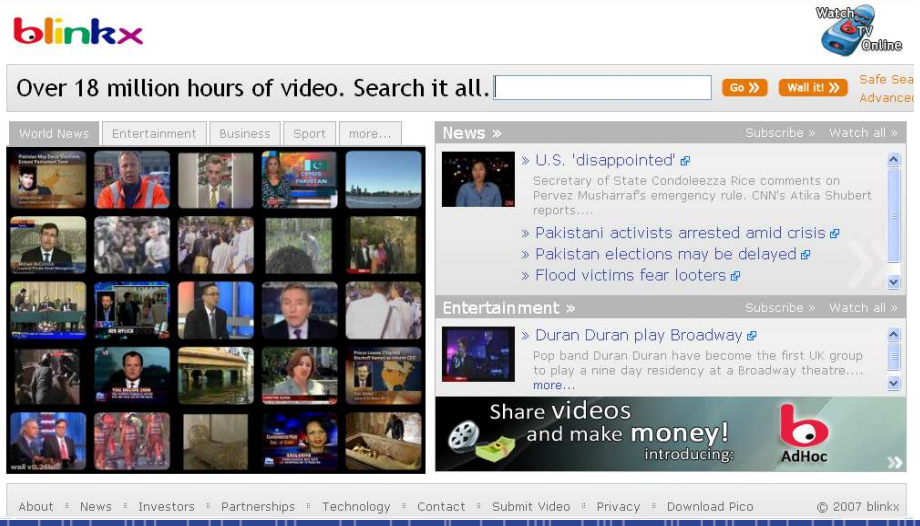
- Input: user request (in speech or text)
- Output: desired audio/video segments

- Data Preparation: video/audio segments with semantic description and (recognized) text for easy browsing, like MPEG7 descriptions (creation of indexing info for access is key)

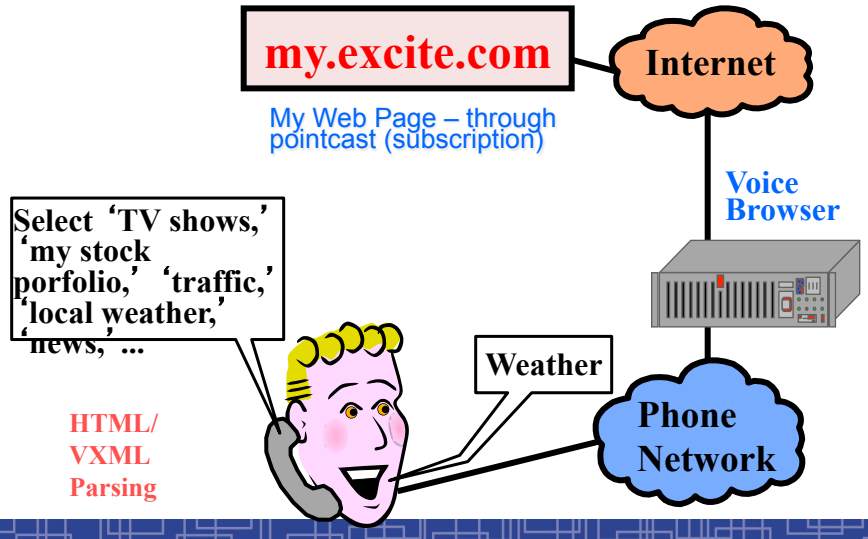
- Technologies: speech recognition, video processing, multimedia segmentation and data mining, fusion of audio/video/caption information and presentation, etc.

Video Search -- Blinkx

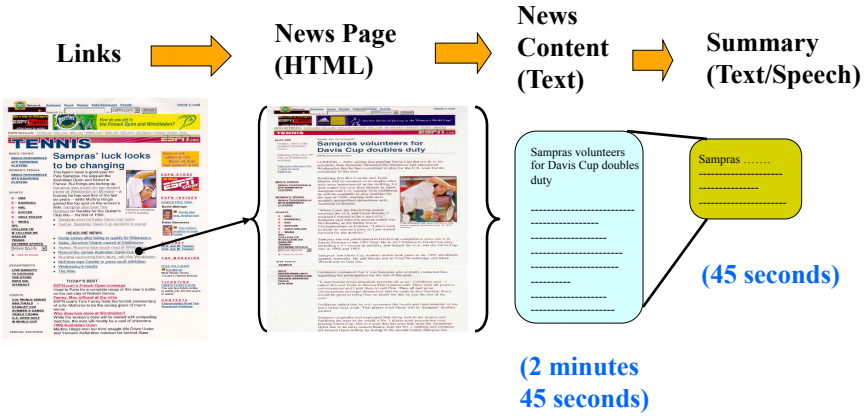
- WWW: http://www.blinkx.com/



Voice Browsing Applications



Web Document Processing, Navigation & Presentation



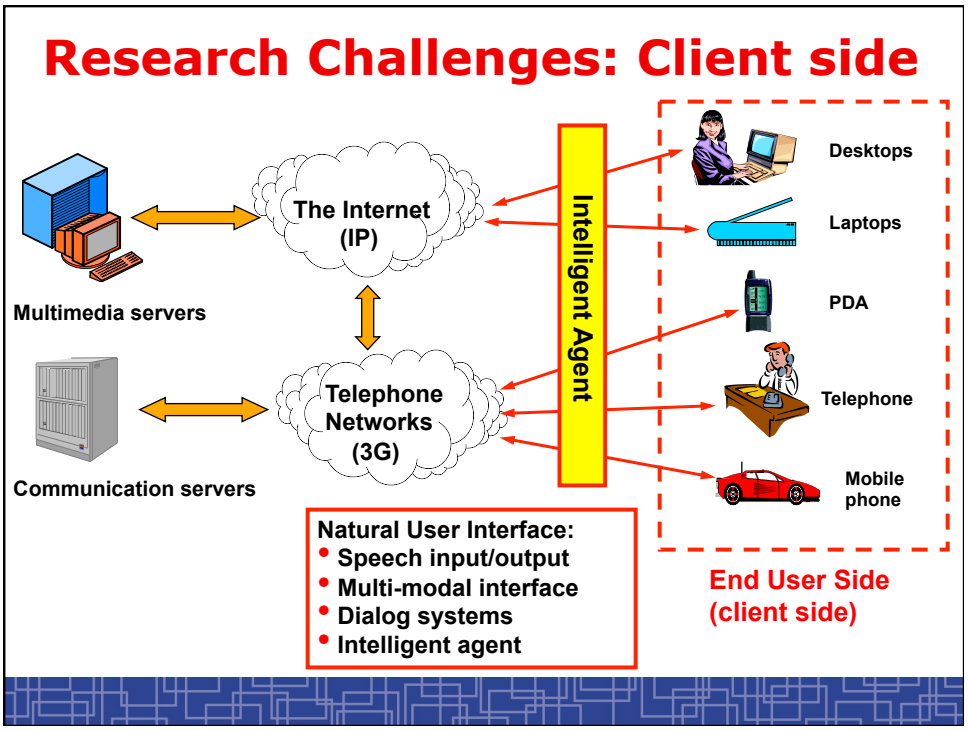
Google's Voice Search

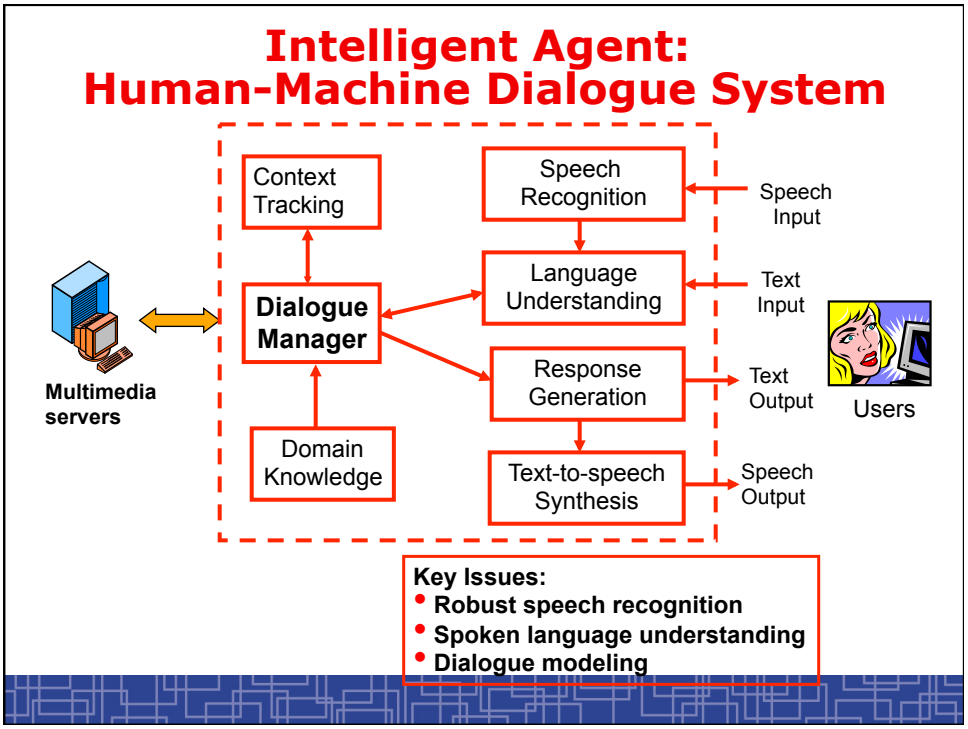
- Google's voice search

Search by voice

Speak your queries instead of typing.

Watch video Learn more


Research Challenges: Client side
The Internet
(IP)
Intelligent Agent
Multimedia servers
Telephone
Networks
(3G)
Communication servers
Desktops
Laptops
PDA
Telephone
Mobile
phone
Natural User Interface:
• Speech input/output
• Multi-modal interface
• Dialog systems
• Intelligent agent
End User Side
(client side)


Intelligent Agent:
Human-Machine Dialogue System
Context
Tracking
Speech
Recognition
Speech
Input
Language
Understanding
Text
Input
Dialogue
Manager
Response
Generation
Text
Output
Users
Multimedia
servers
Domain
Knowledge
Text-to-speech
Synthesis
Speech
Output
Key Issues:
• Robust speech recognition
• Spoken language understanding
• Dialogue modeling

Apple's Siri

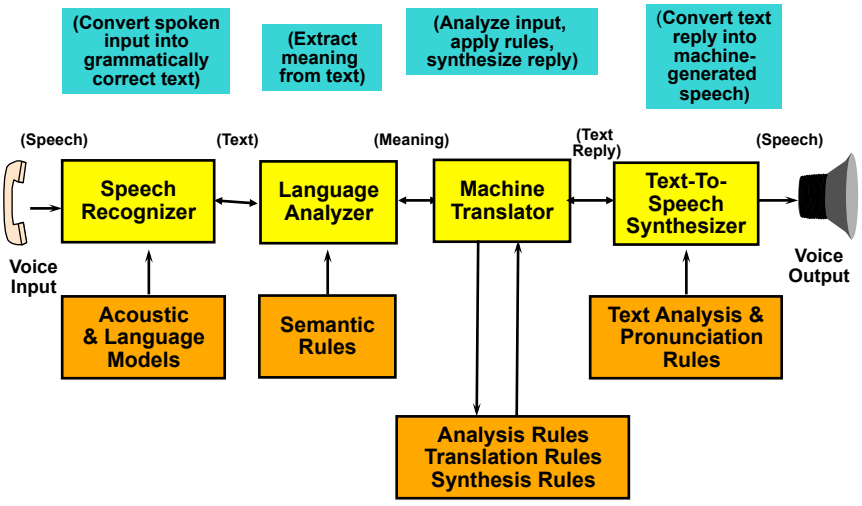
- Voice Assistant: *Siri*

Iflytek Chinese Voice Assistant

- Quite popular in China: >10M users

Speech-To-Speech Translation

Multilingual Speech-to-Speech Translation



Pattern Classification: Paradigm Shift

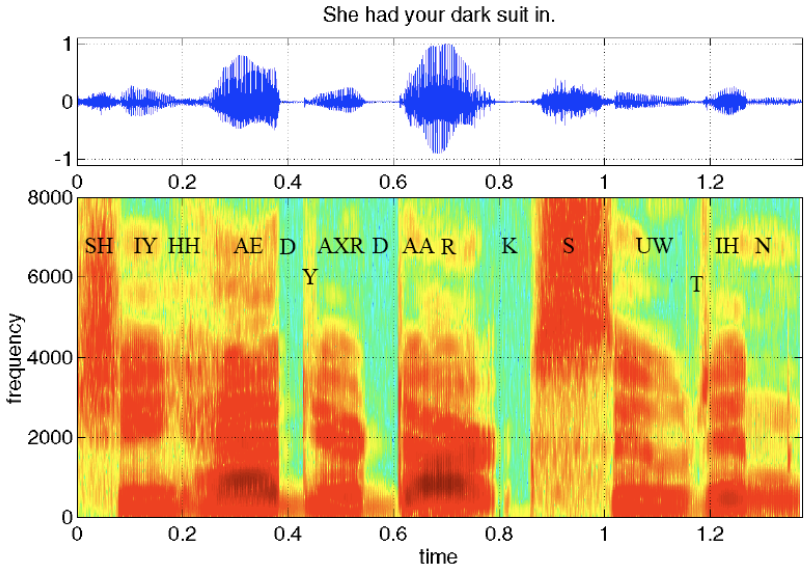
- Knowledge based
  - Reply on expert(s); Small data samples
  - Simple toy problems
- Data-Driven
  - Large data samples
  - Statistical models; machine learning algorithms
- Mass (Big) Data Era
  - Massive real-world data samples
  - Data intensive computing
  - Parallel/distributed platform: e.g. GPU, map-reduce

Statistical Pattern Classification

- Feature extraction:
  - Need to know objects to extract good features
  - Varies a lot among different applications (speech, audio, text, image, video, biological sequences, etc)
- Statistical model training/learning
- Inference, matching, decision

The basic theories common to various applications

Speech Signals



Fundamental Speech Units

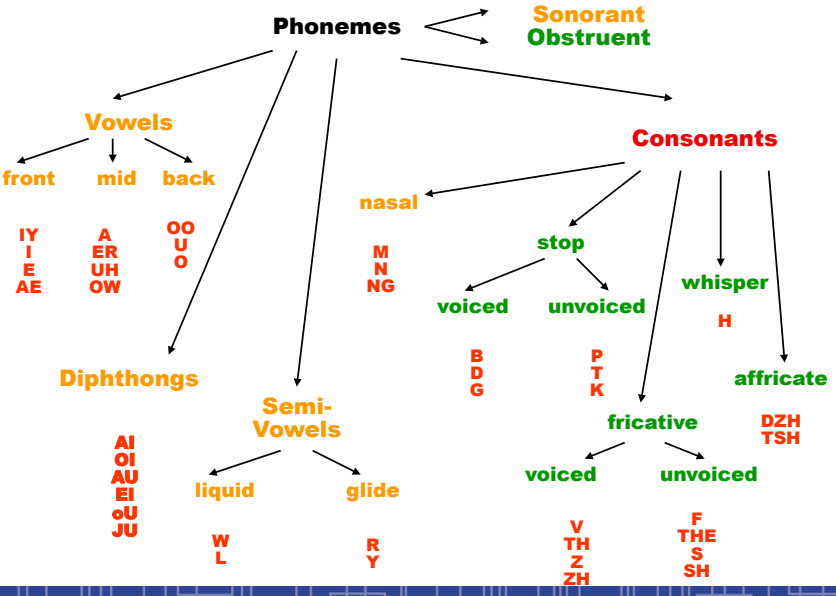
- Sentence/utterance ➔ Phrase ➔ Word ➔ Syllable ➔ Phone
- Phone
  - abstract name is called "phoneme"
  - infinite number of acoustic realization
  - monophone: context-independent phone
  - allophone: context-dependent phone
- Other considerations:
  - Language dependency
  - Task or vocabulary dependency
    - digit (small size but critically important)
- Example:

  Sentence: How do they turn out later ?

  Syllables: How do they turn out la-ter?

  Phones: h aw d uh dh eh t er n aw t l ai t er

Phonemes in American English



Coarticulation

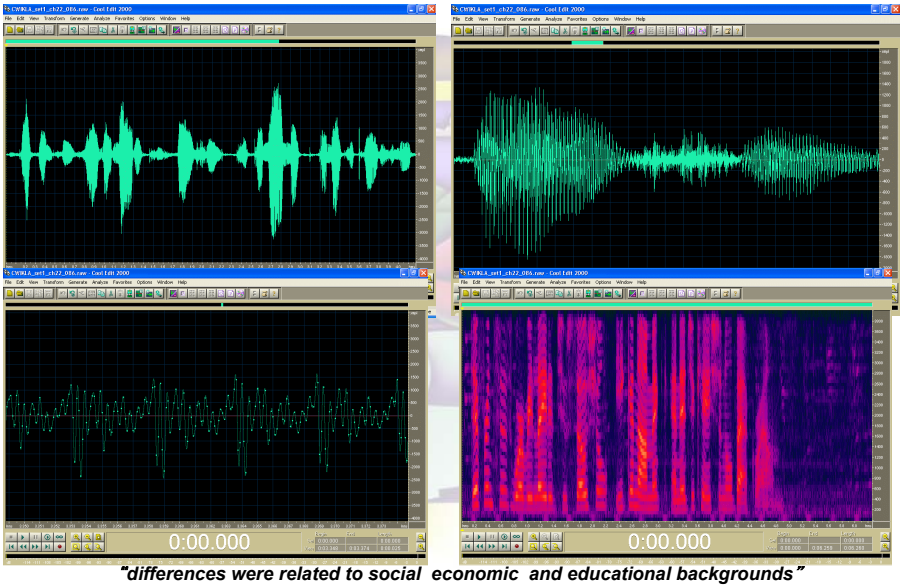
- Phones exhibit consistent acoustic characteristics if pronounced in isolated; but large acoustic variations may appear if uttered in different contexts.
- Coarticulation: acoustic realization of a phone is largely affected by its neighboring contexts.
- Reason: in speech production, articulatory gestures follow dynamics constrained by mechanical time constants associated with the articulator to keep the effort of muscles to a minimum.
- In speech recognition, how to model a phone:
  - Context-independent phone modeling – monophone: treat each phoneme equally no matter where it appears.

    (in American English → 42 distinct phone units to model)
  - Context-dependent phone modeling:

    Left (or right) biphone: a phone unit varies based on left(right) neighboring phone. (American English → 42X42 distinct units)

    Triphone: a phone varies based on both left and right adjacent phones. (American English → 42X42X42 distinct units)

Acoustic Realization: speech waveform



"differences were related to social economic and educational backgrounds"

Speech Waveform: Digital form

```
  ........
1400:   -529  -405  -601 -1038    51   323  -324   115   698   465
1410:    485   251   166   433  -346  -908  -303  -414  -773  -475
1420:     65   406   672   566  1160  1000  -354   519   417  -702
1430:   -728  -487  -769  -511  -719  -811   227   149  -130   476
1440:    726   439   556   273   175    49  -718  -733  -363  -661
1450:   -754   -11   318   684   782  1088   999  -108   559   409
1460:   -704  -789  -509  -833  -735  -762  -712   205    80   -88
1470:    576   847   390   552   369   170  -193  -833  -719  -481
1480:   -739  -707   143   408   811   888  1321   685  -101   815
1490:     33  -963  -795  -498  -966  -741  -809  -456   399    66
1500:     -5   817   892   294   496   279    -9  -696  -820  -698
1510:   -534  -753  -254   392   757   985  1265  1187  -266   657
1520:    517  -887 -1134  -406  -830  -987  -568  -691   239   424
1530:     15   507  1212   474   325   435   -24  -784  -741  -812
1540:   -653  -532  -278   240   982   999  1221  1196  -463   630
1550:    500 -1023 -1331  -298  -819 -1110  -597  -520   344   443
1560:     49   526  1297   406   184   367  -438  -883  -589  -949
1570:   -704   -90   -74   261  1413  1188  1332   292  -234   895
1580:   -213 -1468 -1065  -191 -1017  -838  -640    20   688   379
1590:    157   941  1170   194    88  -313  -689  -674  -952  -938
1600:   -124   257   -30  1089  1539  1506   545  -636   687   269
1610:  -1439 -1751  -253  -534 -1033  -691   -74   862   709   156
1620:    555  1408   382  -249  -600  -476  -632 -1063  -938   -96
1630:    548    57   902  1527  1922   309  -874   618   315 -1606
1640:  -1961  -326  -416  -789  -673   118   970   917   256   494
1650:   1231   439  -591  -940  -278  -724 -1031  -728   223   613
1660:    420  1039  1578  2126  -260 -1047   674    16 -2048 -1771
......
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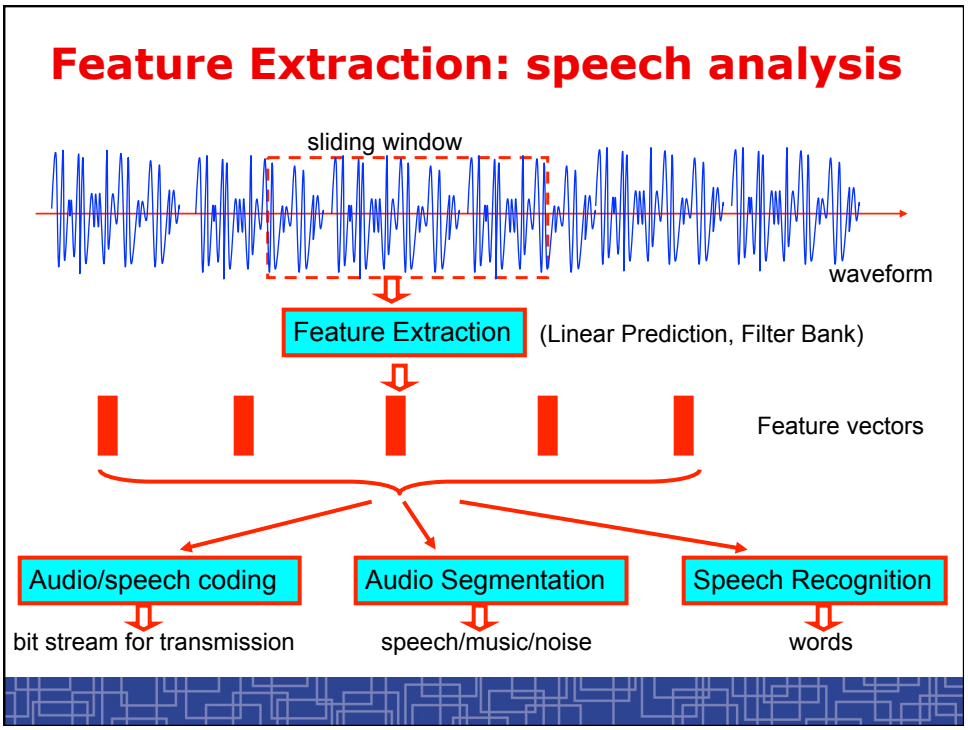
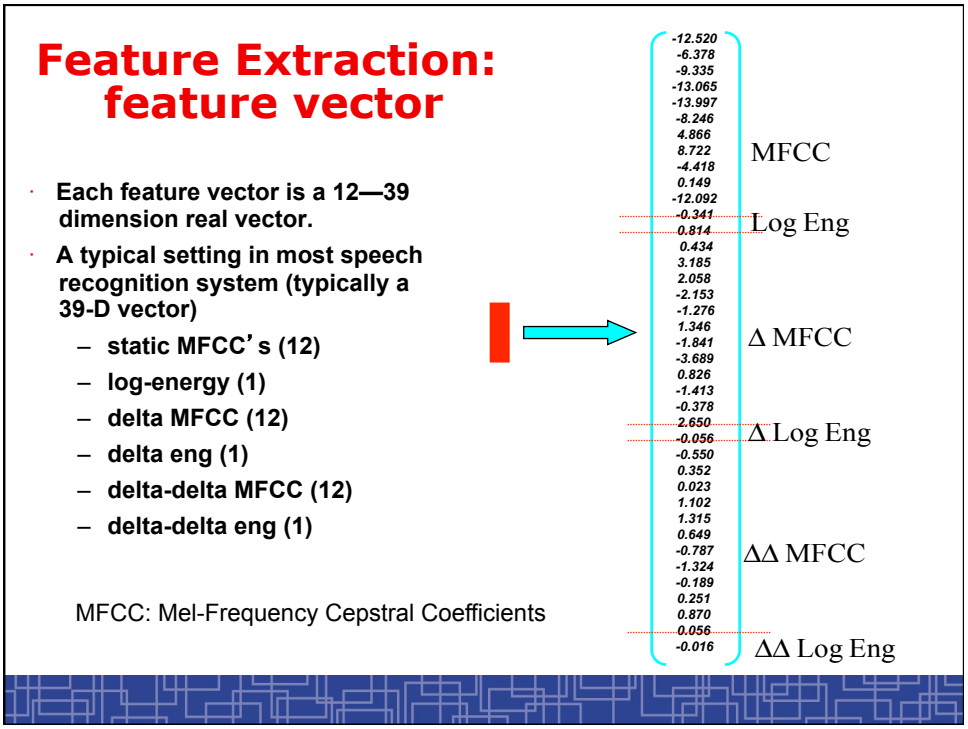

Feature Extraction: speech analysis
sliding window
waveform
Feature Extraction
(Linear Prediction, Filter Bank)
Feature vectors
Audio/speech coding
Audio Segmentation
Speech Recognition
bit stream for transmission
speech/music/noise
words


Feature Extraction: feature vector
Each feature vector is a 12—39 dimension real vector.
A typical setting in most speech recognition system (typically a 39-D vector)
– static MFCC's (12)
– log-energy (1)
– delta MFCC (12)
– delta eng (1)
– delta-delta MFCC (12)
– delta-delta eng (1)
MFCC: Mel-Frequency Cepstral Coefficients
-12.520
-6.378
-9.335
-13.065
-13.997
-8.246
4.866
8.722
-4.418
0.149
-12.092
-0.341
0.814
0.434
3.185
2.058
-2.153
-1.276
1.346
-1.841
-3.689
0.826
-1.413
-0.378
2.650
-0.056
-0.550
0.352
0.023
1.102
1.315
0.649
-0.787
-1.324
-0.189
0.251
0.870
0.056
-0.016
MFCC
Log Eng
Δ MFCC
Δ Log Eng
ΔΔ MFCC
ΔΔ Log Eng

What's MFCC?

Step 1:

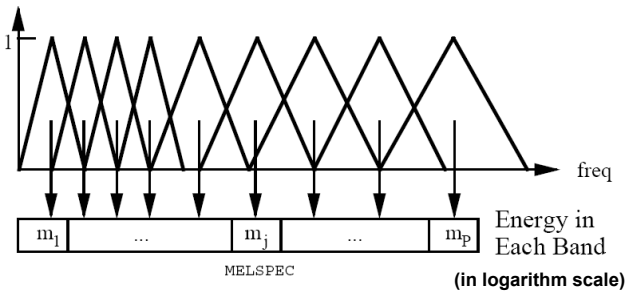


Fig. 5.3 Mel-Scale Filter Bank

Step 2: DCT (Discrete Cosine Transform) to de-correlate

$$c_i = \sqrt{\frac{2}{N}} \sum_{j=1}^{N} m_j \cos\left(\frac{\pi i}{N}(j-0.5)\right)$$

MFCC: Mel-Frequency Cepstral Coefficients

Energy Measure

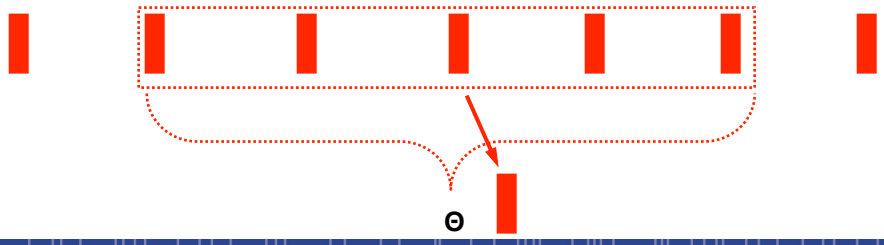
- **For each frame, log-energy is calculated as:**

$$E = log \sum_{n=1}^{N} s_n^2$$

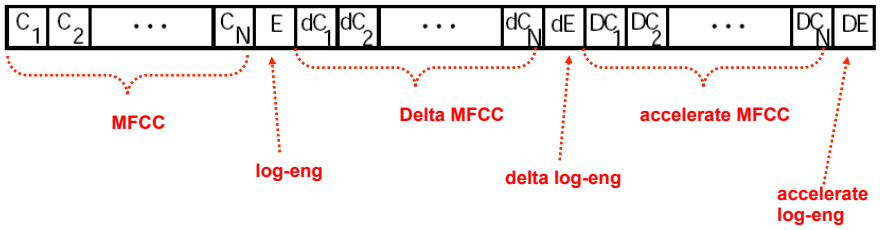
What Delta (Δ) and Acceleration(ΔΔ) Coefficients?

1. Delta coefficients: difference of MFCC among consecutive frames.
2. Acceleration coefficients: difference of delta among consecutive frames

$$d_t = \frac{\sum_{\theta=1}^{\Theta} \theta(c_{t+\theta} - c_{t-\theta})}{2\sum_{\theta=1}^{\Theta} \theta^2}$$



Feature Vector Layout for each frame of speech



In most cases, N=12 ➔ 39-dimension feature vector for each frame

Spoken Language Processing

- Style: written vs. spoken language
  - Written → formal; spoken → casual
- Disfluencies in spoken language:
  - Filled pauses: *um*
  - Repetitions: *… the—the …*
  - Repairs: *… on Thursday – on Friday …*
  - False starts: *I like … – what I always get is …*
- Lots of ungrammatical sentences exist in spoken language.
- In spoken language system:
  - speech recognition errors
- Obviously, spoken language processing is much harder.
- Our goal: build spoken language systems in some very constrained domains to perform shallow understanding:
  - Topic identification
  - Key-word spotting ➔ to obtain gist and/or key message.
  - etc.

Feature Extraction to represent Text Document

- Text document ==> bag of words
- Key words vs. stop words
- "Russia cancels an exhibition of Russian art in London over fears the art could be seized to settle legal claims."
- => "exhibition(1) art(2)" <=> "art(2) exhibition(1)"
- Raw Feature vector:

$$\begin{bmatrix} 0 \\ \vdots \\ 2 \\ 0 \\ \vdots \\ 1 \\ 0 \\ \vdots \end{bmatrix}$$

- May need some normalization:
  - e.g. *TF-IDF,…*

Statistical Machine Translation

- Score and rank all possible combinations…