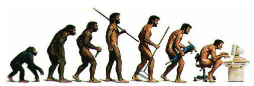
# Human-Computer Interaction

**Session 8**
Spoken Language Interaction



## The evolution of user interfaces (and the rest of this lecture)



| Year | Paradigm | Implementation |
|---|---|---|
| 1950s | None | Switches, punched cards |
| 1970s | Typewriter | Command-line interface |
| 1980s | Desktop | Graphical UI (GUI), direct manipulation |
| 1980s+ | Spoken Natural Language | Speech recognition/synthesis, Natural language processing, dialogue systems |
| 1990s+ | Natural interaction | Perceptual, multimodal, interactive, conversational, tangible, adaptive |
| 2000s+ | Social interaction | Agent-based, anthropomorphic,social, emotional, affective, collaborative |

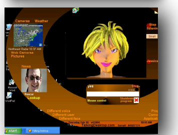


## Overview: machines as...

tools ➜ operate

smart tools ➜ instruct

interactive interlocutors ➜ converse



companions ➜ collaborate



## Overview: machines as...

tools ➜ operate

The computer as a multi-functional tool for solving problems and achieving tasks.

User and computer have a continuous interaction

- user operates the machine
- machine performs local problem solving task
- machine gives feedback

# Overview: machines as...

tools ➜ operate

smart tools ➜ instruct



# Using *speech* to interact with systems

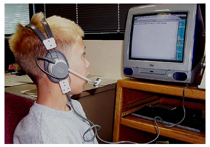
- Intuitive form of communication, no need for training
- Relates to (one) way of thinking; *but* images, maps, …
- Paradigm: Computer adapts to human way of interaction




# Speech interaction

Used today

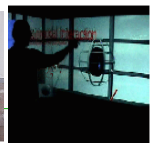
- on the desktop, e.g. dictate
- on the phone, e.g. ticket booking, pizza ordering



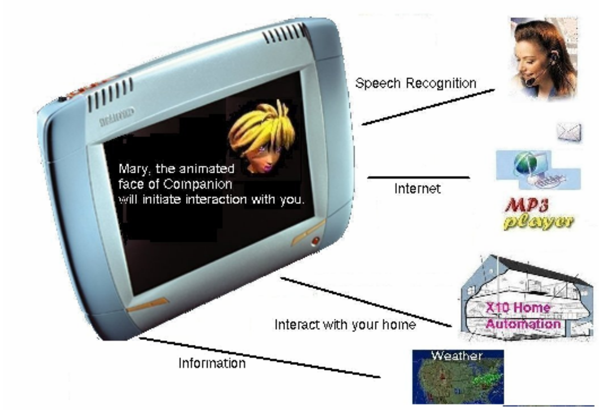
Research on

- natural language
- mobile devices & robots
- automotive interaction
- Virtual Reality
- conversational systems

SmartKom-Mobile








Speak to Mary using our close-talk headset. Mary is an **animated character** that represents our software running on your computer.

Mary listens using **speech recognition** and talks to you with a **natural sounding voice**.

Do dictation and email. Mary can read back text and headline news.

Voice surf the Internet. Request MP3 music.

Ask for weather radar or live web cam shots. On-line news and lead story tracking.

http://www.talkingdesktop.com/concept.htm

## Spoken Language Dialogue Systems (SLDS)

- A system that allows a user to *speak* his queries in natural language and receive useful spoken *responses* from it
- Provides an interface between the user and a computer-based application that permits *spoken interaction* with the application in a "relatively natural manner"



## Levels of sophistication

- **Touch-tone replacement:**
  System Prompt: "For checking information, press or say one."
  Caller Response: "One."
- **Directed dialogue:**
  System Prompt: "Would you like checking account information or rate information?"
  Caller Response: "Checking", or "checking account," or "rates."
- **Natural language:**
  System Prompt: "What transaction would you like to perform?"
  Caller Response: "Transfer 500 dollars from checking to savings."



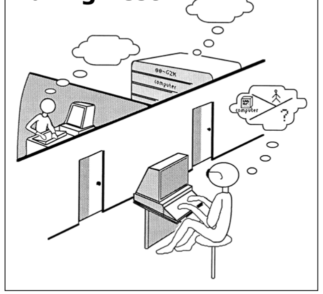
## Levels of sophistication

| | |
|---|---|
| **Controlled language** | limited vocabulary, simple grammar (e.g. command language) |
| ↓ **Natural language** | huge vocabulary, complex grammar, grammatical variation, ambiguities, unclear sentence boundaries, omissions, word fragments |
| ↓ **Natural dialogue** | turn-taking, initiative switch, discourse grounding, restarts, interruptions, interjections, speech repairs |



## Perfect natural dialogue - „Holy Grail" of AI

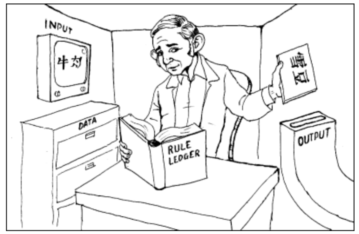
**Turing Test**



*I propose to consider the question "Can machines think?" This should begin with definitions of the terms "machine" and "think."*
[Turing, 1950]

Critics: Understanding not really needed (intelligence?)

- "Chinese Room" (Searl, 1980)
- ELIZA (Weizenbaum, 1966)

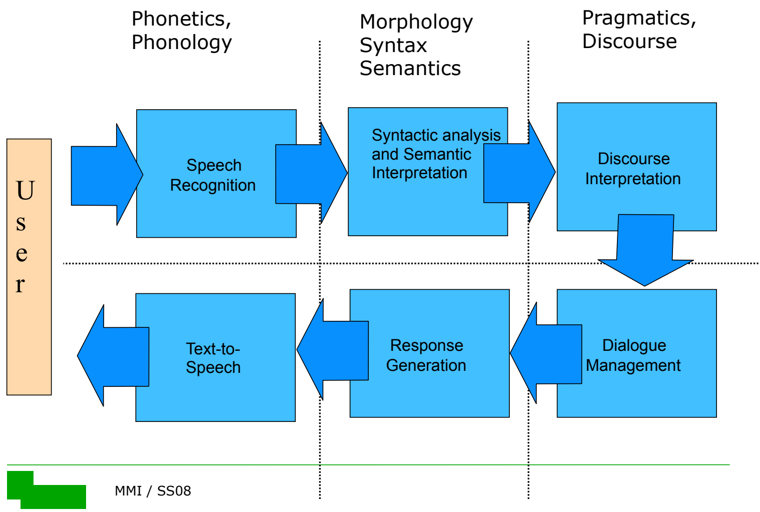


# Natural language – things to think of

- **Phonology and Phonetics**
  study of speech sounds and their usage
- **Morphology**
  study of meaningful components of words
- **Syntax**
  study of structural relationship between words
- **Semantics**
  study of meaning, of words (lexical semantics) and of word combinations (compositional semantics)
- **Pragmatics**
  study of how language is used to accomplish things (said: „I'm cold" → meant: „shut the window")
- **Discourse**
  study of linguistic units larger than single utterances



# Classical SLDS



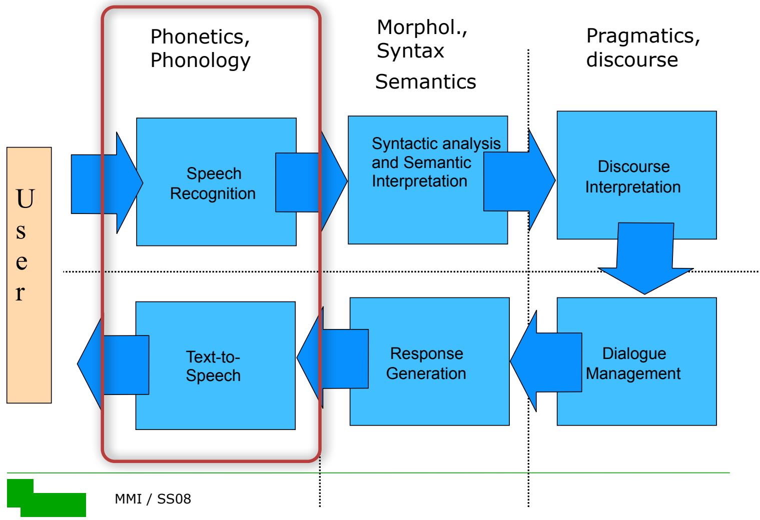



# Spoken Dialogue System - overview

- **Speech Recognition**
  - Decode the sequence of feature vectors into a sequence of *words*.
- **Syntactic Analysis and Semantic Interpretation**
  - Determine the utterance *structure* and the *meaning* of the words.
- **Discourse Interpretation**
  - Understand what the *utterance means* and what the user *intends* by interpreting in *context*.
- **Dialogue Management**
  - Determine *goals* and *plans* to be carried out to respond properly to the user intentions.
- **Response Generation**
  - Turn communicative act(s) into a *natural utterance*
- **Text-to-speech**
  - Turn the words into *synthetic speech*

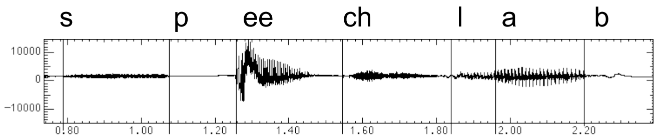


# Spoken Dialogue System



## Starting and end point: acoustic waves

- Human speech generates a wave
- A wave for the words "speech lab":






## Basics

- **Phonetics**: study of speech sounds
  - *Phone* (*segment*) = speech sound (e.g. „[t]")
  - Phones = *vowels*, *consonants*
  - *Diphone*, *triphone*, … = combination of phones
  - *Syllables* = made up of vowels and consonants, not always clearly definable („syllabification problem")
  - *Prominence* = *Accented* syllables that stand out
    - Louder, longer, pitch movement, or combination
  - *Lexical stress* = accented syllable if word is accented
    - „CONtent" (noun) vs „conTENT" (adjective)
  - *Allophone:* different pronounciations of one phone
    - [t] in „tunafish" → aspirated, voicelessness thereafter
    - [t] in „starfish" → unaspirated

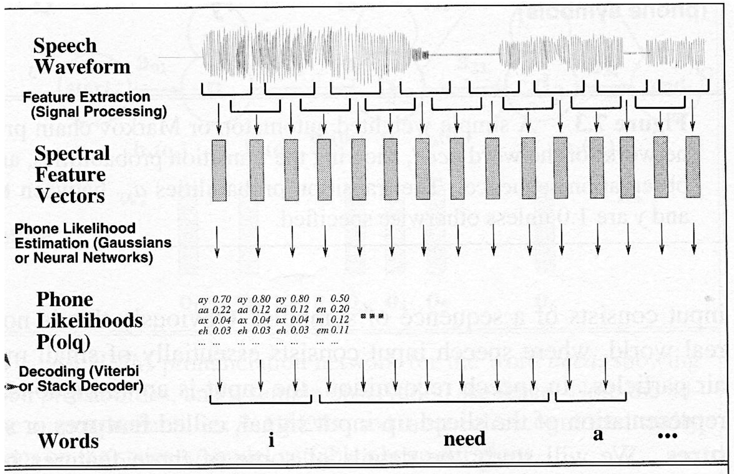


## Basics cont.

- **Phonology**: describes the systematic ways that sounds are differently realized
  - *Phoneme* = smallest meaning-distinguishing, but *not meaningful* articulatory unit
    - Phones [b] (`bill´) and [ph] (`pill´) discriminate two meanings → different phonemes /b/ und /p/
    - Subsume different elemental sounds under one phoneme, e.g. [p] in `spill´ and [ph] in `pill´ → /p/
  - *Phonological rules* = relation between phoneme and its allophones
  - Every language has ist own set of phonemes and rules



# Speech recognition



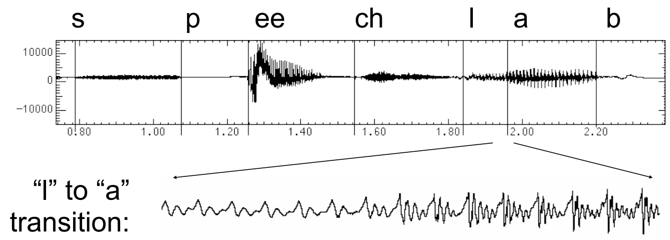

2 Schematic architecture for a (simplified) speech recognizer.

(Jurafsky & Martin, 2000)



# Acoustic Waves

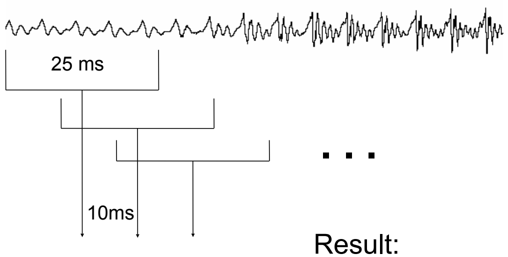
- A wave for the words "speech lab" looks like:






# Acoustic Sampling

- 10 ms frame (= 1/100 second)
- ~25 ms window around frame to smooth signal processing




$\mathbf{a}_1$ $\mathbf{a}_2$ $\mathbf{a}_3$

Result:
*Acoustic Feature Vectors*



# The Speech Recognition Problem

- **Recognition problem**
  - Find most likely sequence **w** of "words" given the sequence of acoustic observation vectors **a**
- Use *Bayes' law* to create a generative model
  - $P(a,b) = P(a|b)\,P(b) = P(b|a)\,P(a)$
  - Joint probability of *a* and *b* = a priori probability of *b* times the probability of *a* given *b*
- Apply to recognition problem:
  - *acoustic model*: $P(\mathbf{a}|\mathbf{w})$ (→ HMMs for subword units)
  - *language model*: $P(\mathbf{w})$ (→ Grammars, etc.)
  - $\mathrm{ArgMax}_{\mathbf{w}}\ P(\mathbf{w}|\mathbf{a}) = \mathrm{ArgMax}_{\mathbf{w}}\ P(\mathbf{a}|\mathbf{w})\,P(\mathbf{w})\,/\,P(\mathbf{a})$
    $\sim \mathrm{ArgMax}_{\mathbf{w}}\ P(\mathbf{a}|\mathbf{w})\,P(\mathbf{w})$

## Crucial properties of ASRs

- Speaker:
  - independent vs. dependent
  - adapt to speaker vs. non-adaptive
- Speech:
  - recognition vs. verification
  - continuous vs. discrete (single words)
  - spontaneous vs. read speech
  - large vocabulary (2K-200K) vs. limited (2-200)
- Acoustics
  - noisy environment vs. quiet environment
  - high-res microphone vs. phone vs. cellular
- Performance
  - real time, low vs. high Latency
  - anytime results vs. final results



# Text-to-speech



## Text-to-speech

- Problem: mapping text to phones

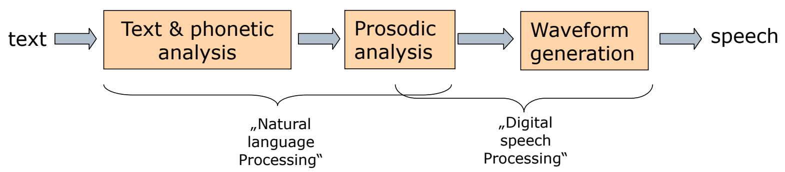
- Simplest (and common) solution
  - record prompts spoken by a (trained) human
  - Produces human quality voice
  - Limited by number of prompts that can be recorded
  - Can be extended by limited cut-and-paste or template filling



## Text-to-speech

Central steps:

1. Analyse text and select sound **segments**
2. Determine prosody and how to model it with single **segments**
3. Turn into acoustic waveform (*speech synthesis*)



# Which segments?

*Co-articulation* = change in segments due to movement of articulators in neighboring segments

- Use phonemes?
  - problematic due to co-articulatory effects
- Use allophones?
  - Variants of a phoneme in specific contexts
  - Example: Phoneme /p/ → [p] in spill and [ph] in pill
- Use diphones („Zweilautverbindungen")?
  - Diphones start half-way thru 1st phone and end half-way thru 2nd
  - ⇒ critical phone transition is contained in the segment itself, need not be calculated by synthesizer
  - Example: diphones for German word „Phonetik":
    f-o, o-n, n-e, e-t, t-i, i-k



# Phonetic analysis
from words to segments

| Word | Pronunciation |
|---|---|
| goose | [gus] |
| geese | [gis] |
| hedgehog | [ˈhɛdʒ.hɔg] |
| hedgehogs | [ˈhɛdʒ.hɔgz] |

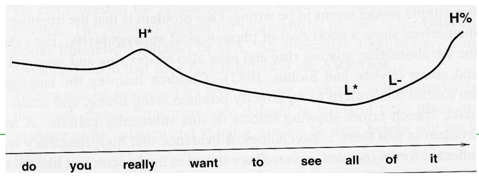
- Look up pronunciation dictionary
- Words/wordforms
  - e.g. CMUdict: ~125.000 wordforms
  - primary stress, secondary stress
  http://www.speech.cs.cmu.edu/cgi-bin/cmudict
- always a lot of unknown words left
- map letters to sounds with rules
  - MITalk (1987): 10.000 rules repository: p – [p]; ph – [f]; phe – [fi]; phes – [fiz]; … … …
  - Festival: rules account for co-articulation: [ c h ] + any consonant = `k´, else `ch´ (`christmas´ vs. `choice´)
  - Usually machine learned from large data sets



# Prosodic analysis
from words+segments to boundaries, accent, F0, duration

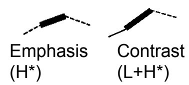
TTS systems need to create proper prosody by adapting:

- Prosodic phrasing/boundaries:
  - Break utterances into units
  - Punctuation and syntactic structure useful, but not sufficient
- Duration of segments:
  - Predict duration of each segment
  - Helps to create prominence
- Intonation/accents on/over segments:
  - Predict accents: which syllables should be accented?
  - Realize as F0 contour („pitch") with special form for accents




# Pitch *accents*

- In the first place, properties of *words*
- Decisive for how words are interpreted, used to…
  - emphasize new information ("Then I saw a **church**.")
  - contrast parts („I like **blue** tiles better than **green** tiles.")
  - explicitly focus parts („I said I saw a **church**.")
- Different pitch accents serve different functions in discourse




- What to choose depends on content and context
  - Given (topic, theme) or new information (rheme)?
  - Information mutually agreed or not?
  - → „concept-to-speech, content-to-speech"

# Waveform synthesis

from segments, f0, duration to waveform

- Signal modeling
  - **Rule-based**
    - Formant synthesis
  - **Data-based**
    - Diphone concat.
    - Unit selection
- Physiological modeling, Articulatory synthesis

Start with acoustics, rules to create formants

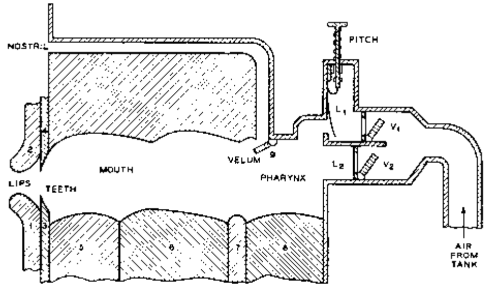
Use databases of stored speech to assemble new utterances

Model movements of articulators and acoustics of the human vocal tract



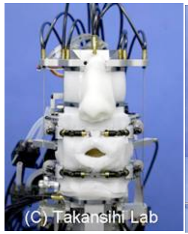
# Articulatory synthesis

- based on physical or nowadays computational models of the human vocal tract and the articulation processes occurring there
- few of them currently sufficiently advanced or computationally efficient

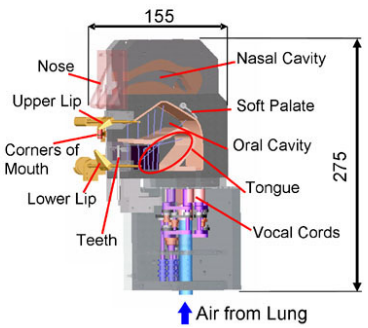


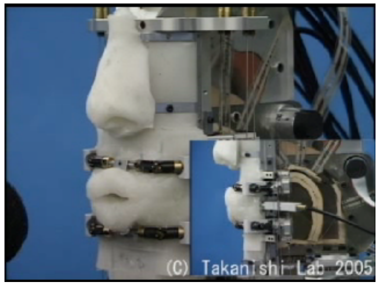

# Articulatory synthesis

Talking robots WT-4, WT-5
Waseda University, Tokyo







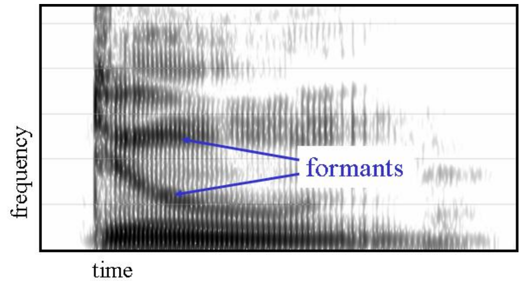




„sasisuseso"



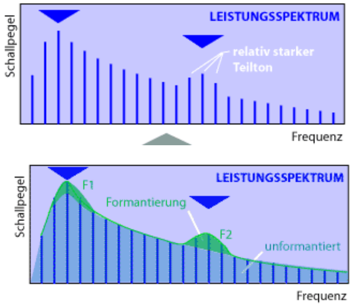
# Formant synthesis

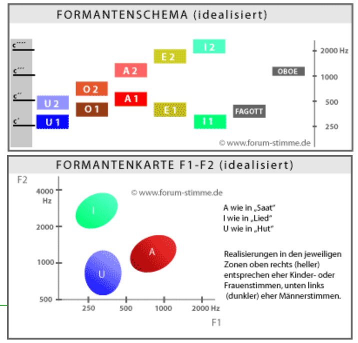
- **Formant**: Frequenzregion, in der die dort hineinfallenden Teiltöne besonders stark sind
- Wesentliche Elemente der Klangbildung, je nach Lage und Stärke verschiedene Vokale und Timbre



## Formant Synthesis

- Annahme: Die für die menschliche Perzeption wesentliche Information ist durch die Töne in den Formanten kodiert
- Dabei prägen vor allem die beiden am tiefsten gelegenen Formanten (F1, F2) die Lautwahrnehmung, mitunter reicht zur Wahrnehmung bestimmter Vokale auch nur ein Hauptformant



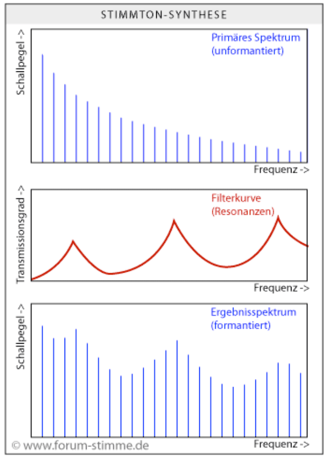




www.forum-stimme.de



## Formant Synthesis

- Rules model relations between tones and acoustic features
- Advantages
  - flexibilty
  - not much storage space needed
- Disadvantages
  - Sounds mechanical
  - Complicated rule sets
- Common while computers were relatively underpowered
  - 1979 MIT MITalk (Allen, Hunnicut, Klatt),
  - 1983 DECtalk system, 'Klatt synthesizer'






## Data-based synthesis

- Nowadays all current commercial systems (1990's-)
- Steps:
  1. Record basic inventory of sounds (offline)
  2. Retrieve sequence of units at run time (at run-time)
  3. Concatenate and adjust prosody (at run-time)
- What kind of units?
  - Minimize context contamination, capture *co-articulation*
  - Enable efficient search
  - Segmentation and concatenation problems
- How to join the units?
  - dumb (just stick them together)
  - PSOLA (Pitch-Synchronous Overlap and Add), MBROLA (Multi-band overlap and add)



| Einheiten-länge | Einheit | #Einheiten (Englisch) | #Regeln | Qualität |
|---|---|---|---|---|
| kurz | Allophone | 60-80 | hoch | gering |
| ↓ | Diphone | $<40^2-65^2$ | ↓ | ↓ |
| | Triphone | $<40^3-65^3$ | | |
| | Halbsilben | 2K | | |
| | Silben | 11K | | |
| | Doppelsilben | <11K2 | | |
| | Wort | 100K-1.5M | | |
| | Phrasen | ∞ | | |
| lang | Satz | ∞ | gering | hoch |

Source: E. Andre

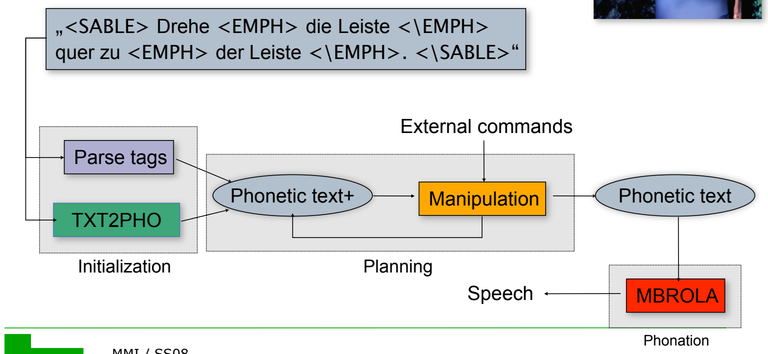
# Diphone synthesis

- Units = diphones
  - Phones are more stable in middle than at the edges
- Typically 1500-2000 diphones, need to reduce number
  - *phonotactic constraints*: constraints on the way in which phonemes can be arranged to form syllables
  - collapse in cases of no co-articulation
- Record 1 speaker saying each diphone
  - "Normalized": monotonous, no emotions, constant volume
- Example: MBROLA (Dutoit & Leich, 1993)
  http://tcts.fpms.ac.be/synthesis/mbrola.html



# Example: TTS in *Max*

- TXT2PHO (IKP) → lexical stress, neutral prosody
- MBROLA + German diphon database
- SABLE tags for additional intonation commands

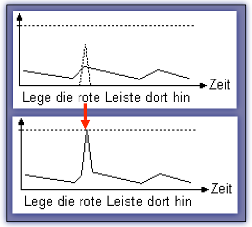


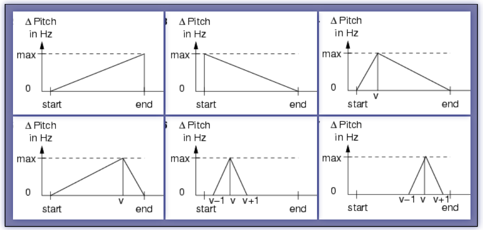



# Example: TTS for *Max*

Manipulation of phonetic text

- Overlay stereotyped contours to create accents + durations
- No suprasegmental analysis
- Flexible form, height, duration



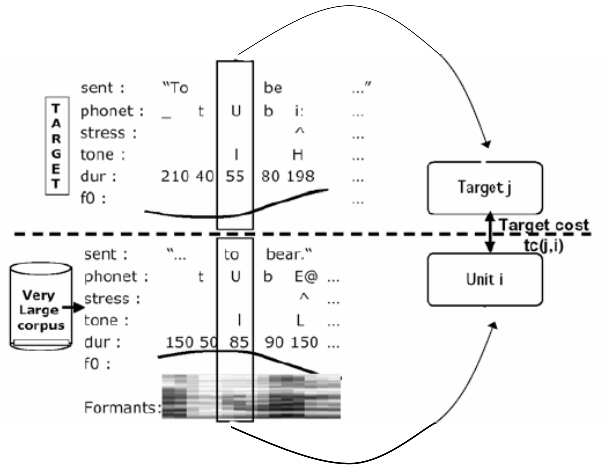

Beispiel: Kontrastierung
Wer arbeitet in Bielefeld?
Wo arbeitest du?
Was tust du in Bielefeld?



# Unit selection

- One example of a diphone is not enough!
- Unit selection:
  - Record multiple copies of each unit with different pitches and durations
  - How to pick the right units? Search!
  - Example (Hunt & Black, 1996):
    - Input: three F0 values per phone
    - Database: phones+duration+3 pitch values
    - Cost-based selection algorithm
- Non-uniform unit selection
  - Units of *variable* length
  - Reduced need of automatic prosody modeling

# Unit selection






# Academic TTS systems - demos

| | | |
|---|---|---|
| BOSS (IKP, Bonn) | non-uniform unit-selection | Mp3 (2001) |
| IMS Stuttgart | Diphone concat., Festival+MBROLA | Mp3 (2000) |
| Uni Duisburg | Formant synthesis | Mp3 (1996) |
| Mary (DFKI) | Diphone synthesis, MBROLA | Mp3 (2000) |
| VieCtoS (ÖFAI, Wien) | Halbsilben, schlechte Tobi-Labelung | Mp3 (1998) |
| SVox (ETH Zürich) | Diphone concat., | Mp3 (1998) |
| HADIFIX (IKP, Bonn) | HSlbsilben, DIphone und sufFIXe | Mp3 (1995) |



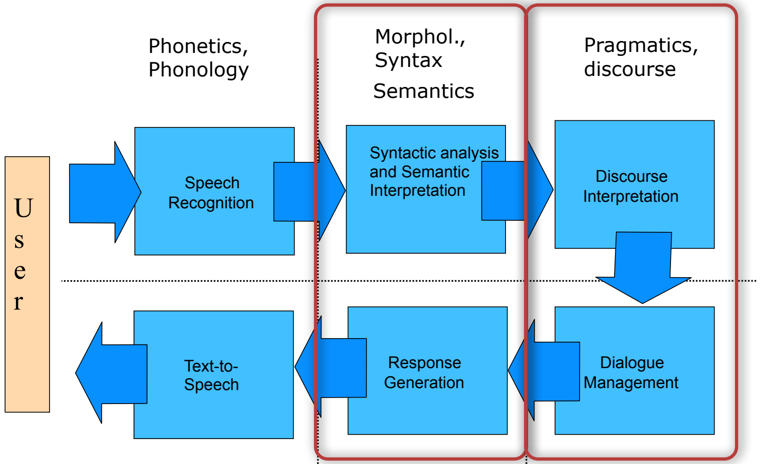
# Commercial TTS systems - demos

| | | |
|---|---|---|
| BabelTech Babil | Diphone concat., MBROLA-like | Mp3 (2000) |
| AT&T | non-uniform unit-selection | Mp3 (1998) |
| BabelTech BrightSpeech | non-uniform unit-selection | Mp3 (2003) |
| IBM ctts | non-uniform unit-selection | Mp3 (2002) |
| Loquendo | non-uniform unit-selection | Mp3 (2003) |
| Nuance RealSpeak | non-uniform unit-selection | Mp3 (2006) |
| SVox Corporate | Diphone concat. | Mp3 (2005) |



- Comparison of state-of-the-art TTS systems
  http://ttssamples.syntheticspeech.de/deutsch/index.html
- Janet Cahn's Master Thesis, PhD Thesis
  http://xenia.media.mit.edu/~cahn/
- Demos and links for speech synthesizers
  http://felix.syntheticspeech.de/
- Lecture on speech synthesis by Bernd Möbius http://www.ims.uni-stuttgart.de/~moebius/teaching.shtml

# Next week



Phonetics, Phonology
Morphol., Syntax
Semantics
Pragmatics, discourse
User
Speech Recognition
Syntactic analysis and Semantic Interpretation
Discourse Interpretation
Text-to-Speech
Response Generation
Dialogue Management