Language and Computers (Ling 384)

Topic 1: Text and Speech Encoding

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Winter 2005

* The course was created together with Markus Dickinson and Chris Brew.

Language and Computers – where to start?

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- If we want to do anything with language, we need a way to represent language.
- We can interact with the computer in several ways:
  - write or read text
  - speak or listen to speech
- Computer has to have some way to represent
  - text
  - speech

Outline

Writing systems

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Encoding written language

Outline

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Spoken language

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Spoken language

Relating written and spoken language

Writing systems used for human languages

What is writing?

> *"a system of more or less permanent marks used to represent an utterance in such a way that it can be recovered more or less exactly without the intervention of the utterer."*
> *(Peter T. Daniels, The World's Writing Systems)*

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Different types of writing systems are used:

- Alphabetic
- Syllabic
- Logographic

Much of the information on writing systems and the graphics used are taken from the amazing site http://www.omniglot.com.

Alphabetic systems

Alphabets (phonemic alphabets)

- represent all sounds, i.e., consonants and vowels
- Examples: Etruscan, Latin, Korean, Cyrillic, Runic, International Phonetic Alphabet

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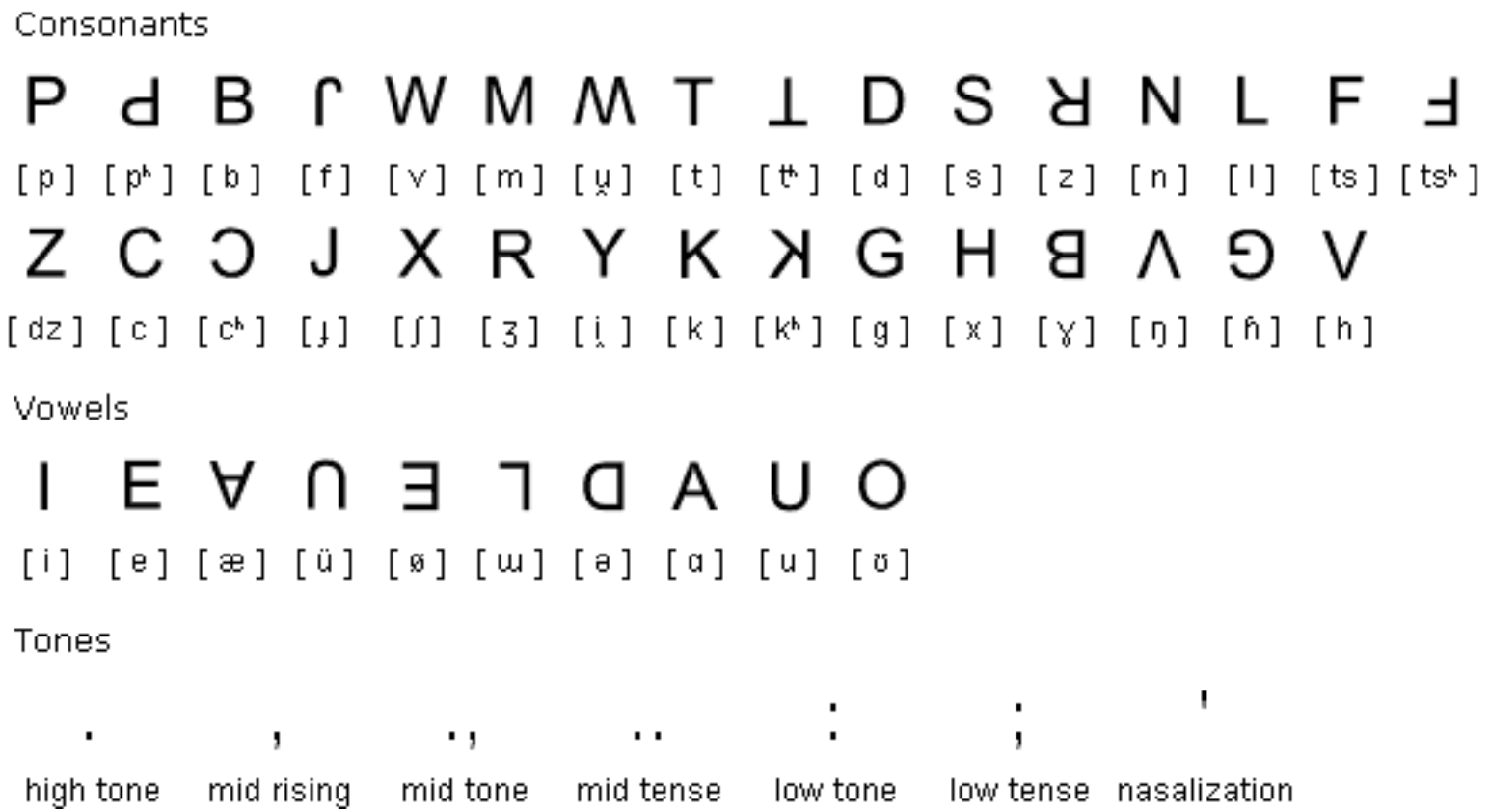
Abjads (consonant alphabets)

- represent consonants only (sometimes plus selected vowels; vowel diacritics generally available)
- Examples: Arabic, Aramaic, Hebrew

Alphabet example: Fraser

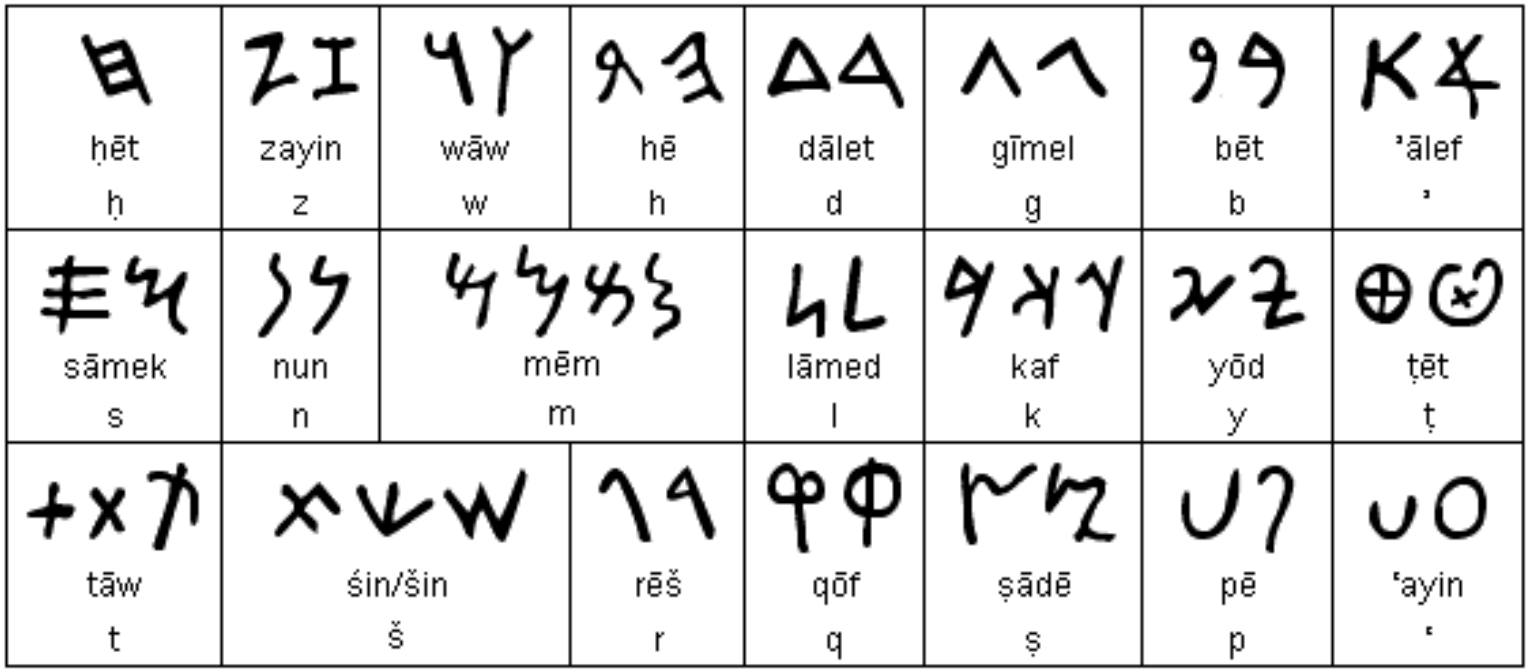
An alphabet used to write Lisu, a Tibeto-Burman language spoken by about 657,000 people in Myanmar, India, Thailand and in the Chinese provinces of Yunnan and Sichuan.



(from: http://www.omniglot.com/writing/fraser.htm)

Abjad example: Phoenician

An alphabet used to write Phoenician, created between the 18th and 17th centuries BC; assumed to be the forerunner of the Greek and Hebrew alphabet.



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  - silent letters: *knee*, *knight*, *knife*, *debt*, *psychology*, *mortgage*
  - one letter – multiple sounds: *exit*, *use*
  - multiple letters – one sound: *the*, *revolution*
  - alternate spellings: *jail* or *gaol*; but not possible *seagh* for *chef* (despite *sure*, *dead*, *laugh*)

More examples for non-transparent letter-sound correspondences

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(1) a. *Versailles* → [versai]

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What is the notation used within the []?

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- Interactive example chart: http://web.uvic.ca/ling/resources/ipa/charts/IPAlab/IPAlab.htm

Syllabic systems

Syllabic alphabets (Alphasyllabaries)

- writing systems with symbols that represent a consonant with a vowel, but the vowel can be changed by adding a **diacritic** (= a symbol added to the letter).
- Examples: Balinese, Javanese, Tibetan, Tamil, Thai, Tagalog

(cf. also: http://www.omniglot.com/writing/syllabic.htm)

Syllabaries

- writing systems with separate symbols for each syllable of a language
- Examples: Cherokee. Ethiopic, Cypriot, Ojibwe, Hiragana (Japanese)

(cf. also: http://www.omniglot.com/writing/syllabaries.htm#syll)

Syllabary example: Cypriote

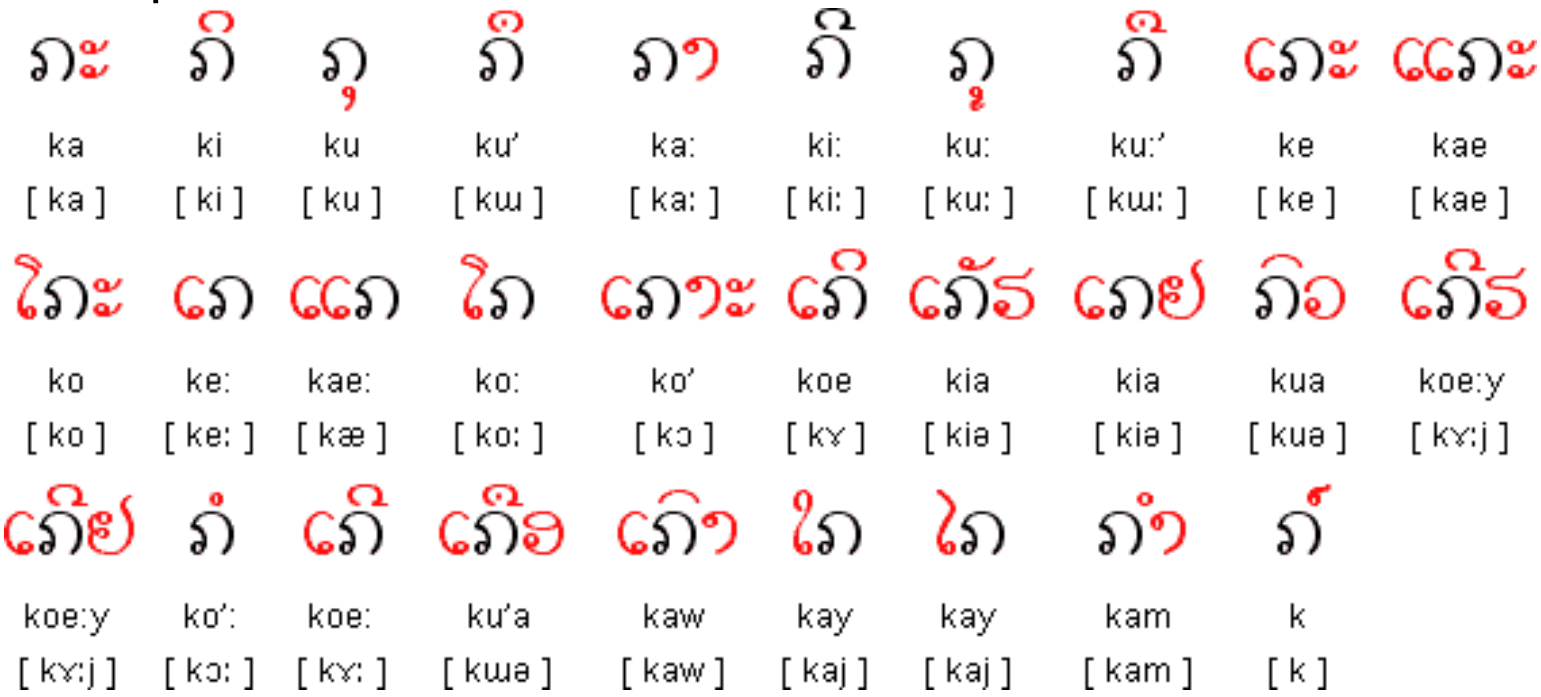
The Cypriot syllabary or Cypro-Minoan writing is thought to have developed from the Linear A, or possibly the Linear B script of Crete, though its exact origins are not known. It was used from about 800 to 200 BC.

(from: http://www.omniglot.com/writing/cypriot.htm)

Syllabic alphabet example: Lao

Script developed in the 14th century to write the Lao language, based on an early version of the Thai script, which was developed from the Old Khmer script, which was itself based on Mon scripts.

Example for vowel diacritics around the letter k:



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  - **Pictographs (Pictograms)**: originally pictures of things, now stylized and simplified.

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- Examples: Chinese (Zhōngwén), Japanese (Nihongo), Mayan, Vietnamese, Ancient Egyptian

Logograph writing system example: Chinese

Pictographs

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Pictographs

Ideographs

Logograph writing system example: Chinese

Pictographs

Ideographs

Compounds of Pictographs/Ideographs

(from: http://www.omniglot.com/writing/chinese_types.htm)

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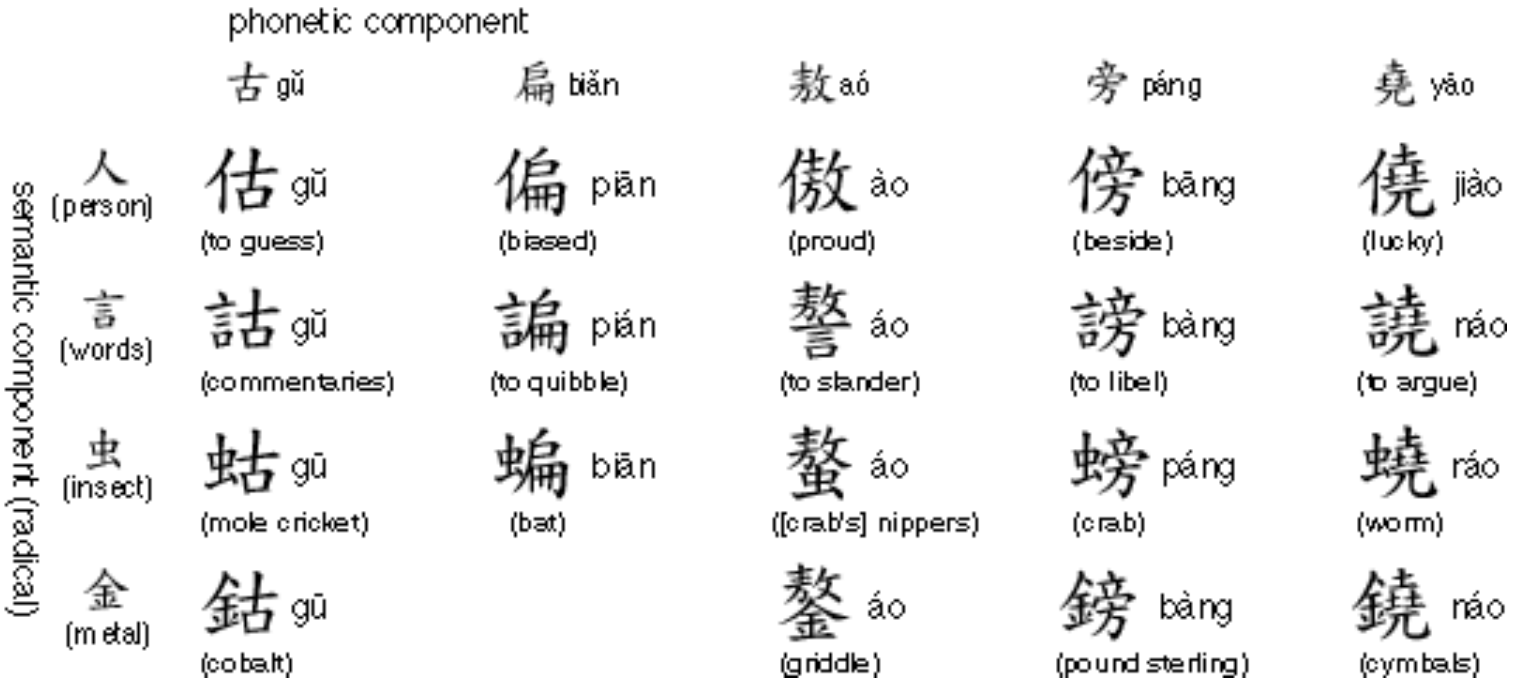
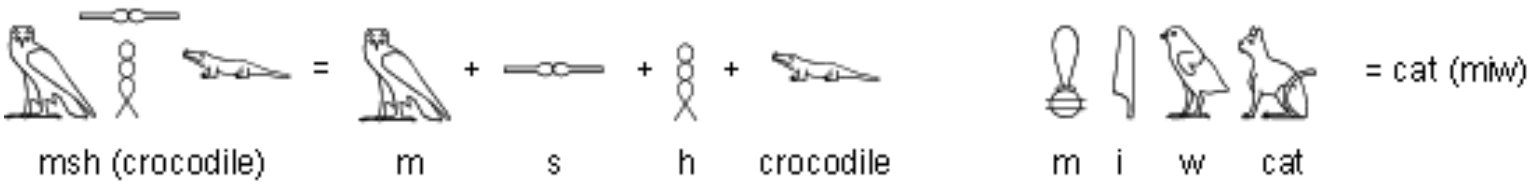


An example from Ancient Egyptian



(from: http://www.omniglot.com/writing/egyptian.htm)

Two writing systems with unusual realization

Tactile

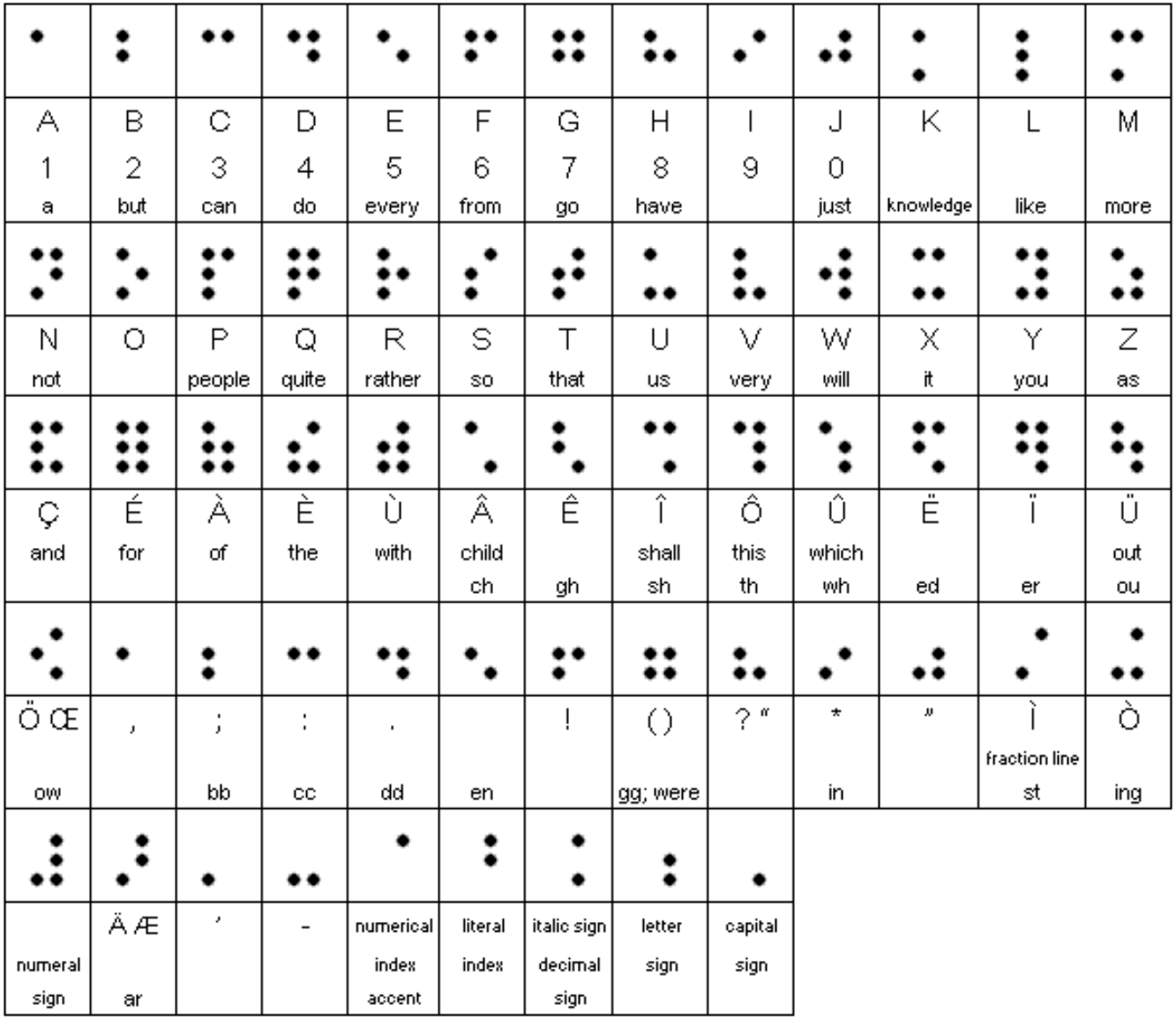
- Braille is a writing system that makes it possible to read and write through touch; primarily used by the (partially) blind.
- It uses patterns of raised dots arranged in cells of up to six dots in a 3 x 2 configuration.
- Each pattern represents a character, but some frequent words and letter combinations have their own pattern.

Chromatographic

The Benin and Edo people in southern Nigeria have developed a system of writing based on different color combinations and symbols.

(cf. http://www.library.cornell.edu/africana/Writing_Systems/Chroma.html)

Braille alphabet



Chromatographic system

Relating writing systems to languages

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- We'll look at three other examples:
  - Japanese
  - Korean
  - Azeri

Japanese

Japanese: logographic system *kanji*, syllabary *katakana*, syllabary *hiragana*

- kanji: 5,000-10,000 borrowed Chinese characters

Japanese

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- Romaji: Roman characters

Japanese example

カプセルホテル
各室がカプセル形の簡易ホテル。終電に乗り遅れたサラリーマンなどが高いタクシー代を払って帰宅するより安く済むことから、手軽に利用している。

kanji (red), hiragana (black), katakana (blue)

Translation:

> *Capsule Hotel*
> *A simple hotel where each room is capsule-shaped. When businessmen miss the last train home, they can stay overnight very cheaply instead of paying a lot of money to go home by taxi.*

(from: http://www.omniglot.com/writing/japanese.htm#origin)

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- The *hangul* system was developed in 1444 during King Sejong's reign.
  - There are 24 letters: 14 consonants and 10 vowels
  - But the letters are grouped into syllables, i.e. the letters in a syllable are not written separately as in the English system, but together form a single character.

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- In South Korea, *hanja* (logographic Chinese characters) are also used.

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- 1991: Back to Latin alphabet, but slightly different than before.
  → Latin typewriters and computer fonts were in great demand in 1991

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- language-particular differences: English has thousands of possible syllables; Japanese has very few in comparison
- connection to history/culture: Will changing a writing system have social consequences?

Encoding written language

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- Information on a computer is stored in **bits**.
- A bit is either on (= 1, yes) or off (= 0, no).
- A list of 8 bits makes up a **byte**, e.g., 01001010
- Just like with the base 10 numbers we're used to, the order of the bits in a byte matters:
  - **Big Endian**: most important bit is leftmost (the standard way of doing things)
    - The positions in a byte thus encode: 128 64 32 16 8 4 2 1
    - "There are 10 kinds of people in the world; those who know binary and those who don't"

      (from: http://www.wlug.org.nz/LittleEndian)
  - **Little Endian**: most important bit is rightmost (only used on Intel machines)
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Using bytes to store characters

With 8 bits (a single byte), you can represent 256 different characters. Why would we want so many?

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With 8 bits (a single byte), you can represent 256 different characters. Why would we want so many?

- If you look at a keyboard, you will find lots of non-English characters.
- With 256 possible characters, we can store every single letter used in English, plus all the things like commas, periods, space bar, percent sign (%), back space, and so on.

An encoding standard: ASCII

- **ASCII** = the American Standard Code for Information Interchange
- 7-bit code for storing English text
- 7 bits = 128 possible characters.
- The numeric order reflects alphabetic ordering.

The ASCII chart

Codes 1–31 are used for control characters (backspace, line feed, tab, . . .).

32		48	0	65	A	82	R	97	a	114	r
33	!	49	1	66	B	83	S	98	b	115	s
34	“	50	2	67	C	84	T	99	c	116	t
35	#	51	3	68	D	85	U	100	d	117	u
36	$	52	4	69	E	86	V	101	e	118	v
37	%	53	5	70	F	87	W	102	f	119	w
38	&	54	6	71	G	88	X	103	g	120	x
39	’	55	7	72	H	89	Y	104	h	121	y
40	(	56	8	73	I	90	Z	105	i	122	z
41	)	57	9	74	J	91	[	106	j	123	{
42	*	58	:	75	K	92	\	107	k	124	—
43	+	59	;	76	L	93	]	108	l	125	}
44	,	60	<	77	M	94	ˆ	109	m	126	˜
45	-	61	=	78	N	95	_	110	n	127	DEL
46	.	62	>	79	O	96	‘	111	o		
47	/	63	?	80	P			112	p		
		64	@	81	Q			113	q		

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36	$	52	4	69	E	86	V	101	e	118	v
37	%	53	5	70	F	87	W	102	f	119	w
38	&	54	6	71	G	88	X	103	g	120	x
39	’	55	7	72	H	89	Y	104	h	121	y
40	(	56	8	73	I	90	Z	105	i	122	z
41	)	57	9	74	J	91	[	106	j	123	{
42	*	58	:	75	K	92	\	107	k	124	—
43	+	59	;	76	L	93	]	108	l	125	}
44	,	60	<	77	M	94	ˆ	109	m	126	˜
45	-	61	=	78	N	95	_	110	n	127	DEL
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E-mail issues

- Have you ever had something like the following at the top of an e-mail sent to you?

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[The following text is in the ‘‘ISO-8859-1’’ character set.]
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- Mail sent on the internet used to only be able to transfer the 7-bit ASCII messages. But now we can detect the incoming character set and adjust the input.
- Note that this is an example of **meta-information** = information which is printed as part of the regular message, but tells us something about that message.

Multipurpose Internet Mail Extensions (MIME)

MIME provides meta-information on the text, which tells us:

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MIME provides meta-information on the text, which tells us:

- which version of MIME is being used
- what the charcter set is
- if that character set was altered, how it was altered

```
Mime-Version:  1.0 Content-Type:  text/plain; charset=US-ASCII
Content-Transfer-Encoding:  7bit
```

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- Extend the ASCII system with various other systems, for example:
  - ISO 8859-1: includes extra letters needed for French, German, Spanish, etc.
  - ISO 8859-7: Greek alphabet
  - ISO 8859-8: Hebrew alphabet
  - JIS X 0208: Japanese characters

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- Extend the ASCII system with various other systems, for example:
  - ISO 8859-1: includes extra letters needed for French, German, Spanish, etc.
  - ISO 8859-7: Greek alphabet
  - ISO 8859-8: Hebrew alphabet
  - JIS X 0208: Japanese characters
- Have one system for everything → **Unicode**

Unicode

Problems with having multiple encoding systems:

- Conflicts: two encodings can use the same number for two different characters and use different numbers for the same character.
- Hassle: have to install many, many systems if you want to be able to deal with various languages

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Unicode tries to fix that by having a single representation for every possible character.

> *"Unicode provides a unique number for every character, no matter what the platform, no matter what the program, no matter what the language." (www.unicode.org)*

How big is Unicode?

Version 3.2 has codes for 95,221 characters from alphabets, syllabaries and logographic systems.

- Uses 32 bits – meaning we can store $2^{32} = 4,294,967,296$ characters.
- 4 billion possibilities for each character? That takes a lot of space on the computer!

Compact encoding of Unicode characters

- Unicode has three versions
  - UTF-32 (32 bits): direct representation
  - UTF-16 (16 bits): $2^{16} = 65536$
  - UTF-8 (8 bits): $2^8 = 256$
- How is it possible to encode 2^{32} possibilities in 8 bits (UTF-8)?
  - Several bytes are used to represent one character.
  - Use the highest bit as flag:
    - highest bit 0: single character
    - highest bit 1: part of a multi byte character
  - Nice consequence: ASCII text is in a valid UTF-8 encoding.

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  e.g. Highly noticeable how much slower your English typing is when using a Danish-designed keyboard.

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- Use combinations of characters.
  An *e* followed by an ’ might result in an *é*
- Pick and choose from a table of characters.

So, now we can encode every language, as long as it’s written.

Unwritten languages

Many languages have never been written down. Of the 6700 spoken, 3000 have never been written down.

- Salar, a Turkic language in China.
- Gugu Badhun, a language in Australia.
- Southeastern Pomo, a language in California

The need for speech

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Many applications for encoding speech:

- Building spoken dialogue systems, i.e. speak with a computer (and have it speak back).
- Helping people sound like native speakers of a foreign language.
- Helping speech pathologists diagnose problems

What does speech look like?

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  $\Rightarrow$ We need to know:

  - some properties of speech
  - how to measure these speech properties
  - how these measurements correspond to sounds we hear

What makes representing speech hard?

Difficulties:

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  e.g. *k* is said differently depending on if it is followed by *ee* or by *oo*.
- What we think of as two sounds are not always all that different.
  e.g. The *s see* is very acoustically similar to the *sh* in *shoe*

Articulatory properties: How it's produced

We could talk about how sounds are produced in the vocal tract, i.e. **articulatory phonetics**

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- *place of articulation* (where): [t] vs. [k]
- *manner of articulation* (how): [t] vs. [s]
- *voicing* (vocal cord vibration): [t] vs. [d]

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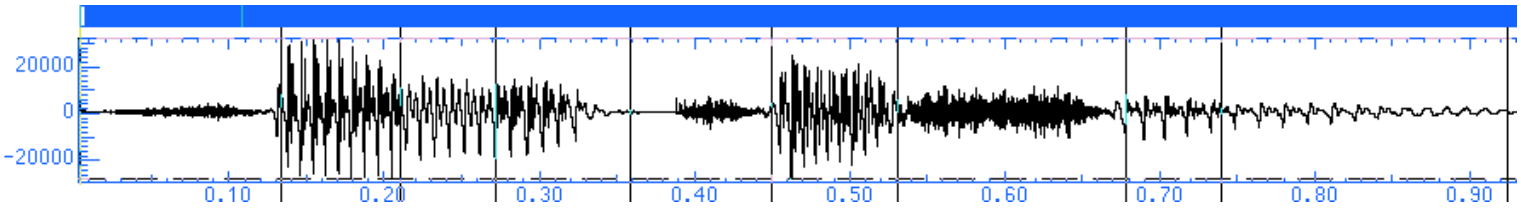
But unless the computer is modeling a vocal tract, we need to know acoustic properties of speech which we can *quantify*.

Acoustic properties: What it sounds like

Sound waves = “small variations in air pressure that occur very rapidly one after another” (Ladefoged, *A Course in Phonetics*)
⇒ Akin to ripples in a pond

- **speech flow** = rate of speaking, number and length of pauses (seconds)
- **loudness** (amplitude) = amount of energy (decibels)
- **frequencies** = how fast the sound waves are repeating (cycles per second, i.e. Hertz)
  - **pitch** = how high or low a sound is
  - In speech, there is a **fundamental frequency**, or pitch, along with higher-frequency **overtones**.
- **intonation** = rise and fall in pitch

Oszillogram (Waveform)



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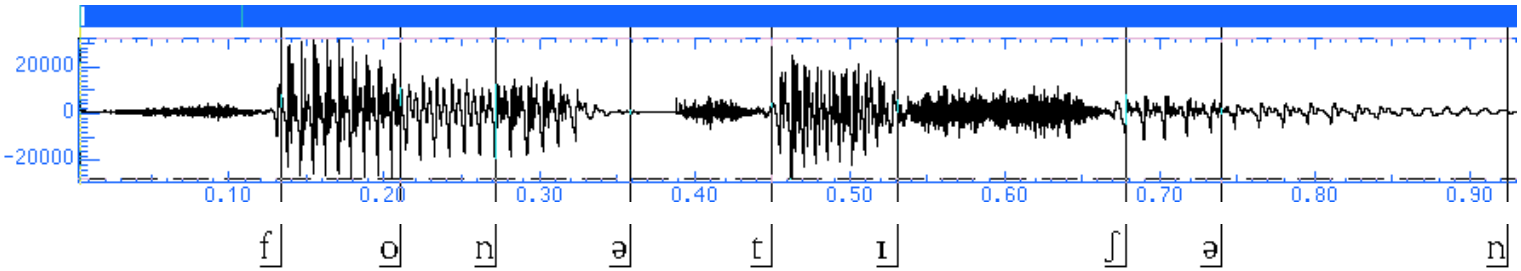
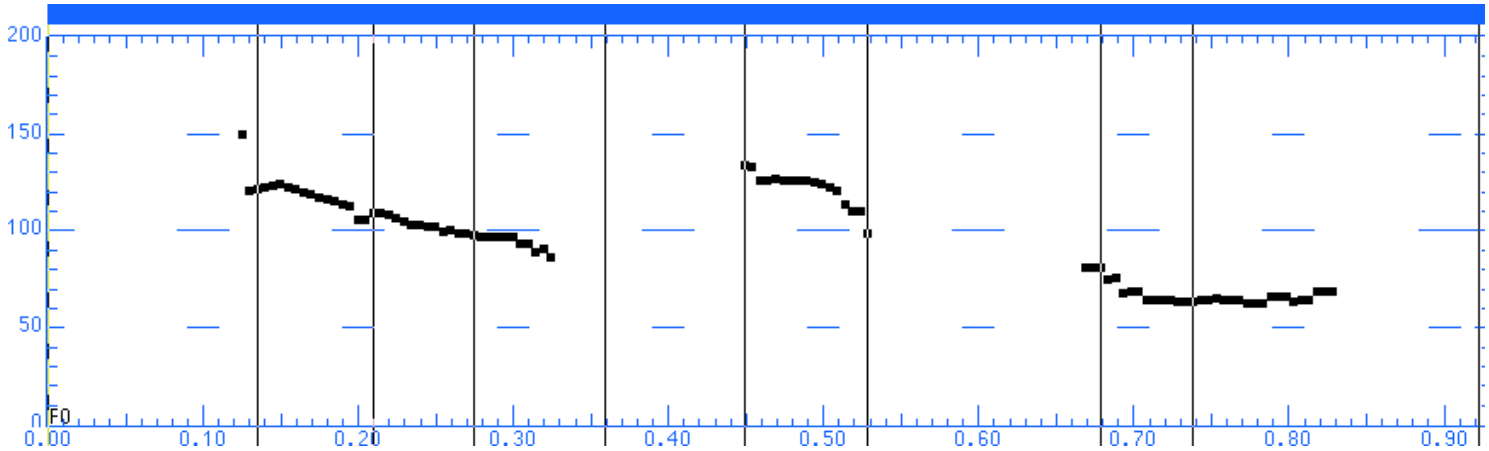


(Check out the *Speech Analysis Tutorial*, of the Deptartment of Linguistics at Lund University, Sweden at http://www.ling.lu.se/research/speechtutorial/tutorial.html, from which the illustrations on this and the following slides are taken.)

Fundamental frequency (F0, pitch)



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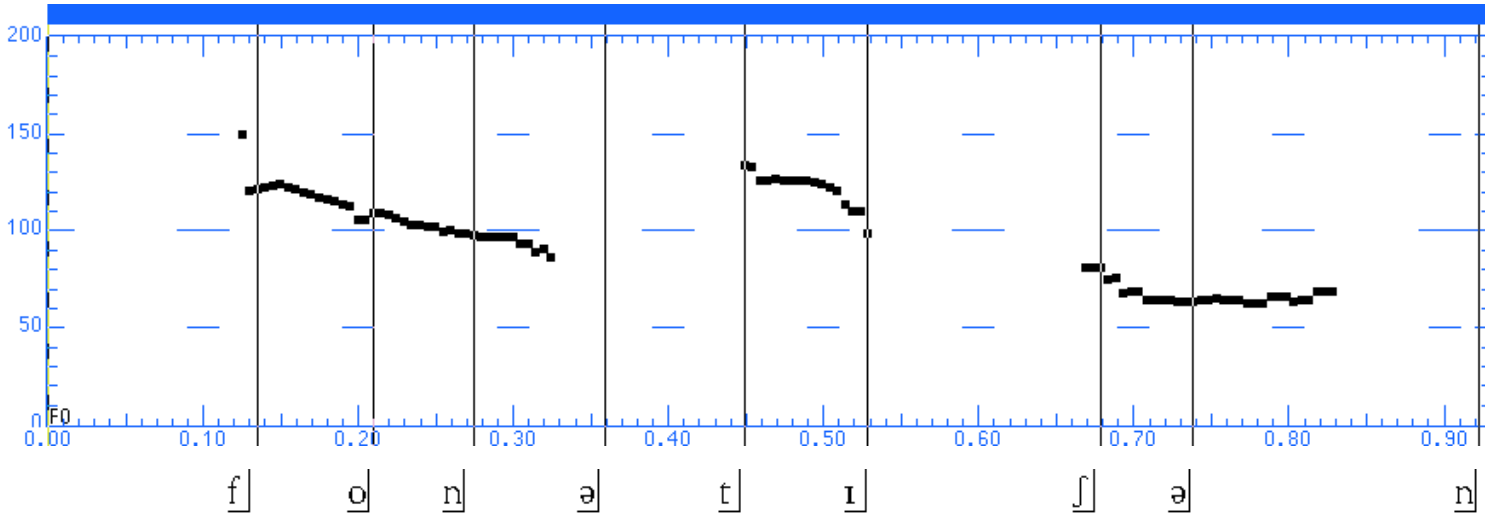
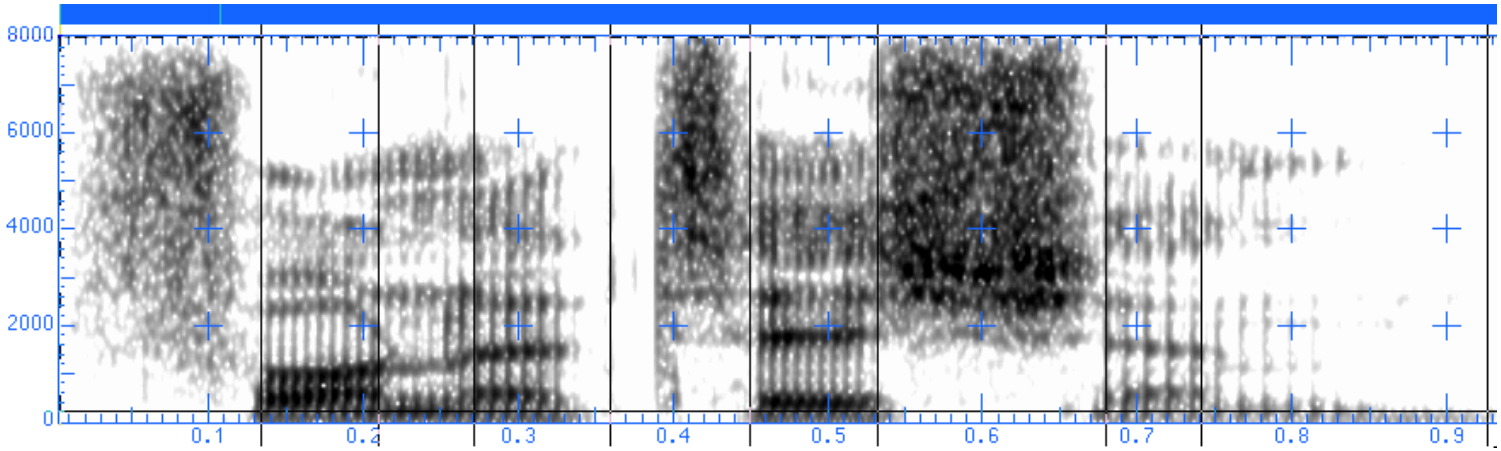


Spectrograms

Spectrogram = a graph to represent (the frequencies of) speech over time.



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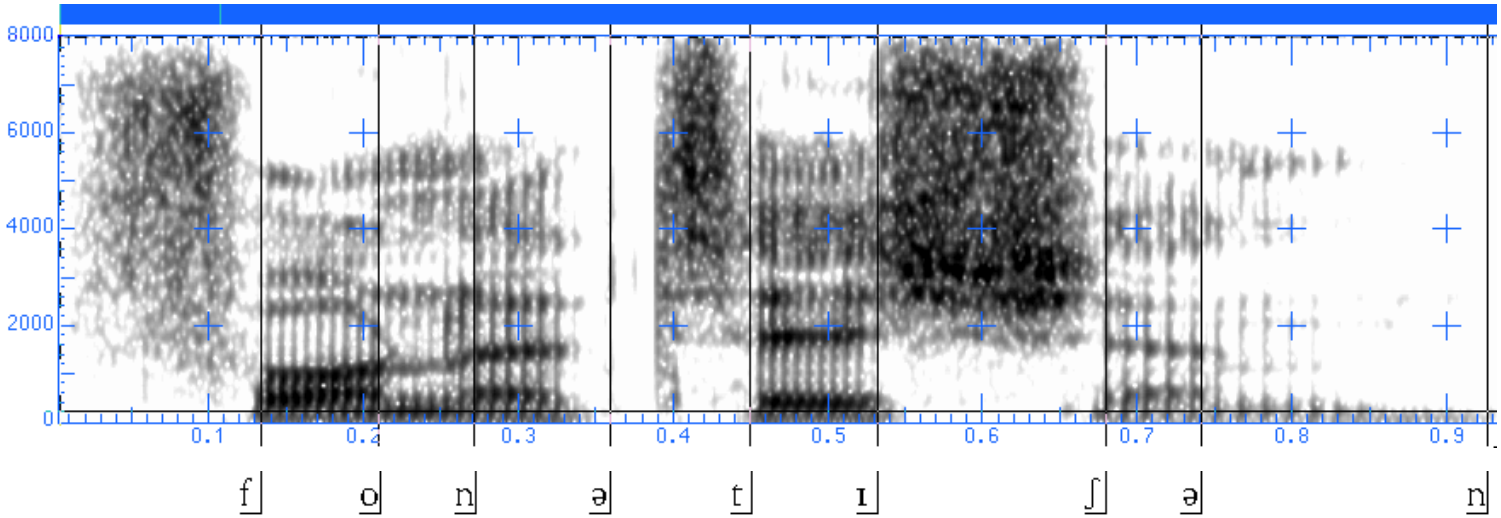

How measurements correspond to sounds we hear

- How dark is the picture? → How loud is the sound? We can measure this in decibels.

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- How dark is the picture? → How loud is the sound?
  We can measure this in decibels.
- Where are the lines the darkest? → Which frequencies are the loudest and most important?
  We can measure this in terms of Hertz, and it tells us what the vowels are.
- How do these dark lines change? → How are the frequencies changing over time?
  Which consonants are we transitioning into?

How did we get these measurements?

sampling rate = how many times in a given second we extract a moment of sound; measured in samples per second

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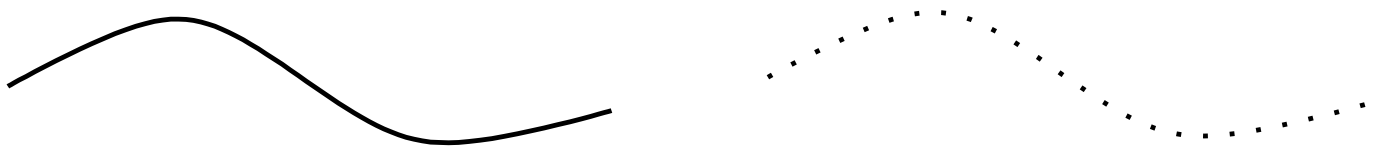
- Sound is **continuous**, but we have to store data in a **discrete** manner.



CONTINUOUS DISCRETE

- We store data at each discrete point, in order to capture the general pattern of the sound

Sampling rate

- The sampling rate is often 8000 or 16,000 samples per second. The rate for CDs is 44,100 samples/second (or **Hertz** (Hz))

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Sampling rate

- The sampling rate is often 8000 or 16,000 samples per second. The rate for CDs is 44,100 samples/second (or **Hertz** (Hz))
- The higher the sampling rate, the better quality the recording ... but the more space it takes.
- Speech needs at least 8000 samples/second, but most likely 16,000 or 22,050 Hz will be used nowadays.

Applications of speech encoding

Mapping sounds to symbols (alphabet), and vice versa, isn't all that easy.

- **Automatic Speech Recognition (ASR)**: sounds to text
- **Text-to-Speech Synthesis (TTS)**: texts to sounds

Automatic Speech Recognition (ASR)

Automatic speech recognition = process by which the computer maps a speech signal to text.

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Automatic speech recognition = process by which the computer maps a speech signal to text.
Uses/Applications:

- Dictation
- Telephone conversations
- People with disabilities – e.g. a person hard of hearing could use an ASR system to get the text

Kinds of ASR systems

Different kinds of systems:

- Speaker dependent = work for a single speaker
- Speaker independent = work for any speaker of a given variety of a language, e.g. American English
- Speaker adaptive = start as independent but begin to adapt to a single speaker to improve accuracy

Kinds of ASR systems

- Differing sizes of vocabularies, from tens of words to tens of thousands of words

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- **continuous speech** vs. **isolated-word** systems:
  - continuous speech systems = words connected together and not separated by pauses
  - isolated-word systems = single words recognized at a time, requiring pauses to be inserted between words
    → easier to find the endpoints of words

Steps in an ASR system

1. Digital sampling of speech

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May or may not use more sophisticated analysis of the utterance to help.

Text-to-Speech Synthesis (TTS)

Could just record a voice saying phrases or words and then play back those words in the appropriate order.
Or can break the text down into smaller units

1. Convert input text into phonetic alphabet
2. Synthesize phonetic characters into speech

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To synthesize characters into speech, people have tried:

- using formulas which adjust the values of the frequencies, the loudness, etc.
- using a model of the vocal tract and trying to produce sounds based on how a human would speak

It's hard to be natural

When trying to make synthesized speech sound *natural*, we encounter the same problems as what makes speech encoding in general hard:

- The same sound is said differently in different contexts.
- Different sounds are sometimes said nearly the same.
- Different sentences have different intonation patterns.
- Lengths of words vary depending on where in the sentence they are spoken.
  The car crashed into the tree.
  It's my car.
  Cars, trucks, and bikes are vehicles.

Speech to Text to Speech

If we convert speech to text and then back to speech, it should sound the same, right?

- But at the conversion stages, there is **information loss**. To avoid this loss would require a lot of memory and knowledge about what exact information to store.
- The process is thus **irreversible**.

Demos

Text-to-Speech

- AT&T mulitilingual TTS system: http://www.research.att.com/projects/tts/demo.html
- various systems and languages: http://www.ims.uni-stuttgart.de/~moehler/synthspeech/