Language and Computers

Prologue: Encoding Language

L245
(Based on Dickinson, Brew, & Meurers (2013))

Indiana University

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Language and Computers

Computers have a variety of applications involving language:

- textual searching
- grammar correction
- automatic translation
- question answering
- plagiarism detection
- ...

Language and Computers – where to start?

- 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

Encoding written language

Spoken language

Relating written and spoken language

Language modeling

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)*

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 great site http://www.omniglot.com.

Alphabetic systems

Alphabets (phonemic alphabets)

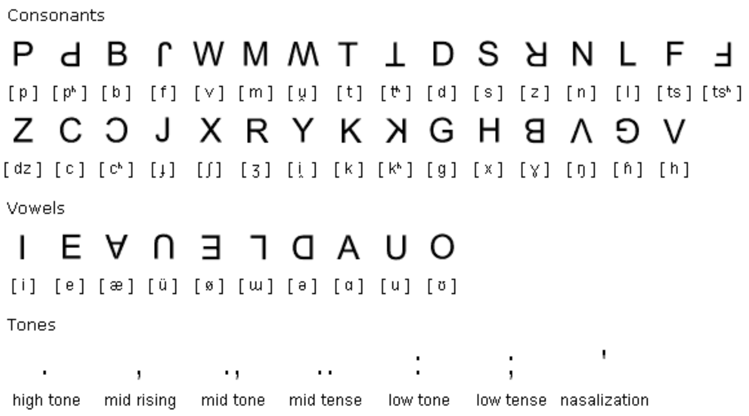
- represent all sounds, i.e., consonants and vowels
- Examples: Etruscan, Latin, Korean, Cyrillic, Runic, International Phonetic Alphabet

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 Burma, India, Thailand and in the Chinese provinces of Yunnan and Sichuan.



Consonants

ꓑ	ꓒ	ꓐ	ꓩ	ꓪ	ꓟ	𑾰	ꓔ	ꓕ	ꓓ	ꓢ	ꓤ	ꓠ	ꓡ	ꓝ	ꓞ
[p]	[pʰ]	[b]	[f]	[v]	[m]	[ɰ]	[t]	[tʰ]	[d]	[s]	[z]	[n]	[l]	[ts]	[tsʰ]
ꓜ	ꓚ	ꓛ	ꓙ	ꓫ	ꓣ	ꓬ	ꓗ	ꓘ	ꓖ	ꓧ	ꓭ	ꓥ	ꓨ	ꓦ	
[dz]	[c]	[cʰ]	[ɟ]	[ʃ]	[ʒ]	[i̯]	[k]	[kʰ]	[g]	[x]	[ɣ]	[ŋ]	[ɦ]	[h]	

Vowels

ꓲ	ꓰ	ꓯ	ꓵ	ꓱ	ꓶ	ꓷ	ꓮ	ꓴ	ꓳ
[i]	[e]	[æ]	[ü]	[ø]	[ɯ]	[ə]	[ɑ]	[u]	[ʊ]

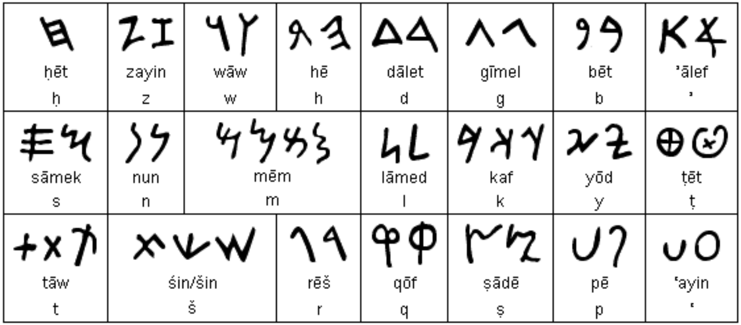
Tones

ꓸ	ꓹ	ꓻ	ꓺ	ꓽ	ꓼ	'
high tone	mid rising	mid tone	mid tense	low tone	low tense	nasalization

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

Abjad example: Phoenician

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



ḥēt	zayin	wāw	hē	dālet	gīmel	bēt	ʾālef
ḥ	z	w	h	d	g	b	ʾ
sāmek	nun	mēm		lāmed	kaf	yōd	ṭēt
s	n	m		l	k	y	ṭ
tāw	śin/šin		rēš	qōf	ṣādē	pē	ʿayin
t	š		r	q	ṣ	p	ʿ

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

A note on the letter-sound correspondence

- Alphabets use letters to encode sounds (consonants, vowels).
- But the correspondence between spelling and pronunciation in many languages is quite complex, i.e., not a simple one-to-one correspondence.
- Example: English
  - same spelling – different sounds: *ough*: *ough*t, cough, tough, through, though, hiccough
  - 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

French

(1) a. *Versailles* → [versai]

b. *ete*, *etais*, *etait*, *etaient* → [ete]

Irish

(2) a. *samhradh* (summer) → [sauruh]

b. *scri'obhaim* (I write) → [shgriːm]

What is the notation used within the []?

The International Phonetic Alphabet (IPA)

- Several special alphabets for representing sounds have been developed, the best known being the International Phonetic Alphabet (IPA).
- The phonetic symbols are unambiguous:
  - designed so that each speech sound gets its own symbol,
  - eliminating the need for
    - multiple symbols used to represent simple sounds
    - one symbol being used for multiple sounds.
- Interactive example chart: http://web.uvic.ca/ling/resources/ipa/charts/IPAlab/IPAlab.htm

Syllabic systems

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)

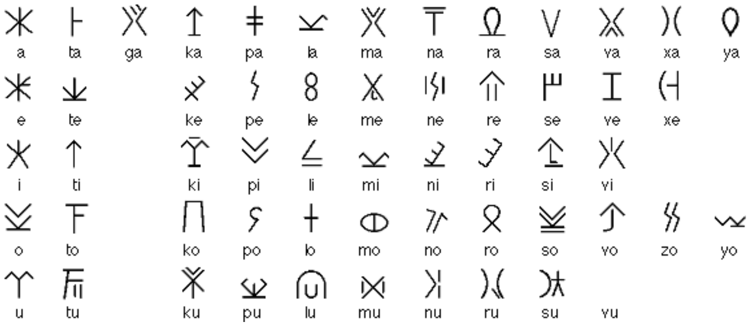
Abugidas (Alphasyllabaries)

- writing systems organized into families
- symbols 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, Tamil, Thai, Tagalog

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

Syllabary example: Cypriot

The Cypriot syllabary or Cypro-Minoan writing is thought to have developed from the Linear A script of Crete, though its exact origins are not known. It was used from about 1500 to 300 BC.


a
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su
vu

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

Abugida 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:

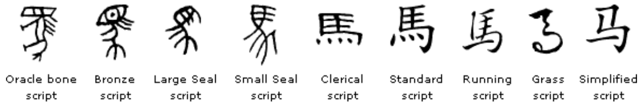
ກະ	ກິ	ກຸ	ກຶ	ກາ	ກີ	ກູ	ກື	ເກະ	ແກະ
ka	ki	ku	ku’	ka:	ki:	ku:	ku:’	ke	kae
[ka]	[ki]	[ku]	[kɯ]	[kaː]	[kiː]	[kuː]	[kɯː]	[ke]	[kae]
ໂກະ	ເກ	ແກ	ໂກ	ເກາະ	ເກິ	ເກັຽ	ເກຍ	ກົວ	ເກີຽ
ko	ke:	kae:	ko:	ko’	koe	kia	kia	kua	koe:y
[ko]	[keː]	[kæ]	[koː]	[kɔ]	[kɤ]	[kiə]	[kiə]	[kuə]	[kɤːj]
ເກີຍ	ກໍ	ເກີ	ເກືອ	ເກົາ	ໄກ	ໃກ	ກໍາ	ກ໌	
koe:y	ko’:	koe:	ku’a	kaw	kay	kay	kam	k	
[kɤːj]	[kɔː]	[kɤː]	[kɯə]	[kaw]	[kaj]	[kaj]	[kam]	[k]	

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

Logographic writing systems

- Logographs (also called Logograms):
  - General idea: one symbol ≈ one word/meaning
    - **Pictographs (Pictograms)**: originally pictures of things, now stylized and simplified.

      Example: development of Chinese character *horse*:



    - **Ideographs (Ideograms)**: representations of abstract ideas
  - **Compounds:** combinations of two or more logographs.
    - **Semantic-phonetic compounds:** symbols with a meaning element (hints at meaning) and a phonetic element (hints at pronunciation).
- Examples: Chinese (Zhōngwén), Japanese (Nihongo), Mayan, Vietnamese, Ancient Egyptian

Logograph writing system example: Chinese

Pictographs

女	子	口	日	月	山	川	豕	目	心	雨	田	木	龜
woman	child	mouth	sun	moon	mountain	river	pig	eye	heart	rain	field	tree	turtle

Ideographs

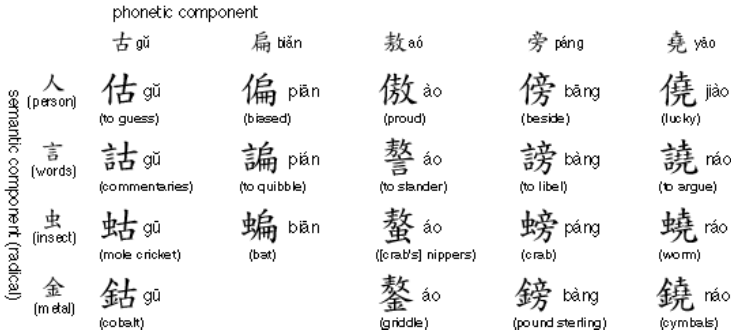
一	二	三	上	下	中	力	凸	凹
one	two	three	above	below	middle	stength (plough)	convex	concave

Compounds of Pictographs/Ideographs

好	安	明	家	思	牢	雷	男
good (woman + child)	peaceful (woman under a roof)	bright (sun + moon)	home/family (pig under a roof)	thought (heart + field)	prison (cow under a roof)	thunder (rain cloud over a field)	man/male (field + strength)

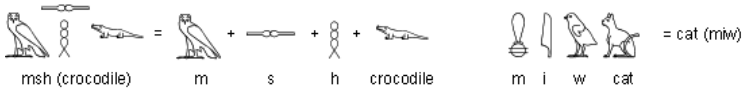
(from: http://www.omniglot.com/chinese/types.htm)

Semantic-phonetic compounds



semantic component (radical)	phonetic component: 古 gŭ	扁 biǎn	敖 aó	旁 páng	堯 yáo
人 (person)	估 gū (to guess)	偏 piān (biased)	傲 ào (proud)	傍 bàng (beside)	僥 jiǎo (lucky)
言 (words)	詁 gŭ (commentaries)	諞 pián (to quibble)	謷 áo (to slander)	謗 bàng (to libel)	譊 náo (to argue)
虫 (insect)	蛄 gū (mole cricket)	蝙 biān (bat)	螯 áo ([crab's] nippers)	螃 páng (crab)	蟯 ráo (worm)
金 (metal)	鈷 gū (cobalt)		鏊 áo (griddle)	鎊 bàng (pound sterling)	鐃 náo (cymbals)

An example from Ancient Egyptian



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

Two writing systems with unusual realization

Tactile

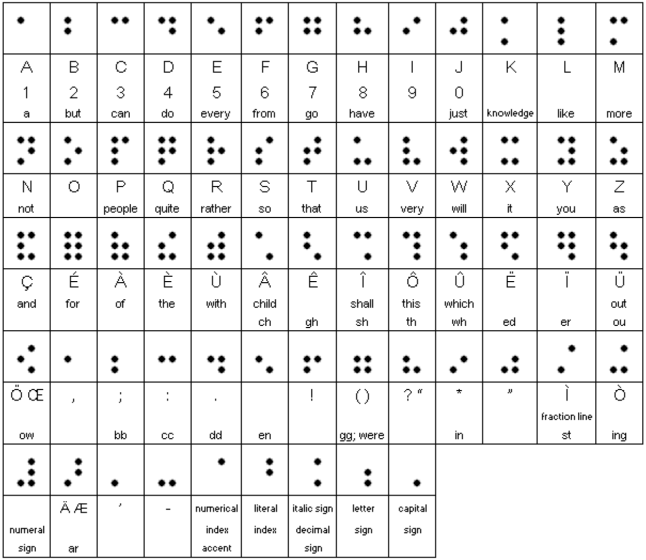
- Braille is a writing system that makes it possible to read and write through touch; primarily used by the (partially) blind.
- It uses patterns of raised dots arranged in cells of up to six dots in a 3 x 2 configuration.
- Each pattern represents a character, but some frequent words and letter combinations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

Chromatographic

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

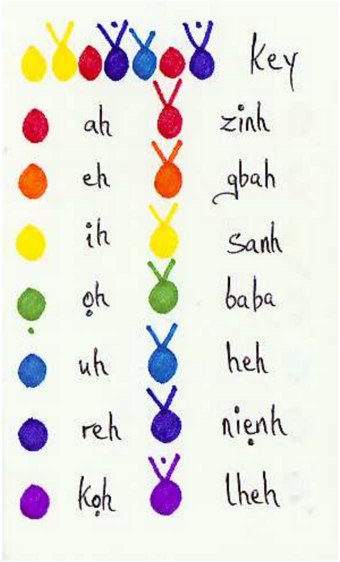
(cf. http://nigerianwiki.com/wiki/African_Writing_Systems#Edo.2FBenin_Script)

Braille alphabet



⠁	⠃	⠉	⠙	⠑	⠋	⠛	⠓	⠊	⠚	⠅	⠇	⠍
A 1 a	B 2 but	C 3 can	D 4 do	E 5 every	F 6 from	G 7 go	H 8 have	I 9	J 0 just	K knowledge	L like	M more
⠝	⠕	⠏	⠟	⠗	⠎	⠞	⠥	⠧	⠺	⠭	⠽	⠵
N not	O	P people	Q quite	R rather	S so	T that	U us	V very	W will	X it	Y you	Z as
⠯	⠿	⠷	⠮	⠾	⠡	⠣	⠩	⠹	⠱	⠫	⠻	⠳
Ç and	É for	À of	È the	Ù with	Â child ch	Ê gh	Î shall sh	Ô this th	Û which wh	Ë ed	Ï er	Ü out ou
⠪	⠂	⠆	⠒	⠲	⠢	⠖	⠶	⠦	⠔	⠴	⠌	⠬
Ö Œ ow	,	; bb	: cc	. dd	en	!	( ) gg; were	? “	* in	”	Ì fraction line st	Ò ing
⠼	⠜	⠄	⠤	⠈	⠘	⠨	⠰	⠠				
numeral sign	Ä Æ ar	’	-	numerical index accent	literal index	italic sign decimal sign	letter sign	capital sign				

Chromatographic system



Relating writing systems to languages

- There is not a simple correspondence between a writing system and a language.
- For example, English uses the Roman alphabet, but Arabic numerals (e.g., 3 and 4 instead of III and IV).
- 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
- katakana
  - used mainly for non-Chinese loan words, onomatopoeic words, foreign names, and for emphasis
- hiragana
  - originally used only by women (10th century), but codified in 1946 with 48 syllables
  - used mainly for word endings, kids' books, and for words with obscure kanji symbols
- romaji: Roman characters

Korean

- 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.

  E.g., "Hangeul" (from: http://www.omniglot.com/writing/korean.htm):

  한 (han) ㅎ(h) + ㅏ(a) + ㄴ(n) 글 (geul) ㄱ(g) + ㅡ(eu) + ㄹ(l
- In South Korea, *hanja* (logographic Chinese characters) are also used.

Azeri

A Turkish language with speakers in Azerbaijan, northwest Iran, and (former Soviet) Georgia

- 7th century until 1920s: Arabic scripts. Three different Arabic scripts used
- 1929: Latin alphabet enforced by Soviets to reduce Islamic influence.
- 1939: Cyrillic alphabet enforced by Stalin
- 1991: Back to Latin alphabet, but slightly different than before.

Encoding written language

How, then, do we work with all of these written languages on a computer?

- How do we **encode** languages on a computer?
- How do we encode anything on a computer?

Roughly speaking: we need to assign each character its own “place” in the computer

- ... and we need more details to know how to do this ...

Computer encodings

- 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"
    - **Little Endian**: most important bit is rightmost (only used on Intel machines)
        - The positions in a byte thus encode: 1 2 4 8 16 32 64 128

Converting decimal numbers to binary

Tabular Method

Using the first 4 bits, we want to know how to write *10* in bit (or *binary*) notation.

8	4	2	1
?	?	?	?
$8 < 10$	?	?	?
1	$8 + 4 = 12 > 10$	?	?
1	0	$8 + 2 = 10$	?
1	0	1	0

Converting decimal numbers to binary

Division Method

Decimal	Remainder?	Binary
10/2 = 5	no	0
5/2 = 2	yes	10
2/2 = 1	no	010
1/2 = 0	yes	1010

An encoding standard: ASCII

With 8 bits (a single byte), you can represent 256 different 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.

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		

E-mail issues

- 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.

Different coding systems

But wait, didn't we want to be able to encode *all* languages?

There are ways ...

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

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 8.0 has codes for 120,672 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.

UTF-8 details

- First byte unambiguously tells you how many bytes to expect after it
  - e.g., first byte of 11110xxx has a four total bytes
- all non-starting bytes start with 10 = *not* the initial byte

Byte 1	Byte 2	Byte 3	Byte 4	Byte 5	Byte 6
0xxxxxxx					
110xxxxx	10xxxxxx				
1110xxxx	10xxxxxx	10xxxxxx			
11110xxx	10xxxxxx	10xxxxxx	10xxxxxx		
111110xx	10xxxxxx	10xxxxxx	10xxxxxx	10xxxxxx	
1111110x	10xxxxxx	10xxxxxx	10xxxxxx	10xxxxxx	10xxxxxx

Example: Greek α ('alpha') has a code value of 945

- Binary: 11 10110001
- 11 10110001 = 011 10110001 = 01110 110001
- Insert these numbers into *x*'s in the second row:
  110**01110** 10**110001**

Information Theory

(if time)

This idea of getting the shortest encoding first comes from **information theory**

- Goal: encode information using the smallest number of bits
- We can look at a few examples here: http://www.cs.cmu.edu/~dst/Tutorials/Info-Theory/ (Focus on **Variable Length Codes** & don't worry about all the details)

We'll revisit this issue with writers' aids, when we discuss the noisy channel model

Unwritten languages

Many languages have never been written down. Of the approximately 7000 spoken languages, approximately half have “a developed writing system”.

Some examples:

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

(See: http://www.ethnologue.com/ and

https://www.ethnologue.com/enterprise-faq/how-many-languages-world-are-unwritten)

The need for speech

We want to be able to encode any spoken language

- What if we want to work with an unwritten language?
- What if we want to examine the way someone talks and don't have time to write it down?

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?

We can **transcribe** (write down) the speech into a **phonetic alphabet**.

- It is very expensive and time-consuming to have humans do all the transcription.
- To automatically transcribe, we need to know how to relate the audio file to the individual sounds that we hear.
  $\Rightarrow$ 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?

Sounds run together, and it's hard to tell where one sound ends and another begins.

People say things differently from one another:

- People have different dialects
- People have different size vocal tracts

People say things differently across time:

- What we think of as one sound is not always (usually) said the same: **coarticulation** = sounds affecting the way neighboring sounds are said

  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* in *see* is 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**

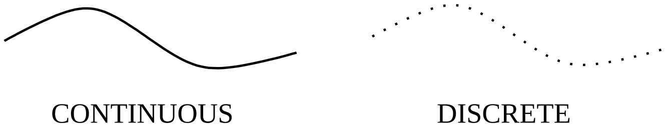
- *place of articulation* (where): [t] vs. [k]
- *manner of articulation* (how): [t] vs. [s]
- *voicing* (vocal cord vibration): [t] vs. [d]

But we need to know acoustic properties of speech which we can *quantify*.

Measuring sound

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

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



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

Now, we can talk about what we need to measure

Acoustic properties: What it sounds like

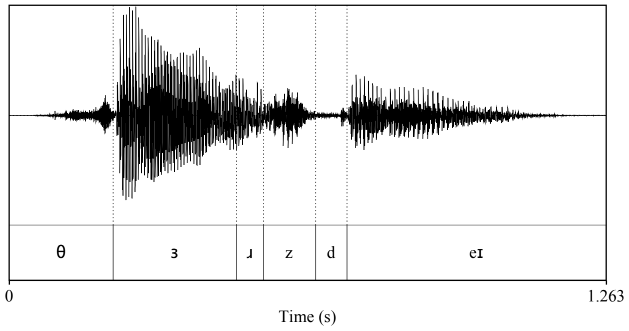
Sound waves = "small variations in air pressure that occur very rapidly one after another" (Ladefoged, *A Course in Phonetics*), akin to ripples in a pond

The main properties we measure:

- **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**.

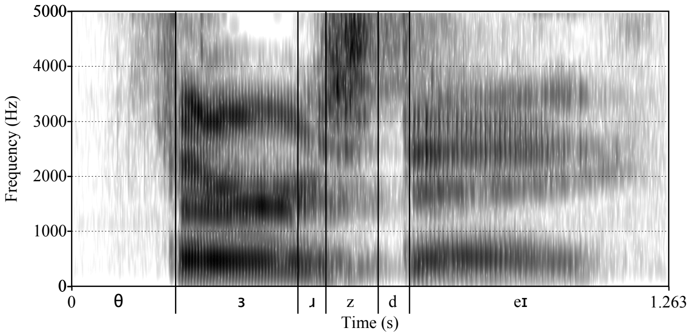
Researchers also look at things like **intonation**, i.e., the rise and fall in pitch

Oscillogram (Waveform)



Spectrograms

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



Measurement-souund correspondence

- 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?

Applications of speech encoding

Mapping sounds to symbols (alphabet), and vice versa, has some very practical uses.

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

As we'll see, these are not easy tasks.

Automatic Speech Recognition (ASR)

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

Uses/Applications:

- Dictation
- Dialogue systems
- Telephone conversations
- People with disabilities – e.g. automatic closed captioning

Steps in an ASR system

1. Digital sampling of speech
2. **Acoustic signal processing** = converting the speech samples into particular measurable units
3. Recognition of sounds, groups of sounds, and words

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

- e.g., a $[\mathrm{t}]$ might sound like a $[\mathrm{d}]$, and so word information might be needed (more on this later)

Kinds of ASR systems

Different kinds of systems, with an accuracy-robustness tradeoff:

- Speaker dependent = work for a single speaker
- Speaker independent = work for any speaker of a given variety of a language, e.g. American English

Thus, a common type of system starts general, but learns:

- Speaker adaptive = start as independent but begin to adapt to a single speaker to improve accuracy
  - Adaptation may simply be identifying what type of speaker a person is and then using a model for that type of speaker

Kinds of ASR systems

- Differing sizes and types of vocabularies
  - from tens of words to tens of thousands of words
  - might be very domain-specific, e.g., flight vocabulary
- **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 $\rightarrow$ easier to find the endpoints of words

Text-to-Speech Synthesis (TTS)

Could just record a voice saying phrases or words and then play back those words in the appropriate order.

- This won't work for, e.g., dialogue systems where speech is generated on the fly.

Or can break the text down into smaller units

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

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

Synthesizing Speech

In some sense, TTS really is the reverse process of ASR

- Since we know what frequencies correspond to which vowels, we can play those frequencies to make it sound like the right vowel.
- However, as mentioned before, sounds are always different (across time, across speakers)

One way to generate speech is to have a database of speech and to use the **diphones**, i.e., two-sound segments, to generate sounds.

- Diphones help with the context-dependence of sounds

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.wizzardsoftware.com/text-to-voice.php
- various systems and languages: http://www.ims.uni-stuttgart.de/~moehler/synthspeech/

N-grams: Motivation

Let's say we're having trouble telling what word a person said in an ASR system

- We could look it up in a phonetic dictionary
- But if we hear something like *ni*, how can we tell if it's *knee*, *neat*, *need*, or some other word?
  - All of these are plausible words
  - One bit of help: we can assign a probability, or weight, to each change:
    - i.e., measure how far off a word is from the pronunciation (we'll return to *minimum edit distance* with spell checking)
    - e.g., deleting a [t] at the end of a word may be slightly more common than deleting a [d]
- But if the previous word was *I*, the right choice becomes clearer ...

Material originally based upon chapter 5 of Jurafsky and Martin (2000)

N-gram definition

An **n-gram** is a stretch of text *n* words long

- Approximation of language: information in *n*-grams tells us something about language, but doesn't capture the structure
- Efficient: finding and using every, e.g., two-word collocation in a text is quick and easy to do

N-grams help a variety of NLP applications, including **word prediction**

- *N*-grams can be used to aid in predicting the next word of an utterance, based on the previous *n* – 1 words

Simple n-grams

Let's assume we want to predict the next word, based on the previous context of *I dreamed I saw the knights in*

- Find the likelihood of *armor* being the next word, given that we've seen *I*, *dreamed*, ..., *knights*, *in*
  - Notate this as: $P(armor|I, dreamed, ..., knights, in)$
    - Read as: "The probability of *armor* given *I dreamd ... in*"
    - $P(A|B)$ = the probability of A given B
  - To do this, it helps to examine the whole sequence: $P(I, dreamed, ..., in, armor)$

And the following is true:

(3) $P(I, dreamed, ..., in, armor) = P(I)P(dreamed|I)...P(armor|I, dreamed, ..., in)$

- Choose the first word (*I*), then the second given the first, then the third given the first two, etc.

Simple n-grams: abstracting to a general form

More generally, we use variables like w_i:

- e.g., find the likelihood of w_8 being the next word, given that we've seen $w_1, ..., w_7$

(4) $P(w_1, ..., w_n) = P(w_1)P(w_2|w_1)...P(w_n|w_1, ..., w_{n-1})$

Probabilities like $P(w_8|w_1, ...w_7)$ are impractical to calculate: they hardly ever occur in a corpus, if at all.

- Plus: it's a lot of data to store
- Plus: a lot of language dependencies are very **local**

Unigrams

So, we can approximate these probabilities to a particular *n*-gram, for a given *n*. What should *n* be?

- How about unigrams ($n = 1$)?

  (5) $P(w_n|w_1, ..., w_{n-1}) \approx P(w_n)$

- Easy to calculate, but we have no contextual information

  (6) The quick brown fox jumped

  (7) $P(jumped|The, quick, brown, fox) \approx P(jumped)$

- We would like to say that *over* has a higher probability in this context than *lazy* does.

Bigrams

Bigrams ($n = 2$) are a better choice and still easy to calculate:

(8) $P(w_n|w_1, ..., w_{n-1}) \approx P(w_n|w_{n-1})$

(9) $P(over|The, quick, brown, fox, jumped) \approx P(over|jumped)$

And thus, we obtain for the probability of a sentence:

(10) $P(w_1, ..., w_n) = P(w_1)P(w_2|w_1)P(w_3|w_2)...P(w_n|w_{n-1})$

In general, many language tasks use bigrams or trigrams to do **language modeling**

- Many software packages available for langauge modeling; see, e.g., https://en.wikipedia.org/wiki/Language_model#External_links

Examples

With a bigram model, the probability of seeing the sentence *The quick brown fox jumped over the lazy dog* is:

(11) P(The quick brown fox jumped over the lazy dog) = $P(The|\text{START})P(quick|The)P(brown|quick)...P(dog|lazy)$

For our ASR examples, we can compare:

(12) $P(need|I) > P(neat|I)$

(13) $P(armor|in) > P(armoire|in)$, $P(armor|in) > P(harm|in)$, etc.

For trigrams, we would have:

- $P(armor|knights, in) > P(armoire|knights, in)$, etc.