PHONOLOGY

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Chapter – II
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What is Phonology?

Phonology is the study of sounds and speech patterns in language.

Vowels : Is a sound that is characterized by an open configuration of the vocal tract so that there is no build-up of air pressure above the glottis.

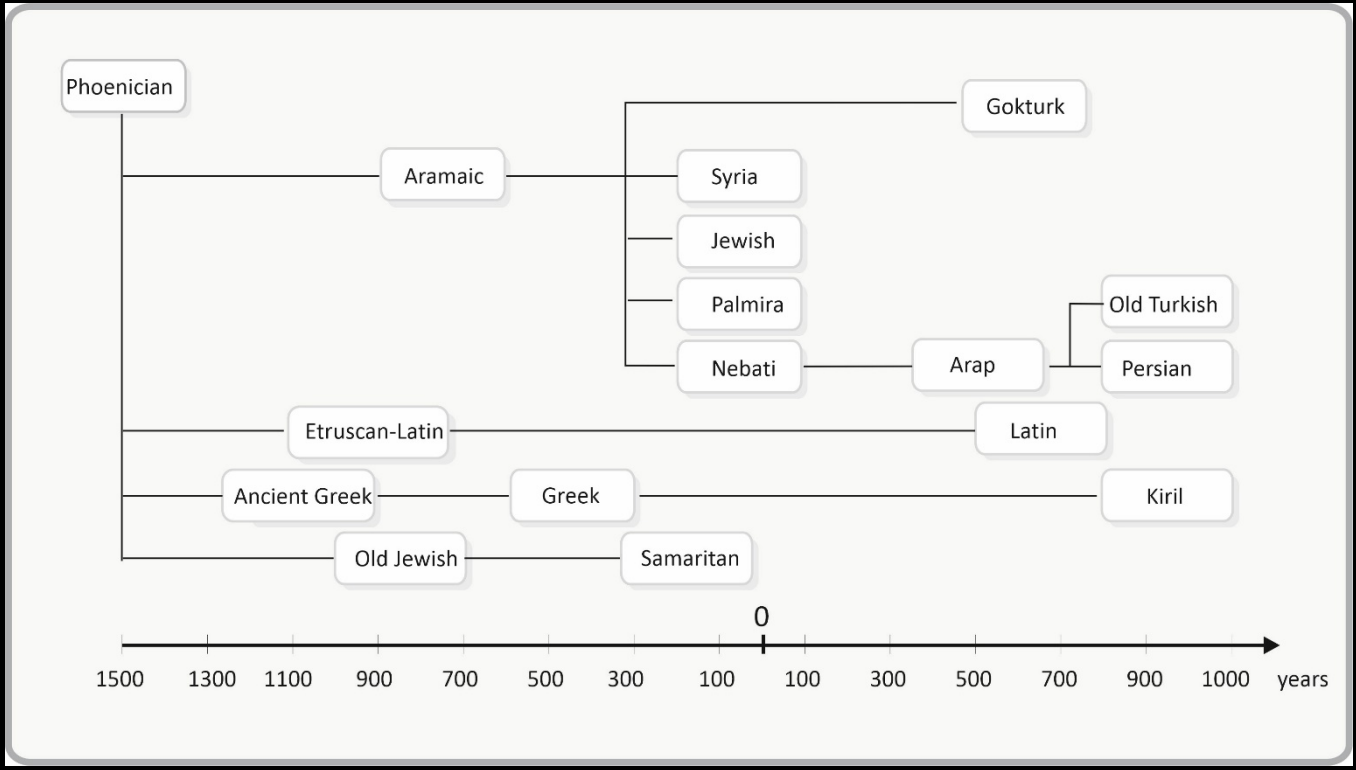
Consonants : Is a sound that is articulated with complete or partial closure of the upper vocal tract.

Phoneme : Is the smallest unit of language recognized by a native speaker.

Syllables : Is a unit of organization for a sequence of speech sounds

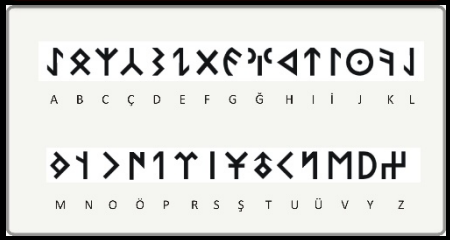
Language	Number of Vowels	Number of Consonants
Turkish	8+3	21
Arabic	3	28
German	8	20
English	5	21
French	6	29
Russian	10	21

Alphabet



Phoenician Alphabet

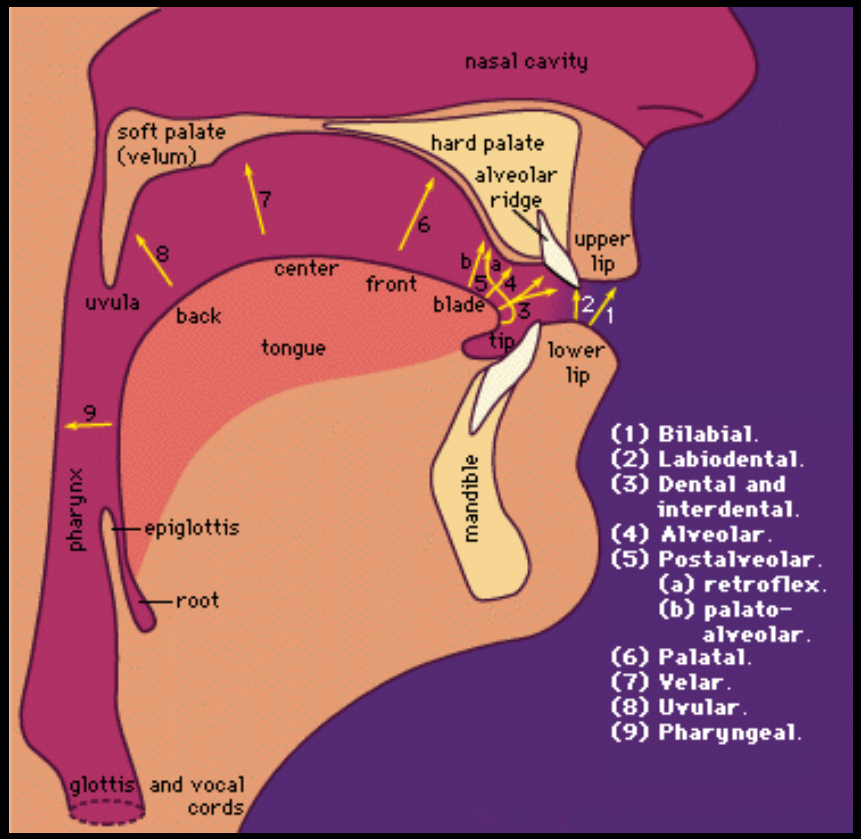
Gokturk Alphabet



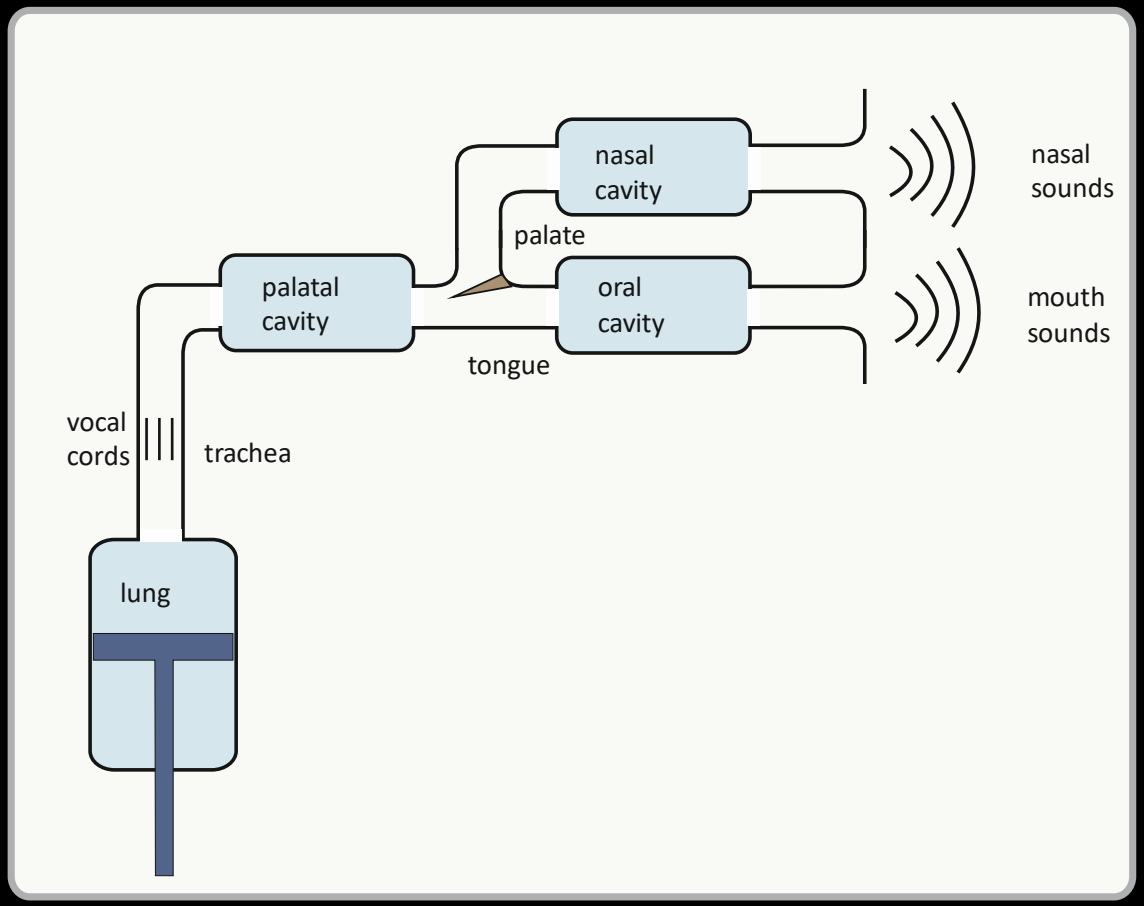
Vocal Organ

- Sound is produced by the air flow coming from lung. The air passing through larynx (Adem's apple or voicebox).
- The larynx has two muscle which are called vocal cords. If these two cords are apart they will not vibrate as air passes through them. If they are together, they will vibrate.
- If vocal cords vibrate, voiced sounds and if not unvoiced or voiceless sounds are produced.

- Vowels are melody sounds of a language.
- The aesthetics of a language is directly proportional to the multiplicity of its vowels.
- Extending the duration of vowel sounds brings fluency to the language

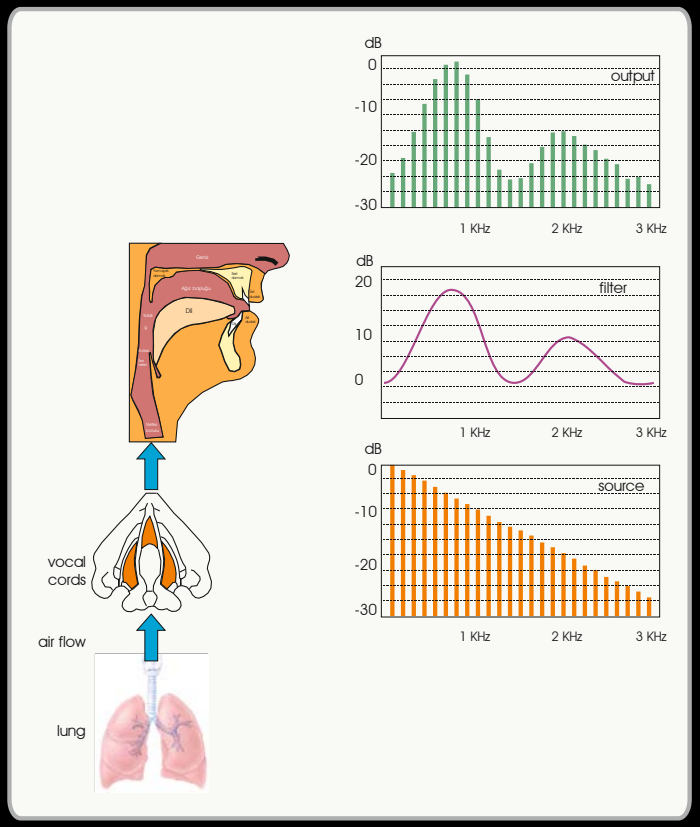


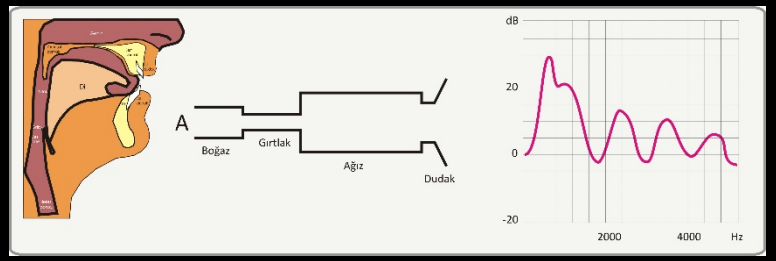
Model of Vocal Organ

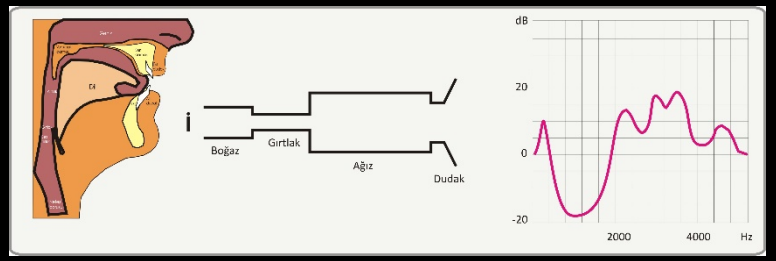


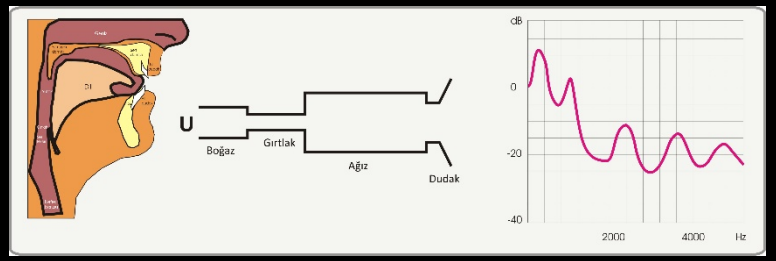
Sound Signals

The formation of the voice in vocal organ









Ne mutlu Türküm diyene

How The Sound Made (Vowels)

High-mid-low: height of the tongue in the mouth

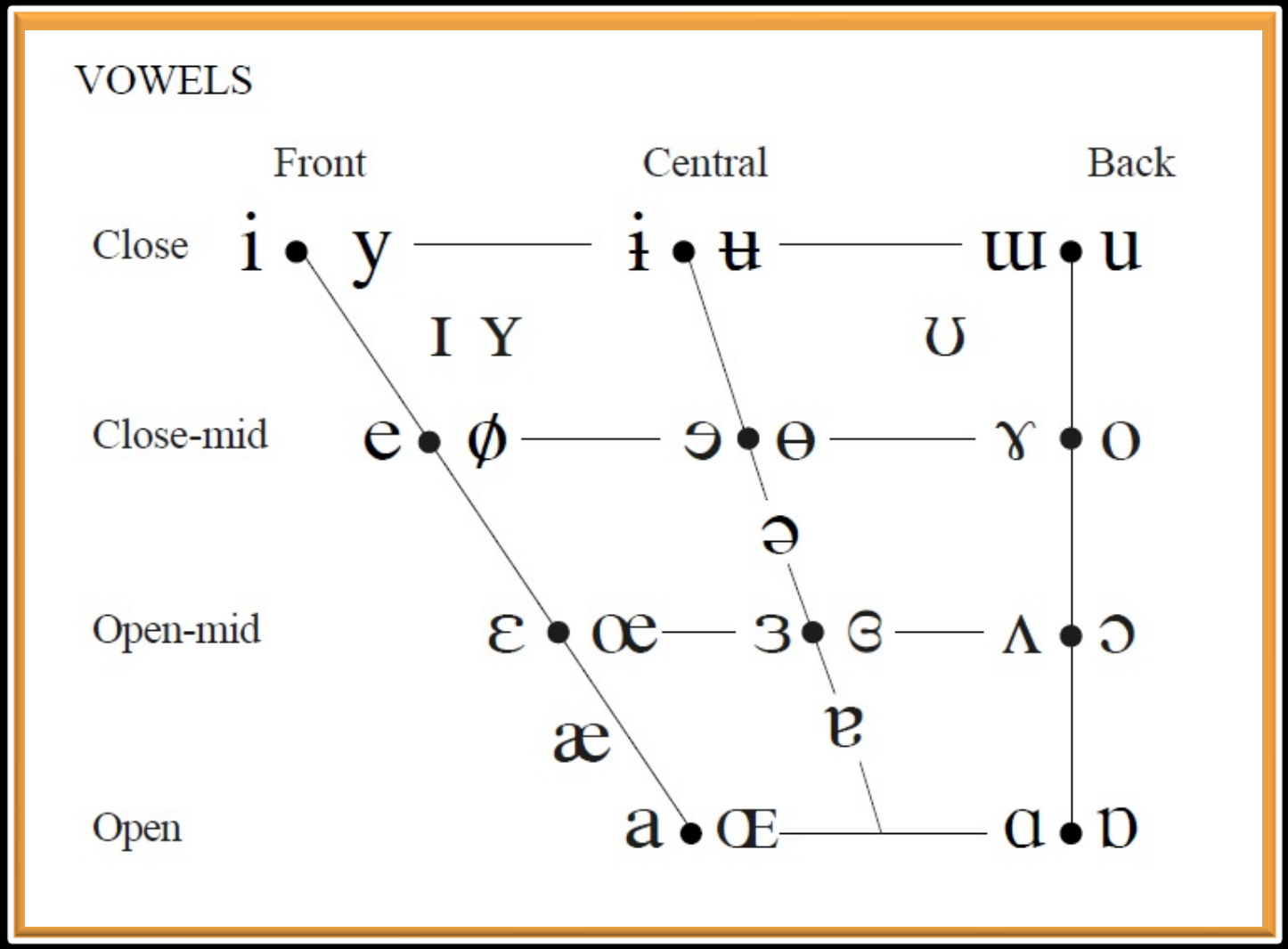
Front-central-back: frontness or backness of the tongue in the mouth

Rounded-unrounded: the state of the lips, in English, as in many languages this is predictable: rounded for high back and mid back vowels, unrounded for other vowels.

Tense-lax : roughly, the degree of tension in the tongue

		Front	Central	Back
High	*Tense*	**i**		**u**
	Lax	**I**		**U**
Mid	*Tense*	**e**	**ə**	**o**
	Lax	**e**		
Low	*(Lax)*	**æ**	**a**	

Position of Vowels



How The Sound Made (Consonants)

Place of articulation: **where** the sound is made

- **Bilabial** : with the two lips
- **Labiodental** : with the lower lip and upper teeth
- **Interdental** : with the tongue between the teeth, or just behind the upper teeth (also called "dental")
- **Alveolar** : with the tongue tip at the alveolar ridge, behind the teeth
- **Palatal** : with the front or body of the tongue raised to the palatal region
- **Velar** : with the back of the tongue raised to the soft palate ("velum")
- **Glottal** : at the larynx (the glottis is the space between the vocal cords)

Manner of articulation: how the tongue, lips, etc. are configured to produce the sound

- **Stop** : complete closure, resulting in stoppage of the airflow
- **Affricate** : closure followed by frication (: stop + fricative)
- **Fricative** : narrow opening, air forced through
- **Nasal** : air allowed to pass through the nose (generally while blocked in mouth)
- **Liquid** : minimal constriction allowing air to pass freely through center of mouth, as in [r], called arhotic around side of tongue, as in [l], called a lateral
- **Glide** : minimal constriction corresponding to a vowel (thus also called "semi-vowel") [j] corresponds to [i], [w] corresponds to [u]
- **Flap** : the tongue briefly taps the ridge behind the teeth, as in the standard American pronunciation of "tt" in *butter*

Vowels and Consonants

Vowels	
Turkish	English
a	a
e	e
ı	
i	i
o	o
ö	
u	u
ü	

Consonants					
Turkish	English	Turkish	English	Turkish	English
b	b	j	j	s	s
c	c	k	k	ş	
ç		l	l	T	t
d	d	m	m	v	v
f	f	n	n		w
g	g	p	p	y	y
ğ			q	z	z
h	h	r	r		x

Vowels and Consonants (Turkish)

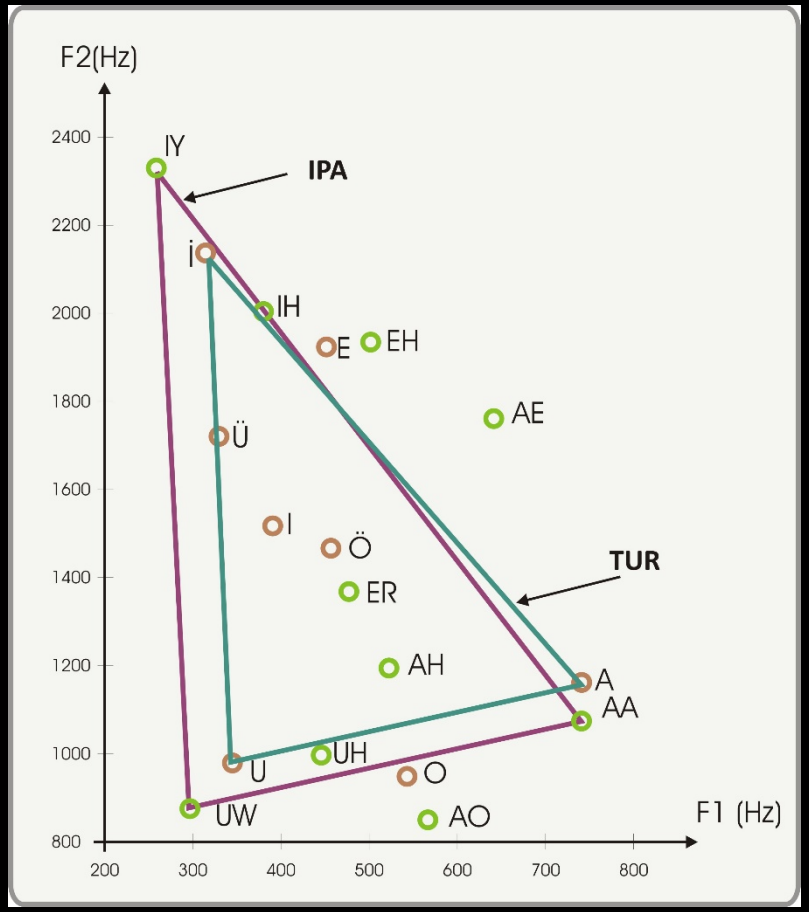
Vowels	Unrounded		Rounded	
	wide	narrow	wide	narrow
Back vowel	a	ı	o	u
Front vowel	e	i	ö	ü

Consonants		Labial	labio-dental	Dental	Plato-alveolar	Palatal	Velar	Glottal
Voiceless stop	Hard	p		t	ç	k (front)	k(back)	
Voiced stop	Soft	b		d	c	g (front)	g(back)	
Voiceless fricative	Hard		f	s	ş			
Voiced fricative	Soft		v	z	j			
Nasal		m		n				
Liquid				l,r				
Approximant						y		h

Formants of Vowels

IPA	Latin	F1(Hz)	F2(Hz)	F3(Hz)
i	IY	270	2290	3010
I	IH	390	1990	2550
e	EH	539	1840	1480
ae	AE	660	1720	2410
A	AH	520	1190	2390
a	AA	730	1090	2440
]	AO	570	840	2410
U	UH	440	1020	2240
u	UW	300	870	2240
g	ER	490	1350	1690

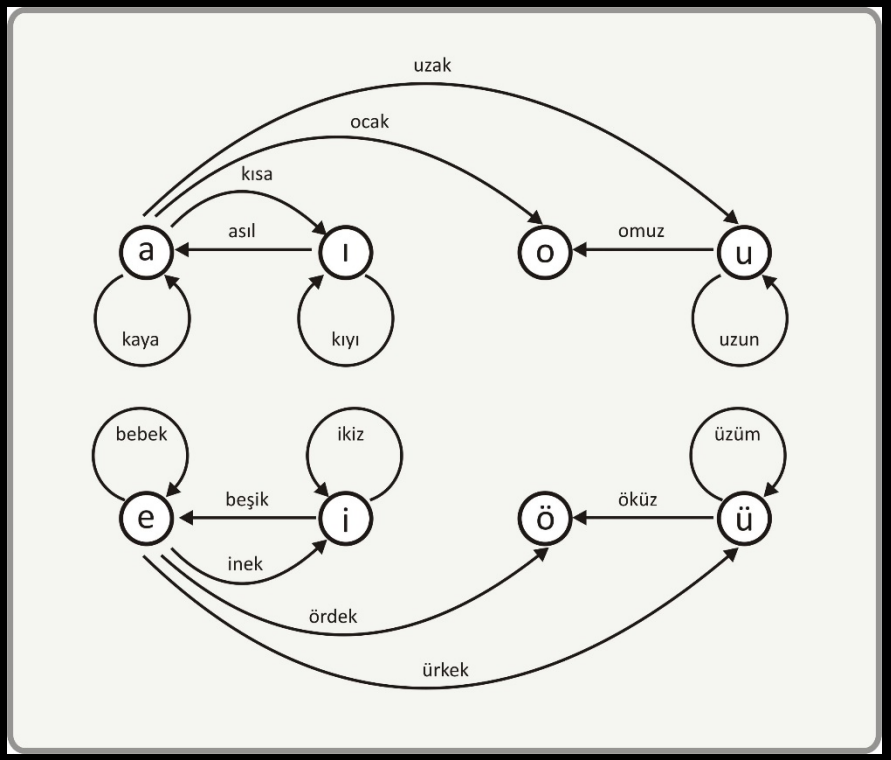
Turkish	Gender	F1(Hz)	F2(Hz)	F3(Hz)	F34Hz)
a	woman	236	771	2998	4168
	man	130	642	2714	3707
e	woman	231	578	2961	4128
	man	127	470	2563	3715
ı	woman	233	492	2976	4232
	man	128	396	2479	3782
i	woman	245	430	3325	4308
	man	138	306	2897	3751
o	woman	243	564	2976	3794
	man	130	483	2733	3668
ö	woman	212	543	2764	3947
	man	124	469	2439	3554
u	woman	247	452	2940	3825
	man	141	379	2490	3558
ü	woman	234	424	2742	3694
	man	139	333	2337	3342



Harmony of Vowels

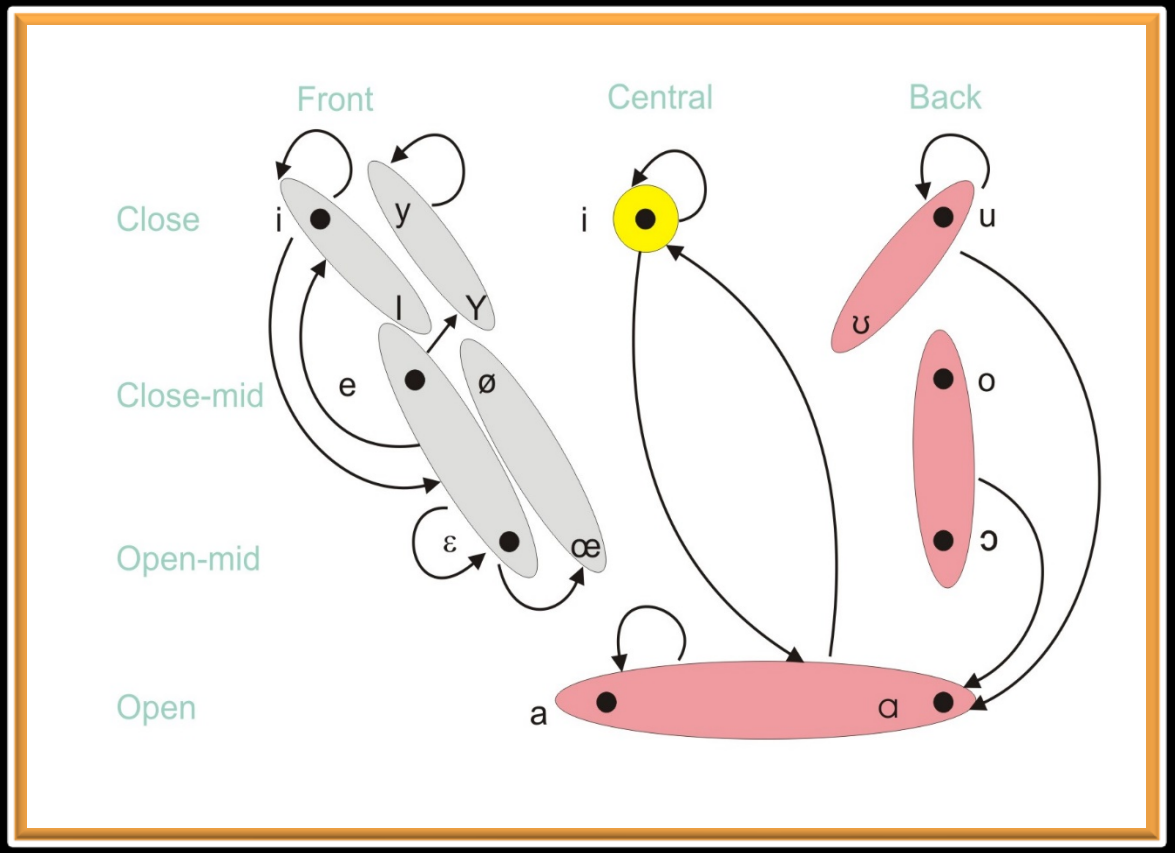
	Unrounded		Rounded	
	wide	narrow	wide	narrow
Back vowel	a	ı	o	u
Front vowel	e	i	ö	ü

Turkish has harmony rule for vowels.



Harmony of Vowels

- We can think of the human tongue as a flexible mass that is rooted and can move longitudinally and transversely.
- When the situation of such a mass moving from one position to another is examined, it is clear that the transition to the neighboring state/position will be easier than the transition to the far state/position.
- Therefore, the transition from **e** to **i** and **ö** to **ü** is easy. Similarly, the transition from **a** to **ı** and **o** to **u** is easy. This explains the origin of the vowel harmony.
- In other words, **vowel harmony is a result of the nature of the human vocal organ.**



Which one is easy to pronounce?

tenteredi

tintoridö

Rules of Sound (for Vowels)

Harmony of vowels

exeptions

Vowel harmony is not applied in compound words, eg: *Kocatürk, karasinek, gecekondu, vatansever*.

Vowel harmony is not applied in borrowed, eg: *Demokrasilerde, kitaplık, kalemlik.*

Some old words don't have vowel harmony, eg: *karpuz, kavun, armut, savunma, avuç, tabur, yağmur*

Clash of vowels

Two vowels are not allowed to come together. This rule is applied in two ways:

- If a word ends with a vowel and there is a suffix that begins with a vowel in that word, one of the letters n, s, y enters between the word and the suffix.

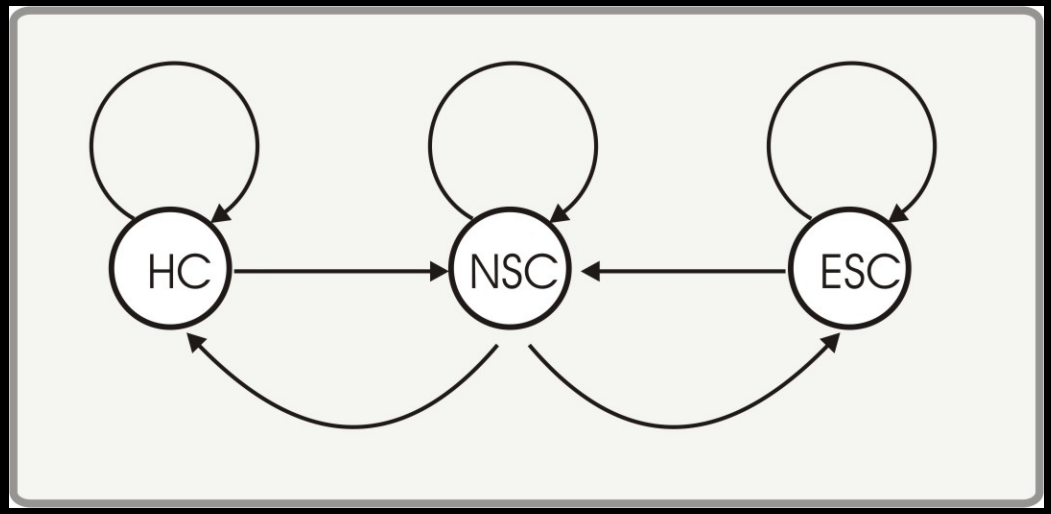
  kapı+i>kapıyı, bahçe+e>bahçeye
- If a preposition with -(H)dH, -(H)mHş, -(H)sA, -(H) is added to a word ending with a vowel and the prefix with or is combined, the "I"s of these suffixes turn into –y

  kapı+ile>kapıyla, yazı+imiş>yazıymış, okul+idi>okuldu

Harmony of Consonants

Some language, likes Turkish have harmony rule for consonants.

Hard consonants (**HC**)	ç f h k p s ş t
Soft consonants do not have hard equivalence consonants (**NSC**)	l m n r y
Soft consonants have hard equivalence consonants (**ESC**)	b c d g ğ j v z



Rules of Sound (for Consonants)

Double consonants at the end of words and Syllable.

Ölç, kıskanç, kalp, hişt

First letter	Second letter
l	ç, k, p, t
n	ç, k, t
r	ç, k, p, s, t
s	t
ş	t

Number of consonants that can be conjoinedle.

tren ve stratosfer

- There cannot be more than one consonant at the beginning of a word.
- More than three consonants cannot be found side by side in a word.

Consonant Affinity

- When a word ending with one of the hard consonants is added with a suffix that starts with one of the soft consonants, the soft consonant becomes

  kebab+ci> kebapçı, kümes+de> kümeste

- There are no discontinuous soft consonants (b, c, d, g) at the end of a Turkish word. Such sounds turn into discontinuous hard consonants (p, ç, t, k).

  Eb>ev, sab>sav, yad+mak>yaymak, dög>döğ>döv, ög>öğ>öv, beg>bey, ilaç>ilaç,kitab>kitap, aheng>ahenk, derd>dert

Rules of Sound-I

Sound found and absent

Two vowels do not come together in Turkish words. Those who break this rule are words taken from foreign languages: poet, craft, verb, ideology.

Turkish words do not have “c, f, ğ, h, l, m, n, p, r, v, z” sounds at the beginning. However, words that imitate nature and words of foreign origin are excluded from this rule.

There are no discontinuous soft consonants (b, c, d, g) at the end of a Turkish word, such sounds turn into discontinuous hard consonants (p, ç, t, k): ilaç instead of ilac, kitap instead of kitab.

Change of sound

If one of the suffixes -en, -ecek, -erek, -e, -yor is added to the verb ending with a wide flat vowel (a, e), the broad flat vowel at the end of the root or stem becomes a narrow straight vowel (ı, i) . If this narrow flat vowel falls between two round vowels, it turns into a narrow round vowel (u, ü). This rule is valid for the -yor suffix both in written language and in speech, while the others are valid in speech

Rules of Sound-II

Sound drop

Middle syllable drop: In some two-syllable words whose first syllable is open (ending with a vowel) and the second syllable is closed (ending with a consonant), a production or inflectional suffix that starts with a vowel drops the vowel of the middle syllable of the word.

burun+i>burnu

If the suffix -Al is added to the noun roots ending with a vowel, the vowel of the suffix is dropped.

ince+el>incel-, kısa+al>kısal-, doğru+el>doğrul-

If a suffix ends with pronoun roots ending in "k", it drops the "k" consonant in the pronoun except for its own vowel.

alçak+el>alçal-, yüksek+el>yüksel-, küçük+el>küçül-

If the suffix -Ar is used for pronoun roots ending with a vowel, the last sound of the pronoun root is dropped.

sarı+ar>sarar-, kara+ar>karar-

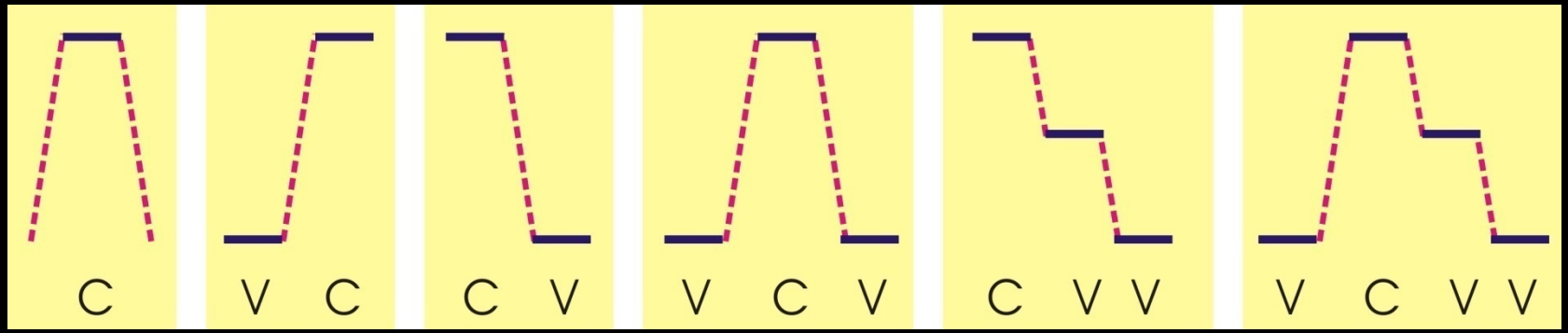
If the suffix -Ar is added to the pronoun roots ending in a consonant, the last sound and the after (usually 'l') of the pronoun root are dropped.

kızıl+er>kızar-, yeşil+er>yeşer-

Syllable of Turkish

Some language likes Turkish have rules for syllable, some do not have.

Syllable rules of Turkish	*Vowel (V), Consonants (C)*
V	o
VC	at
CV	ye
CVC	tek
VCC	alt
CVCC	türk



Phoneme of Turkish

In phonetic language one phoneme corresponds to one letter

Vowels and Consonants						
a	front	f		l	front	t
a	back	g	front	l	back	u
a	long	g	back	m		ü
b		ğ		n		v
c		h		o		y
ç		ı		ö		z
d		i		p		
e	open	j		r		
e	close	k	front	s		
e	long	k	back	ş		

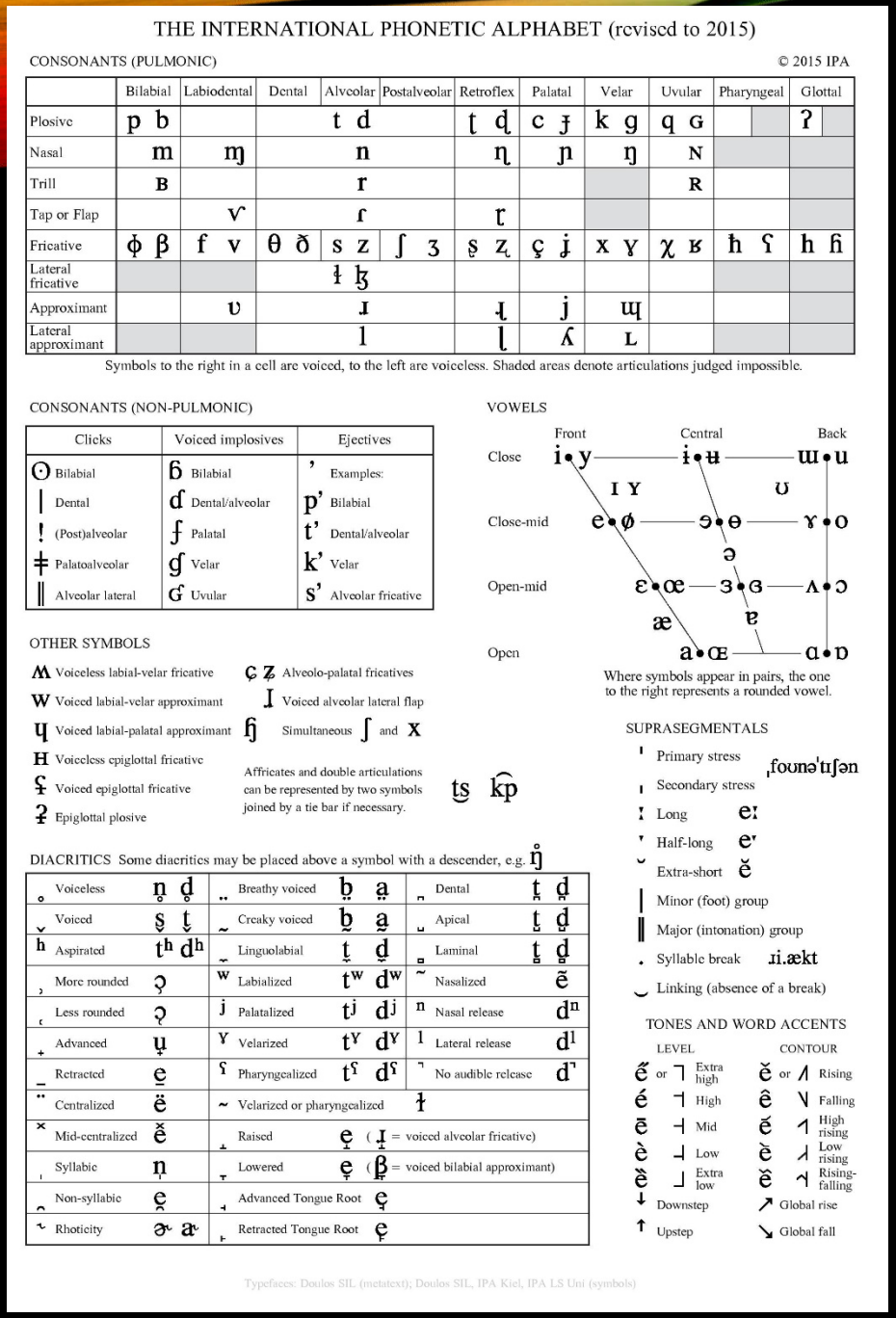
Phoneme of English

In non-phonetic language one phoneme corresponds to one or more letters

Vowels			
IPA	Words	IPA	Words
A	c*u*p, l*u*ck	u	p*u*t, c*ou*ld
Ψ	*a*rm, f*a*ther	u:	bl*ue*, f*oo*d
Ψε	c*a*t, bl*a*ck	aı	f*i*ve, *eye*
ε	m*e*t, b*e*d	au	n*ow*, *ou*t
X	*a*way, cine*ma*	ou	g*o*, h*o*me
ɸ:ρ	t*ur*n, l*ear*n	ear	wh*ere*, *air*
I	h*i*t, s*itt*ing	eı	s*ay*, *eigh*t
ι:	s*ee*, h*ea*t	ıar	n*ear*, h*ere*
Z	h*o*t, r*o*ck	ı	b*oy*, j*oi*n
	c*a*ll, f*our*	uar	p*ure*, t*our*ist

Consonants			
IPA	Words	IPA	Words
b	*b*ad, la*b*	r	*r*ed, t*r*y
d	*d*id, la*d*y	s	*s*un, mi*ss*
f	*f*ind, i*f*		*sh*e, cra*sh*
g	*g*ive, fla*g*	t	*t*ea, ge*tt*ing
h	*h*ow, *h*ello	t	*ch*eck, *ch*ur*ch*
j	*y*es, *y*ellow		*th*ink, bo*th*
k	*c*at, ba*ck*		*th*is, mo*th*er
l	*l*eg, *l*itt*l*e	v	*v*oice, fi*v*e
m	*m*an, le*m*on	w	*w*et, *w*indo*w*
n	*n*o, te*n*	z	*z*oo, lazy
	si*ng*, fi*n*ger		pleasure, vi*s*ion
p	*p*et, ma*p*		*j*ust, lar*ge*

International Phonetic Alphabet - IPA



THE INTERNATIONAL PHONETIC ALPHABET (revised to 2015)

CONSONANTS (PULMONIC) © 2015 IPA

	Bilabial	Labiodental	Dental	Alveolar	Postalveolar	Retroflex	Palatal	Velar	Uvular	Pharyngeal	Glottal
Plosive	p b			t d		ʈ ɖ	c ɟ	k g	q ɢ		ʔ
Nasal	m	ɱ		n		ɳ	ɲ	ŋ	ɴ		
Trill	ʙ			r					ʀ		
Tap or Flap		ⱱ		ɾ		ɽ					
Fricative	ɸ β	f v	θ ð	s z	ʃ ʒ	ʂ ʐ	ç ʝ	x ɣ	χ ʁ	ħ ʕ	h ɦ
Lateral fricative				ɬ ɮ							
Approximant		ʋ		ɹ		ɻ	j	ɰ			
Lateral approximant				l		ɭ	ʎ	ʟ			

Symbols to the right in a cell are voiced, to the left are voiceless. Shaded areas denote articulations judged impossible.

CONSONANTS (NON-PULMONIC)

Clicks	Voiced implosives	Ejectives
ʘ Bilabial	ɓ Bilabial	’ Examples:
| Dental	ɗ Dental/alveolar	pʼ Bilabial
! (Post)alveolar	ʄ Palatal	tʼ Dental/alveolar
ǂ Palatoalveolar	ɠ Velar	kʼ Velar
‖ Alveolar lateral	ʛ Uvular	sʼ Alveolar fricative

OTHER SYMBOLS

ʍ Voiceless labial-velar fricative
ɕ ʑ Alveolo-palatal fricatives
w Voiced labial-velar approximant
ɺ Voiced alveolar lateral flap
ɥ Voiced labial-palatal approximant
ʃʒ Simultaneous ʃ and x
ʜ Voiceless epiglottal fricative
ʢ Voiced epiglottal fricative
ʡ Epiglottal plosive

Affricates and double articulations can be represented by two symbols joined by a tie bar if necessary. t͡s k͡p

DIACRITICS Some diacritics may be placed above a symbol with a descender, e.g. n̥ŋ̊

◌̥ Voiceless	n̥ d̥	◌̤ Breathy voiced	b̤ a̤	◌̪ Dental	t̪ d̪
◌̬ Voiced	s̬ t̬	◌̰ Creaky voiced	b̰ a̰	◌̺ Apical	t̺ d̺
◌ʰ Aspirated	tʰ dʰ	◌̼ Linguolabial	t̼ d̼	◌̻ Laminal	t̻ d̻
◌̹ More rounded	ɔ̹	◌ʷ Labialized	tʷ dʷ	◌̃ Nasalized	ẽ
◌̜ Less rounded	ɔ̜	◌ʲ Palatalized	tʲ dʲ	◌ⁿ Nasal release	dⁿ
◌̟ Advanced	u̟	◌ˠ Velarized	tˠ dˠ	◌ˡ Lateral release	dˡ
◌̠ Retracted	e̠	◌ˤ Pharyngealized	tˤ dˤ	◌̚ No audible release	d̚
◌̈ Centralized	ë	◌̴ Velarized or pharyngealized	ɫ		
◌̽ Mid-centralized	e̽	◌̝ Raised	e̝ (ɹ̝ = voiced alveolar fricative)		
◌̩ Syllabic	n̩	◌̞ Lowered	e̞ (β̞ = voiced bilabial approximant)		
◌̯ Non-syllabic	e̯	◌̘ Advanced Tongue Root	e̘		
◌˞ Rhoticity	ɚ a˞	◌̙ Retracted Tongue Root	e̙		

VOWELS

Where symbols appear in pairs, the one to the right represents a rounded vowel.

SUPRASEGMENTALS

ˈ Primary stress ˌfoʊnəˈtɪʃən
ˌ Secondary stress
ː Long eː
ˑ Half-long eˑ
◌̆ Extra-short ĕ
| Minor (foot) group
‖ Major (intonation) group
. Syllable break ɹi.ækt
‿ Linking (absence of a break)

TONES AND WORD ACCENTS

LEVEL		CONTOUR	
e̋ or ˥	Extra high	ě or ˧˥	Rising
é ˦	High	ê ˥˩	Falling
ē ˧	Mid	e᷄ ˧˦	High rising
è ˨	Low	e᷅ ˨˩	Low rising
ȅ ˩	Extra low	e᷈ ˩˨	Rising-falling
↓	Downstep	↗	Global rise
↑	Upstep	↘	Global fall

Typefaces: Doulos SIL (metatext); Doulos SIL, IPA Kiel, IPA LS Uni (symbols)

Regular Expressions-I

The method developed by Kleene in 1956 to find a character string in a text is called the regular expressions method.
Today, this method is used in

- search engines,
- word processing programs,
- operating systems and
- some programming languages.

In a text using regular expressions;

- a letter or character,
- to a string of letters and characters

accessible.

Regular expressions have been developed for alphabets based on the Latin alphabet. Regular expressions operate on the numerical equivalents of letters and characters when searching in text.
For example:
A: 65, a: 148, B:66, b: 149, ğ: 167, Ğ: 166, İ: 152, ş: 159, Ş: 158,

0: 48, 1: 49, +: 43, -: 45 space: 32.

Regular Expressions-II

Usual character maching

Searched pattern	text and matching part	explanation
e	Eren ekmek getirdi mi?	matched the first ‘e’
?	Eren ekmek getirdi mi?	matched the first ‘?’
ekmek	Eren ekmek getirdi mi?	matched the first ‘ekmek’
getir	Eren ekmek getirdi mi?	matched the first ‘getir’
getirdi mi	Eren ekmek getirdi mi?	matched the first ‘getirdi mi’

Matching characters in a set

Searched pattern	text and matching part	explanation
[eE]ren	Eren ekmek getirdi mi?	matched the first ‘e’ or ‘E’ rest ‘ren’
[rnk]	Eren ekmek getirdi mi?	matched the first ‘r’ in set r,n,k
[0123456789]	Eren 3 ekmek getirdi mi?	matched the ‘3’
l[ea]r	Erenler geldi mi?	matched the plural suffix ‘ler’ or ‘lar’

Exclusion characters in a set

Searched pattern	text and matching part	explanation
[^A-Z]	Eren ekmek getirdi mi?	First letter other than capital letters matched
[^?]	Eren ekmek getirdi mi?	First letter other than ? matched
[^Ee]	Eren ekmek getirdi mi?	First letter other than ‘E’ and ‘e’ matched
[^\.]	E. Çalışkan dün geldi.	First letter other than ‘.’matched

Regular Expressions-III

Separation of Patterns

Searched pattern	text and matching part	Explanation
(ler)|(lar)	Erenler ekmek getirdi mi?	only 'ler' or 'lar' can match
e|k	Eren ekmek getirdi mi?	only 'ek' can match

Optional match

Searched pattern	text and matching part	explanation
kalemi?	kalem veya kalemi	Do not care the character 'i' before '?'
omu?zu	omzu veya omuzu	Do not care the character 'u' before '?'
A[nm]bar	Anbar veya ambar	
Çiçek(ler)?	çiçek veya çiçekler	

Positive Ending

Searched pattern	text and matching part	explanation
buraya+	buraya veya burayaa veya burayaaa	Deletes or repeats the character before +
bura[ya]+	buraa veya buraya veya buraay	Deletes or repeats the pattern preceding the +
(buraya)+	buraya veya burayaburaya	Deletes or repeats the pattern preceding the +

Kleene Ending

Searched pattern	text and matching part	explanation
Buraya*	buraya veya burayaa veya burayaaa	Deletes or repeats the character before *
bura[ya]*	buraa veya buraya veya buraay	Deletes or repeats the pattern preceding the *
(buraya)*	buraya veya burayaburaya	Deletes or repeats the pattern preceding the *

Two Level Presentation

Chomsky introduced 'Transformational Generative Grammar' (Productive Grammar) in 1957, Chomsky's aim, working on the relations between natural languages and computer science, can be summarized as investigating the usability of formal languages in modeling syntax of natural languages. As a result of these studies, he showed that syntax of natural languages can be modeled with finite state language. This method suggested for syntax may not be considered valid for phonology. However, Jonson and K. Koskenniemi have applied finite state tools to phonology.

It is clear that Koskenniemi developed the two-level notation method for the agglutinative language Finnish. Therefore, the method is important for agglutinative languages. The two-level representation includes two components:

- Rule component: Consists of the phonology rules of the language represented in the finite state form.
- Lexicon component : It is the lexicon of the language and consists of root and stems (main word), affixes, ordering rules of affixes and the class of the words.

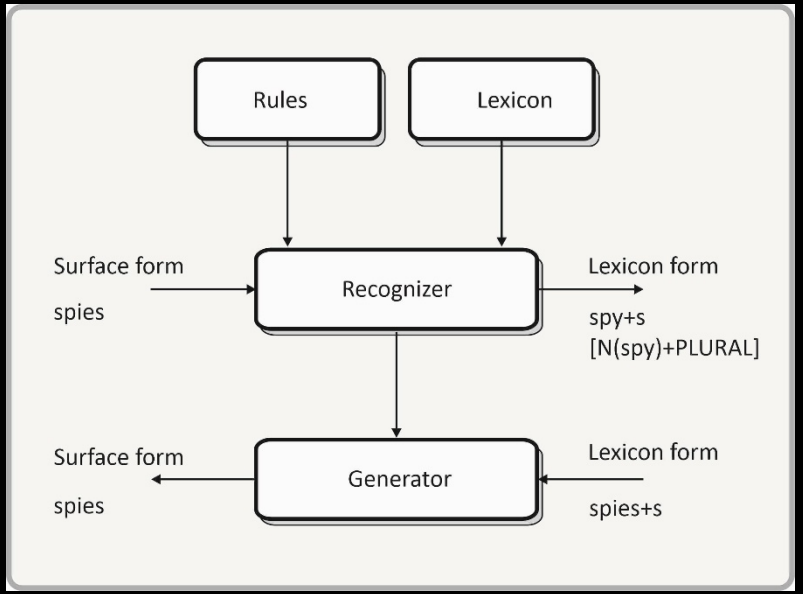
Rules of Two Level Presentation

a:b < c_d This rule is also known as the coercion rule, and it says that in the context of c_d (media or content that starts with c and ends with d), a will always be met as b.

a:b > c_d This rule is also known as the crestriction rule and says that only in the c_d context a can be met as b.

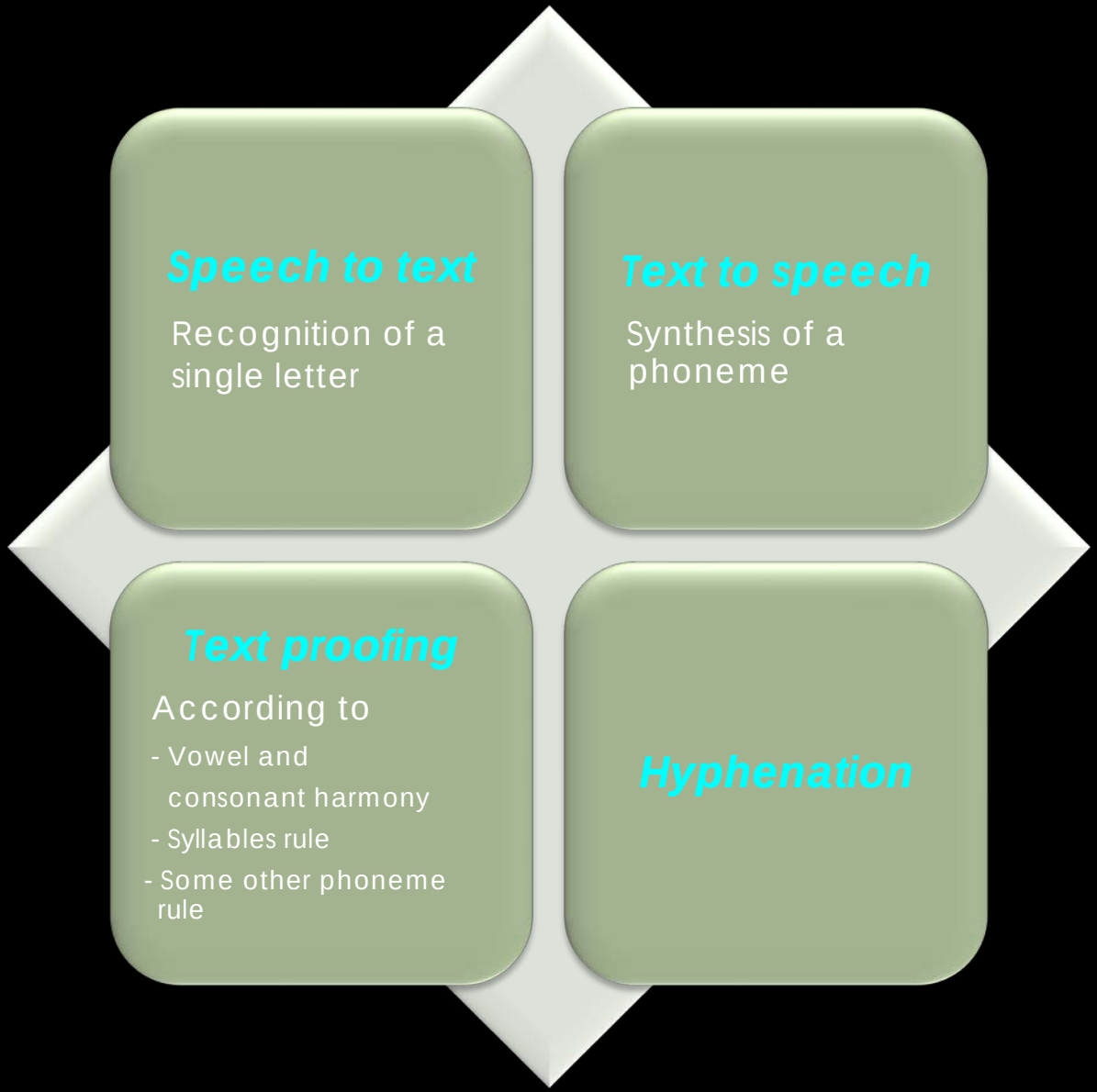
a:b <> c_d This rule is also known as the composite rule, and it says that in the c_d context, a should always be met as b, otherwise it should not be met.

a:b / c_d This rule is also known as the exclusion rule and says that a can never be met as b in the c_d context.



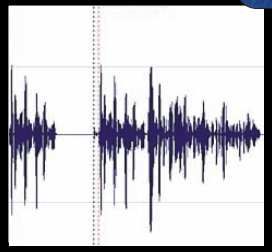
PC_KIMMO

Where We Use Phonology



Speech to Text Phonology -STT

- A STT system converts the speech signal into words
- The recognized words can be
  - The final output, or
  - The input to natural language processing



Speech Signal

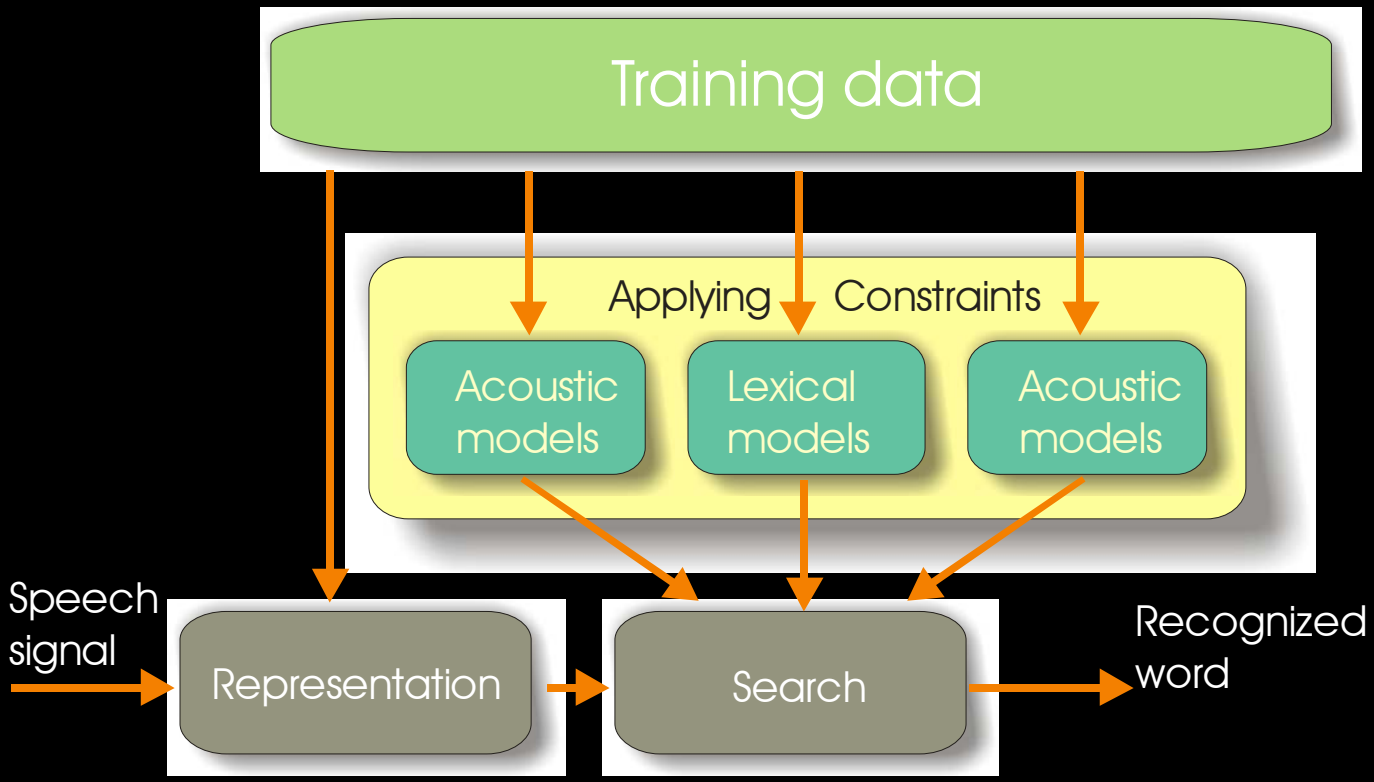
Automatic Speech Recognition System ASR

HELLO

Recognized word

Speech Recognition System

Speech recognition is the problem of deciding on
- How to *represent the signal*
- How to *model the constraints*
- How to *search for the most optimal answer*



Application Area of STT and Challenges

Applications

- Mostly input *(recognition only)*
  - Simple command and control
  - Simple data entry (over the phone)
  - Dictation
- Interactive conversation *(understanding needed)*
  - Information kiosks
  - Transactional processing
  - Intelligent agents

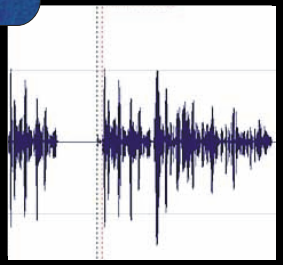
Challenges

- Co-articulation *(clear pronunciation)*
- Speaker independence
  - Dialect variations
  - Non-native speakers
- Spontaneous speech
  - Disfluencies
  - Out-of-vocabulary words
- Language modelling
- Noise robustness

Text to Speech - TTS

An TTS system converts the text into sound signals

Sound System

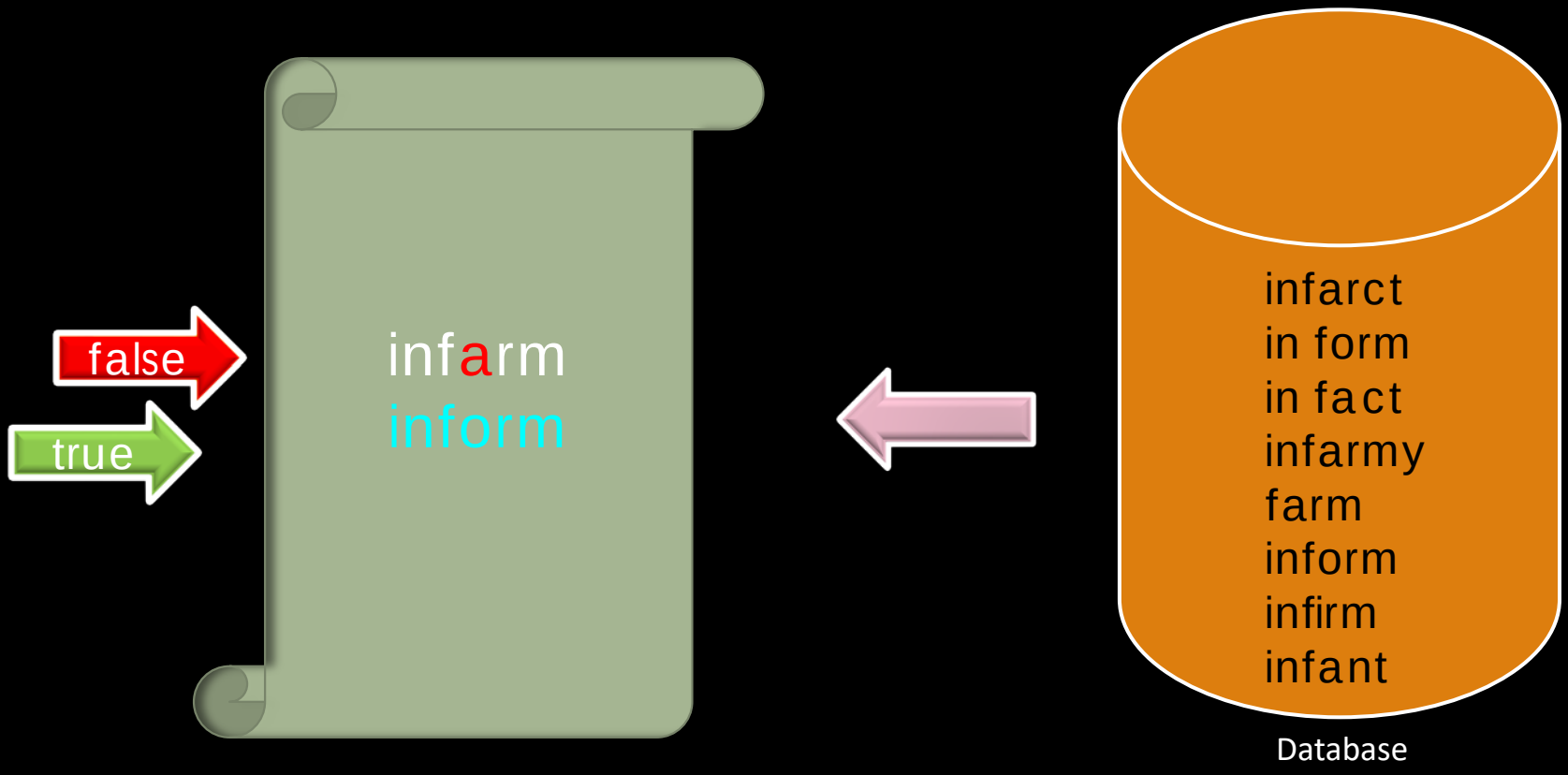


Text Proofing - I

Spelling

Some language do not have concrete rules such as

- Vowel and consonant harmony
- Syllables rule



Edit Distance

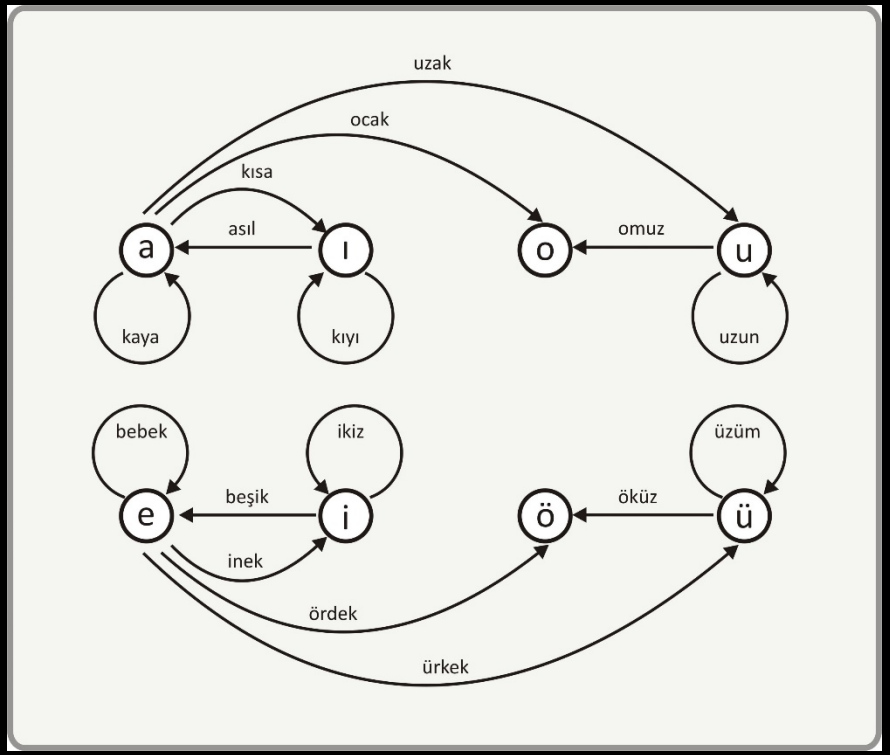
i	n	f	a	r	c	t		5/7
i	n		f	o	r	m		2/7
i	n		f	a	c	t		2/7
i	n	f	a	r	m	y		6/7
f	a	r	m					0/4
i	n	f	o	r	m			6/6
i	n	f	i	r	m			5/6
i	n	f	a	n	t			3/6
i	n	f	o	r	m	a	l	6/8

Text Proofing - II

Some language have concrete rules such as

- Vowel and consonant harmony
- Syllables rule

kelebakler
kelebekler



"a" cannot come after "e"
Therefore "a" may be either "e" or "i"
Probability of "e" is higher then "i"

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