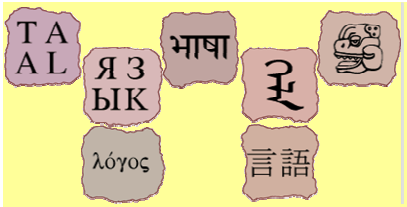
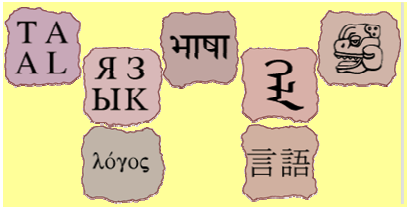


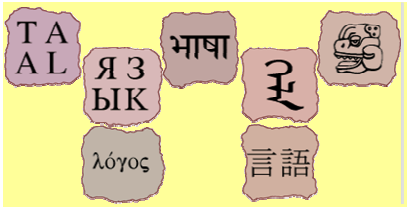
Speech Sounds

Introduction to Linguistics for Computational Linguists



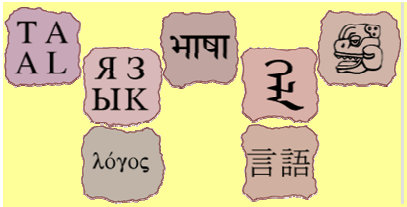
Speech Sounds

- Phonetics - Physical basis of speech sounds
  - Physiology of pronunciation, perception
  - Acoustics of speech sounds
- Phonology - Patterns of combination of speech sounds
  - Which sequences are allowed (phonotactics)
  - Effects of context on speech



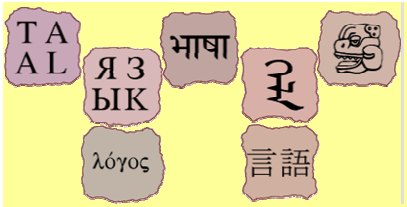
Design Problem

- 10^4 -10^5 words in vocabulary
  - Compare to animal systems << 100
- "Open" system -- new items added easily
- Rapid learning: 10 year-old has 40K items
  - 11 new words daily
  - Some learned after a single experience
- Problem: how can all this be learned?



Large, Learnable Symbol Set

- 40K independent symbols would be unlearnable.
- Solution:
  - No direct pairing of pronunciation-meaning
  - Symbols are combinations of small set of discrete elements
  - Rules of combination are general -- independent of the meaning of the sign
  - Combination rules learned through entire experience



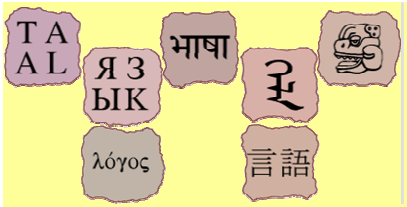
Miller's "Exponential Principle"

- Small set of discrete elements combine into large numbers of strings
  - consider (very simple!) language with 8 cons., 5 vowels, syllables only in form CV, words with 4 syllables

    CV. CV.CV.CV

    $8 \times 5 \times \ \ldots \ \times 8 \times 5 = 40^4 = 2{,}560{,}000$ words

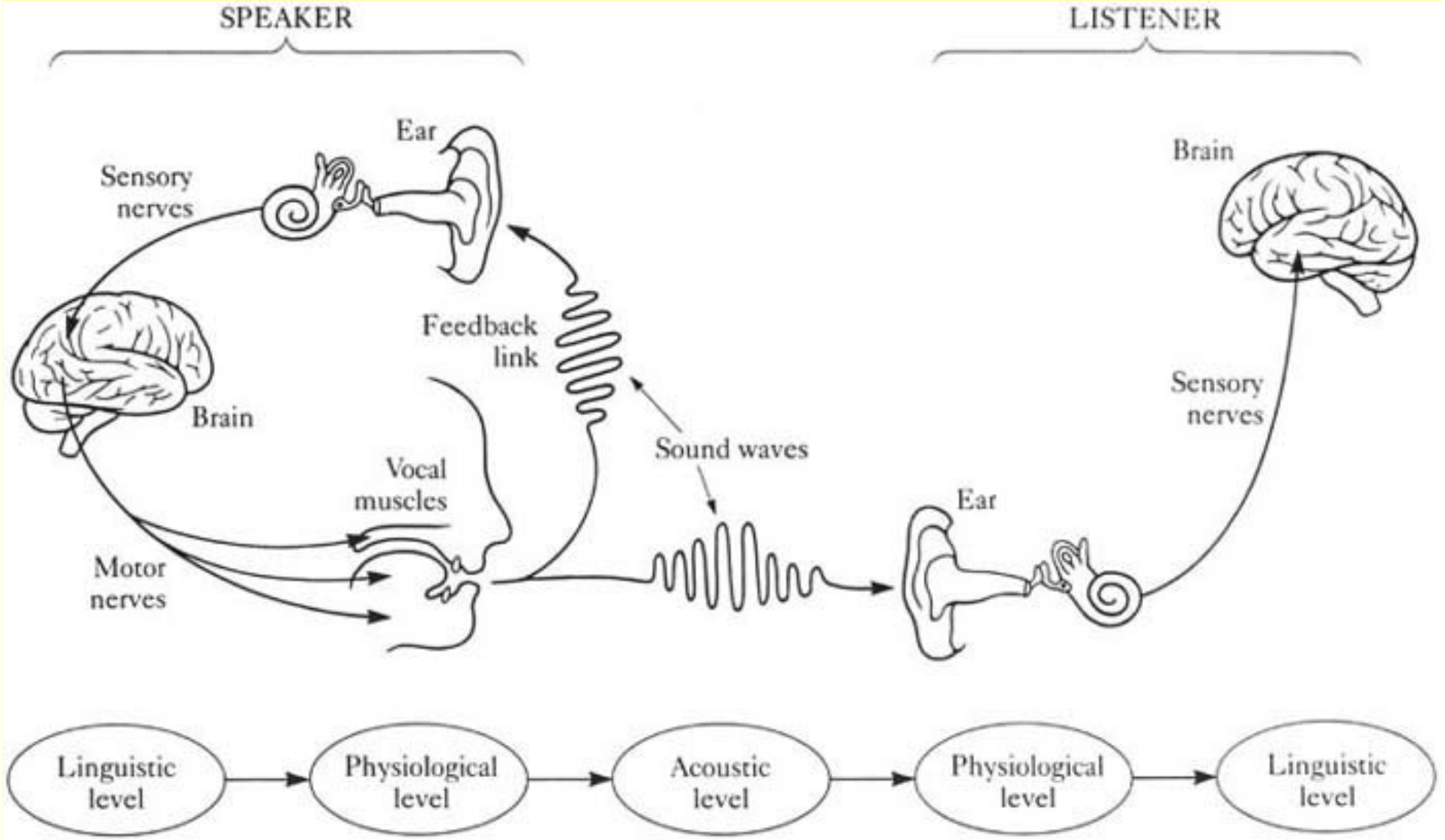
- Symbols created through combination

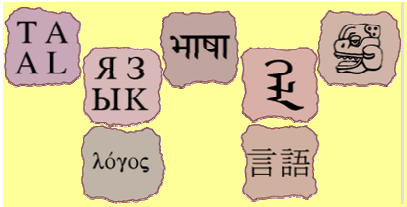


Phonology

- Elements (8 consonants, 5 vowels) are *phonemes*.
- *Syllables* (only in form CV) are one form of organizing principle.
- Organizing (phonological) principles are neuropsychology
- Physical (phonetic) encoding/decoding is physical/physiological

Speech Chain

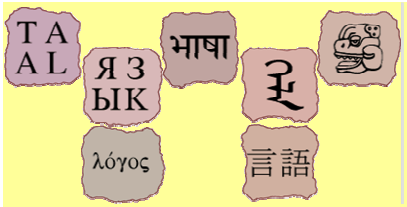




Speech Organs

- "Second-Hand Use"

Organ	Primary	Speech
Lungs	Breath	Power
Vocal Folds	Protection, Rigidity	Fluid -> Acoustic Conversion
Tongue	Digestion	Fine Resonance
Lips, Teeth	Chewing	Resonance



“Buzz, Hiss, Pop”

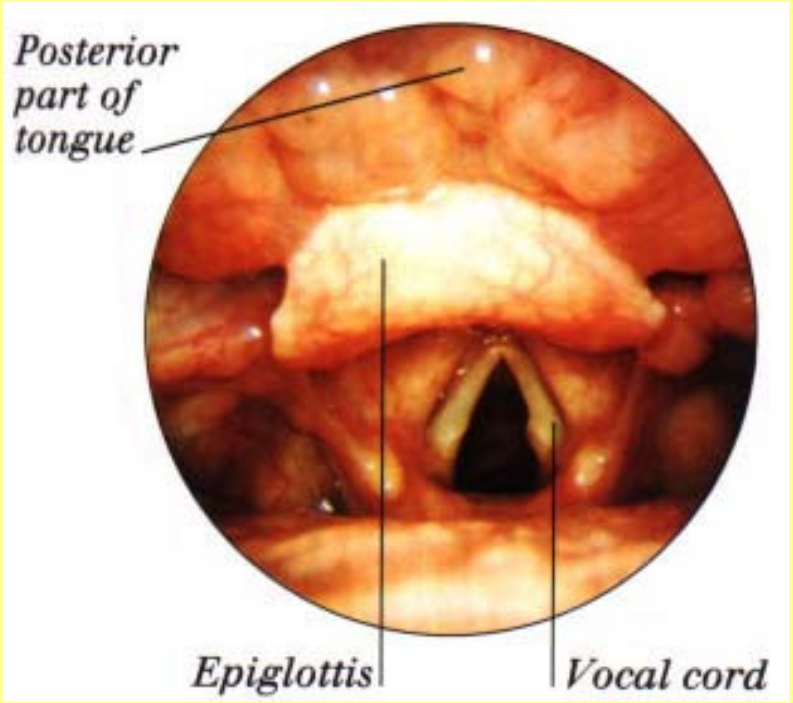
- Speech sounds mostly can be described as
  - buzz of air through larynx
  - hiss of air through tight passageway ([s])
  - pop of air after pressure build-up ([p])
- Often in combination

Speech Breathing

- Every syllable powered by muscle contraction (intracostal muscles between ribs)
- 80/20 exhalation/inhalation (vs. 60/40 during quiet breathing)
- Flow of air through *larynx* may result in *voicing* (buzz of vibration)
  - compare [s] vs. [z], [f] vs. [v]
  - listen / fingers on larynx / fingers in ears

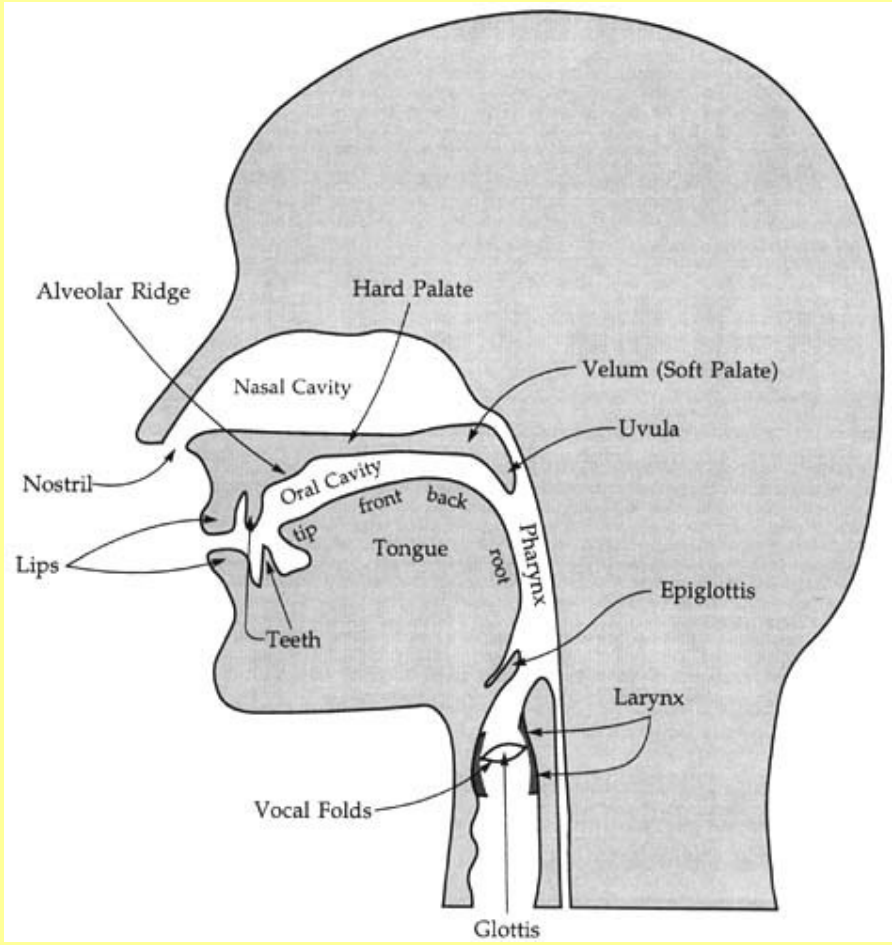
Laryngeal “Buzz”

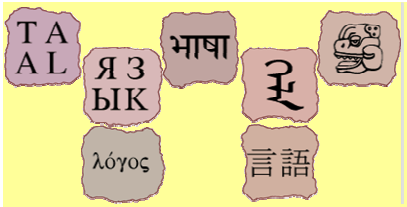
- “Adam’s Apple” at top of *trachea* (windpipe)
- Contain *vocal folds* (cords) that vibrate if close
- Bernoulli effect causes fast opening & shutting (compare “rasberry”).
- Regular vibration results in a perceptible tone.



Shaping the Buzz

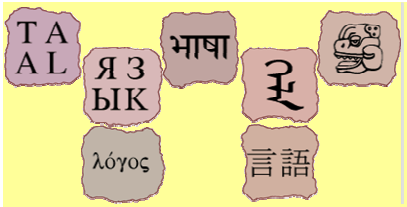
- Tongue tip, front/blade, back, root
- Lips, teeth, alveolar ridge, palate, velum, uvula
- Velum controls passage to nasal cavities





Bell's Visible Speech

- Melville Bell invented a system for transcribing speech "Visible Speech"
- Tool for teaching deaf children
  - But first system for recording sounds exactly
- 1860's lecture tour of Bell's boys -- Melville, Edward & Alexander.
  - One brother leaves room (out of earshot)
  - Volunteers solicited for interesting speech, transcribed
  - Brother returns and repeats on basis of transcription

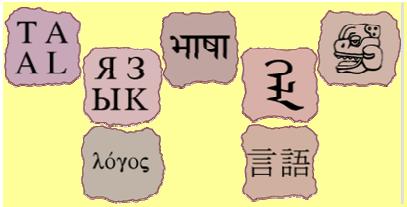


IPA

- One of Bell's boys went on to invent the telephone
- Visible speech evolved into the *International Phonetic Alphabet*, standard for phonetic transcription.
- Enough here to transcribe standard German
- Transcriptions in brackets [ˈbræ.kɛts]

Hiss of Fricatives

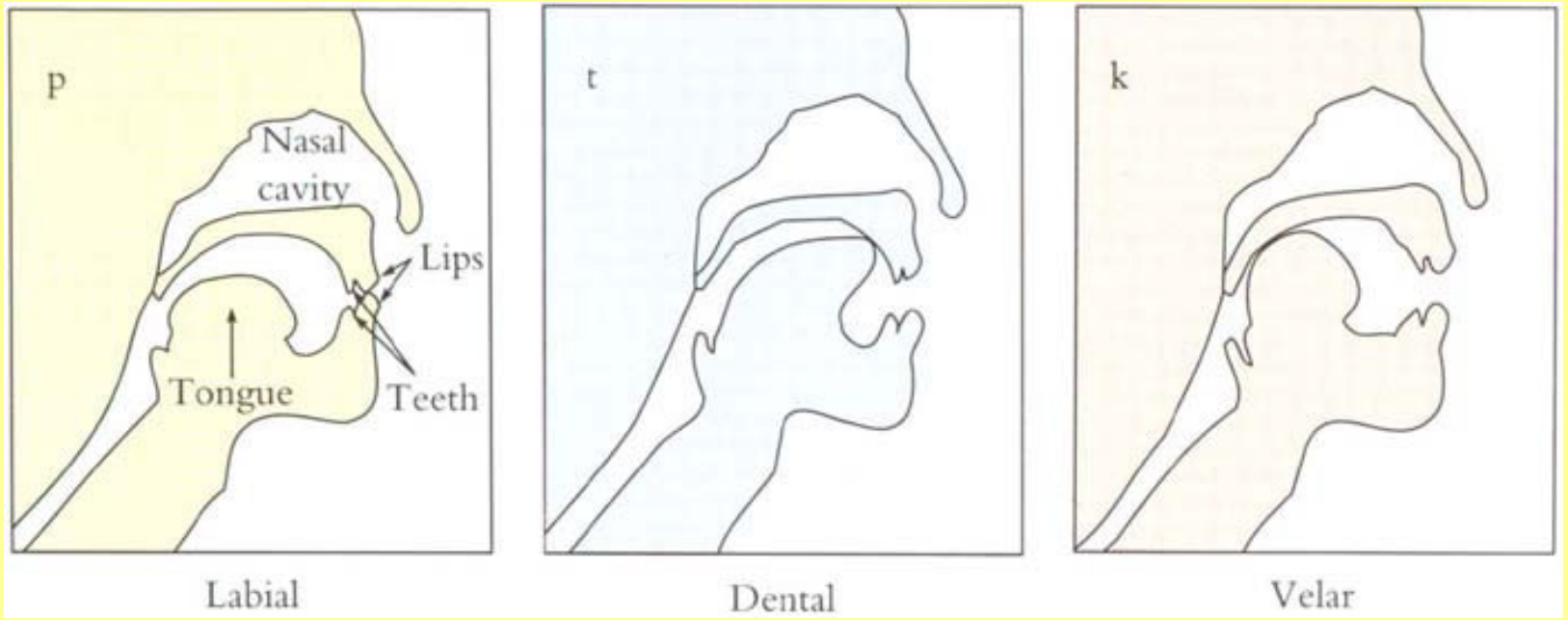
- Turbulent flow past a narrow constriction produces a *hiss* of *frication*
- Present initially in *Fuß* [f], *Wut* [v], *Hut* [h], medially in *lassen* [s], *lasen* [z], *laschen* [ʃ], *lachen* [χ]
- In foreign words a voiced version of [ʃ]: *Journal* [ʒ]



“Pop” of Pressure Release

- When air flow is stopped and then suddenly released, we hear a “pop”
- These are *stop* consonants aka *plosives*
- Initially in *Pass* [p], *Bass* [b], *Tasse* [t], dass [d], *Kasse* [k], *Gasse* [g]
- Also (in German) before initial vowels *As* [ʔ]

Place of Maximal Constriction



- Stops differ in *where* they block flow
  - Velum closed (nonnasal); raised would be [m,n,ŋ]
- Fricatives likewise [f,v], [s,z], [χ], and [h]

(Too Many) Consonants

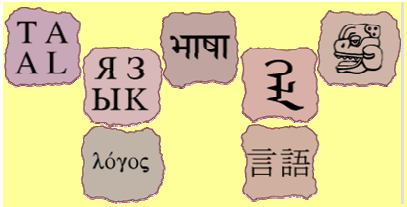
THE INTERNATIONAL PHONETIC ALPHABET (revised to 1993)

CONSONANTS (PULMONIC)

	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				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			

Where symbols appear in pairs, the one to the right represents a voiced consonant. Shaded areas denote articulations judged impossible.

- Standard German /r/ is uvular [R]; Bavarian alveolar [r]
- Affricates are stop + fricative (in one phoneme)
  - *Pfennig* [pf], *Zeit* [ts]
- *Los* [l] is *alveolar lateral*



Vowels

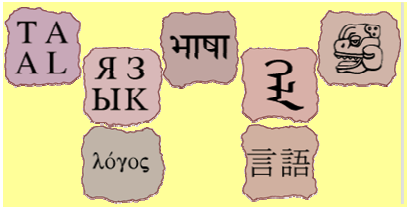
- Vowels involve no constriction of air flow
- More fluid, variable than consonants
- But still a limited set of discrete elements
- Good way to see this is to collect the set of vowels

Lexical Set

- [i] Siehe, Biene, Glied
- [y] Bühne, Blüte, Kühe
- [I] bitte, Schimmel, Blitz
- [ʏ] müssen, füttern, Lücke
- [e] Lehne, nehmen, geben
- [ø] Stöhnen, Föhn, Söhne
- [ɛ] Wetter, besser, kess
- [œ] Löcher, können, Töpfer
- [æ] nähme, gäbe, täte
  - if distinctive from [e:]

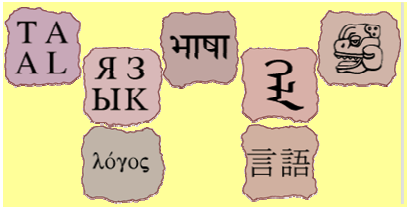
- [u] Huhn, Mut, Kuh
- [ʊ] Mutter, plus, Kuss
- [o] Sohn, Pfote, los
- [ɔ] Motte, Topf, Sonne
- [a] kahl, Aachen, Raten
- [ɐ] Ball, lachen, Ratten

- [au] Haus, Trauben, Couch
- [ai] heiser, mein, leicht
- [ɔI] Häuser, Reue, Meute



More on Vowels

- [ə] unstressed neutral vowel
  - *Lieb**e**, g**e**nau, all**e**mal*
- Lots of dialect variation
  - e.g., Bavarian [iɛ] ***ie**b*
- *Pure* vowels can be extended in pronunciation, while *diphthongs* involved a change
  - [i,I,u,y,..] vs. [au,ai,ɔI]



Relative Properties

Front

- [i] Siehe, Biene, Glied
- [y] Bühne, Blüte, Kühe
- [I] bitte, Schimmel, Blitz
- [ʏ] müssen, füttern, Lücke
- [e] Lehne, nehmen, geben
- [ø] Stöhnen, Föhn, Söhne
- [ɛ] Wetter, besser, kess
- [œ] Löcher, können, Töpfer
- [æ] nähme, gäbe, täte
  - if distinctive from [e:]

Back

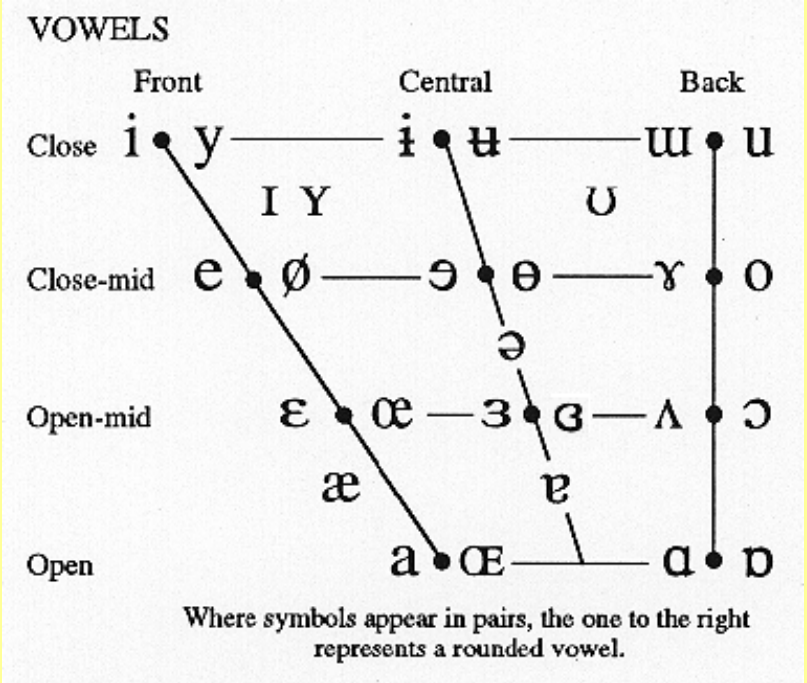
- [u] Huhn, Mut, Kuh
- [ʊ] Mutter, plus, Kuss
- [o] Sohn, Pfote, los
- [ɔ] Motte, Topf, Sonne

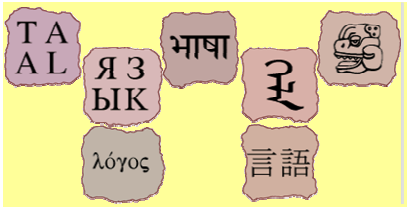
Central

- [a] kahl, Aachen, Raten
- [ɐ] Ball, lachen, Ratten
- [au] Haus, Trauben, Couch
- [ai] heiser, mein, leicht
- [ɔI] Häuser, Reue, Meute

Relations

- Front/Back
  - [i,I,y,ʏ,e,ø,ɛ,œ,æ] Front
  - [u,ʊ,o,ɔ] Back
  - [a,ɐ] Central
- Close/Open (High/Low)
  - [i,I,y,ʏ,u,ʊ] Close
  - [e,ø,o,ɘ] Close-Mid
  - [ɛ,œ,ɔ,ɐ] Open-Mid
  - [æ,a] Open
- Round
  - [y,ʏ,ø,œ] and all back vowels





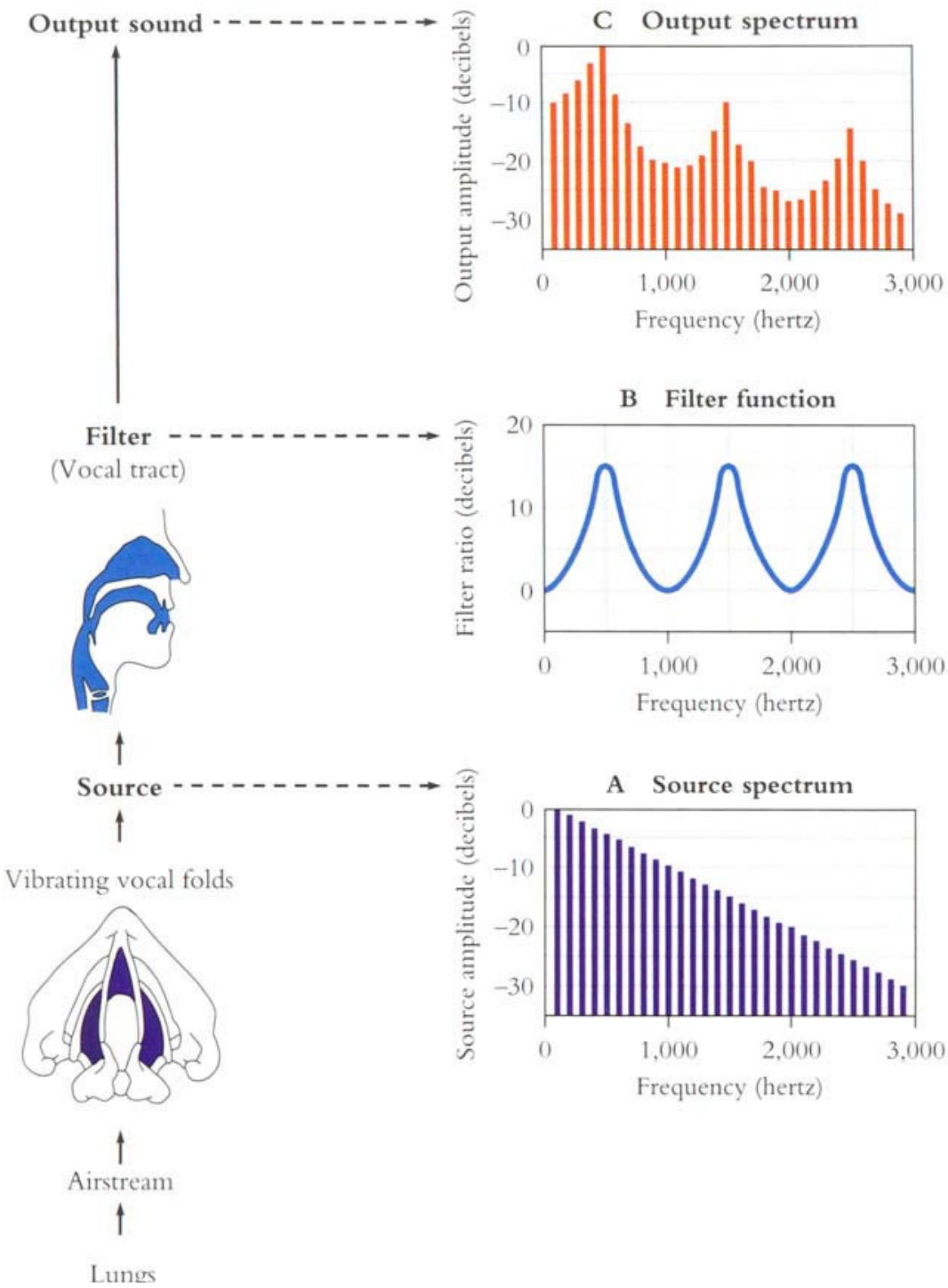
The Sounds Produced

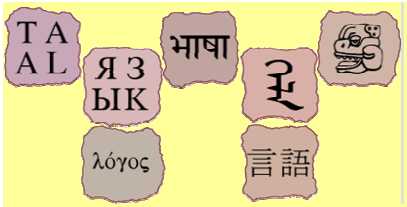
- Source -- Buzz, Hiss, Pop
- Filter -- Resonance of Oral Cavity
- Source/Filter -- Guitar String/Body

- Example: Vocal folds vibrating at 100 Hz produce harmonics (overtones) at 200, 300, 400, etc. (but with decreasing strength). Mouth and nose strengthen some frequencies, dampen others.

Müller's 'Source-Filter Theory of Voice Production'

--From G.Miller's *The Science of Words*



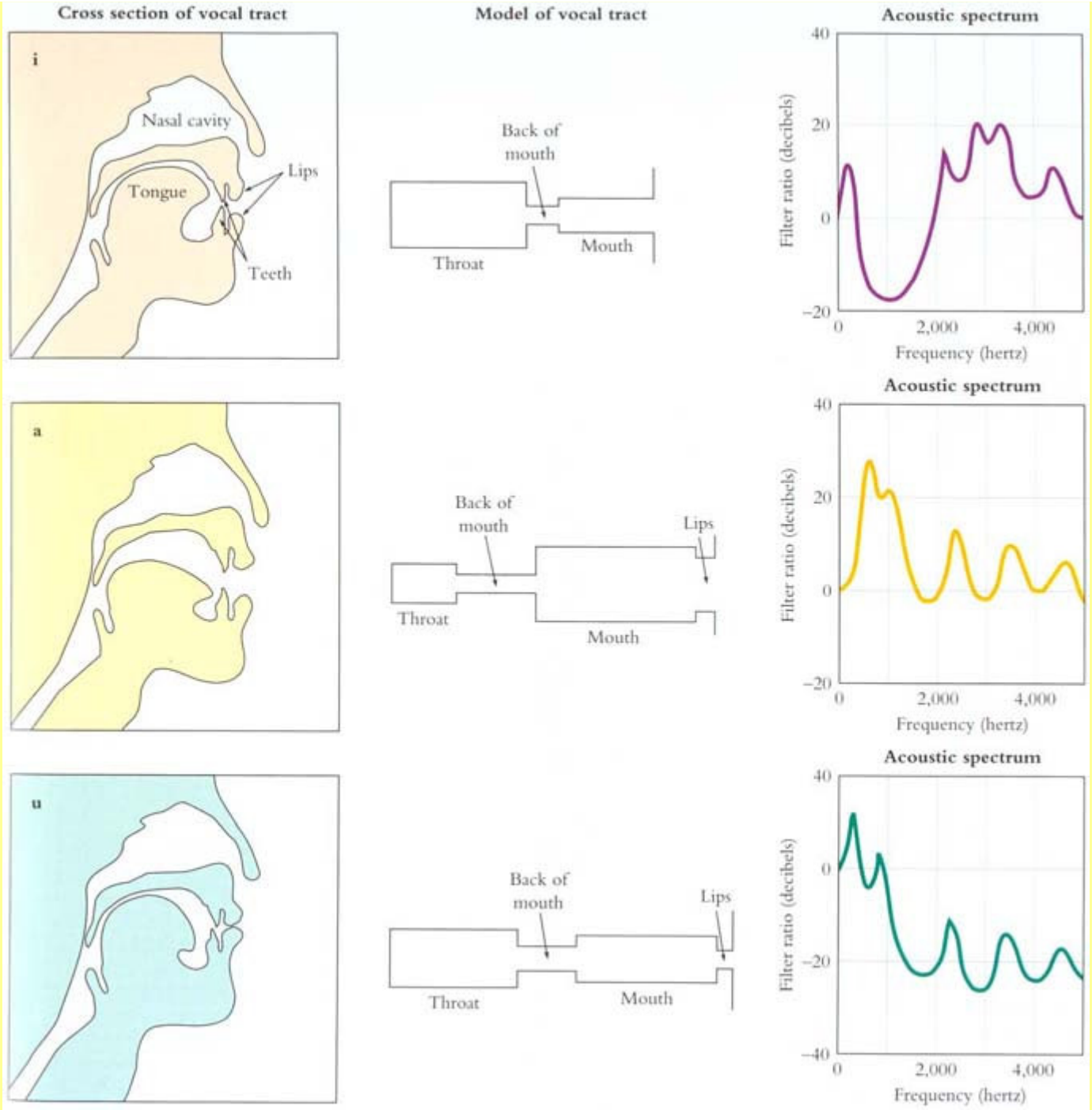


Role of Articulators

- *Articulators* -- organs that shape sound
- Tongue, lips, palate, velum
- Role -- filter that strengthens some frequencies, dampen others

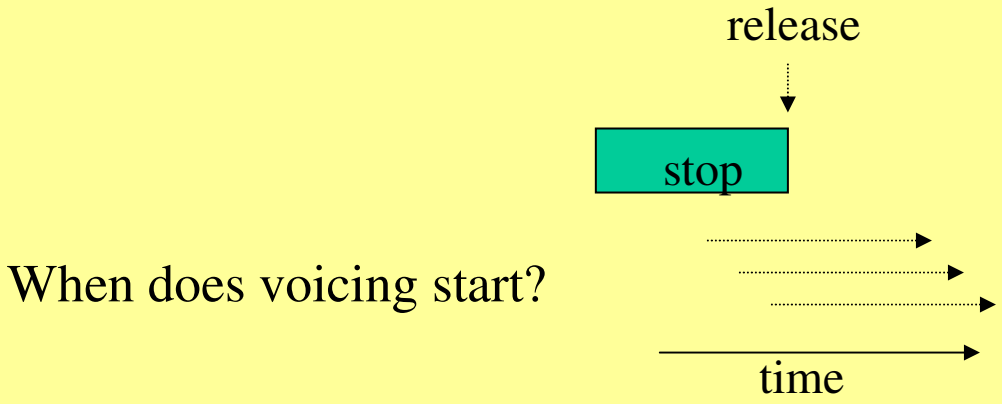
- Formants - characteristic resonant frequencies of vowels, caused by configuration of articulators

3 filters on spectra
--Miller



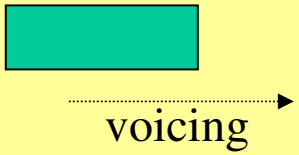
Voicing in Consonants

- [p/b, t/d, k/g] distinguished by voicing
  - stops build pressure above larynx
- Voice Onset Time (VOT) is start of vocal cord vibration relative to stop release

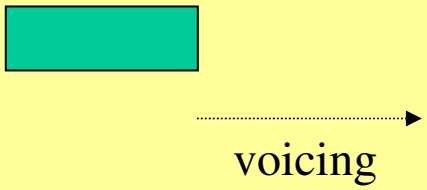


Stop + Vowel

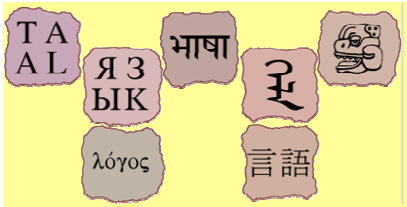
- Prevoicing (French, Russian [b,d,g])



- Unaspirated (French, Russian [p,t,k], German, English [b,d,g])

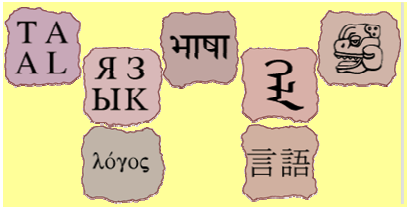


- Aspirated (German, English [p,t,k]) -- note puff!



Voicing Across Languages

- Few languages distinguish three levels of voicing, but, e.g., Thai does
- Most distinguish two levels
  - voiced/unvoiced
  - always adjacent VOT types
    - either prevoiced vs. unaspirated
      - Dutch, Yiddish among Germanic languages
    - of unaspirated vs. aspirated



Phonetics - Summary

- Phonetics - physical basis of speech sounds
- Design problem: provide extendible, learnable symbol set of size 10^5
  - Soln: small set of phonemes in different orders
- Written via visible speech, IPA
- Production has source and filter
  - Example: vowels' source - vocal fold vibration, filter - resonance of oral cavity