

## Formal and Computational Approaches to Phonology

Monday: Introduction; Generative Phonology

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## Phonology and Phonetics

*Phonetics* is the study of the sounds of speech: how they're made, what they sound like (to instruments), what they're perceived as (by us).

*Phonology* is the study of the ways in which the sounds of speech are organized into a code; and of the changes that happen to such codes.

Phonetics deals in continua, and arranges them into convenient labelled regions for notational purposes; phonology takes the labelled regions and makes them abstract symbols in a finite system.

(Where's the boundary? Is phonology really discrete?)

## Outline of the week

Today: review of basic phonetics and phonology, from structuralism to generativism. Computational aspects of generative theories.

Tuesday: Optimality Theory. Introduction to the framework, and problems of the theory. Expressivity, implementations.

Wednesday: Lower level modelling: the emergence of phonology. (de Boer)

Thursday: Maximum entropy phonotactics. (Hayes and Wilson)

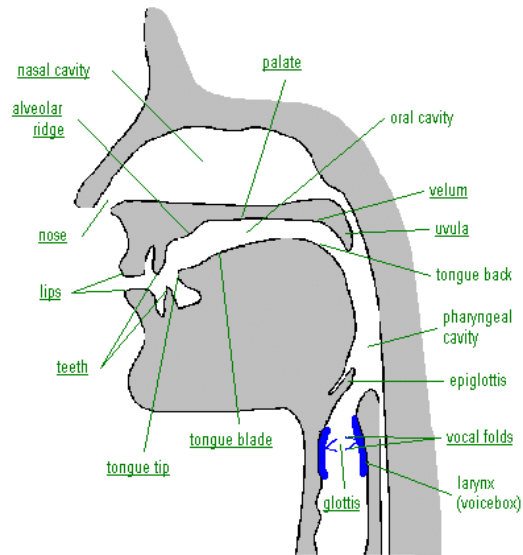
Friday: Auditory dispersion and change. (Boersma and Hamann)

## The landscape we have to deal with

A quick survey of the kinds of sounds and contrasts humans use ...

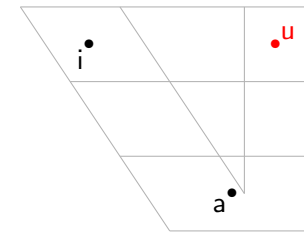
(Canonical reference: Peter Ladefoged and Ian Maddieson, *The Sounds of the World's Languages*), with 80GB of recordings at <http://archive.phonetics.ucla.edu/>

## Speech Organs



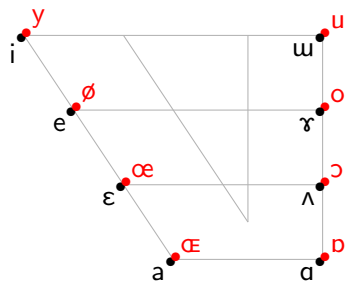
(Diagram: Summer Institute of Linguistics)

## 3 vowel system



Many Australian languages.

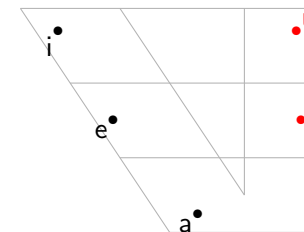
## Vowels



Phonetically, these symbols denote *cardinal* vowels. Phonologically, they're used to denote some vowel phoneme that is phonetically near the cardinal.

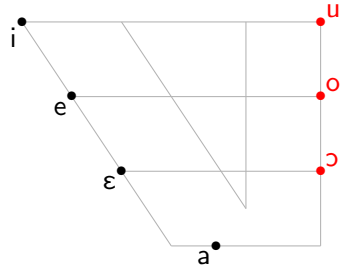
Most languages distinguish short vowels (e.g. /a/) from long vowels (e.g. /a:/) – long vowels typically 50% longer. Some (e.g. Dinka) distinguish three lengths.

## 5 vowel system



Latin (with long vowels), Spanish, Modern Greek, many others.

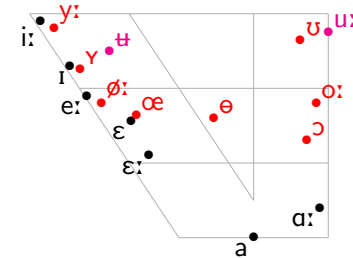
## 7 vowel system



Standard Italian

## Swedish vowels

*sil hel bot*  
*sill häl bott*  
*syl häll mål*  
*syll nött moll*  
*ful nött mat*  
*full matt*

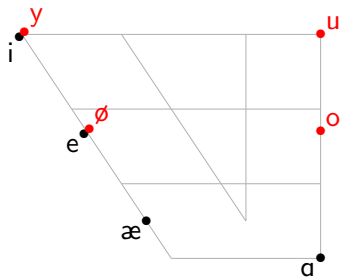


Swedish has a large number of vowels crammed into the high front area. [play all]

The use of a three-way lip-rounding distinction is (almost?) unique.

Data: O. Engstrand, *JIPA* 20(1) 42–44

## 8 vowel system



Finnish (written *i, y, e, ø, ä, a, o, u*).

Finnish has **vowel harmony**: /y/-/u/, /ø/-/o/, /æ/-/ɑ/ form front–back pairs, and a word contains only front vowels or only back vowels, together with /i/ and /e/.

All the 46 diphthongs allowed by vowel harmony exist.

## Bells and whistles: creak, murmur etc.

There are many ways of adding a distinctive quality to a vowel:  
**Nasalization** is widely used (French, Portuguese, Hindi, many others).

**Creaky voice (laryngealization, glottalization)** is part of tones in some (South-East) Asian languages; used in many American languages; and in Danish.

**Breathy voice (murmur)** used in many African and American languages, and Gujarati.

**Pharyngealization** used in African and American languages.

**Advanced Tongue Root (ATR)** is a feature of many central African languages.

## Consonants

are formed by obstructing, wholly or partly, the air stream.  
Traditionally classified by:

*place*: where is the obstruction/constriction? E.g. tongue-tip or back of tongue ([t] vs [k]).

*manner*: how is the obstruction made? E.g. complete block, constriction, almost no constriction, trill, etc.

other aspects: voicing, secondary articulations.

## Voicing and friends

Many (not all) languages distinguish /p/ from /b/, /t/ from /d/, /k/ from /g/, etc. Often phonetically described by *voice onset time*: when you start vocal cord vibration relative to the release of the stop closure.

Many languages distinguish voiced, voiceless and aspirated: typical VOT values initially: -30 ms (voiced: French /b/), 0 to 20 ms (voiceless: French /p/, English /b/), 100 ms (aspirated: English /p/).

Some languages use *breathy voice* to produce 'voiced aspirates'.  
E.g. Hindi [p] [p<sup>h</sup>] [b] [b<sup>h</sup>]

(Are voicing and aspiration independent?)

Some use *creaky voice* to form another variant.

Some use *ejectives* [pʼ].

Some use voiced *implosives* [ɓ], and even voiceless implosives.

Some have aspiration *before* the stop closure.

## Some different places

*Bilabial* [p] occurs in almost all languages.

*Apico-* Made by the tip of the tongue against:

*-dental* [t̪]: teeth. Usually actually made with blade of tongue.  
French etc. /t/.

*-alveolar* [t]: alveolar ridge. English etc. /t/.

*retroflex* [ɭ]: curled up, even to hard palate. Hindi etc.

*lamino-* Made by the blade (front) of the tongue:

*-dental* [t̪]: against the teeth

*-palatal* [ç]: against the hard palate. E.g. Hungarian.

*dorso-* Made by the body or back of the tongue:

*-velar* [k]: against soft palate. almost all languages.

*-uvular* [q]: against uvula or back of soft palate. Arabic, Caucasian, African, etc.

The glottal stop [ʔ] – widely used, phonemically and phonetically.

## Other consonants

Voiced/voiceless *fricatives*: when the obstruction is not quite closed, but narrow enough to produce turbulent airflow: [ɸ/β] [f/v] [ç/ʝ] [x/χ] [χ/ç] [ħ/ʕ] [ħ/ʕ] [h/ɦ]

*Coronal* fricatives are particularly complex, and also phonologically active: [θ/ð] [s/z] [ʃ/ʒ] [ʂ/ʐ] [ʃ/ʒ] [ç/ʝ]. Some languages have four of these – but three is bad enough. Since we're in Poland:

*Approximants* don't have audible friction: [w,j] etc.

*Nasals* [m,n,ɲ,ŋ,ɳ]: every language has some.

*Rhotics* [r,r̄,R,R̄,ʀ] etc. (Just how are an Italian [r] and a Dutch [ʀ] similar?)

*Laterals* [l] etc.

*Clicks* [ǀ,ǁ,ǂ,ǃ] are remarkably rare.

## Chrząszcz, by Jan Brzechwa

W Szczebrzeszynie chrząszcz brzmi w trzcinie

[fʃtʂɛbʒɛʃɪɲɛ ɕʂɔũʃtʂ bʒmi ftʂtʂɪɲɛ]

In the town of Szczebrzeszyn a beetle buzzes in the reeds

I Szczebrzeszyn z tego słynie.

[iʃtʂɛbʒɛʃɪn stɛgɔ swɪɲɛ]

And Szczebrzeszyn is famous for it.

Wół go pyta: „Panie chrząszczu,

[vuw gɔ pɪta paɲɛ ɕʂɔũʃtʂu]

An ox asks him: “Mister beetle,

Po cóż pan tak brzęczy w gąszczu?”

[pɔ tsuʃ pan tak bʒɛntʂɪ vɡɔũʃtʂu]

What are you buzzing for in the bushes?”

and so on

Translation from Wikipedia; transcription adapted from Wikipedia

## Phonology

The job of phonology is to sort out how a language makes a system out of the wealth of possibilities we've just glanced quickly over.

Formal and computational approaches have a strong tendency to deal with easy languages . . . or English . . .

The core problems are when two 'sounds' are the same as far as the language is concerned, and how the resulting set of equivalence(?) classes is organized, and how and why it changes over times.

## Other consonants

Voiced/voiceless *fricatives*: when the obstruction is not quite closed, but narrow enough to produce turbulent airflow: [ɸ/β] [f/v] [ç/j] [x/χ] [χ/ç] [ħ/ʕ] [ħ/ʕ] [h/ħ]

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*Laterals* [l] etc.

*Clicks* [ʘ,!,|,||,‡] are remarkably rare.

## From 600 BC to AD 1950

Concept of *phoneme* implicit in Sanskrit grammars, and more implicitly in grammatical writings throughout. (Pāṇini also more or less invented BNF and re-write systems.)

Early 20th century: explicit definition of the *structuralist* phoneme: 'the smallest unit of sound which contrasts with another in a given language'.

Despite problems such as

- ▶ partial neutralization – archiphonemes etc.
- ▶ the need for phonetic similarity criterion (English ŋ/h)
- ▶ marginal phonemes (English ʒ, x)

the structuralist phoneme is embedded in the psyche of every linguist.

(Is it in the psyche of every language user?)

N.B. the defn presupposes 'unit of sound' . . . segment?

## Features

(Mainly) Jakobson introduced *features*: binary attributes of sounds, so each phonological sound is a vector of features, and distinct phonemes differ in at least one feature.

Originally mainly acoustic (e.g. *compact/diffuse*), nowadays often articulatory (e.g. *velar*).

Issues:

- ▶ binarity: not always obviously right ... e.g. /b, p, p<sup>h</sup>/
- ▶ equipollence vs privativity: does [–voice] have the same status as [+voice], or is only the *presence* of [voice] significant?
- ▶ incompatibility and redundancy: what's a dental velar? Do (middle) English /i/ and /u/ differ because of [round] or because of [front]? (Or the acoustic correlates thereof.)

Features widely used both descriptively and in theories (with a dip in the 1990s).

## Grammar[']s gone mental

*SPE* tried to explain not just phonology, but morphophonology. Your mental lexical entry (*underlying representation – UR*) for a word is essentially how it was pronounced in early Middle English – and the rules recapitulate the historical changes since then.

Is this insane? (Why stop at ME? Why not OE?)

For many years, the formalism of *SPE* dominated phonological writing. But few took the same broad approach of sweeping all morphophonology into the mental grammar. For most people, URs are very close to surface forms.

Currently, features are widely used as *representations*, but *SPE* rewriting is out of fashion as *computation*.

## Radical formalism: *SPE*

Chomsky and Halle's *Sound Pattern of English* threw away structuralist phonemes. Instead:

Phonology is abstract symbolic computation: 'units' in lexical entries are feature vectors, and are changed by re-write rules. Then they get turned into phonetics by an interpretation layer.

Example rewrite rule (20.III):

$$V \rightarrow [-\text{tense}] \quad / \quad \text{---} [+ \text{cons}] \begin{bmatrix} + \text{cons} \\ - \text{voc} \end{bmatrix}$$

"vowels become lax when before a consonant cluster the second of which is not a glide"

In *SPE*, /j/ and /w/ are both consonantal and vocalic; /l/ and /r/ are neither consonantal nor vocalic.

This accounts for *describe* ~ *description*, because later another rule will turn tense /i/ into /ai/.

## A question to ponder

As phonologists, are we:

1. just(!) trying to come up with a formal (mathematical, computational) model that correctly *describes* what happens; or
2. trying to understand the way in which *our brains process* language.

Phonologists quite often write as if (2), but when put to the question, say (1).

## Autosegmentalism

In the late 80s and 90s, autosegmental (Goldsmith) grammars arose. Different levels of phonology work in independent *tiers*, which come together by *associations*. Even in one 'level', e.g. phonemic, different features run concurrently on tiers.

Autosegmental theories include Government Phonology, Dependency Phonology and many other variants. They were the big thing until the sociological phenomenon that is Optimality Theory – see tomorrow.

## SPE in more detail – features

To analyse *SPE*, we need to be more precise about what it is.

We have a set of *features*. In intention, these are *universal*, enough to describe all languages. In practice, they are enough for the language in question; universalism is controversial, and even universalists are not sure what the universal set is.

The *SPE* features relevant to segmental sized *units* in English are:

**vocalic, consonantal, low, high, back, round, tense, nasal, anterior, coronal, continuant, delayed release, strident.**

There are various dependencies between these features, some of which are necessary (e.g. [+low]  $\Rightarrow$  [–high]), some of which are asserted to be universal, and some of which are language-specific.

## Computing with SPE

*SPE* is clearly a *transducer* which takes an input string of feature bundles and produces an output string.

How powerful is it? *Prima facie*, it has context-sensitive re-write rules. Context-sensitive grammars are very powerful . . . recall the **Chomsky hierarchy** of formal languages.

*But* everybody agrees that phonological phenomena are *regular*, both intuitively and in the CS sense; and probably less powerful than general regular transducers. (Would you believe a phonological rule that said '/a/  $\rightarrow$  [e] if followed by at least ten syllables not containing an /u/'?)

## Units – the alphabet of the system

The segments on which the rules operate are *partial* maps from the set of features to the values {+, –}; or alternatively, three-valued {+, –,  $\perp$ } vectors over the feature set. The rules are so arranged that the output segments are fully specified, that is, are feature vectors over {+, –}; but this is not a necessary consequence of the formalism.

So from a formal language viewpoint, we take the *alphabet* to be the set of (three-valued) feature vectors over the given feature set.

## The rules

As we saw, the rule notation is equivalent to the very general form:

$$\alpha\beta\gamma \rightarrow \alpha\delta\gamma$$

where the contexts  $\alpha$  and  $\gamma$  and the substituend  $\beta$  and substitute  $\delta$  are (possibly empty) strings.

Moreover, the rules are *schematic*: the symbols are not units, but classes such as V or [+cons,−voc]. This is understood by instantiating the scheme in all possible ways. Such schematic rules reduce exponentially the space required to represent the rule system; but they do not change the complexity of the class of transducers definable by such rule systems.

So, we still have full context-sensitive power . . . or do we?

## Rule ordering and cyclicity

Usual CS rewriting systems have *unordered rules*: any rule may apply at any point, if the input matches its LHS, and rules may apply repeatedly. (Thus the grammar  $ab \rightarrow aabb$  generates the language  $a^n b^n$  from  $ab$ .)

However, *SPE* rules are *ordered*  $R_1, \dots, R_n$ . The set may be applied in many cycles, but within each cycle, only in rule order.

Moreover, in all actual grammars using *SPE*, it is the case that a rule will never apply to its own output: that is, the substitute will never form part of the substituend for the same rule.

Johnson (and later and more accessibly Kaplan and Kay) showed that these restrictions are sufficient to make *SPE* grammars **equivalent to** regular transducers.

So, *SPE* phonology is finite automata; and the complexity of generating the surface from the UR is linear in the size of the surface form.