Introduction

Alexander Fraser
[fraser@cis.uni-muenchen.de]

CIS, Ludwig-Maximilians-Universität München

Computational Morphology and Electronic Dictionaries
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Outline

Outline

Acknowledgements 1

Some of the content of this lecture is based on previous lectures
by Marion Weller, Boris Haselbach, Özlem Çetinoğlu and Cerstin Mahlow.

Acknowledgements 2

- The first half of this slide set is mainly based on chapter 1 of Haspelmath, M. & Sims, A. D. (2010): *Understanding Morphology*, 2nd edition, London: Hodder Education.

Introduction

Words, words, words ...

- Words in natural languages encode many pieces of information
- What is the meaning of a word?
- How do words in a sentence interact with each other?
  - Subject/Verb agreement
  - Adjective/Noun agreement
  - ...
- What lexical category does a word belong to?
  - Noun (N)
  - Verb (V)
  - Adjective (A/ADJ)
  - ...
- What can we say about the internal structure of a word?
  - Determine the parts a complex word is composed of
  - Specify morphological features such as *number*, *gender*, *tense*, ...

- Morphology: the study of the **internal structure of words**
- Oldest sub-discipline of linguistics: for example well-structured lists of Sumerian words going back as far as 1600 BC
- The term *morphology* was invented in the 2nd half of the 19th century
- Terms for other sub-disciplines had existed for centuries at this point
  - *Phonology*: sound structure
  - *Syntax*: sentence structure

⇒ Thus, in this sense, morphology is also a young discipline

- Internal phonological structure:
  nuts consists of 4 phonogical segments [nʌts]
  - Generally, phonological segments such as [n], [t] have no specific meaning
  - Contrastive value: distinguishes *nuts* from *cuts*, *guts*, *nets*, *notes*, *nights*
- Variations in the shape of words often correlate systematically with **semantic changes**:
  - *nuts*, *nets*, *notes*, *nights* share a phonological element, the final [s]
  - also share the semantic component of referring to a multiplicity of entities from the same class
  - the words without the final [s] (*nut*, *net*, *note*, *night*) consistently refers to only one entity of the respective entity
  - in contrast: *blitz*, *box*, *lapse* do not refer to a multiplicity of entities; there are no related words **blit*, **bok*, **lap*

- Words like *nuts*: **morphologically complex words**
- Morphological analysis: The final [s] on the noun *nuts* expresses a plural meaning
- The final [s] in *lapse* does not have any meaning, and the word *lapse* has no morphological structure

⇒ **Morphological structure** exists groups of words show identical partial resemblances in both form and meaning

Definition 1

Morphology is the study of systematic covariation in the form and meaning of words.

- Semantically meaningful variation needs to occur systematically in groups of words
- Only two words with partial form-meaning resemblances may be merely accidental
  - Relation between *hear* and *ear*?
  - Conceivably, *h* could mean "use": *h-ear* → "use one's ear": *hear*
  - But this is the only word pair of this kind:
    **heye* → "use one's eye"
    **harm* → "use one's arm"

⇒ Accidental resemblance in this case

- Morphological analysis: identification of parts or constituents of words
  - *nuts* consists of two constituents: nut and s
- **Morphemes**: smallest meaningful constituents of a word
- Words consisting of 2 morphemes: *nut-s*, *break-ing*, *hope-less*, *re-write*, *ear-plug*
- Words consisting of 2 morphemes: *hope-less-ness*, *ear-plug-s*

Definition 2

Morphology is the study of the combination of morphemes to yield words.

- Definition 2 will not always hold, stick to more abstract definition 1.

Outline

Morphology in different languages

The role of morphology in different languages

- Morphology is not equally important in all languages
- Concepts might may be expressed by morphology in one language or by the means of e.g. a separate word in another language
- English: plural is expressed morphologically with the morpheme *-s*
- Yoruba: uses a separate word (*àwọn*) to express plural
  - *ọkùnrin*: (the) man
  - *àwọn ọkùnrin*: the men
- Generally, English makes more use of morphology than Yoruba
- But many other languages make more use of morphology than English:
  - English: *I sleep* – *you sleep*
  - Italian: *dormo* – *dormi*

- **Analytic languages**: Morphology plays a relatively modest role; grammatical relationships are conveyed without using inflectional morphemes (e.g. Yoruba, English)

  Example: Yoruba — Rowlands 1969:93

nwọn	*ó*	*maa*	*gbà*	*pwọ́nùn*	*mẹ́wǎ*	*lọ́sọ̀ọ̀eẹ́*
they	FUT	PROG	get	pound	ten	weekly

  "They will be getting 10 £a week"

- A language which has almost no morphology is also called **isolating** (e.g. Yoruba)
  - an isolating language is analytic
  - an analytic language is not necessarily isolating (having derivational, but no inflectional morphemes)

Morphology in different languages

Synthetic languages - 1

- **Synthetic Languages**: Morphology plays an important role;

  Example: Swahili — Ashton 1947:114

ndovu	*wa-wili*	*wa-ki-song-ana*	*zi-umia-zo*	*ni*	*nyika*
elephants	PL-two	3PL-SUBORD-jostle-RECP	3SG-hurt-REL	is	grass

  "When two elephants jostle, what is hurt is the grass"

- A language with an extraordinary amount of morphology and compound words is also called **polysynthetic**

  Example: West Greenlandic — Fortescue 1984:36

paasi-nngil-luinnar-para	*ilaa-juma-sutit*
understand-not-completely-1SG.SBJ.3SG.OBJ.IND	come-want-2SG.PTCP

  "I didn't understand at all that you wanted to come along"

Morphology in different languages

Synthetic languages - 2

Two other important concepts for synthetic languages:

- **Fusional Languages**
  - Morphemes tend to combine with each other in non-trivial ways
  - (e.g., German verb endings)
- **Agglutinative Languages**
  - Morphemes tend to be simply concatenated
  - (e.g., Turkish, Finnish)
- Like all aspects of morphological language typology, should be viewed as a continuum

Outline

Morphology

Describe and explain the morphological patterns of human languages.

(1) Elegant description
(2) Cognitively realistic description
(3) System-external explanation
(4) Restrictive architecture for description

The goals of morphological research

Elegant and Cognitively realistic description

- **Elegant description**
  - Elegant and intuitive description of (morphological) patterns
  - Main criterion is generality
  - Description should reflect generalizations in the data instead of listing individual facts
  - For example: a rule stating that English nouns form their plural by adding *-s*, rather than a list with singular-plural word pairs

- **Cognitively realistic description**
  - Should express the same generalization that a speaker of the language has unconsciously arrived at
  - A speaker does not only know a list of singular/plural words, but can form a plural of an unknown word by adding *-s*
  - More ambitious goal than finding just an "elegant description"; touches the research area of psychology

The goals of morphological research

System external explanation

- Given a description of morphological patterns:
  why are the patterns the way they are?
- Many patterns evolved historically
  - English plural: *-s*
  - Swedish plural: *-r*, Hungarian plural: *-k*, ...
- Which morphological patterns are universal?
  - Adding *-s/r/k* is not universal
  - The expression of plural by morphological means is not universal
  - But: "if a language has morphological plural forms of nouns at all, it will have plurals of nouns denoting people." Corbett2000:ch.3
  - This seems to be true for all languages; reflects a general property of human language
  - → system-external consideration: when referring to people, number plays a more important role than when referring to things

The goals of morphological research

A restrictive architecture for description

- Formulate general design principles of grammatical systems that are valid for all languages
- Construct a **grammatical theory** that all language-particular descriptions conform to
- Example:
  Fronting of syntactic constituents (words/phrases) as opposed to morphologic constituents (morphemes that are parts of longer words)

We can buy cheese.	We can buy a cheeseboard.
What can we buy ____ ?	*What can we buy a ____board?

- This restriction on fronting follows if *fronting rules* and *morpheme-combination rules* are treated separately

- Many linguist assume that the architecture of grammar is innate (Universal Grammar): innate part of speakers' grammatical knowledge

Outline

Motivation

Internal structure of words: example

- **English**

  I am swim-m-ing

  - We know the meaning of *(to) swim*
  - -ing: marks the progressive form
  - Why the extra m?

- **Turkish**

  Ben *yüz-üyor-um*
  I.Nom *swim*-Prog-1P.Sg

  - yüz means 'swim'
  - -üyor corresponds to English *-ing*
  - -um indicates the person

⇒ Inflected Turkish verb contains more information

- **Inflection**
  Modification of a word to express different grammatical categories (*number, gender, tense, ...*)
  - *dog* → *dogs*
  - *write* → *writes*
- **Derivation**
  Process of forming a new word using an existing one
  - *happy* → *happiness*
  - *essen* → *essbar*
- **Compounding**
  Creating a new word containing two or more pre-existing words
  - *Apfel+Kuchen* → *Apfelkuchen*
  - *Donau+Dampf+Schiff+Fahrt+Kapitän+Mütze* → *Donaudampfschifffahrtskapitänsmütze*

Computational Morphology

Two challenges

- **Morphosyntax (Morphotactics)**
- Words are composed of smaller units (morphemes)
- When combining morphemes, certain rules/conditions need to be fulfilled

  piti-less-ness
  *piti-ness-less

- **Pholonogical/Orthographical Alternations**
- The realization of a morpheme might vary depending on its context ($\rightarrow$ allomorph: variation of a morpheme)

  pity $\rightarrow$ piti in pitilessness
  die $\rightarrow$ dy in dying
  swim $\rightarrow$ swimm in swimming

- Many NLP applications need to extract the information encoded in complex words
- Rich morphology leads to data sparsity
  blue $\rightarrow$ *blau, blaues, blaue, blauen, blauem, blauer*
- **Parser**
  To analyze the sentence structure, the parser needs information about
  - subject-verb agreement
  - adjective-noun agreement, ...
- **Information retrieval**
  Better generalization when working on lemmatized forms
- **Machine translation**
  Need to analyze the words on the source-side and generate words with specific features in the target language

- SMT systems learn translations for words and word sequences from word-aligned parallel data
- Only words occurring in the parallel training data can be translated or produced on the target side

- German **compounding** is very productive:

  drückt der fußgänger den ampelknopf, testet der obere radarsensor die verkehrslage.

  - *ampelknopf* has not occurred in the training data → cannot be translated
  - Compound splitting: if the individual translations of the parts *ampel* 'traffic light' and *knopf* 'button' are known, the compound can be translated

- Can we list all word forms and their features in a database?

.....		
harass	harass	V INF
harassed	harass	V PAST
harassed	harass	V PPART WK
harasser	harasser	N 3sg
harasser's	harasser	N 3sg GEN
harassers	harasser	N 3pl
harassers'	harasser	N 3pl GEN
harasses	harass	V 3sg PRES
harassing	harass	V PROG
harassingly	harassingly	Adv
harassment	harassment	N 3sg
harassment's	harassment	N 3sg GEN
harassments	harassment	N 3pl
harassments'	harassment	N 3pl GEN
harbinger	harbinger	N 3sg
harbinger	harbinger	V INF
harbinger's	harbinger	N 3sg GEN
.....		

- Feasible if the word list is "small"
- Creation is time-consuming
- Not feasible for "infinite" vocabulary (e.g. Turkish, ...)

Outline

Finite State Morphology

Overview

- Finite state systems are mathematically well understood
- Finite state systems are computationally efficient (fast and little memory usage)
- Finite state systems provide compact representations for many NLP tasks
- Finite State systems can be used for
  - Tokenization: divide text into tokens (= words)
  - **Morphological analysis/generation**
  - Part-of-speech tagging: assign a single tag such as VERB or NOUN
  - Shallow syntactic parsing: recognition of syntactic patterns (e.g. nominal phrases)

Finite State Morphology

Example: Xerox Finite State Tools (XFST)

- Tools in XFST

xfst	defining and manipulating finite state networks
lexc	specify natural language lexicons
tokenize, lookup	testing/running of implemented systems

- Morphological processes can be encoded as finite state networks

⇒ Lexicon of morphemes

⇒ Rules determining the form of each morpheme can be implemented

⇒ Valid combination of morphemes (morphosyntax) can be modelled as a finite-state network

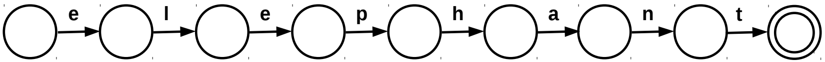
- Alphabet: set of valid symbols
- Words: sequence of accepted symbols
- Language: set of accepted words

- The description of a finite state acceptor is finite
  - Finite number of states
  - Finite number of alphabet symbols
  - Finite number of transitions

  ⇒ Number of accepted strings can be infinite

Finite State Morphology

Example: small finite-state acceptor



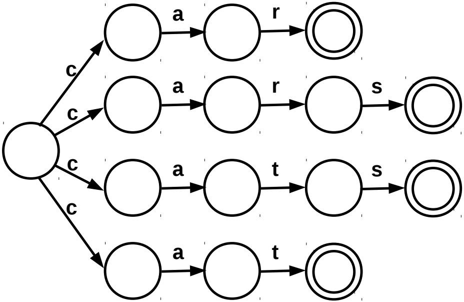
- Network accepts the single **word** “elephant”
  alphabet (set of valid symbols): `e,l,p,h,a,n,t`

- When entering the input sequence `e,l,e,p,h,a,n,t`, the machine transitions through a series of states until the final state and the input word will be accepted
- No other words (e.g. "elephants” or “ant") are accepted by this network
- IMPORTANT NOTE: In this course there will always be a single start state (which is the leftmost state on the slide)

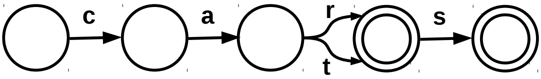
Finite State Morphology

Example: small finite-state network

- Network for the forms “cat”, “cats”, “car”, “cars”



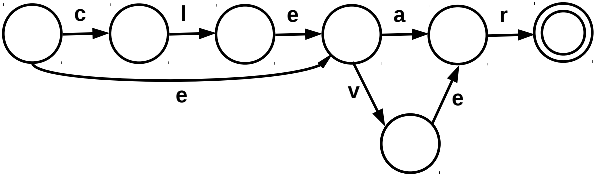
- States and transitions can be shared



Finite State Morphology

Example: shared states

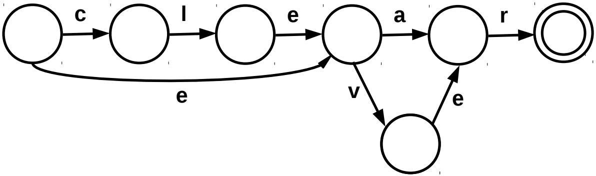
- Which word forms are recognized by this network?



Finite State Morphology

Example: shared states

- Which word forms are recognized by this network?



- "clear", "ear", "clever", "ever"

Outline

Finite State Transducers

Overview

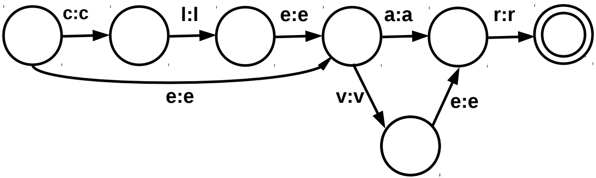
- A finite-state acceptor can only output two responses: ACCEPT or REJECT (→ useful for e.g. spell checking)

- Return more interesting information with a **finite state transducer**
- "Mapping" between *upper language* and *lower language*

- Analysis process of a finite state transducer
  - Start at the start state/beginning of the input string
  - Match the input symbols against the lower-side symbols on the arcs, consume all input symbols and find a path to a final state
  - If successful: return the string of upper-side symbols on the path as result
  - If not successful: return nothing (reject)

Finite State Transducers

Example 1



- input: *clear*, output: *clear*
- input: *clever*, output: *clever*, ...

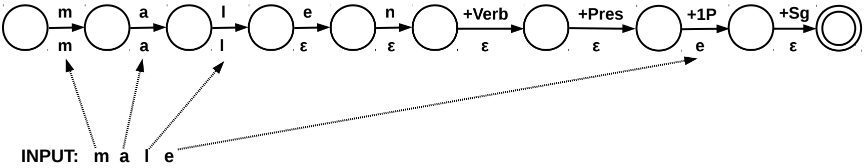
- Alphabet of pairs of symbols u:l
  - upper language: lexical language
  - lower language: surface language
- An acceptor can be viewed as an identity transducer

We'll now introduce a special symbol ϵ:

- **Epsilon as an input symbol**
  - This represents a transition we can take **without consuming an input symbol**
- **Epsilon as an output symbol**
  - This represents a transition which is taken (if the input symbol matches) **without saving an output symbol**
  - So ϵ is never output

Finite State Transducers

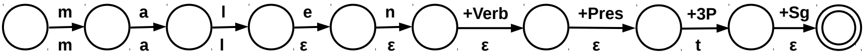
Example 2



OUTPUT: m a l e n +Verb +Pres +1P +Sg

Finite State Transducers

Generation



- Word forms can be generated with the same transducer when applying it backwards

  → generation is the inverse of analysis

- To generate the 3rd Person Singular of *malen* in present tense: use the input string "`malen +Verb +Pres +3P +Sg`"
  - Match the input symbols with the upper-side symbols on the arcs, consume all symbols an find a path to the final state
  - If successful: return the string of the lower-side on the path as a result
  - If not successful: return nothing

Summary

Summary

- **Morphology**
  - Study of the way words are formed
  - Talked (briefly!) about linguistic typology
  - Take home: "Morphology is the study of systematic covariation in the form and meaning of words."
- **Computational Morphology**
  - Discussed challenges and goals
  - Commonly used tool: Finite State Transducers
  - Basic ideas of **morphological analysis** and **morphological generation**

Thank you for your attention.