Introduction to Morphology

Linguistics for Computer Scientists
Session 4

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Outline

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What is Morphology?

Morphology is the study of form and structure.

In linguistics, it generally refers to the study of form and structure of words.

What is morphology?

The term *Morphology* can refer to three different things

a. Description of the behaviour of morphemes and how they are combined.
b. Derivational, inflectional and compositional processes of word formation occurring in a specific language.
e.g. “German has a richer morphology than English”
c. Description of such word formation processes.

What are Morphemes?

- **Morphemes**
  - Morphemes are minimal meaning-bearing units:
    e.g. *talked* contains two morphemes: *talk* and *-ed* (past).
  - Form-function pairs (sound/sign-meaning)
  - Basic units of morphology

Morphemes are the “building stones” of phrases

Why study morphology? (1/2)

- One of the main properties of language are the sound/meaning pairs
- When analyzing language (or learning a foreign language), we can't simply list all expressions: there is an infinite number of them!
- So we compose expressions into smaller units: usually into phrases and words (syntax)

Why study morphology? (2/2)

- Can we use words as basic sound/meaning units?
  - Problems:
    1. Definition of words is unclear
    2. Words can be composed of many components that contribute to meaning and/or grammar

Several applications in Computational Linguistics benefit from morphological analysis (more later)

Words and Morphemes

There are two main usages of the term *word*:

1. Surface form (spoken or written representation)
2. Abstract form (lemma or dictionary entry,
   e.g. bare infinitives in English, nominative single form of nouns in Latin)

   The class of forms representing a word in different contexts is called a **lexeme**
   e.g. sing = {*sing, sings, sang, sung, singing*}

Based on Crysmann 2006

A definition of words?

Words can be described as units of language (either sequences of sounds, or signs) that function as meaning bearers. But this is a fuzzy notion, e.g.:

- *talked* in *she talked* expresses both “talking” and past tense.
- Is *more or less* one word, or are there three words?

A structuralist solution: **morphemes**

A language:

11-112 phonemes

↓

4,000-10,000 morphemes

↓

An infinite number of sentences

Morphs and Morphological Analysis

- The realisations of morphemes are called *morphs*:
  - e.g. English plural morpheme:
    [NUMBER pl]: -s, -es, -en, -∅
    boy-s, box-es, ox-en, sheep
  - These different realisations of the same morpheme are called **allomorphs**.
- **Morphological analysis**
  - Segmentation of expressions into basic units (mostly starting from word-level).
  - Classification of these basic units according to function.

Based on Crysmann 2006

Types of morphemes

- **Free Morphemes**
  Free morphemes can occur independently. Free morphemes are common in both English and German.

  e.g. *boy*, *sing*
- **Bound Morphemes**
  Bound morphemes must be attached to another morpheme, and cannot be used independently.

  e.g. [NUMBER pl] *-s* → *boys*

Based on Crysmann 2006

Types of bound morphemes

Typical bound morphemes are:

- **affixes** (*boy+s*, *talk+ed*)
- **clitics** (French: *je ne sais pas*, *je* and *ne* cannot occur without a verb)
- **roots** (Spanish *habl-* needs an ending indicating person, number, mode, etc.)

Formatives

Morphemes are form-meaning pairs, but not all segmental forms have an identifiable meaning:

- **Formatives** are forms without identifiable meaning

  e.g. Linking elements in German compounds:
  *Geburt+**s**+tag* (Birthday), *Schwan+**en**+hals* (swan neck).

Based on Crysmann 2006

Pseudo Morphemes

- **Pseudo-morphemes** or **cranberry morphemes** are special cases of formatives.
  They are segment-able part of a complex word, but do not have an independent meaning:

  e.g.
  - ***cran***+*berry*, ***rasp***+*berry*
  - *re*+***ceive***, *con*+***ceive***

Based on Crysmann 2006

Outline

Areas of Morphology

We distinguish:

- **Word forming**:
  - Derivational morphology
  - Compounding
- **Inflection**

Derivational Morphology

- allows to build complex words by combining bound and free morphemes.
- Derivational operations are per definition optional, i.e. not required by syntactic criteria.

Changes made by derivational morphemes

(a) semantics,
e.g. [*clear*] $\rightarrow$ [*un*+[*clear*]] = unclear

(b) syntactic category,
e.g. $[derive]_V \rightarrow [[[derive]_V + ation]_N + al]_{Adj}$ = derivational

(c) valency of a verb,
e.g. [*qaw*] 'it breaks' $\rightarrow$ [*t*+[*qaw*]] 'he breaks it' (Havasupai)

(d) several from the above, e.g. $[understand]_V \rightarrow$
$[[understand]_V + able]$ = understandable

Compounding

- allows to build complex words by juxtaposition of free morphemes.
  [[*sale*]+s+[*man*]], [[*dish*]+[*washer*]].
- Productive compounding results in an infinite lexicon.
  $\left\{\begin{array}{l}\textit{English}\\ \textit{German}\\ \textit{Havasupai}\end{array}\right\}\left\{\begin{array}{l}\textit{phonetics}\\ \textit{phonology}\\ \textit{morphology}\end{array}\right\}\left\{\begin{array}{l}\textit{teacher}\\ \textit{researcher}\\ \textit{student}\end{array}\right\}$

Based on Crysmann 2006

Inflectional Morphology (1/2)

- Inflection is required by syntactic criteria, e.g. an English verb must have tense.
- It marks grammatical (=morpho-syntactic) distinctions:
  - Conjugation (verbal categories):
    1. person, number, gender
    2. tense, aspect, mood, agreement
  - Declination (nominal categories)
    - case, number, gender, degree, definiteness

Based on Crysmann 2006

Inflectional Morphology (2/2)

- Meaning or, at least, the general concept is (generally) not changed, though *when, who* or *what* and sometimes *where, how* and *whether* may be specified by inflectional morphemes.
- There are bound and free inflectional morphemes:
  go [TENSE past]: *went*
  go [TENSE future]: *will go*

Based on Crysmann 2006

Inflection — paradigm

Inflectional morphology is typically organised in **paradigms**.

Paradigm

"A set of forms having the same root/stem, one of which must be selected in a certain syntactic environment" (definition based on [Crystal(1997)] (p. 277) and [Payne(1997)] (p. 26))

Paradigm - an example

For instance, German conjugation:

present	NUMBER		*past*	NUMBER	
	singular	*plural*		*singular*	*plural*
1.	dehn-e	dehn-en	1.	dehn-te	dehn-te-n
2.	dehn-st	dehn-t	2.	dehn-te-st	dehn-te-t
3.	dehn-t	dehn-en	3.	dehn-te	dehn-te-n

Taken from Crysmann 2006

Outline

Some Basic Notions

- **Root**: an unanalysable form, expressing the basic lexical content of a word. Also defined as 'what is left of a complex form when all affixes are stripped'.
- **Stem**: consists of at least a root.
  It can contain (an) derivational affix(es).
  In inflectional morphology, *stem* is generally defined as the root + a thematic vowel.
- **Base**: a form to which an affix may be added. A base may be simplex (root) or complex (root + affixes).

Morphological Processes

Bases can be altered by the following processes:

- Affixation
  - Prefixation
  - Suffixation
  - Circumfixation
  - Infixation
- Stem Modification
  - Substitution (vowel mutation, suppletion)
  - Subtraction
- Suprasegmental Modification
  - Tone
  - Stress

Affixation

- Affixes are bound morphemes
- Their position is fixed with respect to the base
  - a **prefix** precedes the base
    - ***im****-possible*
  - a **suffix** follows the base
    - *want-****ed***
  - a **circumfix** surrounds the base
    - ***ge****-dehn-****t***
  - an **infix** is placed within the base
    - *f-****um****-ikas* 'become strong', *fikas* 'be strong' (Bontok, Philippines)
- Affixation can be a recursive process
- **Prefixes** and **suffixes** are most frequent cross-linguistically

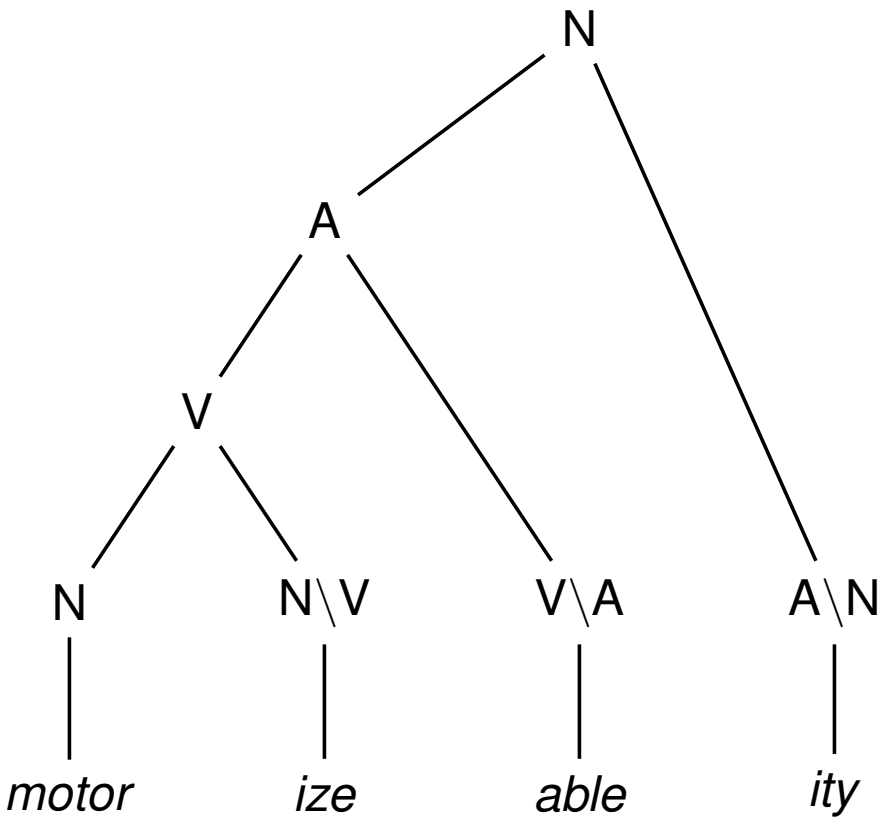
Affixation (cont)

- Words can have an internal structure (see next slide)
- The order of application can be significant, e.g.

  [in-[describe-able]], [[*in-describe]-able]
  [[un-do]-able] vs [un-[do-able]]
- Constraints on morpheme order are described by **morphotactics**
- Morphotactics can be determined by
  - word syntax (e.g. indescribable)
  - lexical strata
    - *non-im-partial* vs. *in-non-partial*

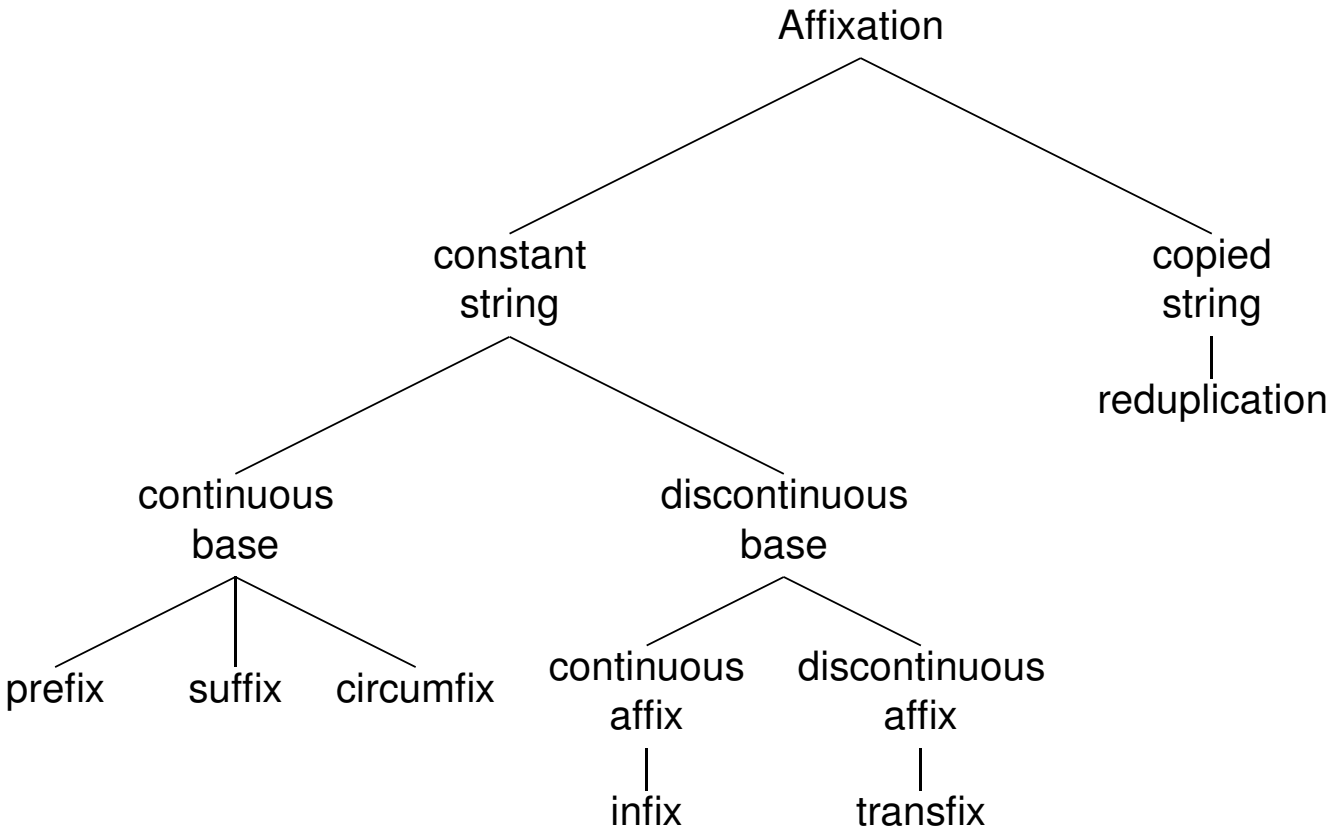
Based on Crysmann 2006

Internal structure of *motorizability*



(Sproat (1992), p. 84)

Types of affixational processes



(Crysmann 2006)

Infixation

- An **infix** is a continuous affix that attaches within the base
- Infixation is rare in European languages
- Infixation is often motivated by prosodic factors
  - Tagalog places affixes in the base to avoid closed syllables (i.e. syllables that end in a consonant)
    - *um-* + *sulat* → *sumulat*
    - *sulat* + reduplication: *susulat* and *sumusulat*
    - *um-* + *aral* → *umaral*
- Infixation can also be purely morphologically conditioned:
  - e.g. Udi (Nakh-Daghestanian, Azerbaijan) infixation:

Root	Transitive		Intransitive	
box	*bo-**ne**-x-sa*	boils	*box-**ne**-sa*	boils
uk	*u-**ne**-k-sa*	eats	*uk-**ne**-sa*	is edible

Based on Crysmann 2006

Transfixation

- A the segment of a **transfix** interleaves with the base's segment (i.e. both base and affix are discontinuous)
- Transfixation is common in Semitic languages (e.g. Arabic and Hebrew)
- The following forms are derived from the root *ktb* in Maltese

Transfix	Word	Gloss
-i-e-	*kiteb*	'he wrote'
-i–u	*kitbu*	'they wrote'
mi–u-	*miktub*	'written'
–ie-	*ktieb*	'book'
-o–a	*kotba*	'books'

Based on Crysmann 2006

Modification

- Morphological processes can effect stem internal segments
- The German vowel mutation ("umlaut" and "ablaut") are typical examples of such a process
- Umlaut:
  - Phonologically predictable segmental alternation (e.g. vowel fronting in German)

    $a \rightarrow ä$ (*Wald, Wälder* ("forest, forests"))
    $u \rightarrow ü$ (*Mutter, Mütter*, ("mother, mothers"))
    $o \rightarrow ö$ (*tot, Tödlich* ("dead, deadly"))
- Ablaut:
  - Phonologically unpredictable segmental alternation
    - *g**e**hen, g**i**ng, geg**a**ngen* vs *s**e**hen, s**a**h, ges**e**hen*

Based on Crysmann 2006

Example of a suprasegmental morpheme

- In Sabaot (Nilotic, Kenya & Uganda) uses advanced tongue root and normal vowels as morphemic contrast.
- This process may be applied to the entire word, as in the example below:

(1) *kɔ̀cmnyccncctɛ́*
ka – a – mnyaan – aa – tɛ – ATR
PAST-1SG-be.sick-STAT-DIR-IMPERF
"I went being sick (but I am not sick now)"

(2) *kɔ́ɔ́mnyɔ́ɔ́nɔ́ɔ́tɛ́*
ka – a – mnyaan – aa – tɛ
PAST-1SG-be.sick-STAT-DIR
"I became sick while going away (and I am still sick)"

(Payne 1997, p.29)

Suppletion

- Suppletion refers to 'stem replacement': a verb has more than one stem which are used in different contexts.
- In many European languages, suppletion occurs with the verb 'to be', e.g. in English, the verb uses three historically different roots:
  - *am*, *are*, *is*
  - *was*, *were*
  - *be*

(Payne, 1997)

Subtractive Morphology (1/2)

- **Subtractive morphology** means that part of the stem is omitted to mark a morphological process.
- For instance Koasati (a Muskogean language, spoken in the US):

Singular	Plural	Gloss
*pit**af**-fi-n*	*pit-li-n*	to slice up the middle
*las**ap**-li-n*	*las-li-n*	to lick something
*acokcan**a:**-kaln*	*acokcan-ka-n*	to quarrel with someone
*obakhit**ip**-li-in*	*obakhit-li-n*	to go backwards

Data taken from Sproat (1992)

Subtractive Morphology (2/2)

- The shape of the base cannot be predicted from the derived form
- Subtractive Morphology is problematic for theories assuming that morphology consists of the addition of morphemes

Based on Crysmann 2006

Reduplication

- Reduplicated morphemes are formed by reduplicating (part of) the base.
- In **total reduplication** the entire base is copied, though minor changes may occur, e.g. ([Kiparsky(1987)] (p. 115-117)
  - Indonesian:

orang	***orang*** *orang*
'man'	'men'

  - Javanese:

Base	Habitual-Repetitive	Gloss
bali	*bola bali*	'return'
udan	*udan udɛn*	'rain'

Based on Crysmann 2006

Suprasegmental Marking

- Stress
  - English verb-noun derivations:

Verb	Noun
pro**duce**	**pro**duce
per**mit**	**per**mit
im**port**	**im**port
in**sult**	**in**sult
dis**count**	**dis**count

- Tone
  - Chichewa:

Form	Tense/aspect
ndi-ná-fótokoza	simple past
ndi-na-fótókoza	recent past
ndí-nâ:-fótókoza	remote past
ndí-ma-fotokózá	present habitual
ndi-ma-fótókoza	past habitual

Morphophonological Processes (1/2)

- The environment of morphemes can influence their appearance (phonological and/or graphemic alternations)
- Morphophonological Alternations
  - Assimilation

    Homographic nasal assimilation
    iN+possible → ***im****possible*
    iN+complete → ***in****complete*
    iN+resistable → ***ir****resistable*
  - Epenthesis: *wish+s* → *wishes*
- Graphemic alternations:
  - *y* + *s* ∼ *ies*

Based on Crysmann 2006

Morphophonological Processes (2/2)

- The environment influencing the morpheme's form need not be directly adjacent to the morpheme
- Harmony rules impose identity of sound features (typically vowel features)

  E.g. Finnish vowel harmony

	low	mid	high
back vowels	a	o	u
front vowels	ä	ö	ü
neutral vowels		e	i

  - taivas + ta → taivasta (*taivastä)
  - lyhyt + ta → lyhyttä (*lyhytta)

(Morpho)phonological rules

- [Chomsky and Halle(1968)] propose phonological rules to derive “surface” morphemes in *The Sound Pattern of English* (SPE)
- They were formalized as (ordered) context-sensitive rewrite rules:

  a → b/v_w
  e.g. *iN-* → *im-*/_*m*

(Morpho)phonological rules

- There was a strong believe that related morphemes are all derived from the same **underlying representation**, even if this form never occurs on the surface (e.g. *divine* and *divinity* would come from the root *divIn*)
- The approach did not take general phonetic constraints within the language in account, nor did it address rules and tendencies in morpheme structures

Declination of *puella*

Latin declination of a noun of the first declination:

case	NUMBER	
	singular	*plural*
NOM	puella	puellae
GEN	puellae	puellarum
DAT	puellae	puellis
ACC	puellam	puellas
ABL	puella	puellis

Syncretism/exponence

We observe both:

- **syncretism**: the same form is used to express different feature combinations.
  e.g. in the declination of *puella*:
  - *-ae*: GEN or DAT singular, or NOM plural
  - *-a*: NOM or ABL singular
  - *-is*: DAT or ABL plural
- **exponence**: the relation between form and function is **m:n**:
  - **multi-exponence** (cumulation): one form expresses several functions.
    Here: *-am* expresses both accusative and singular
  - **Extended exponence**: in *ge-dehn-t*, *ge-* and *-t* express one function together.

Morphological Properties — Synthesis

Synthesis: the number of morphemes that tend to occur within a word.

- In **isolating** languages words tend to consist of only one morpheme. (e.g. Chinese languages)
- **Polysynthetic** languages are known for the large number of morphemes that may occur in a single word. For instance, the Quechua and Inuit languages. The following example is from Yup'ik:

(3) tuntussuqatarniksaitengqiggtuq
tuntu-ssur-qatar-ni-ksaite-ngqiggte-uq
reindeer-hunt-FUT-say-NEG-again-3gg-IND
'He had not yet said again that he was going to hunt reindeer'

([Payne(1997)], p. 28)

Morphological Properties — Fusion (1/2)

Fusion: the number of meaning units that are found in one morphological shape:

- **Agglutinative** languages have little fusion: each meaning component is represented by its own morpheme (e.g. Turkish).
- **Fusional** languages have morphemes that express many meaning units: e.g. *-ó* in Spanish *habló* expresses indicative mode, 3rd person, singular, past tense and perfect aspect.

Morphological Properties — Fusion (2/2)

In English, both examples of agglutinative morphemes, and fusional ones can be found:

- **agglutinative**: anti+dis+establish+ment+arian+ism
- **fusion**: vowel change in plural forming (*goose/geese*) and strong verbs (*sing/sang*).
  Individual morphemes (root and number/tense) cannot be segmented in chunks, therefore these forms are fusional.

Outline

Morphology in Computational Linguistics

Morphology related applications in computational linguistics are:

1. Analysing complex words, defining their component parts:

   anti+dis+establish+ment+arian+ism

2. Analysis of grammatical information, encoded in words:

   sings
   sing[PERSON 3, NUMBER singular,TENSE present]

Morphological Processing

- Inflection
  - lemmatisation/stemming
  - extraction of grammatical (morpho-syntactic) features (preprocessing for parsing)
  - State of the art: finite state technology (to be discussed)

Reduction of lexicon size (English 2:1, German 5:1, Finnish/Turkish >200:1) (Crysmann 2006)

Morphological Processing (cont)

- Derivational Morphology
  - Semi-productivity is still a challenge
    - Rule-based approaches tend to suffer from over-generation
- Compound Analysis
  - Important for languages with productive compounding
  - Additional task: bracketing

Why do we need morphology?

- For linguistic tools, such as parsers:
  significant reduction of lexicon size
- For statistical methods:
  reduces unseen data: in a morphologically rich language, many words will be found in each possible form, even in a large training corpus.

Machine translation runs into problems, in particular when translating from a morphologically poor to a morphologically rich language. This is expected to become a 'hot topic' in MT

State of the art: Finite State Transducers

Non-deterministic Finite Automata (NFA)

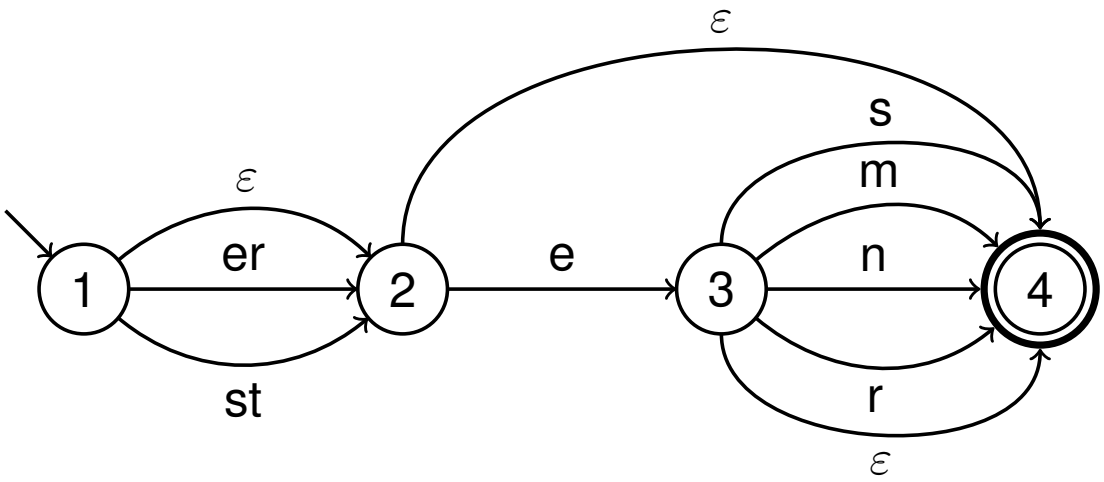
Definition

- A non-deterministic finite automaton is a quintuple (Q, Σ, δ, q_0, F), where
  - Q is a finite set of states
  - Σ is a finite set of symbols
  - δ is a transition function *delta* : $Q \times \Sigma \rightarrow Q$, such that for each $q_i \in Q$ and each $\sigma \in \Sigma$, there is a q_j such that $\delta(q_i, \sigma) = q_j$, where q_j is a non-final sink state, unless σ is licit at state q_i
  - $q_0 \in Q$ is a unique initial state
  - $F \subseteq Q$ is a set of final states
- At worse, a NFA's complexity is exponential at word length

Based on Crysmann 2006

An example of a NFA

- German adjectives
- klein+ er+ es



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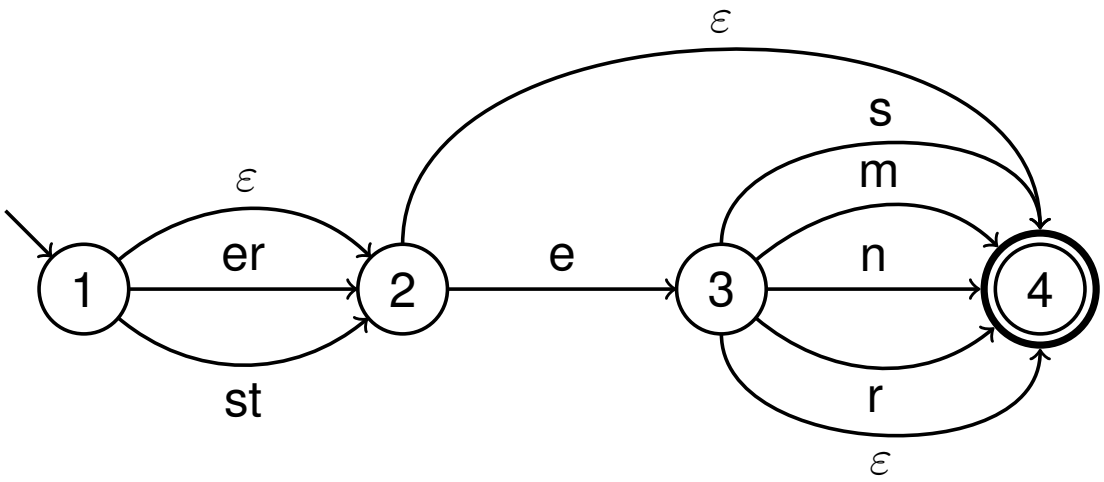

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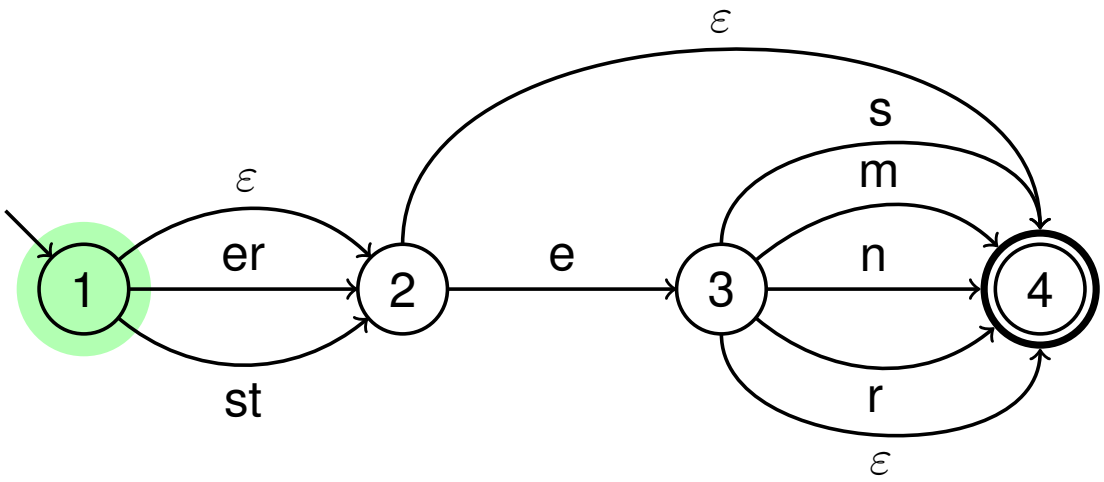

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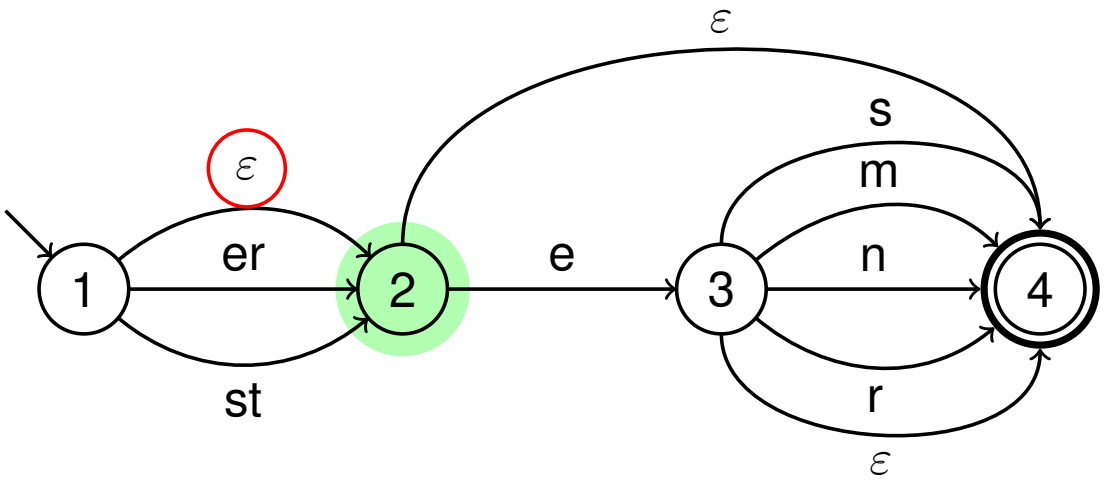

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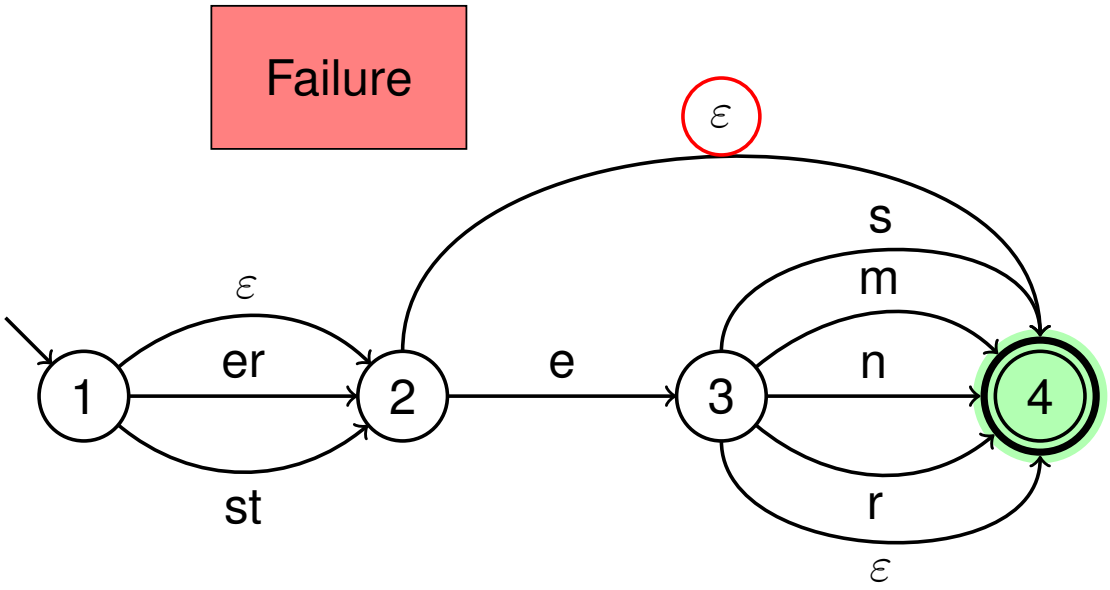

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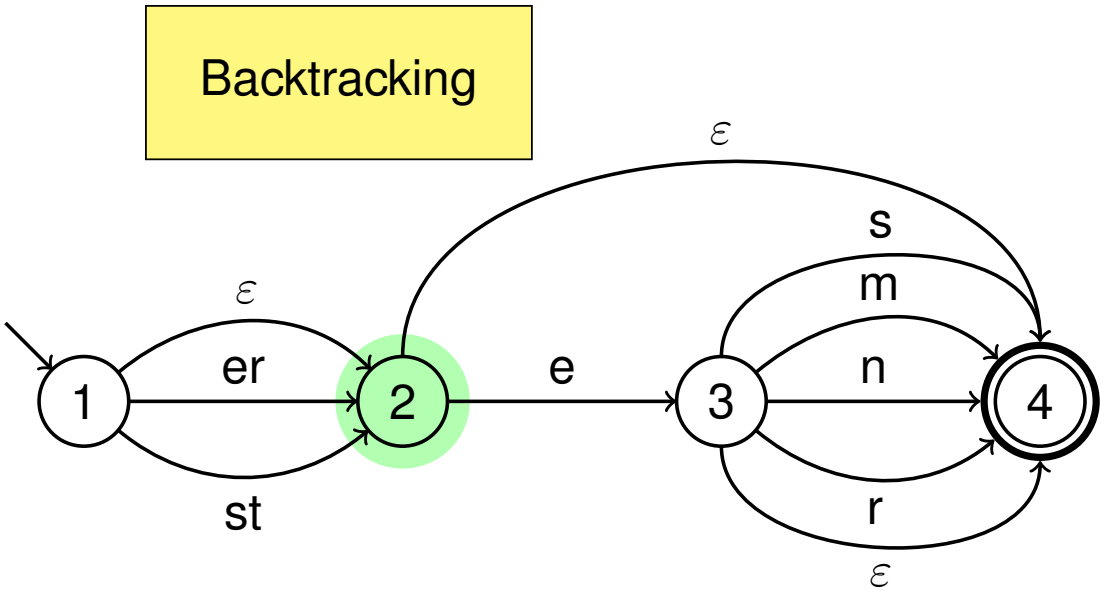

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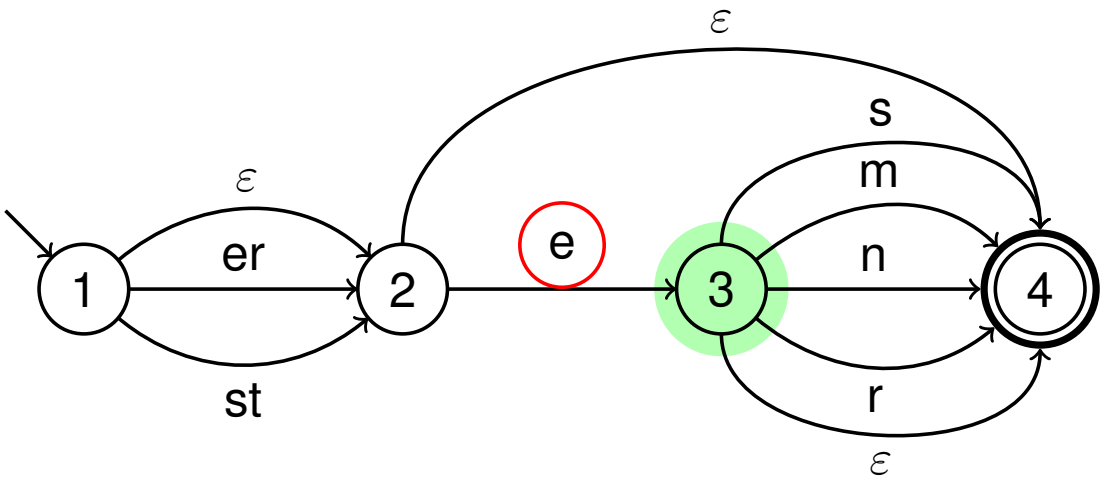

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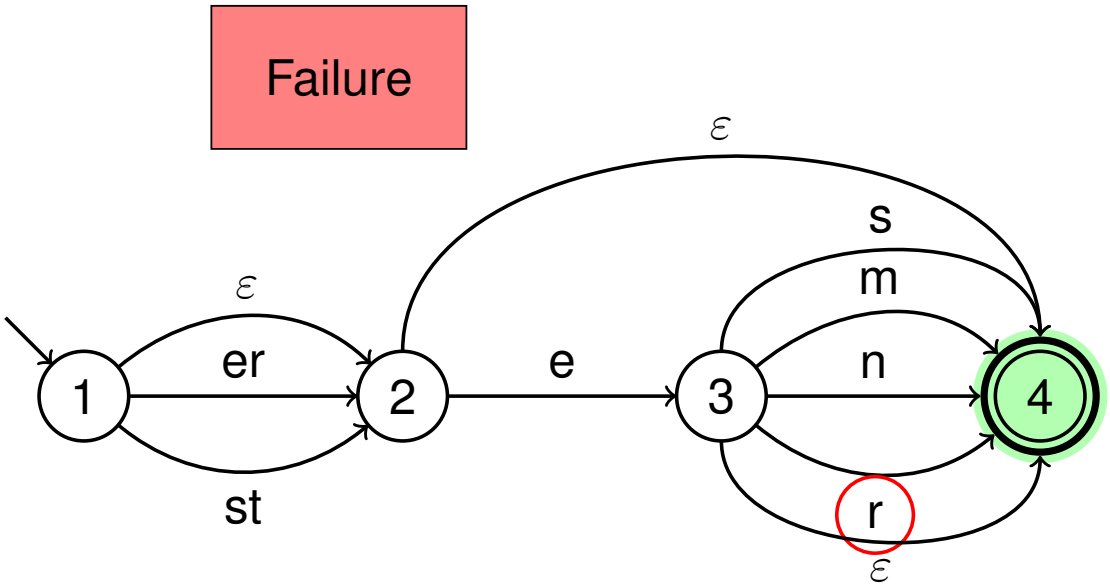

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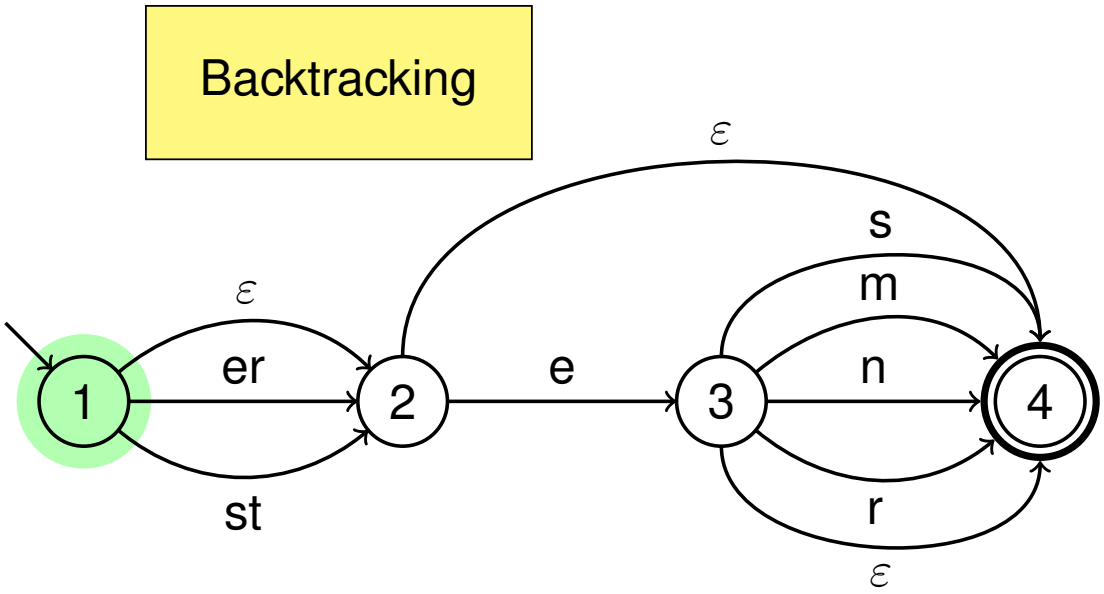

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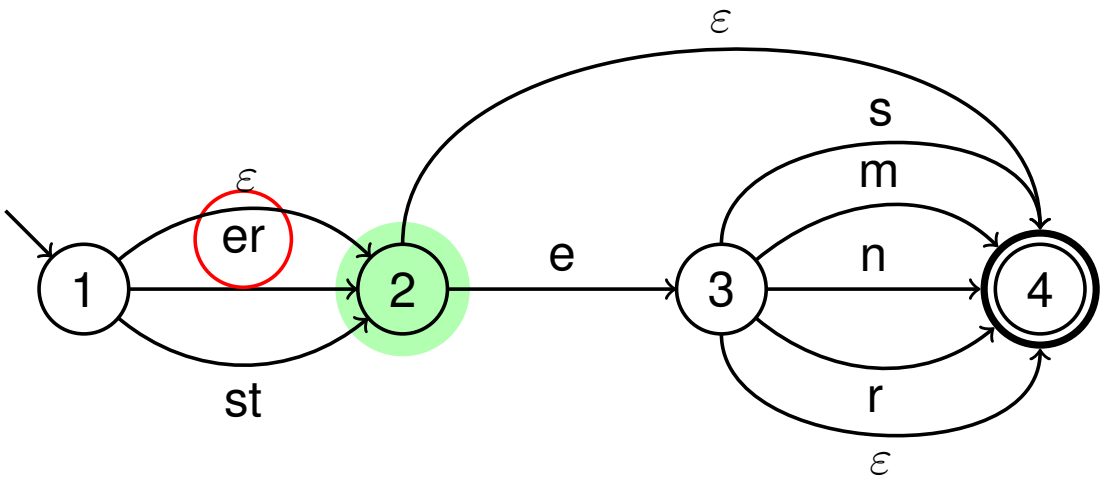

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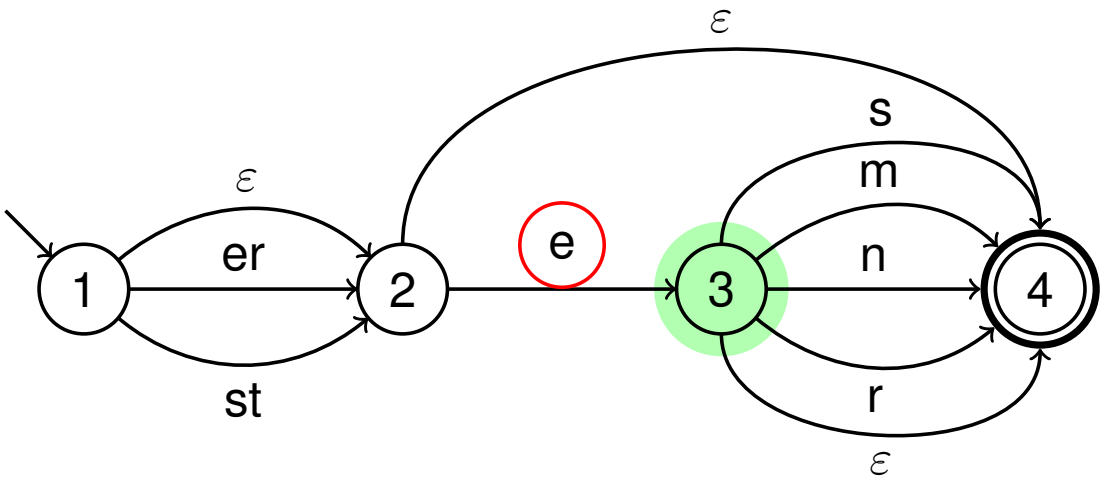

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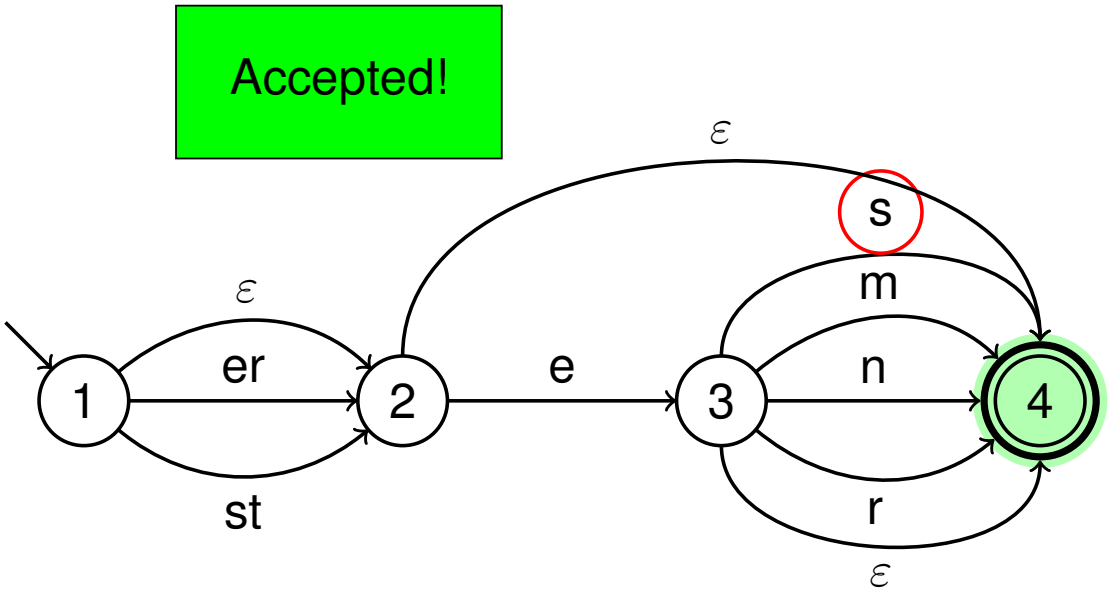
- German adjectives
- klein+ er+ es



Based on Crysmann 2006

Deterministic Finite Automata (DFA)

- So what about the worse case exponential complexity of NFA?
- **Deterministic** Finite Automata (DFA) are linear at worse case
- For each NFA, there is always an equivalent DFA (Hopcroft and Ullman 1979)

DFA, Definition

- A deterministic finite automaton is a quintuple $(Q, \Sigma, \delta, q_0, F)$, where
  - Q is a finite set of states
  - Σ is a finite set of symbols
  - δ is a transition function $\delta : Q \times \Sigma \rightarrow Q$,
  - $q_0 \in Q$ is a unique initial state
  - $F \subseteq Q$ is a set of final states

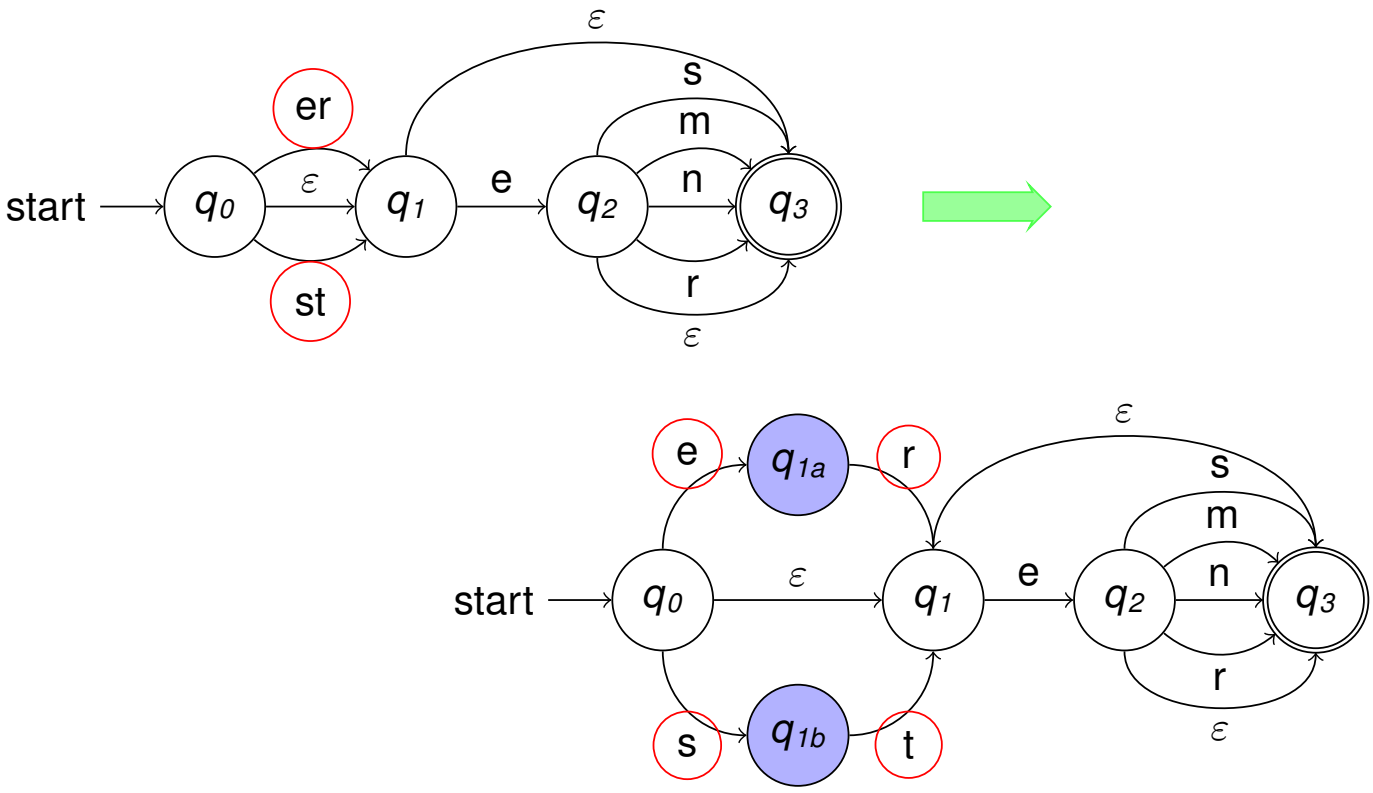
From NFA to DFA

For each **Nondeterminstic** finite state machine, there is an equivalent **deterministic** finite state machine

Step to take:

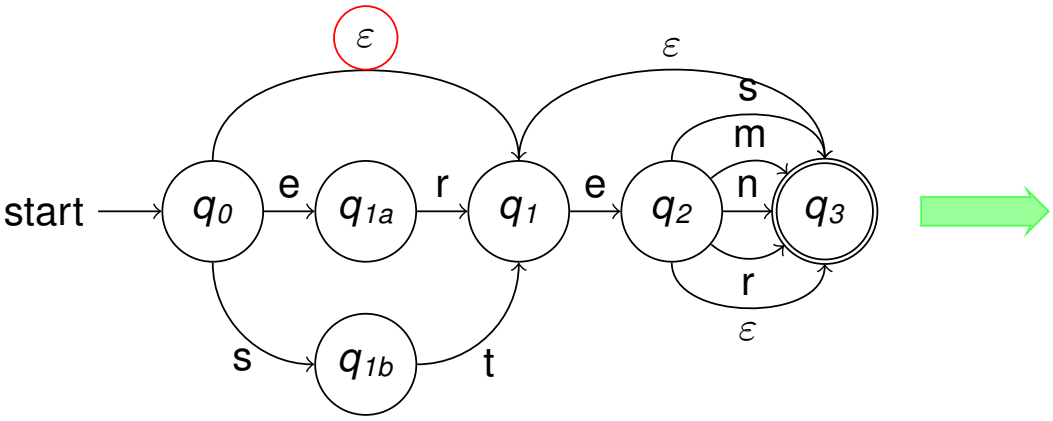
1. Expand edges that take more than one input character
2. Eliminate ε-edges (by adding alternative edges)
3. Construct power automaton (recursively combine states reached by the same input symbol)

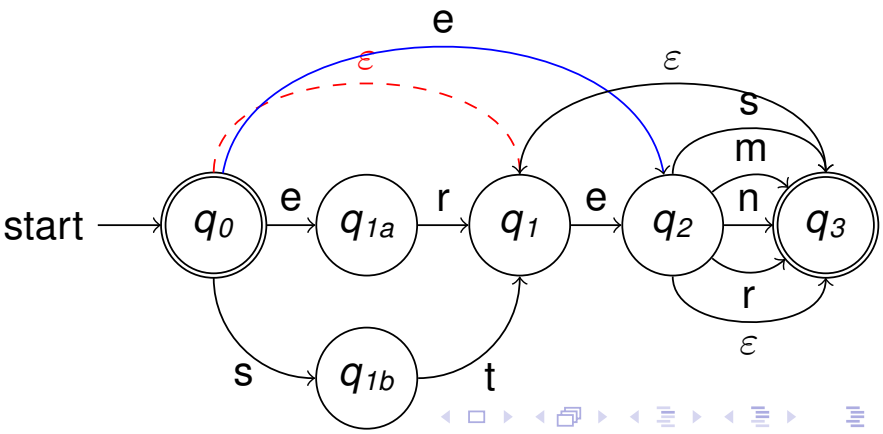
Expanding multiple symbol edges



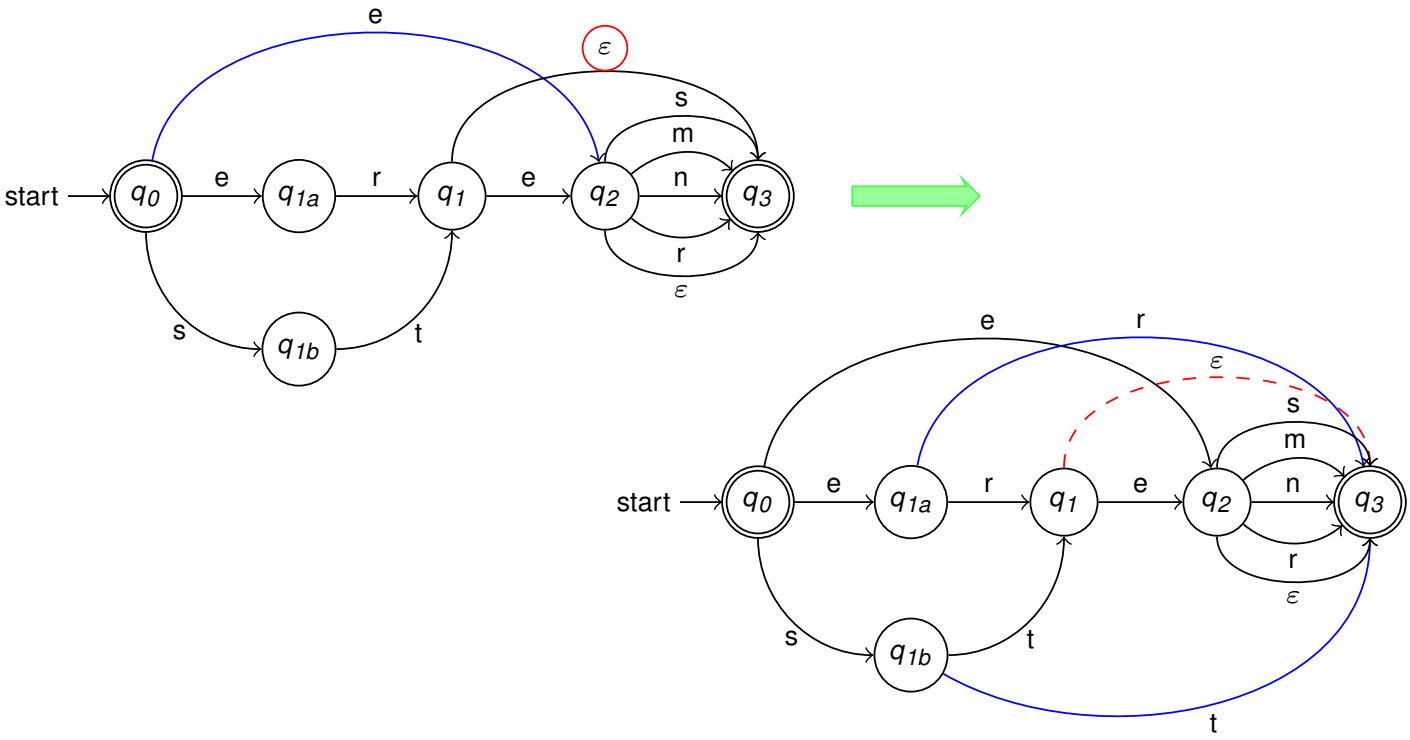
Based on Crysmann 2006

Eliminating ε-edges



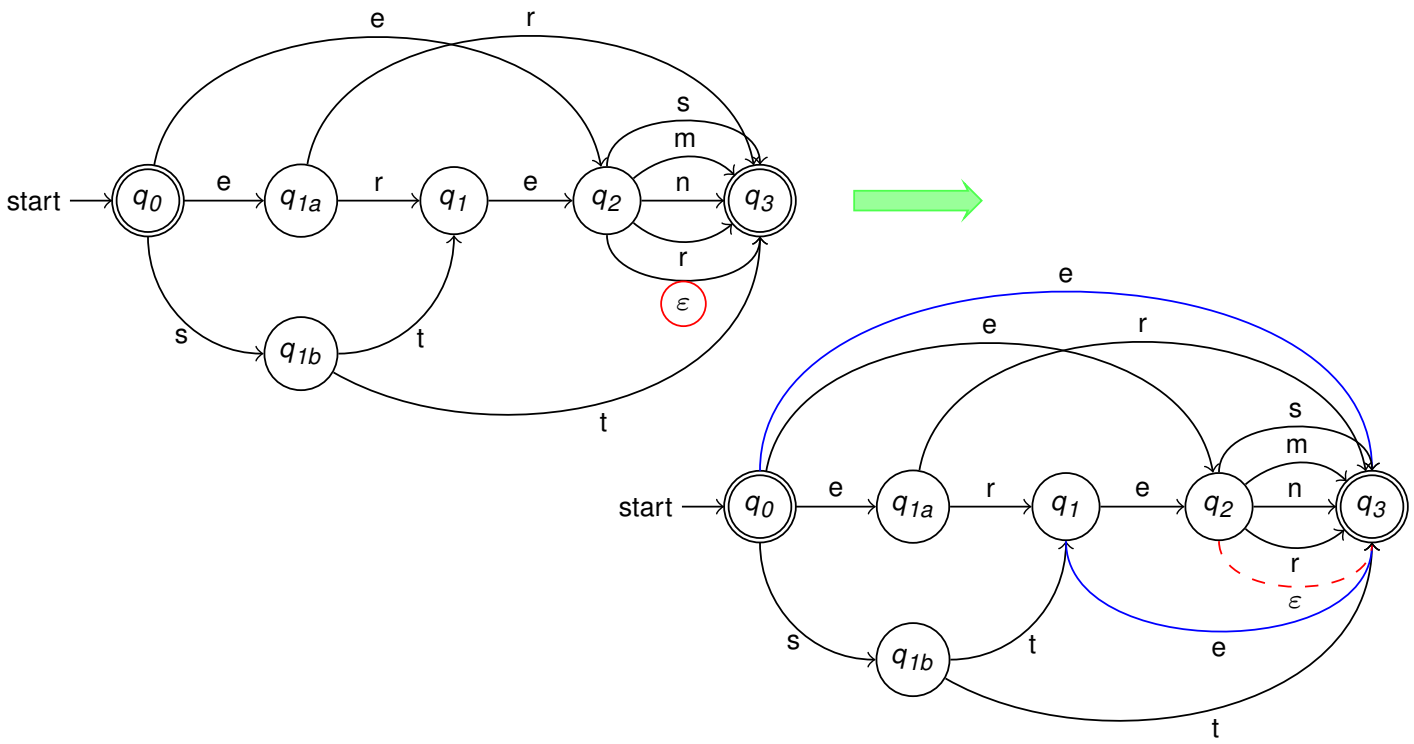


Elimination of ε edges



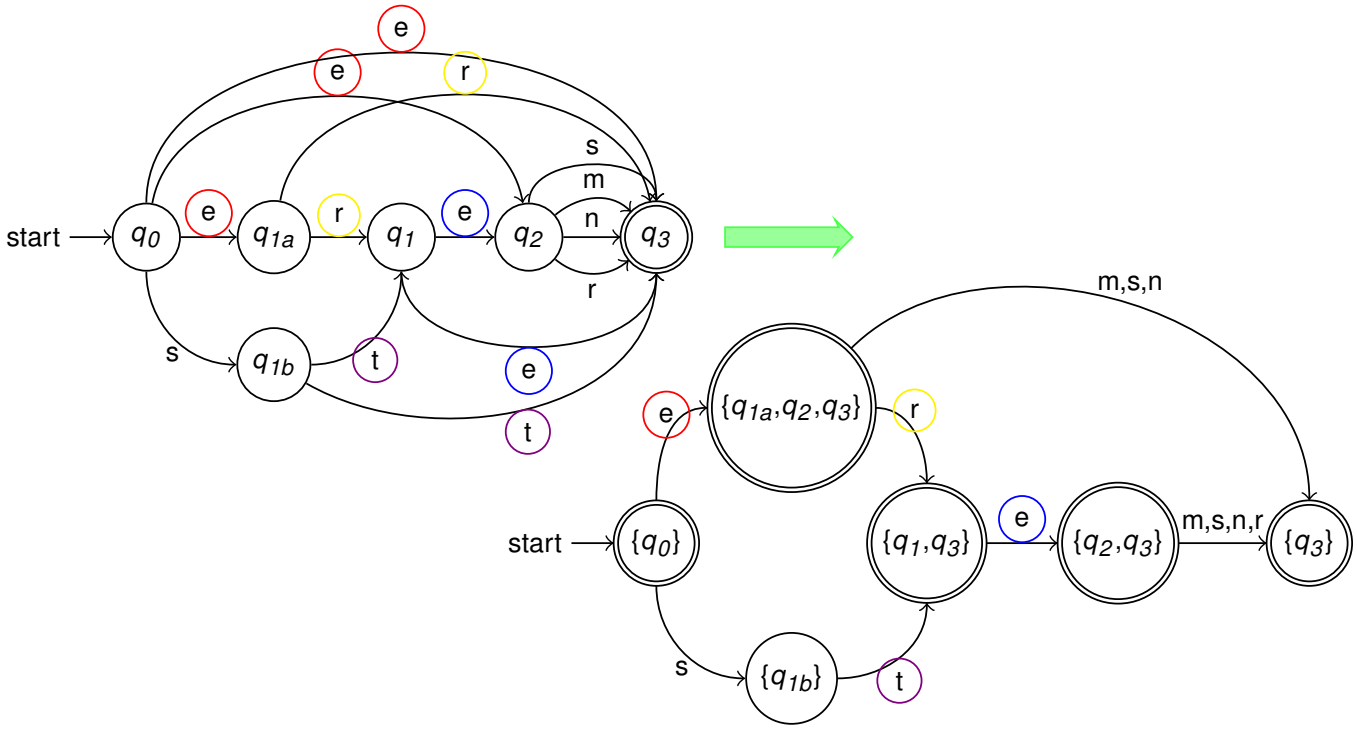
Based on Crysmann 2006

Elimination of ε edges



Based on Crysmann 2006

Constructing a power automaton



Based on Crysmann 2006

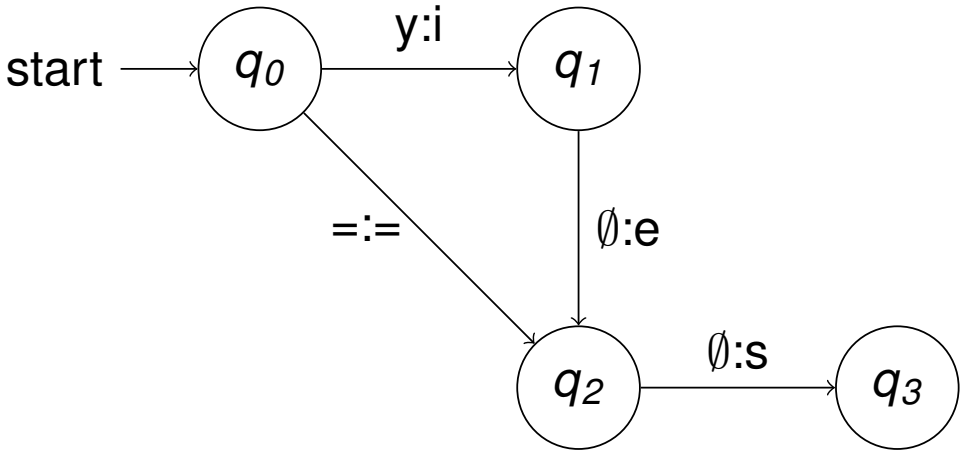
Finite State Transducers

- Finite State Transducers are variants of Finite State Machines that accepts language over symbol pairs (*a*:*a*,*a*:*c*) instead of single symbols
- Conventionally, left hand symbols correspond to lexicon input, and right-hand symbols to the surface string
- The $\emptyset$ can appear both on input string and output string, the symbol “=” (or @) stands for the ’any’ symbol
- FSTs can be used to implement phonological rules ([Johnson(1972)])

Based on Crysmann 2006

A Finite State Transducer

- $y + s \rightarrow ies$



Based on Crysmann 2006

Summary

- Morphemes are minimal sign/meaning pairs
- Morphological analysis plays a role in reduction of lexicon size, unknown word recognition, etc
- Several meaning units can be mapped in one morpheme (multi-exponence)
- Phenomena such as reduplication, syncretism, allomorphism, and morphophonological processes make that morphemes are not necessarily easily recognizable
- FSM forms the standard (basic) technique for morphological analysis

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