Language Processing with Perl and Prolog

Chapter 6: Words, Parts of Speech, and Morphology

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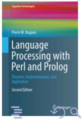
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The Parts of Speech

The parts of speech (POS) are classes that correspond to the lexical – or word – categories

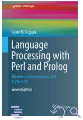
Plato made a distinction between the verb and the noun.

After him, the word categories further evolved and grew in number until Dionysus Thrax formulated and fixed them.

Aelius Donatus popularized the list of the eight parts of speech: noun, pronoun, verb, participle, conjunction, adverb, preposition, and interjection.

Grammarians have adopted these POS for most European languages although they are somewhat arbitrary

POS divide between two main classes: the open class and the closed class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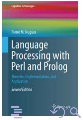
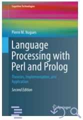
Parts of Speech: Open Class Words

POS	**English**	**French**	**German**
Nouns	*name, Frank*	*nom, François*	*Name, Franz*
Adjectives	*big, good*	*grand, bon*	*groß, gut*
Verbs	*to swim*	*nager*	*schwimmen*
Adverbs	*rather, very, only*	*plutôt, très, uniquement*	*fast, nur, sehr, endlich*



Parts of Speech: Closed Class Words

POS	**English**	**French**	**German**
Determiners	*the, several, my*	*le, plusieurs, mon*	*der, mehrere, mein*
Pronouns	*he, she, it*	*il, elle, lui*	*er, sie, ihm*
Prepositions	*to, of*	*vers, de*	*nach, von*
Conjunctions	*and, or*	*et, ou*	*und, oder*
Auxiliaries and modals	*be, have, will, would*	*être, avoir, pouvoir*	*sein, haben, können*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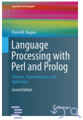
Features

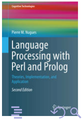
Main parts of speech	Features (subcategories)
Adjective, noun, pronoun	Regular base comparative superlative interrogative person number case
Adverb	Regular base comparative superlative interrogative
Article, determiner, preposition	Person case number
Verb	Tense voice mood person number case



Parts of Speech for Swedish

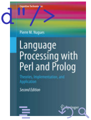
Bilen framför justitieministern svängde fram och tillbaka över vägen så att hon blev rädd.
'The car in front of the Justice Minister swung back and forth and she was frightened.'

```
<tokens>
  <token id="1">Bilen</token>
  <token id="2">framför</token>
  <token id="3">justitieministern</token>
  <token id="4">svängde</token>
  <token id="5">fram</token>
  <token id="6">och</token>
  <token id="7">tillbaka</token>
  <token id="8">över</token>
  <token id="9">vägen</token>
  <token id="10">så</token>
  <token id="11">att</token>
  <token id="12">hon</token>
  <token id="13">blev</token>
  <token id="14">rädd</token>
  <token id="15">.</token>
</tokens>
```



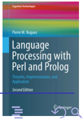
Parts of Speech for Swedish

```
<taglemmas>
  <taglemma id="1" tag="nn.utr.sin.def.nom" lemma="bil"/>
  <taglemma id="2" tag="pp" lemma="framför"/>
  <taglemma id="3" tag="nn.utr.sin.def.nom" lemma="justitieminister"
  <taglemma id="4" tag="vb.prt.akt" lemma="svänga"/>
  <taglemma id="5" tag="ab" lemma="fram"/>
  <taglemma id="6" tag="kn" lemma="och"/>
  <taglemma id="7" tag="ab" lemma="tillbaka"/>
  <taglemma id="8" tag="pp" lemma="över"/>
  <taglemma id="9" tag="nn.utr.sin.def.nom" lemma="väg"/>
  <taglemma id="10" tag="ab" lemma="så"/>
  <taglemma id="11" tag="sn" lemma="att"/>
  <taglemma id="12" tag="pn.utr.sin.def.sub" lemma="hon"/>
  <taglemma id="13" tag="vb.prt.akt.kop" lemma="bli"/>
  <taglemma id="14" tag="jj.pos.utr.sin.ind.nom" lemma="rädd"/>
  <taglemma id="15" tag="mad" lemma="."/>
</taglemmas>
```



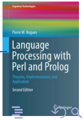
Categories from the Stockholm–Umeå Corpus (SUC)

Code	Swedish category	Example	English translation
AB	Adverb	*inte*	Adverb
DT	Determinerare	*denna*	Determiner
HA	Frågande/relativt adverb	*när*	Interrogative/relative adverb
HD	Frågande/relativ determinerare	*vilken*	Interrogative/relative determiner
HP	Frågande/relativt pronomen	*som*	Interrogative/relative pronoun
HS	Frågande/relativt possessivt pronomen	*vars*	Interrogative/relative possessive
IE	Infinitivmärke	*att*	Infinitive marker
IN	Interjektion	*ja*	Interjection
JJ	Adjektiv	*glad*	Adjective
KN	Konjunktion	*och*	Conjunction



Categories from the Stockholm–Umeå Corpus (SUC)

Code	Swedish category	Example	English translation
NN	Substantiv	*pudding*	Noun
PC	Particip	*utsänd*	Participle
PL	Partikel	*ut*	Particle
PM	Egennamn	*Mats*	Proper noun
PN	Pronomen	*hon*	Pronoun
PP	Preposition	*av*	Preposition
PS	Possessivt pronomen	*hennes*	Possessive
RG	Grundtal	*tre*	Cardinal number
RO	Ordningstal	*tredje*	Ordinal number
SN	Subjunktion	*att*	Subjunction
UO	Utländskt ord	*the*	Foreign word
VB	Verb	*kasta*	Verb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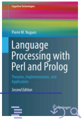
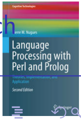
Features from the Stockholm–Umeå Corpus (SUC)

Feature	Value	Legend	POS where feature applies
Gender	UTR	Uter (common)	DT, HD, HP, JJ, NN, PC, PN, PS, (RG, RO)
	NEU	Neuter	
	MAS	Masculine	
Number	SIN	Singular	DT, HD, HP, JJ, NN, PC, PN, PS, (RG, RO)
	PLU	Plural	
Definiteness	IND	Indefinite	DT, (HD, HP, HS), JJ, NN, PC, PN, (PS, RG, RO)
	DEF	Definite	
Case	NOM	Nominative	JJ, NN, PC, PM, (RG, RO)
	GEN	Genitive	
Tense	PRS	Present	VB
	PRT	Preterite	
	SUP	Supinum	
	INF	Infinite	



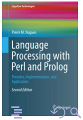
Features from the Stockholm–Umeå Corpus (SUC)

Feature	Value	Legend	POS where feature applies
Voice	AKT	Active	
	SFO	S-form (passive or deponential)	
Mood	KON	Subjunctive (Sw. konjunktiv)	
Participle form	PRS	Present	PC
	PRF	Perfect	
Degree	POS	Positive	(AB), JJ
	KOM	Comparative	
	SUV	Superlative	
Pronoun form	SUB	Subject form	PN
	OBJ	Object form	
	SMS	Compound (Sw. sammansättningsform)	All parts-of-speech

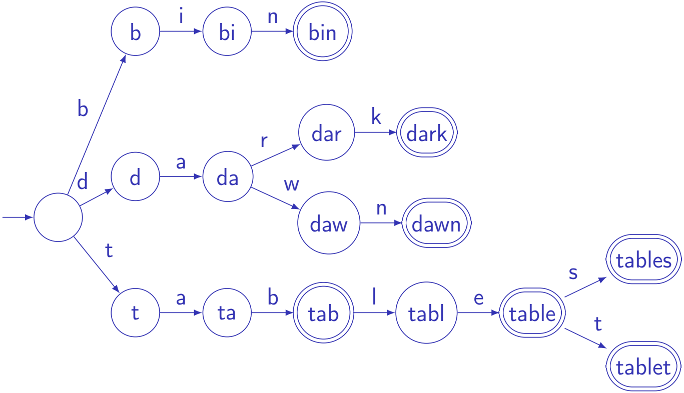


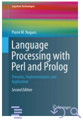
Lexicons: An Excerpt from the Oxford Advanced Learner’s Dictionary

Word	Pronunciation	Syntactic tag	Syllable count or verb pattern (for verbs)
a	@	S-*	1
a	EI	Ki$	1
a fortiori	eI ,fOtI’OraI	Pu$	5
a posteriori	eI ,p0sterI’OraI	OA$,Pu$	6
a priori	eI ,praI’OraI	OA$, Pu$	4
a’s	Eiz	Kj$	1
ab initio	&b I’nISI@U	Pu$	5
abaci	’&b@saI	Kj$	3
aback	@’b&k	Pu%	2
abacus	’&b@k@s	K7%	3
abacuses	’&b@k@sIz	Kj%	4
abaft	@’bAft	Pu$,T-$	2
abandon	@’b&nd@n	H0%,L@%	36A,14
abandoned	@’b&nd@nd	Hc%,Hd%,OA%	36A,14



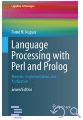
Letter Trees





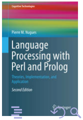
Letter Trees in Prolog

```
[
 [b, [i, [n, bin]]]
 [d, [a, [r, [k, dark]],
         [w, [n, dawn]]]]
 [t, [a, [b, tab,
             [l, [e, table,
                     [s, tables],
                     [t, tablet]]]]]]]
]
```



Finding a Word in a Trie

```
% Checks if a word is in a trie
% is_word_in_trie(+WordChars, +Trie, -Lex)
is_word_in_trie([H | T], Trie, Lex) :-
  member([H | Branches], Trie),
  is_word_in_trie(T, Branches, Lex).
is_word_in_trie([], Trie, LexList) :-
  findall(Lex, (member(Lex, Trie), atom(Lex)), LexList),
  LexList \= [].
% We assume that the word lexical entry is an atom
```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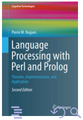
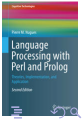
Morphemes

	Word	Morpheme decomposition
English	*disentangling*	*dis*+*en*+***tangle***+*ing*
	rewritten	*re*+***write***+*en*
French	*désembrouillé*	*dé*+*em*+***brouiller***+*é*
	récrite	*re*+***écrire***+*te*
German	*entwirrend*	*ent*+***wirren***+*end*
	wiedergeschrieben	*wieder*+*ge*+***schreiben***+*en*



Inflection

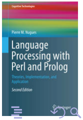
	Plural of nouns	Morpheme decomposition
English	*hedgehogs*	*hedgehog+s*
	churches	*church+es*
	sheep	*sheep+∅*
French	*hérissons*	*hérisson+s*
	chevaux	*cheval+ux*
German	*Gründe*	*Grund+(¨)e*
	Hände	*Hand+(¨)e*
	Igel	*Igel+∅*



Derivation

Creation of a new word

	English	**French**	**German**
Prefixes	***fore***_see_,	***pré***_voir_,	***vorher***_sehen_,
	un_pleasant_	***dé***_plaisant_	***un***_angenehm_
Suffixes	_manage_***able***,	_gér_***able***,	_vorsicht_***ich***,
	rigor***ous***	_rigour_***eux***	_streit_***bar***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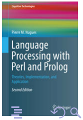
Morphological Processing

Generation →

English		**French**		**German**	
dog+s	*dogs*	*chien+s*	*chiens*	*Hund+e*	*Hunde*
work+ing	*working*	*travailler+ant*	*travaillant*	*arbeiten+end*	*arbeitend*
un+do	*undo*	*dé+faire*	*défaire*		

← Parsing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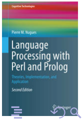
Language Differences (Source: Xerox)

Language	# stems	# inflected forms		Lex. size (kb)
English	55,000	240,000		200–300
French	50,000	5,700,000		200–300
German	50,000	350,000	or	450
		infinite	(compounding)	
Japanese	130,000	200	suffixes	500
		20,000,000	word forms	500
Spanish	40,000	3,000,000		200–300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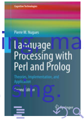
Ambiguities

	Words	Words in context	Lemmatization
E	*Run*		
		1. *A **run** in the forest*	1. **run**: noun sing.
		2. *Sportsmen **run** everyday*	2. **run**: verb present third pers. pl.
F	*Marche*		
		1. *Une **marche** dans la forêt*	1. **marche**: noun sing. fem.
		2. *Il **marche** dans la cour*	2. **marcher**: verb present third pers. sing.
G	*Lauf*		
		1. *Der **Lauf** der Zeit*	1. **Der Lauf**: noun, sing. masc
		2. ***Lauf** schnell!*	2. **laufen**: verb, imp., sing.

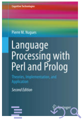


Two-Level Morphology

Current morphological parsers are based on the two-level model of Kimmo Koskenniemi (1983).

It links the surface form of a word – the word as it is in a text – to its lexical or underlying form – its sequence of morphemes

Surface:	disentangled
Lexical (or underlying):	dis+en+tangle+ed



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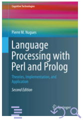
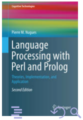
Examples

Generation: Lexical to surface form →		
English	*dis+en+tangle+ed*	*disentangled*
	happy+er	*happier*
	move+ed	*moved*
French	*dés+em+brouiller+é*	*désembrouillé*
	dé+chanter+erons	*déchanterons*
German	*ent+wirren+end*	*entwirrend*
	wieder+ge+schreiben+en	*wiedergeschrieben*
Parsing: ← Surface to lexical form		



Aligning the Two Forms

English	dis+en+tangle+ed ↕↕ . . . dis0en0tangl00ed	happy+er ↕↕ . . . happi0er	move+ed ↕↕ . . . mov00ed
French	dé+chanter+erons ↕↕ . . . dé0chant000erons	cheval+ux ↕↕ . . . cheva00ux	cheviller+é ↕↕ . . . chevill000é
German	singen+st ↕↕ . . . singe00st	Grund+¨e ↕↕ . . . Gründ00e	Igel+∅ ↕↕ . . . Igel00



Interpreting the Morphemes

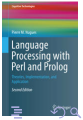
Suffixes have a grammatical interpretation: *erons* in a French verb corresponds to verb + future + 1st person + plural

Morphological parsers can represent the lexical form as a concatenation of the stem and its features instead of the stem and the suffix.

The Xerox parser output for *disentangled* and *happier* is:

```
disentangle+Verb+PastBoth+123SP
happy+Adj+Comp
```

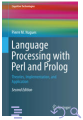
where `+Verb` denotes a verb, `+PastBoth`, either past tense or past participle, and `+123SP` any person, singular or plural; `+Adj` denotes an adjective and `+Comp`, a comparative.



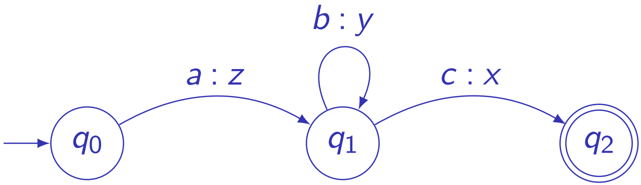
Aligning Morphemes and Features

Lexical:	d	i	s	e	n	t	a	n	g	l	e	+Verb	+PastBoth	+123sp
	↕	↕	↕	↕	↕	↕	↕	↕	↕	↕	↕	↕	↕	↕
Surface:	d	i	s	e	n	t	a	n	g	l	0	0	e	d

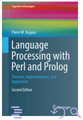
Lexical:	h	a	p	p	y	+Adj	+Comp
	↕	↕	↕	↕	↕	↕	↕
Surface:	h	a	p	p	i	e	r



Transducers



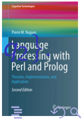
The string abbbc is transduced into zyyyx



Mathematical Definition of a FST

1. Q is a finite set of states.
2. Σ is a finite set of symbol or character pairs $i:o$, where i is a symbol of the input alphabet and o of the output alphabet. As we saw, both alphabets may include epsilon transitions.
3. q_0 is the start state, $q_0 \in Q$.
4. F is the set of final states, $F \subseteq Q$.
5. δ is the transition function $Q \times \Sigma \rightarrow Q$, where $\delta(q,i,o)$ returns the state where the automaton moves when it is in state q and consumes the input symbol pair $i:o$.

The quintuple defining automaton is $Q = \{q_0, q_1, q_2\}$,
$\Sigma = \{a:z, b:y, c:x\}$,
$\delta = \{\delta(q_0, a:z) = q_1, \delta(q_1, b:y) = q_1, \delta(q_1, c:x) = q_2\}$, and $F = \{q_2\}$.



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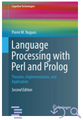
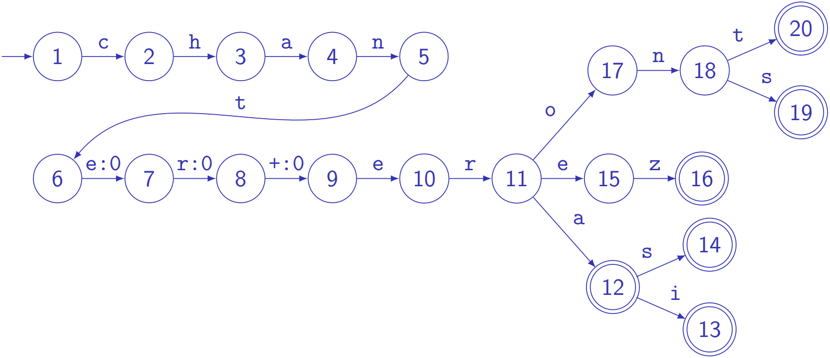
French Verb Transducers for *chanter*

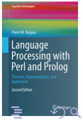
Number\Person	First	Second	Third
singular	*chanterai*	*chanteras*	*chantera*
plural	*chanterons*	*chanterez*	*chanteront*

Number\Pers.	First	Second	Third
singular	`chanter+erai`	`chanter+eras`	`chanter+era`
	`chant000erai`	`chant000eras`	`chant000era`
plural	`chanter+erons`	`chanter+erez`	`chanter+eront`
	`chant000erons`	`chant000erez`	`chant000eront`



Transducer for *chanter*

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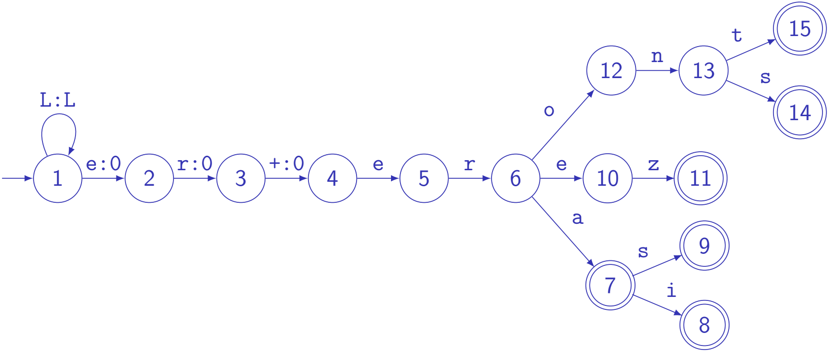
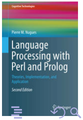
French Verb Transducers: Future, 1st Group



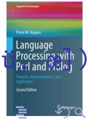


Transducers in Prolog

```
arc(1,1,C,C) :- letter(C).
arc(1,2,e,0).   arc(6,7,a,a).     arc(6,12,o,o).
arc(2,3,r,0).   arc(7,8,i,i).     arc(12,13,n,n).
arc(3,4,+,0).   arc(7,9,s,s).     arc(13,14,s,s).
arc(4,5,e,e).   arc(6,10,e,e).    arc(13,15, t, t).
arc(5,6,r,r).   arc(10,11,z,z).

final_state(7).    final_state(9).     final_state(14).
final_state(8).    final_state(11).    final_state(15).

% letter(+L) describes the French lower-case letters
letter(L) :- name(L, [Code]), 97 =< Code, Code =< 122, !.
letter(L) :-
  member(L, [à, â, ä, ç, é, è, ê, ë, î, ï, ô, ö, ù, û, ü, œ]),
```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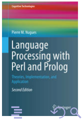
Running the Transducer

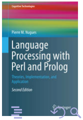
```
transduce(+Start, ?Final, ?Underlying, ?Surface).
% arc(Start, End, UnderlyingChar, SurfaceChar) describes the automat

% transduce(+Start, ?Final, ?UnderlyingString, ?SurfaceString)
transduce(Start, Final, [U | UnderlyingString], SurfaceString) :-
  arc(Start, Next, U, 0),
  transduce(Next, Final, UnderlyingString, SurfaceString).
transduce(Start, Final, UnderlyingString, [S | SurfaceString]) :-
  arc(Start, Next, 0, S),
  transduce(Next, Final, UnderlyingString, SurfaceString).
transduce(Start, Final, [U | UnderlyingString],
    [S | SurfaceString]) :-
  arc(Start, Next, U, S),
  U \== 0, S \== 0,
  transduce(Next, Final, UnderlyingString, SurfaceString).
transduce(Final, Final, [], []) :- final_state(Final).
```



Romance Languages

Language	Number\Person	First	Second	Third
Italian				
	singular	*canterò*	*canterai*	*canterà*
	plural	*canteremo*	*canterete*	*canteranno*
Spanish				
	singular	*cantaré*	*cantarás*	*cantará*
	plural	*cantaremos*	*cantaréis*	*cantarán*
Portuguese				
	singular	*cantarei*	*cantarás*	*cantará*
	plural	*cantaremos*	*cantareis*	*cantarão*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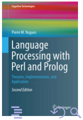
Ambiguity

In the transducer for future tense, there is no ambiguity: A surface form has only one lexical form with a unique final state.
This is not the case with the present tense

> *(je) chante 'I sing'*
> *(il) chante 'he sings'*

Number\Person	First	Second	Third
singular	*chante*	*chantes*	*chante*
plural	*chantons*	*chantez*	*chantent*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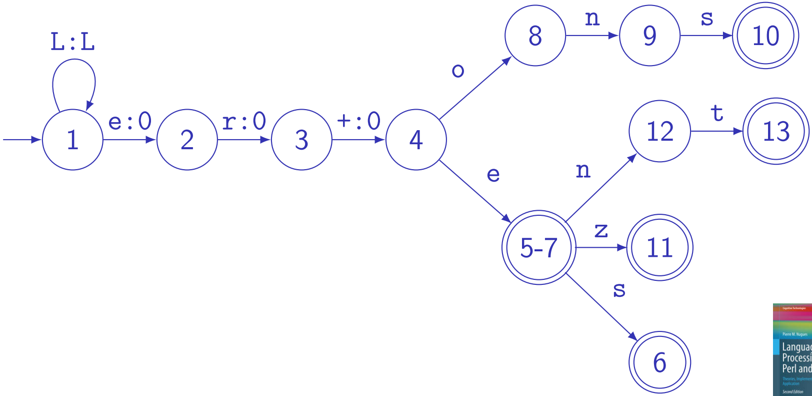
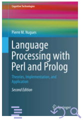
Transducer Ambiguity

Final states 5 and 7 are the same.
The implementation in Prolog is similar to that of the future tense.
Using backtracking, the transducer can produce all the final states reflecting the morphological ambiguity.

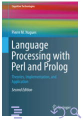




Koskenniemi's Rules

Koskenniemi described morphology with declarative rules.
They use the left and right context and the ⇒, ⇐, ⇔, or /⇐ operators
In English, a lexical *y* can correspond to a surface *i* as in *happier*.
It occurs when *y* is preceded by a consonant and followed by *-er*, *-ed*, or *-s*.

1. `y:i ⇐ C:C __ +:0 e:e r:r`
2. `y:i ⇐ C:C __ +:e s:s`
3. `y:i ⇐ C:C __ +:0 e:e d:d`



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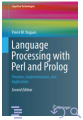
Two-level Rules

Lexical:surface transduction is described by rules.

Rules	Description
a:b ⇒ lc __ rc	a is transduced as b **only** when it has lc to the left and rc to the right
a:b ⇐ lc __ rc	a is **always** transduced as b when it has lc to the left and rc to the right
a:b ⇔ lc __ rc	a is transduced as b **always and only** when it has lc to the left and rc to the right
a:b /⇐ lc __ rc	a is **never** transduced as b when it has lc to the left and rc to the right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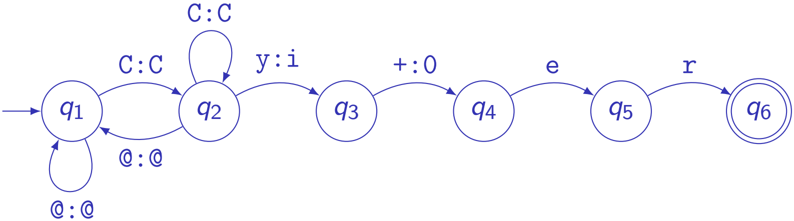
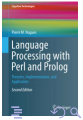
Parallel Rules

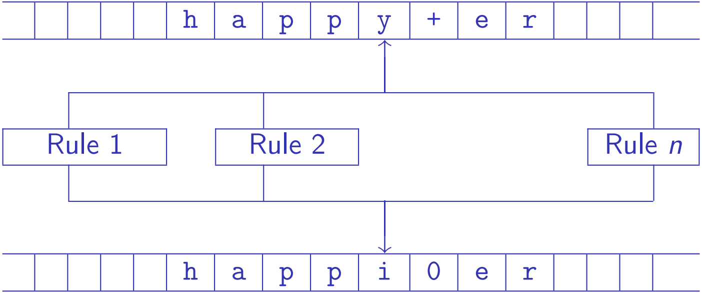
All the rules are applied in parallel (provided that their context match)





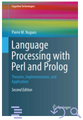
Rules and Transducers

Rules can be compiled as an equivalent transducer



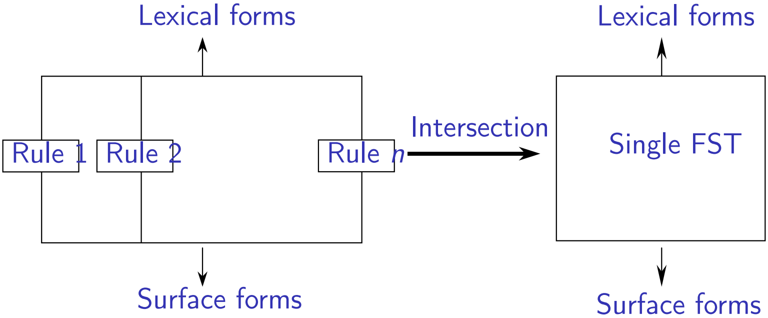
h a p p y + e r

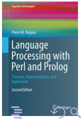
h a p p i 0 e r



Rule Intersection

The parallel transducers are then combined into a single one using the transducer intersection.





Problems with Intersection

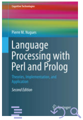
The intersection of two finite automata defines a finite-state automaton

It is not always the case for finite-state transducers.

Kaplan and Kay (1994) demonstrated that when surface and lexical pairs have the same length – without ε –, the intersection is a transducer.

This property is sufficient to intersect the rules in practical applications.

In fact, transducers obtained from two-level rules are intersected by treating the ε symbol as an ordinary symbol (Beesley and Karttunen 2003, p. 55).



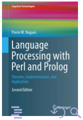
Xerox

Originally, rules were compiled by hand.

However, it can quickly become intractable especially when it comes to managing conflicting rules or when rule contexts interfere with transduced symbols.

To solve it, we can use a compiler that creates transducers automatically from two-level rules.

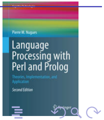
The Xerox's XFST is an example of it. It is a publicly available tool and to date the only serious implementation of a morphological rule compiler.



Morphology of French Verbs

We used the stem and a set of suffixes for French regular verbs.
French irregular verbs are notoriously more complex.
Chanod (1994) gives an example of decomposition into simple rules.

Infinitive	**courir**	**dormir**	**battre**	**peindre**	**écrire**
First person sing.	cour**s**	**dors**	**bats**	**peins**	écris
Second person sing.	cour**s**	**dors**	**bats**	**peins**	écris
Third person sing.	cour**t**	**dort**	**bat**	**peint**	écrit
First person pl.	cour**ons**	dormons	battons	peignons	**écrivons**
Second person pl.	cour**ez**	dormez	battez	peignez	**écrivez**
Third person pl.	cour**ent**	dorment	battent	peignent	**écrivent**

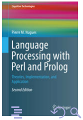


French Morphology

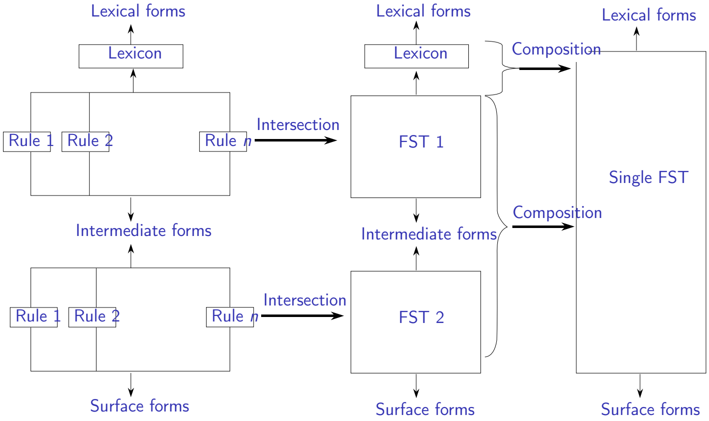
Lexical form: stem	dormir	+IndP	+SG	+P1
	↕		↕	
Intermediate form: inflection	dorm	+IndP	+SG	+P1
	↕		↕	
Intermediate form: deletion of *m* followed by *s*	dorm		s	
	↕		↕	
Surface form:	dor		s	

From *peindre* to *peins*

$n{:}0 \Leftrightarrow g \ \_\_ \ [s|t]$



Composition and Intersection


Lexical forms
Lexicon
Rule 1
Rule 2
Rule *n*
Intersection
Intermediate forms
Rule 1
Rule 2
Rule *n*
Intersection
Surface forms
Lexical forms
Lexicon
FST 1
Intermediate forms
FST 2
Surface forms
Composition
Composition
Lexical forms
Single FST
Surface forms