Modeling Morphological Learning

Tolerance Principle on Turkish past tense -DI

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The morpheme -DI

- 8 allomorphs conditioned by phonology (Göksel & Kerslake, 2004)

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(1)	gel	-di	(3)	ısır	-dı	(5)	oku	-du	(7)	gör	-dü
	come	-DI		bite	-DI		read	-DI		see	-DI
	They(sg.) came.			They(sg.) bit.			They(sg.) read.			They(sg.) saw.	
(2)	git	-ti	(4)	yap	-tı	(6)	somurt	-tu	(8)	düş	-tü
	go	-DI		do	-DI		frown	-DI		fall	-DI
	They(sg.) went.			They(sg.) did.			They(sg.) frowned.			They(sg.) fell	

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- Rules apply consistently for all verbal stems.
- used productively by children as young as 1;5 with very little error (Aksu-Koç & Ketrez, 2003) (Aksu-Koç & Slobin, 1985)
- -tü $\rightarrow$ as young as 1;3 with less than seven verbs in lexicon (Aksu-Koç & Ketrez, 2003).

Tolerance Principle

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Let R be a rule applicable to N items, of which e are exceptions.
R is productive if and only if
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N	θ_N	%
10	4	40.0
20	6	30.0
50	12	24.0
100	21	21.0
200	37	18.5
500	80	16.0
1,000	144	14.4
5,000	587	11.7

Abduction of Tolerable Productivity

- A greedy search algorithm that recursively generates a decision tree based on the Tolerance Principle (Belth et al., 2021)

Motivation

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Data

form	occurrence
dı	270
di	180
tı	89
ti	75
du	55
dü	35
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tü	22
Total	751

Table: Number of verb types for each allomorph

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- 328 verbs from CHILDES Turkish corpora (Aksu-Koç, 2004) (Altınkamış, 2012), extracted using UDPipe 2.0 (Straka, 2018)

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- Inflected using a context-free grammar with NLTK (Bird et al., 2009)

Training and evaluation

- 7 experiments to check for phonological feature pairings

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- 7 experiments to check for phonological feature pairings
- Precision, recall and F1 calculations on the test data
- Decision trees provided by the model for explicit analysis of formulated rules.

Metrics

	Features	Precision	Recall	F1
Experiment 1	[+/-VOICE]	1.0	1.0	1.0
Experiment 2	[+/- BACK]	0.955539	0.934803	0.943099
Experiment 3	[+/- ROUND]	0.734524	0.650497	0.675638
Experiment 4	[+/-VOICE] [+/- BACK]	0.951042	0.942859	0.946500
Experiment 5	[+/-VOICE] [+/- ROUND]	0.867888	0.777437	0.805699
Experiment 6	[+/- BACK] [+/- ROUND]	0.906071	0.891674	0.893532
Experiment 7 (Turkish forms)	[+/-VOICE] [+/- BACK] [+/- ROUND]	0.883886	0.888727	0.880219

Metrics

Expected \ Output	dɪ	di	tɪ	ti	du	dü	tu	tü
dɪ	57	0	0	0	0	0	0	0
di	0	43	0	0	0	0	0	0
tɪ	0	0	31	3	0	0	0	0
ti	0	1	1	17	0	0	0	3
du	0	0	0	0	9	3	0	0
dü	1	0	0	0	0	9	0	1
tu	0	0	0	0	0	0	2	0
tü	0	0	0	0	0	1	0	6

Figure: Confusion matrix for Experiment 7

Decision trees

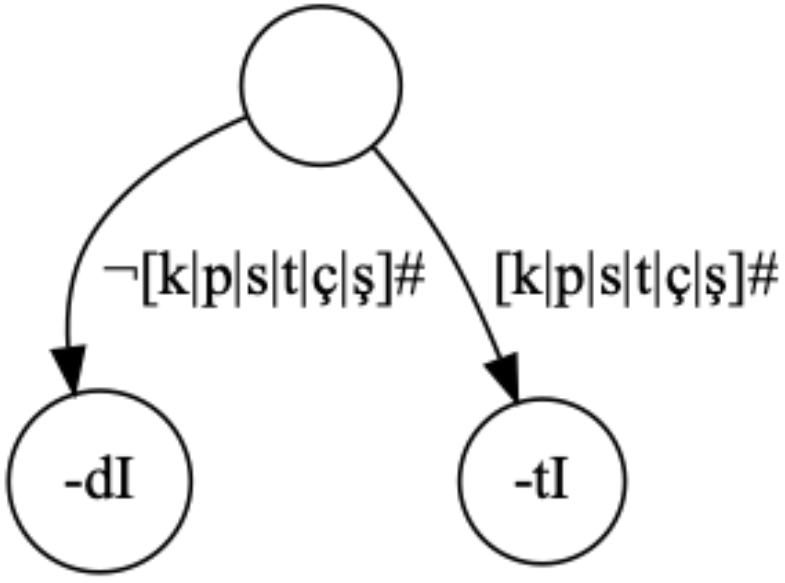


Figure: Experiment 1

Decision trees

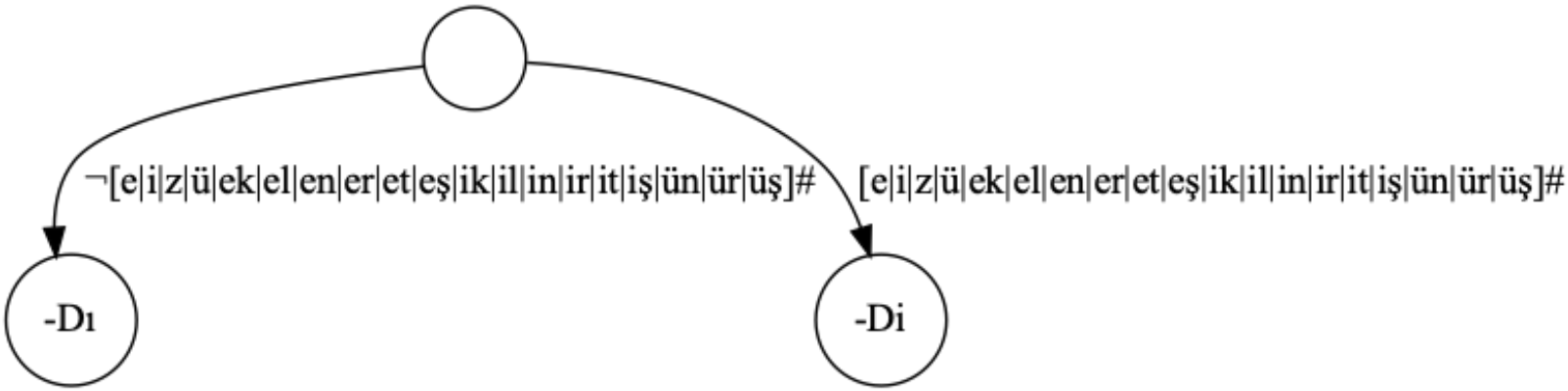


Figure: Experiment 2

Decision trees

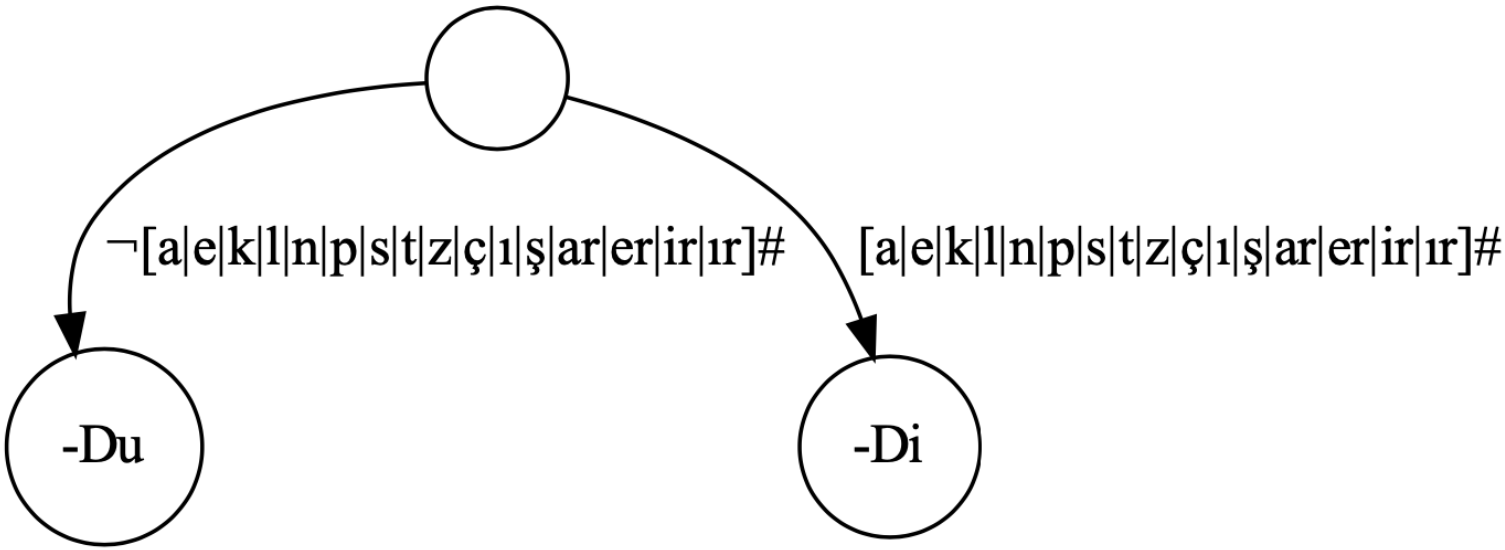


Figure: Experiment 3

Decision trees

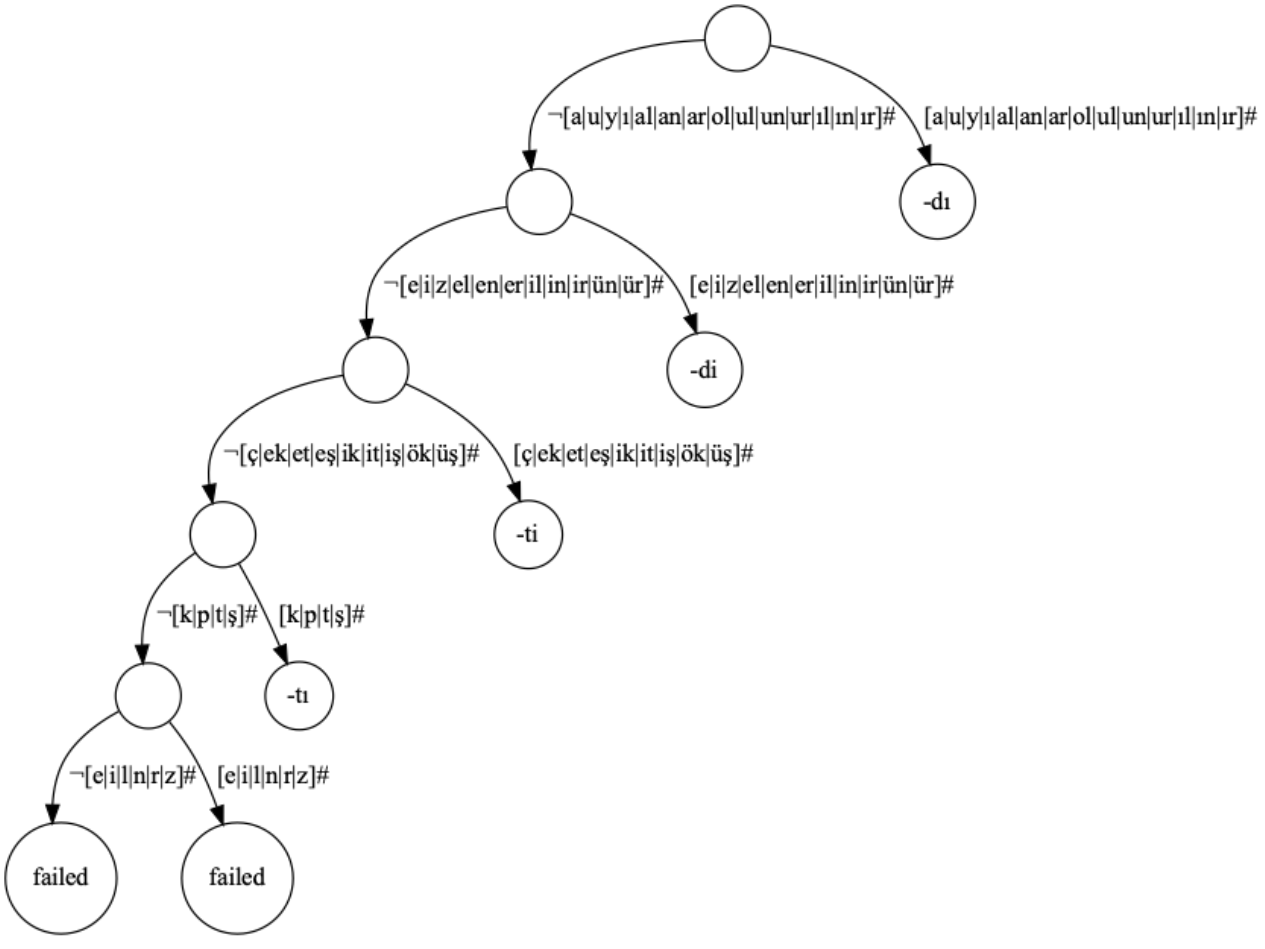


Figure: Experiment 4

Decision trees

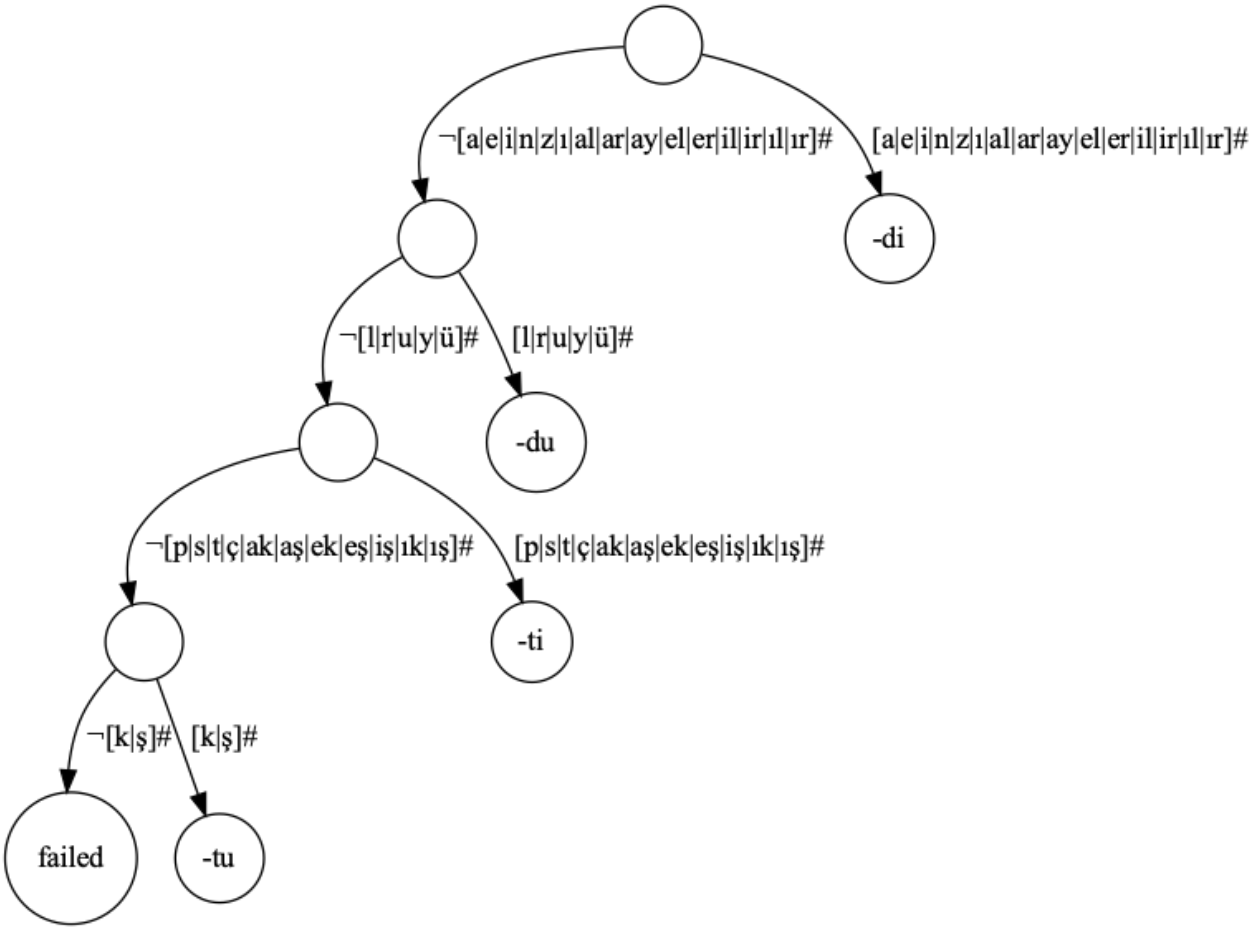


Figure: Experiment 5

Decision trees

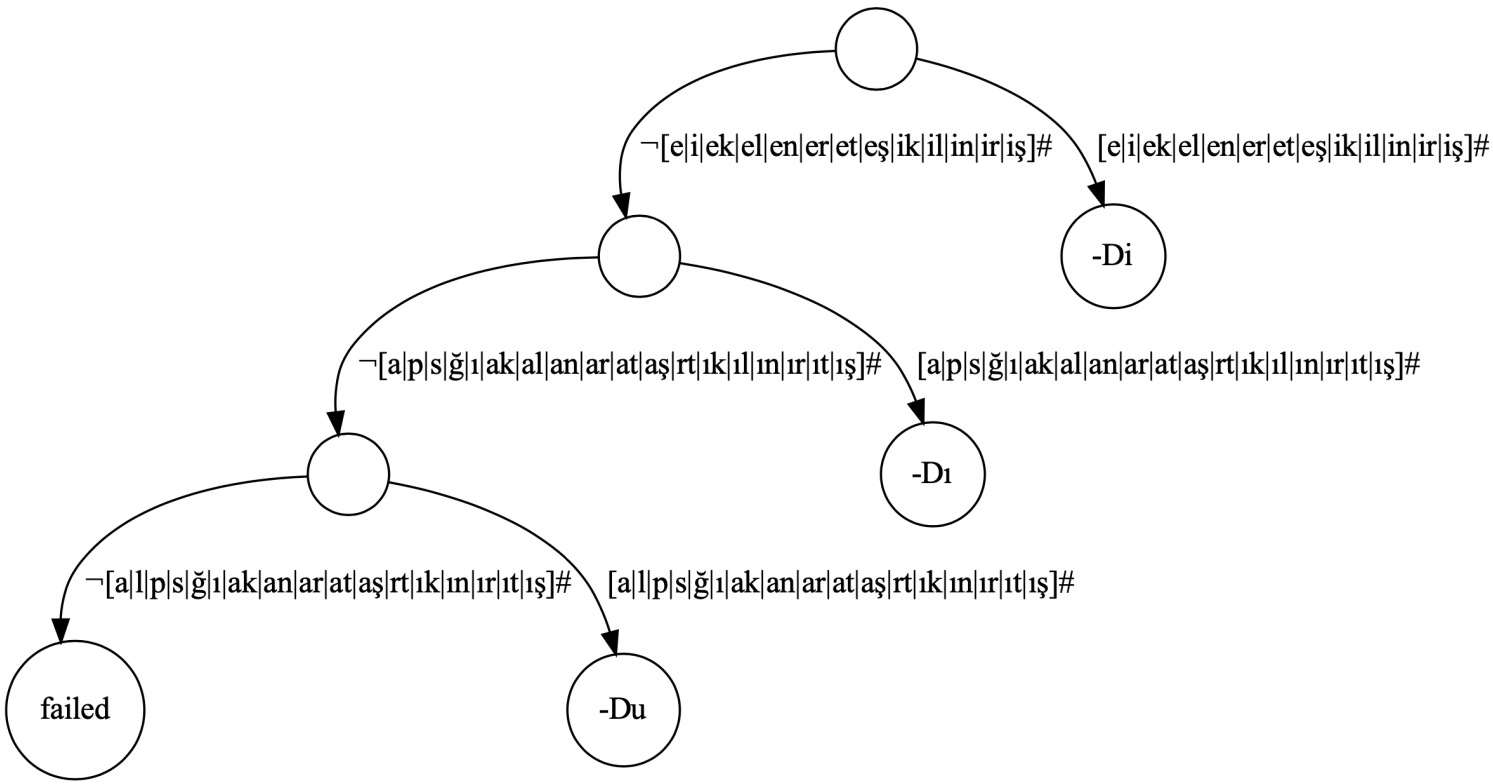
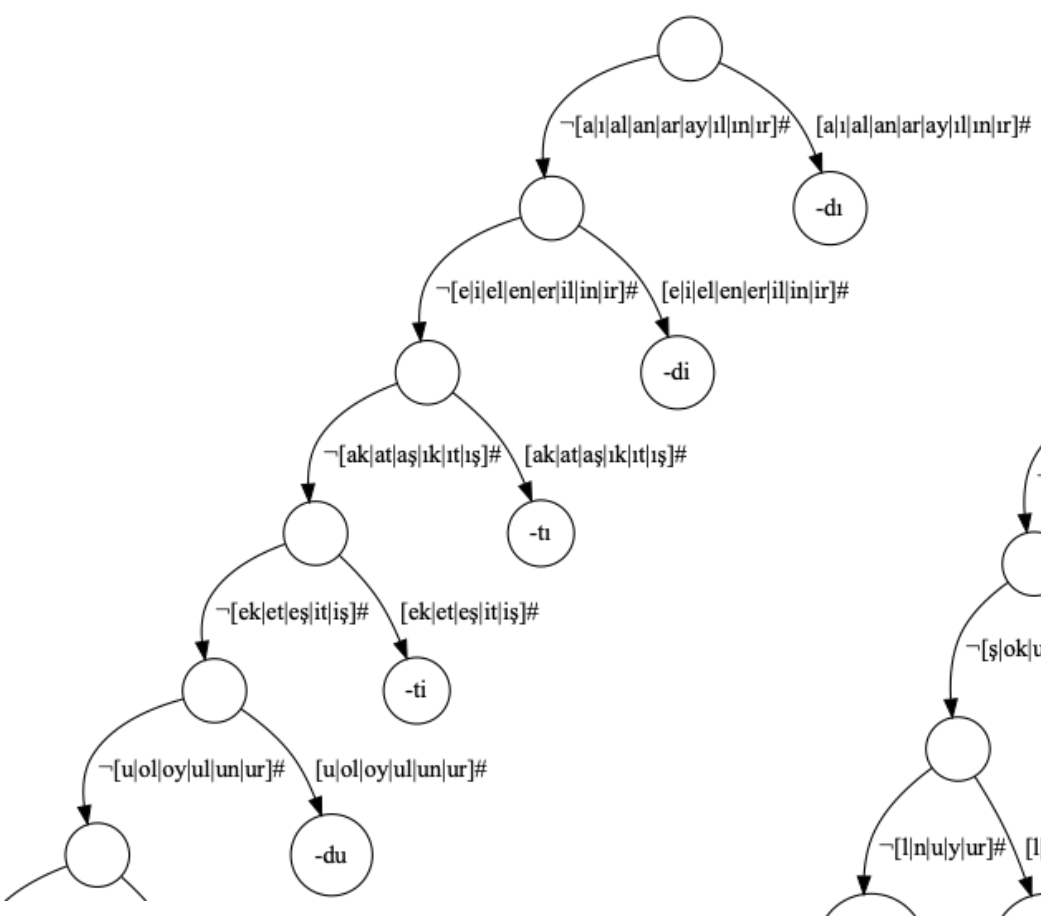
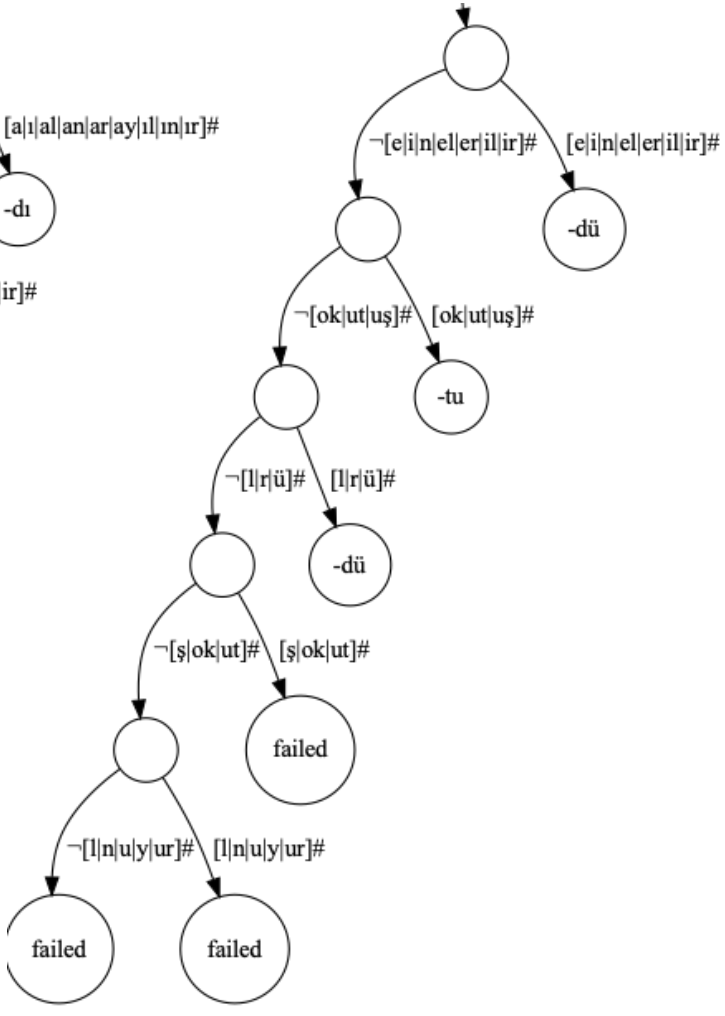


Figure: Experiment 6

Decision trees: Experiment 7





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- Maybe we also need an analogy-based process, like in Albright and Hayes, 2003, to acquire this morpheme.
- ATP has no abstraction, no features, no natural classes, so it can't generalize over them. $\rightarrow$ A Turkish-acquiring child has access to them.

Data

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- multiplied by the number of occurrence of verb + DI in Universal Dependencies Turkish corpora.
(Bakay et al., 2021) (Kuzgun et al., 2020) (Marșan et al., 2021) (Marșan et al., 2022) (Sulubacak et al., 2016) (Sulubacak & Eryiğit, 2018) (Zeman et al., 2017)

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verb	verbform
acı	acıdı
2_acı	2_acıdı
3_acı	3_acıdı
acık	acıktı
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form	occurrence
dı	101
di	52
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du	31
dü	17
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tü	6
Total	328

Table: CHILDES verbs

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Total	328

Table: CHILDES verbs

form	occurrence
dɪ	2039
di	3118
tɪ	1098
ti	1008
du	1101
dü	360
tu	333
tü	270
Total	9327

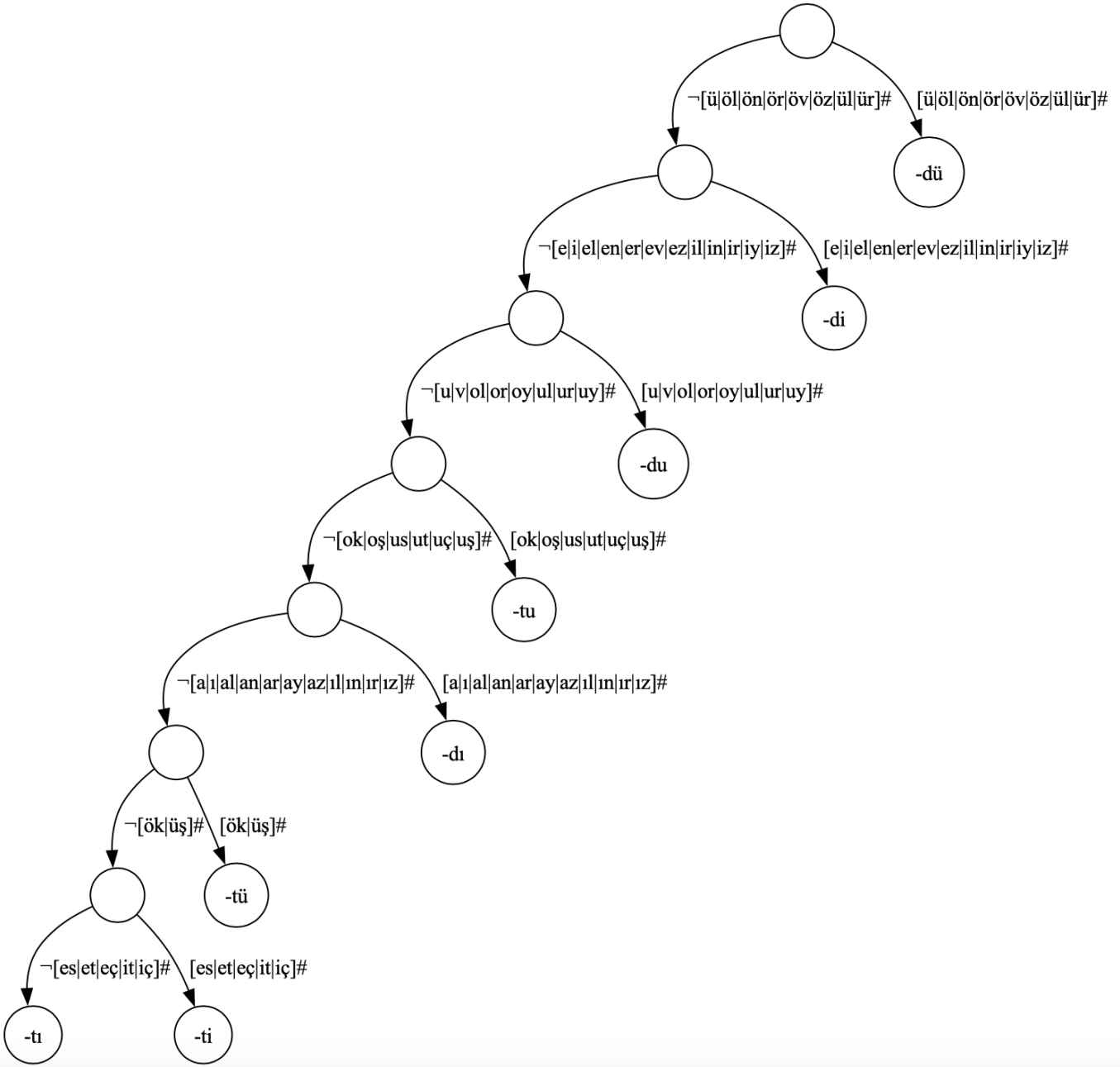
Table: Augmented data

Metrics

Expected \ Output	dɪ	di	tɪ	ti	du	dü	tu	tü
dɪ	507	0	2	0	0	0	0	0
di	0	754	2	0	0	0	0	0
tɪ	0	0	260	0	0	0	0	0
ti	0	0	30	247	0	0	0	0
du	0	0	11	0	277	0	0	0
dü	0	0	0	0	0	89	0	0
tu	0	0	4	0	0	0	78	0
tü	0	0	1	0	0	0	0	70

Metrics:	Precision: 0.98201	Recall: 0.97855	F1: 0.97906

Figure: Metrics for the new experiment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-dü
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[e|i|el|en|er|ev|ez|il|in|ir|iy|iz]#
-di
¬[u|v|ol|or|oy|ul|ur|uy]#
[u|v|ol|or|oy|ul|ur|uy]#
-du
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[ok|oş|us|ut|uç|uş]#
-tu
¬[a|ı|al|an|ar|ay|az|ıl|ın|ır|ız]#
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-dı
¬[ök|üş]#
[ök|üş]#
-tü
¬[es|et|eç|it|iç]#
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- Decision tree has the right rules.
- Rules not posited for some endings (e.g. dik - dikti)
- Even though rounded allomorphs are still on the infrequent side of the data, a productive rule is learned.
- The model still has no abstraction, it only considers the ortographic forms.

Discussion

- What's the takeaway for Tolerance Principle?

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- Type input only is not sufficient to learn, even though this is a very regular rule.
- in line with existing research that says token frequency is necessary for productivity (Jarosz, 2023)
- Hypothesis confirmation: another indicator for lack of 'exceptions'

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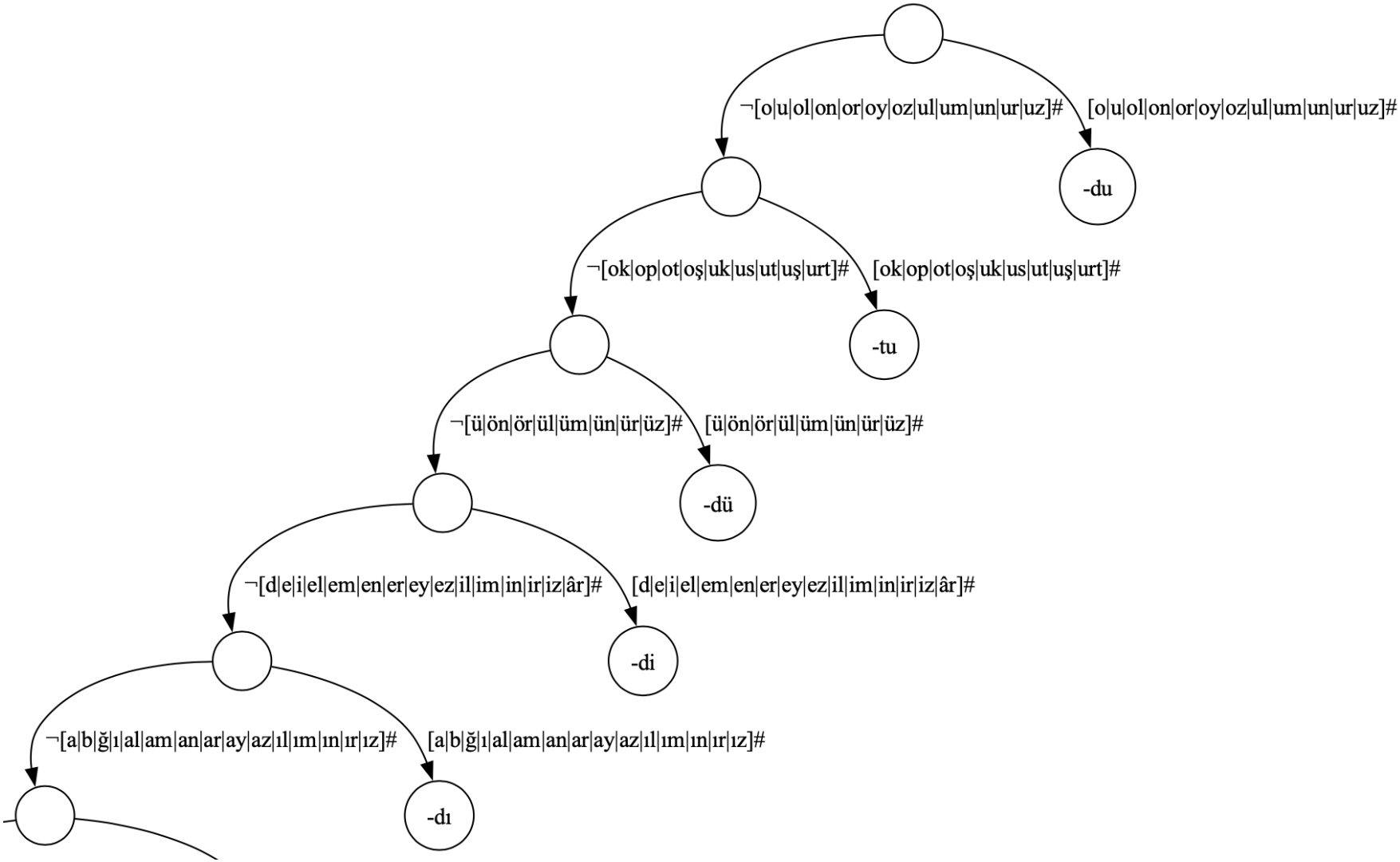
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-du
¬[ok|op|ot|oş|uk|us|ut|uş|urt]#
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-tu
¬[ü|ön|ör|ül|üm|ün|ür|üz]#
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-dü
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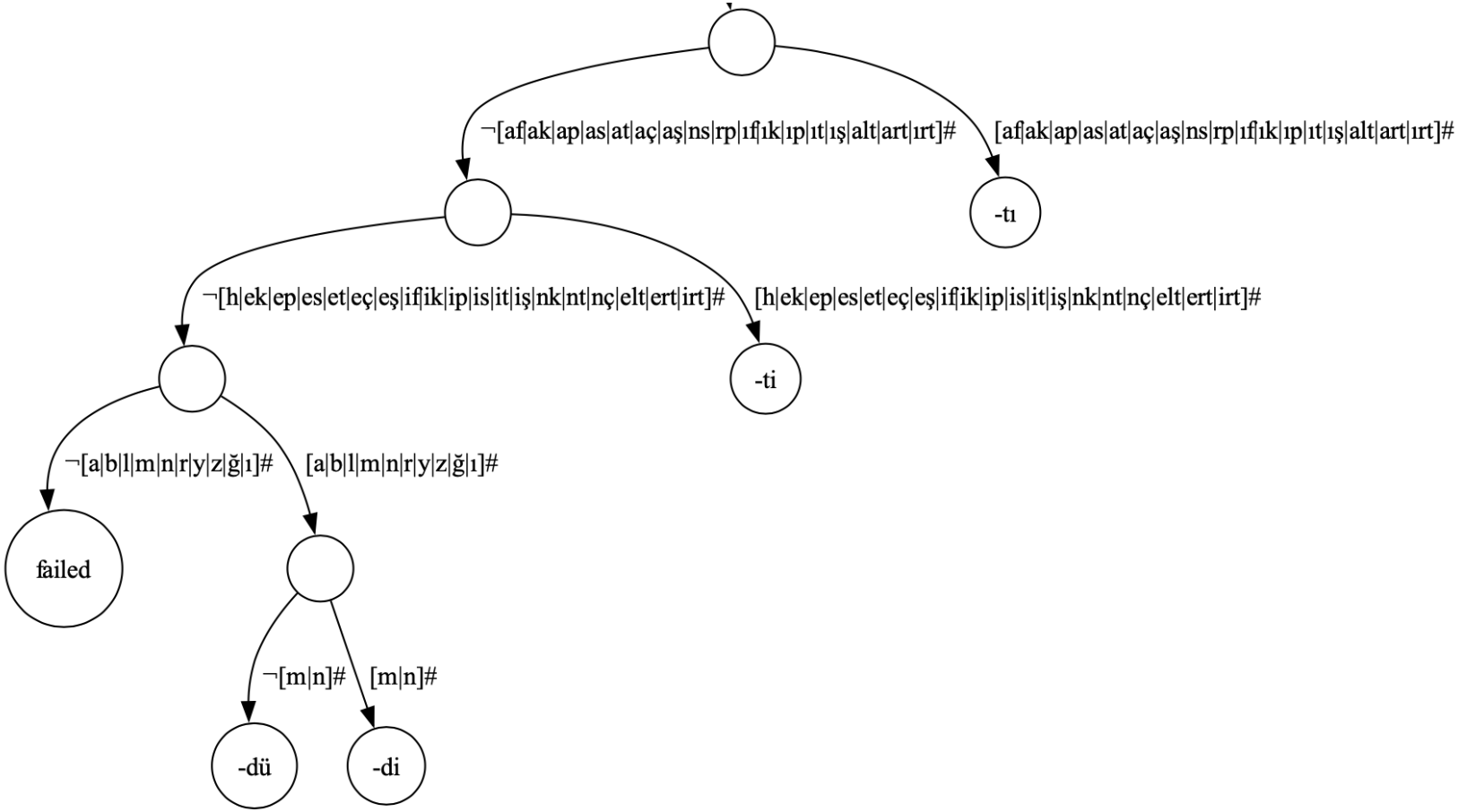
[a|b|ğ|ı|al|am|an|ar|ay|az|ıl|ım|ın|ır|ız]#
-dı


¬[af|ak|ap|as|at|aç|aş|ns|rp|ıf|ık|ıp|ıt|ış|alt|art|ırt]#
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