THE NEW STATUS OF EXCEPTIONS WHEN PHONOLOGY IS PROBABILISTIC

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Introduction

- What is an exception?
  - *Generally, something that deviates from the phonology*
  - *Unpredictable*
  - *Marked in the lexicon in some way*
- How we think of the phonology affects how we think about exceptions
  - *Which words are exceptions*
  - *How they are marked as exceptions*
  - *Is 'exception' a useful notion that distinguishes some forms from others?*
- Probabilistic Phonology

Goals for today:

1. Present a few cases of Probabilistic Phonology
   - *Dutch voicing alternations (Ernestus & Baayen, 2003)* - Neutralization
   - *Tagalog nasal substitution (Zuraw 2000, 2010)* - Morphology
   - *English stress assignment (Guion et al., 2003)* - Phonotactics
2. Argue that they really are Probabilistic Phonology

   (and explain what I mean by that)

3. Discuss a few different ways of doing exceptionality within Probabilistic Phonology
   - *Lexical Listing*
   - *Constraint Indexation*
   - *Representational Strength Theory*

→ Get us all thinking about *Redundancy, Efficiency,* and *Psychological Reality*

→ And! *Is there lexically-specific phonology?*

Productivity:

Finnish speakers	Initial Stress (sýli, jǽkælæ, hɑ́mpurilainen...)	*Final Stress (none)

ki + gæt   ni + sin   dæ + læt   ...

speaker 1	**kígət**	**nísən**	**dɛ́lət**
speaker 2	**kígət**	**nísən**	**dɛ́lət**
speaker 3	**kígət**	**nísən**	**dɛ́lət**
speaker 4	**kígət**	**nísən**	**dɛ́lət**
speaker 5	**kígət**	**nísən**	**dɛ́lət**
...	...	...	...

- Each speaker, and each item, follow the phonology of the language
- There may be occasional speech errors, but other than this no variation in participants responses

Probabilistic Behaviour on wug-tests

English speakers: Initial Stress > Final Stress

(cándy, púrple, pásta…) (guitár, políce…)

	ki + gæt	ni + sin	dæ + læt	…
speaker 1	**kigǽt**	**nísən**	**dǽlət**	
speaker 2	**kígət**	**nísən**	**dəlǽt**	
speaker 3	**kígət**	**nəsín**	**dəlǽt**	
speaker 4	**kəgǽt**	**nísən**	**dǽlət**	
speaker 5	**kígət**	**nəsín**	**dǽlət**	
…	…	…	…	

60% **40%**

- Each speaker behaves probabilistically
- Each item behaves probabilistically
- Not the behaviour we would expect if speakers knew a categorical phonological generalization, and a bunch of listed exceptions

If overall probabilities match the lexicon:
→ **Probability Matching**

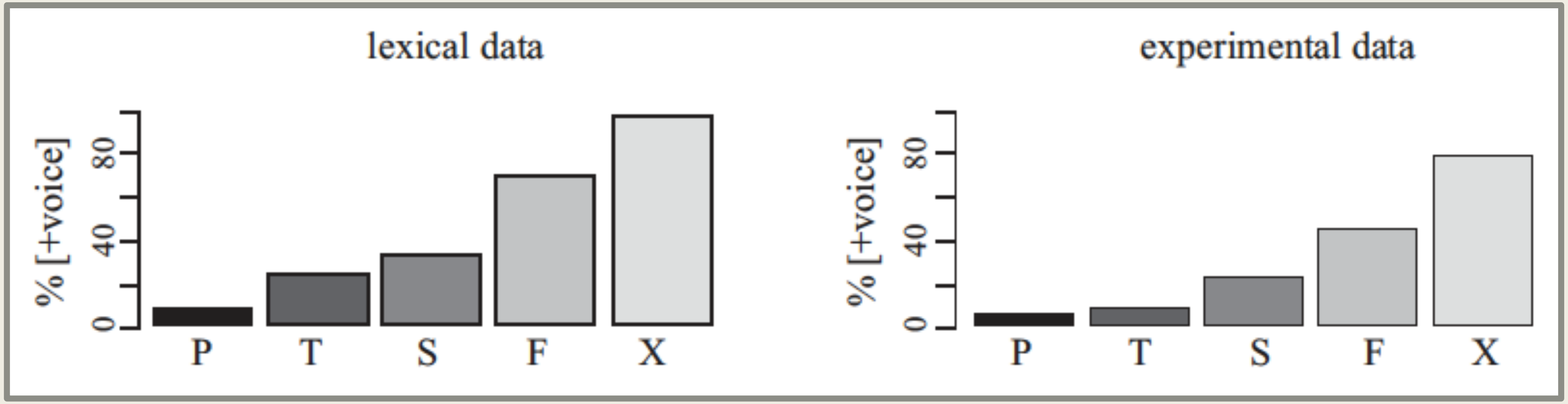
Probability Matching

The distribution of forms in the lexicon is mirrored in the distribution of responses

Ernestus and Baayen, 2003

vɛrʋɛi**t**	vɛrʋɛi**d**ən	*‘widen’-INF*
vɛrʋɛi**t**	vɛrʋɛi**t**ən	*‘reproach’-INF*

ɪk tif	→	ti**ft**ə	ti**vd**ə
ɪk dɑup	→	dɑu**pt**ə	dɑu**bd**ə
ɪk dɛnt	→	dɛn**t**ə	dɛn**d**ə



Probability Matching

The distribution of forms in the lexicon is mirrored in the distribution of responses

- Focus: Cases where real words of the language do not vary
- Compare with e.g. t/d deletion in English: *sexis(t), girlfrien(d)*

→ Speakers know the probabilistic pattern, ***AND*** the behaviour of each specific word

Abstract Generalizations (the probabilistic pattern)

Lexical Specificity (the behaviour of each specific word)

Probability Matching:
Tagalog nasal substitution

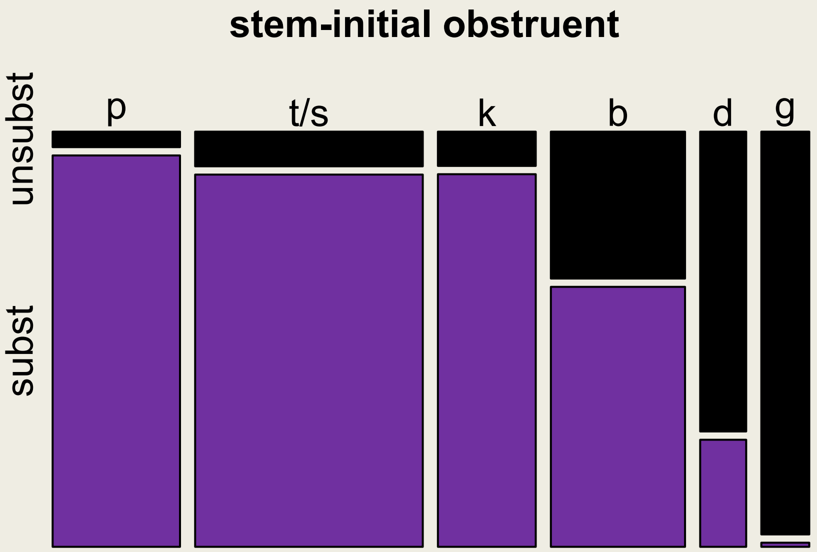
Zuraw, 2000 & 2010

		paŋ	pa**n**-**s**úlat	(*writing instrument*)
súlat	(*write*)	maŋ+RED	má-**n**u-**n**ulát	(*writer*)
kúlam	(*sorcery*)	maŋ+RED	ma**ŋ**-**k**u-**k**úlam	(*witch*)
kamkám	(*usurpation*)	ma+paŋ	ma-pa-**ŋ**amkám	(*rapacious*)

Substitution: nasal and root initial consonant merge

Otherwise: nasal just assimilates to place of root initial consonant

- Each derived form is stable: *pa-núlat
- Roots vary, and affixes vary



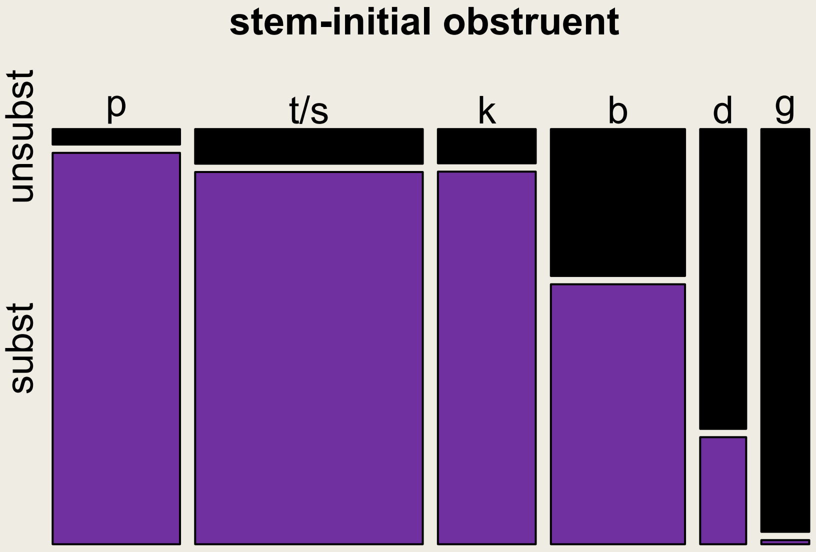
Probability Matching:
Tagalog nasal substitution

Zuraw, 2000 & 2010

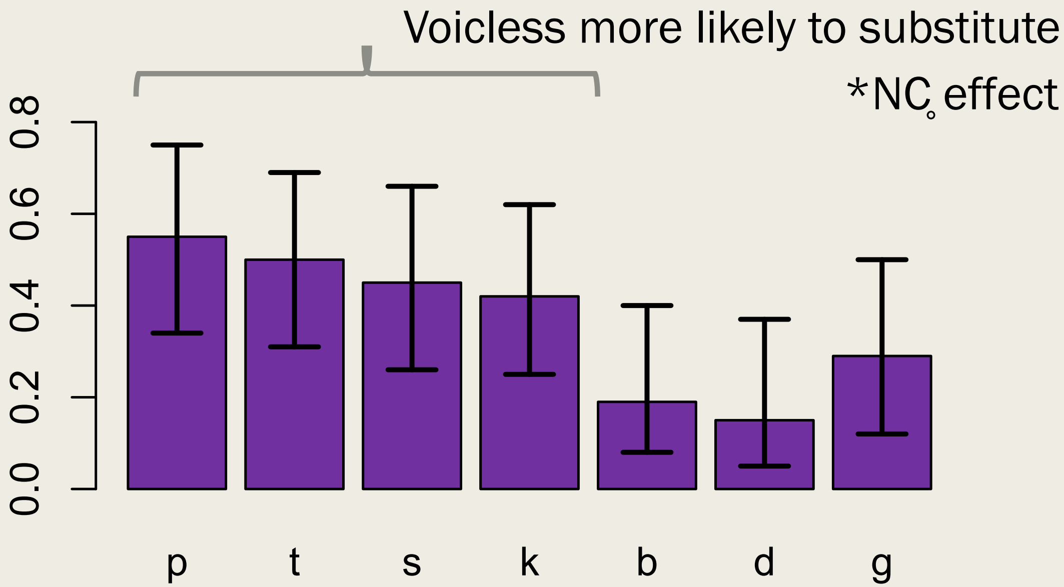
Substitution: nasal and root initial consonant merge
Otherwise: nasal just assimilates

nonwords maŋ+RED

gibat	→	ma**ŋ-g**i-**g**ibat	ma-**ŋ**i-**ŋ**ibat
buŋat	→	ma**m-b**u-**b**uŋat	ma-**m**u-**m**uŋat
paŋlis	→	ma**m-p**a-**p**aŋlis	ma-**m**a-**m**aŋlis



Lexicon

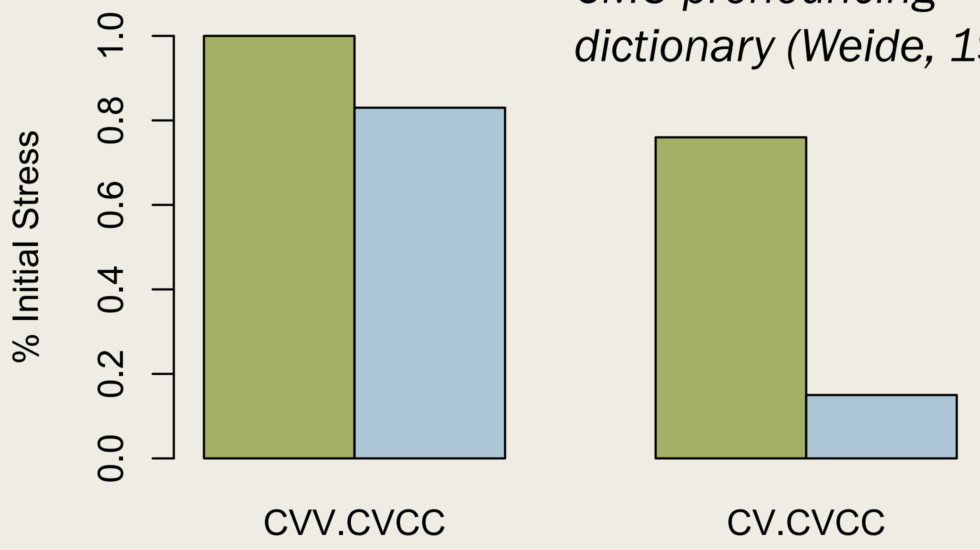


Probability Matching
English Stress

Guion, Clark, Harada, and Wayland, 2003

Noun	rhúbarb	respónse	**CV**.CVCC
	cóbalt	Ø	**CVV**.CVCC
Verb	xérox	resíst	**CV**.CVCC
	fóment	digést	**CVV**.CVCC

CMU pronouncing dictionary (Weide, 1994)



Phonotactic pattern
Albright, yesterday: exceptionality might work differently where phonotactics are concerned!

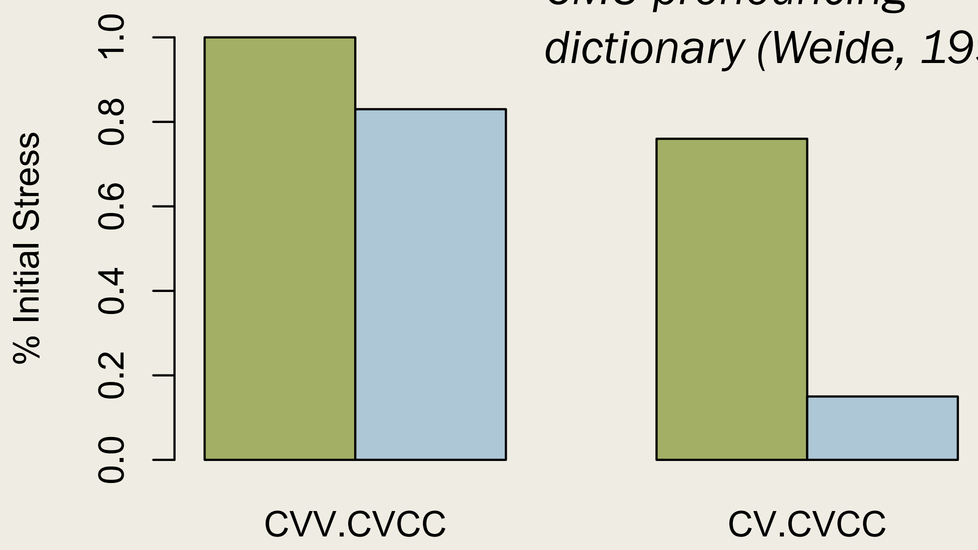
- Nouns more initial stress than Verbs
- **CVV** syllables attract stress

Probability Matching

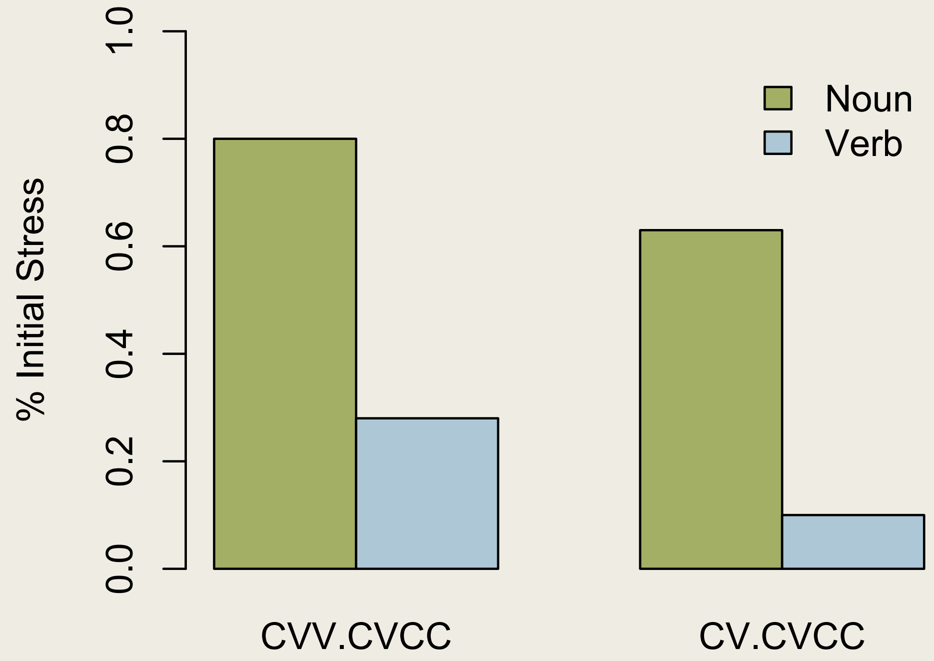
English Stress

Guion, Clark, Harada, and Wayland, 2003

CMU pronouncing dictionary (Weide, 1994)



- **Nouns** more initial stress than **Verbs**
- **CVV** syllables attract stress



CVV.CVCC		CV.CVCC	
poʊ	bɛkt	sɛ	tɪst
taɪ	mɪnz	nɪ	kɪps
beɪ	bɛkt	bɪ	bɛkt

Is Probability Matching phonology?

Yes! Two arguments:

1. Similar features, structures, and constraints as in categorical phonology
   - *Well-established constraints (Clash, Weight-to-Stress, *NC…)*
   - *Similar kinds of processes – voicing, coalescense, stress, vowel harmony…*
2. Alternative models don't work as well: I will pick on Analogy
   - *Model comparison produces ambiguous results (e.g. Ernestus and Baayen 2003, Albright and Hayes, 2003)*
   - *Sometimes Probability Matching isn't perfect – Analogy has trouble predicting when speakers will match and when they won't*
   - *Direct (psycholinguistic) testing of Analogy suggests it may occur, but does not completely explain participants' behaviour*

When Probability Matching isn't perfect

'Surfeit of the Stimulus'

Patterns are sometimes robust in a lexicon but don't get extended to novel forms:

- *Becker, Ketrez, and Nevins (2011)*

  Turkish final obstruents alternate in voicing (like Dutch)

  In the Lexicon, both obstruent place AND height of the preceding vowel matter

  Participants only probability matched to the obstruent place

- *Hayes, Zuraw, Siptár, and Londe (2009)*

  Hungarian genitive: vowel alternates

  In the Lexicon, backness of preceding vowel AND place/manner of final C matter

  Participants matched more strongly with vowel backness than with consonant features

→ Probability matching seems to be subject to the same universals as categorical phonology

Testing for Analogy

Guion et al., 2003

Stage 1: hear **poʊ bɛkt** say **póʊbəkt** or **poʊbɛ́kt**

Stage 2: "What word does **poʊ bɛkt** remind you of?"

Does the stress of participants' chosen 'similar word' predict how they stressed it?

- Yes, but syllable weight also improves the model fit.

→ **Analogy happens, but isn't enough to accout for the probability matching**

(Moore-Cantwell, 2016) found that the 'similar word' did not affect stress choices at all

Modeling probabilistic phonology

Constraints conflict, and choose between candidate pronounciations:

	ALIGN-R (VERB)	ALIGN-L
bɪ bɛkt (V)		
bíbəkt	1	
→ **bəbɛ́kt**		1

OPTIMALITY THEORY
(Prince and Smolensky, 1993)

Need some way to make a probability distribution over winners:

Partially Ordered Constraints (Anttila, 1997)
Stochastic OT (Boersma, 1997 & 1998)
Noisy Harmonic Grammar (Boersma & Weenik, 2007; Coetzee & Pater, 2011, Hayes 2018)
Maximum Entropy Grammar (Goldwater & Johnson, 2003)

Modeling probabilistic phonology

Constraints conflict, and determine a probability distribution over output candidates

	p	$\mathcal{H}$	ALIGN-R (VERB) 2.1	ALIGN-L 0.8
bɪ bɛkt (V)				
→ **bíbəkt**	0.21	-2.1	1	
→ **bəbɛ́kt**	0.79	-0.8		1

MAXIMUM ENTROPY GRAMMAR
(Goldwater and Johnson, 2003)

$$\mathcal{H} = -\sum W_i * Vi$$

"Harmony"
(Smolensky and Legendre, 2006; Pater, 2016)

$$p = \frac{e^{\mathcal{H}}}{\sum e^{\mathcal{H}}}$$

Predicts intra-speaker variation
For a given speaker, **p** is the probability that they will produce that output on any given utterance of the input word.

Non-probabilistic words

What to do with a probabilistic grammar, and a non-probabilistic word?

	p	$\mathcal{H}$	ALIGN-R (VERB) 2.1	ALIGN-L 0.8
/rilæps/				
✗ → **rílæps**	0.21	-2.1	1	
✓ → **rilǽps**	0.79	-0.8		1

English speakers must memorize the stress of 'relapse'

… But this isn't just true of exceptions

Non-probabilistic words

What to do with a probabilistic grammar, and a non-probabilistic word?

	p	$\mathcal{H}$	ALIGN-R (VERB) 2.1	ALIGN-L 0.8
/rispɛkt/				
✓ → ríspɛkt	0.21	-2.1	1	
✗ → rispɛ́kt	0.79	-0.8		1

→ We need some way of integrating lexically specific information together with the probabilistic grammar

What does it mean to be an exception?

Quick answer: It depends on how you model lexical specificity

1. Lexical Listing + Faithfulness (Zuraw 2000, 2010, and many others)
   - *Exceptions have no special relationship to each other*
2. Constraint Indexation (Pater 2000, Becker 2005, Pater 2010, et. seq)
   - *Words belong to idiosyncratic 'classes'*
3. Representational Strength Theory (Moore-Cantwell, forthcoming)
   - *Elements of words are encoded with gradient 'memory strength'*
   - *Elements that align more with the grammar's predictions are encoded more weakly, or not at all*
   - *Elements that contradict the grammar, are encoded more strongly*
   - *Exceptionality is gradient*

Lexical Listing

Simply list the correct form of every word in the lexicon.

English stress: Nouns → Initial stress Verbs → Final stress

The Lexicon: All stresses are stored, whether exceptions or not

/ríłæps/ (V)
/zíraks/ (V)
/bihɛ́st/ (N)

/risíst/ (V)
/səlɛ́kt/ (V)
/rúbarb/ (N)

'bɪ bɛkt' (V)	p	$\mathcal{H}$	IDENT-STRESS 5	ALIGN-R (VERB) 2.1	ALIGN-L 0.8
→ bí bɛkt	0.21	-2.1		1	
→ bɪ bɛ́kt	0.79	-0.8			1
/rílæps/					
✓ → rílæps	0.99	-2.1		1	
✗ riléps	0	-5.8	1		1

Lexical Listing

Simply list the correct form of every word in the lexicon.

Dutch voicing: Labial stops → Voiceless

The Lexicon: All final voicing specifications are stored, whether exceptions or not

/dyb/	dyp ~ dybde	*'wavered'*
/χlip/	χlip ~ χlipte	*'clipped'*
…		

'ɪk dɑup'	p	$\mathcal{H}$	IDENT-VOICE 8	*[+voice LAB - cont.] 2.5	*[- voice LAB - cont.] 0.2
/dɑu**P**/ + **tə**					
→ **dɑuptə**	0.91	-0.2			1
(→) **dɑubdə**	0.09	-2.5		1	
/dyb/ + tə					
✗ **dyptə**	0	-8.2	1		1
✓ → **dybdə**	0.99	-2.5		1	

Lexical Listing

Simply list the correct form of every word in the lexicon.

Tagalog nasal substitution: b, g are unikely to substitute, while s is likely to substitute

The Lexicon: All morphologically complex forms are stored

/pan-sulát/
/ma-migáj/
/pa-ŋi-ŋindáj/
/ma-nu-nulát/
/mam-bi-bigkás/
/maŋ-ga-gawáj/
…

‘buŋat’	p	$\mathcal{H}$	FAITH 10	*CROSS-MORPH 2.9	NOCODA 1.4
maŋ+RED +/buŋat/					
→ mam-bu-buŋat	0.82	-1.4			1
→ ma-mu-muŋat	0.18	-2.9		1	
~~maŋ +/bigáj/~~					
ma-migáj					
✗ mam-bigáj	0	-11.4	1		1
✓ → ma-migáj	0.99	-2.9		1	

Lexical Listing

Exceptions have no special status!

→ Redundancy between lexicon and grammar

- English stress, Dutch voicing, are quite straightforward
- A little harder: Tagalog *How do we make sure that forms are stored, and not composed?*
  1. *Constraint in Zuraw, 2000* USELISTED
  2. *Psycholinguistics: lexical access prefers whole forms (Prasada & Pinker, 1993)*
- If all words' specifications are listed, how/why is probabilistic phonology even learned?
  - *Epiphenomenon of certain learning algorithms*

What is stored?

Doesn’t always have to be that the full form is stored, like **/pan-sulát/**, or **/ma-nu-nulát/**

- *In some cases a non-obvious UR for one morpheme may work*
- Floating Features, e.g. Worbs & Zimmerman, 2016
- Non-obvious tonal specifications (Trommer, this session)
- Gradience in representation (Goldrick & Smolensky, 2014; Zimmerman, to appear)
  (Segments are only half-voiced, or 32% labial)

But – not all cases lend themselves easily to these alternatives

Constraint Indexation

Constraints are 'cloned', but indexed to a some words and not others

English stress: Nouns → Initial stress Verbs → Final stress

Note: This grammar doesn't actually need to be probabilistic

The Lexicon: Some words go with an index

/rilæps/$_i$	(V)
/zirɑks/$_i$	(V)
/bihɛst/$_j$	(N)
/risɪst/	(V)
/səlɛkt/	(V)
/rubɑrb/	(N)

	p	$\mathcal{H}$	ALIGN-L$_i$ 10	ALIGN-R (VERB) 5	ALIGN-L 0.1
/rílæps/$_i$					
✓ → rílæps	0.99	-5		1	
✗ riléps	0	-10.1	1		1

'bɪ bɛkt' (V) → /bɪ bɛkt/$_i$? /bɪ bɛkt/ ?

Assign indexes according to their probability in the lexicon

Constraint Indexation

Constraints are 'cloned', but indexed to a some words and not others

Dutch voicing: Labial stops → Voiceless

The Lexicon: Some words are stored with an index determining their voicing behaviour

/dyp/$_i$	dy**p** ~ dy**b**de	*'wavered'*
/χlip/	χli**p** ~ χli**p**te	*'clipped'*
…		

'ɪk daup'	p	$\mathcal{H}$	*[- voice, LAB, - cont.]$_i$ 10	*[+voice, LAB, - cont.] 5	*[- voice, LAB, - cont.] 0.1
/dyp/$_i$ + tə					
✗ **dyptə**	0	-10.1	1		1
✓ → **dybdə**	0.99	-5		1	

/daup/ → /daup/$_i$? /daup/ ?

Assign indexes according to their probability in the lexicon

→ Using indexes AS voicing specification (may seem weird, but see Nazarov, talk yesterday)

Constraint Indexation

Constraints are 'cloned', but indexed to a some words and not others

Tagalog nasal substitution: b, g are unikely to substitute, while s is likely to substitute

The Lexicon: Indexes determine substitution behaviour

/bigáj/$_i$
/gindáj/$_i$
/bigkás/
/gawáj/
...

'buŋat'	p	$\mathcal{H}$	NoCoda$_i$ 10	*Cross-Morph 5	NoCoda 0.1
maŋ + /bigáj/$_i$					
✗ mam-bigáj	0	-10.1	1		1
✓ → ma-migáj	0.99	-5		1	

Problem! Not all roots have consistent substitution behaviour
/pan-sulát/ ~ **/ma-nu-nulát/**
Affixes are not consistent either. Where does the index go?

Constraint Indexation

Exceptions have an index in the lexicon, non-exceptions don't

→ Very little redundancy between lexicon and grammar

- Works well for cases like English Stress, Dutch voicing
  - *BUT need an extra mechanism for assigning wug-words to indexes*
- Has potential for modeling class-level behaviour
  - *Imagine for English stress: Instead of a constraint Align-L (Verb),* $Align\text{-}L_V$
  - *More about the need for such classes from Smith (next talk)*
- Efficiency in lexical storage
  - *Non-exceptions can be simplified*
  - *In principle, morphologically complex forms don't have to be stored*
- Downside: Sometimes it's not easy to see what entity should get an index

Representational Strength Theory

Similar to the Lexical Listing approach, but:

- *Elements of a lexical entry are gradient*
- *Memory resources allocated efficiently*
- *Predictable features/elements are weaker*
- *Unpredictable features/elements are stronger*

1. Lexical Entries consist of **Phonological Form Constraints (PFC's)**
2. They make demands about an output form, competing with Markedness constraints
3. (PFC's are learned gradually, and unnecessary ones decay from memory over time)

Representational Strength Theory

Phonological Form Constraints (PFC's)

Initial Stress – **RELAPSE:** Assign a violation to any output form for the input **RELAPSE** which does not have Initial stress

	p	$\mathcal{H}$	*Initial Stress* 5.4	ALIGN-L (VERB) 2.1	ALIGN-R 0.8
RELAPSE					
→ **ríleæps**	0.99	-6.2	1		1
riléæps	0	-2.1		1	

RELAPSE *5.4 initial stress*
7.2 1st segment rhotic
6.7 two syllables long
7.9 verb
…

Representational Strength Theory

No Underlying Form!
No Faithfulness constraints

Weighted **P**honological **F**orm **C**onstraints

	initial Stress 5.4	Pos1 +RHOTIC 6.2	Pos2 +HIGH 5.8	Pos4 +FRONT 7.4	Pos5 +LABIAL 10.1	Pos1 +VOICE 0.7	Pos2 +SYLLABIC 1.2	…
RELAPSE								
rilǽps	1							
lílæps		1						
rélæps			1					
ríləps				1				
rílæks					1			
r̥ílæps						1		
rjlæps							1	
→ rílæps								

PFC's **are** the phonological part of the lexical entry
(compare: Direct OT *Golston, 1996)*

Gradient weight ~ gradient memory resource allocation

Representational Strength Theory

Relapse (V)	*Initial Stress: 5.4*	
Behest (N)	*Final Stress: 7.1*	
Resist (V)	*Final Stress: 1.2*	
Rhubarb (N)	*Initial Stress: 2.1*	

(dyb)	Waver	*Pos3: +voice*	*6.8*
(χlip)	Clip	*Pos4: -voice*	*1.1*

(pan-sulát)	Writing Instr.	*Pos 3:+nas 6.1; Pos 4: +sibilant 4.3 ...*
(ma-migáj)	Distribute	*Pos 3:+nas 7.2; Pos 4: +syllabic 6.2 ...*
(ma-nu-nulát)	Writer	*Pos 3:+nas 0.8; Pos 4: +syllabic 1.1 ...*
(maŋ-ga-gawáj)	Witch	*Pos 3:+nas 0.9; Pos 4: -continuant 1.2 ...*

Where do the weights come from?

Phonological Form Constraint weights are learned, just like Markedness constraint weights

1. 'Induced' when the learner first hears a word
2. Decay gradually when unused
   But are updated when needed
   → stabilize at strong or weak weights over time

Representational Strength Theory

Exceptions are quantitavely, not qualitatively different from non-exceptions

→ Reduces redundancy, but does not eliminate it

- Works well for phonotactics (English stress), and alternations (Dutch voicing)
  - *Although Markedness constraint weights are an issue*
- Still requires morphologically complex forms to get their own lexical entry
- Has potential for helping us understand the psycholinguistic behaviour of exceptions
  - *More frequent items get learned more thoroughly*
  - *More stable as exceptions, more likely to become exceptions*

Conclusions

1. *Probabilistic Grammar is real*
2. The status of exceptions within a probabilistic system is unclear
   a) *Lexical Listing + Faithfulness* *(Zuraw 2000, 2010, and many others)*
      - Exceptions have no special relationship to each other
   b) *Constraint Indexation* *(Pater 2000, Becker 2005, Pater 2010, et. seq)*
      - Words belong to idiosyncratic 'classes'
   c) *Representational Strength Theory* *(Moore-Cantwell, forthcoming)*
      - Elements of words are encoded with gradient 'memory strength'
      - Exceptionality is gradient
3. We can maybe start to choose between these theories on grounds of *Redundancy*, *Efficiency,* and *Psychological Reality*

Thank You!

Markedness can overcome PFCs

	p	$\mathcal{H}$	*V́tV̆ 10	*Pos4 +stop 5*	*Pos4 +cor 10*	…	Pos1 +high 8	…
GREET + PROG								
→ gríɾɪŋ	0.99	-5		1				
grítɪŋ	0	-10	1					
grípɪŋ	0	-10			1			
gríɾəŋ	0	-13		1			1	

Morphological Composition
with Rep. Strength Theory

Person

Pos1: -voice 8
Pos1: +stop 6.2
Pos2: +voice 3.1
Pos3: +sibilant 7.7
Pos3: -voice 6
Initial stress 10
...

composed version

Pl

Pos1: -voice 8
Pos1: +sibilant 6.2
Pos1: +cont 3.1
...

	p	$\mathcal{H}$	*[-voi][+voi] 10	*Pos1 -voice 6.2*	*Pos2 +high 3.1*	...
People + Pl						
→ pipl	0.99	-0.2				
prsnz	0	-9.3		1	1	
prsns	0	-13.1	1		1	

stored version

Person Pl *(people)*

Pos1: -voice 8
Pos1: +stop 6.2
Pos2: +high 7.9
Pos3: +stop 7.7
Pos4: -lateral 6
Initial stress 10
...

Choose between the stored version and the composed version however you want.