Modeling inflectional defectiveness as usage-based probability: Lessons from Modern Greek

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Outline

1) The challenge: How do speakers know/learn that certain lexemes have paradigmatic gaps?
   - The negative evidence "problem"
   - The sampling problem
   - The minority behavior problem
2) The phenomenon: Greek genitive plural gaps
3) Our account: Morphosyntactic learning as Bayesian estimation over the paradigm
   - A.k.a., How a proper understanding of expected behavior helps solve the sampling and minority behavior problems
4) Testing the account: A social network model
5) A quick comparison to Russian: Balancing number of gaps and lexical clustering
6) Conclusions

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The challenge

- The challenge
  - Under what conditions can paradigmatic gaps lose their original motivating factors and still persist? In other words, under what conditions can gaps become lexicalized?
  - What (type of) information must be available to a speaker for lexicalized defectiveness to be learnable?
- Three aspects of the problem (for usage-based accounts)
  - The negative evidence "problem": A belief that children cannot or do not learn from implicit negative evidence limits the range of possible evidence from which defectiveness can (under such a claim) be learned.
  - The sampling problem: Even allowing negative evidence, low frequency items are an inherent challenge for any usage-based account because morphological behavior cannot be reliably estimated from small samples.
  - The minority behavior problem: Inasmuch as we often cannot define a morphological class in which the majority of lexemes are defective, well-formedness is more probable than defectiveness. The reliability of the defectiveness pattern is thus low.

The challenge

- Today's goals:
  - To outline a usage-based learning model in which the sampling problem and minority behavior problems can be resolved – given the right input language conditions.
  - To explore, via computational modeling, the language conditions required for gaps to be successfully learned (and therefore to persist) in the absence of grammar-internal motivation.
    - Including conditions under which transmission of defectiveness is predicted to fail.
  - (To demonstrate the viability of a corpus-based definition of paradigmatic gaps.)
- Note: Our account does *not* contradict (most) accounts which seek synchronic grammar-internal explanation for defectiveness. We simply suggest that defective paradigms need not have any active synchronic explanation, and sometimes do not. We seek to understand the conditions under which this is possible.

The negative evidence "problem"

- Despite widespread belief that negative evidence (explicit or implicit) is not available in the learning process, there is strong and ever-increasing evidence that this is incorrect.
  - Child language acquisition data (see Sokolov & Snow 1994 for summary)
  - Experimental work on sensitivity to usage probabilities (Baayen 2007; Maye, Werker & Gerken 2002)
  - Language change (Zuraw 2003:140).
  - Language modeling (Regier & Gahl 2004, Tenenbaum & Griffiths 2001)
- **Our starting assumption:** Speakers are sensitive to the probability of a given combination of lexeme + inflectional property set (i.e., usage probability calculated over content paradigm cell). This includes sensitivity to the absence of an expected structure. The negative evidence problem is a false problem.

A sneak peak at the main point

- Summary of our learning model
  - (In the absence of synchronic motivation), learning a gap involves estimating the (low) probability of a given combination of lemma and inflectional property set being used.
    - Estimates are derived from a combination of expected behavior and observed data.
    - Expected behavior comes from lexical neighbors.
  - Hypothesis: Two ways to learn gaps
    - Word-specific learning for highly frequent lemmas
    - Analogically-driven learning from lexical neighbors for lower frequency lemmas

A sneak peak at the main point

- How this will help with the sampling problem
  - Gaps among low frequency items are predicted iff defectiveness is expected behavior

- How this will help with the minority behavior problem
  - Successful learning of defectiveness results from a confluence of factors, only one of which is morphological class. Allows us to pick out a group of lexemes that are a subset of a larger morphophonologically-defined class.

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Modern Greek genitive plural gaps

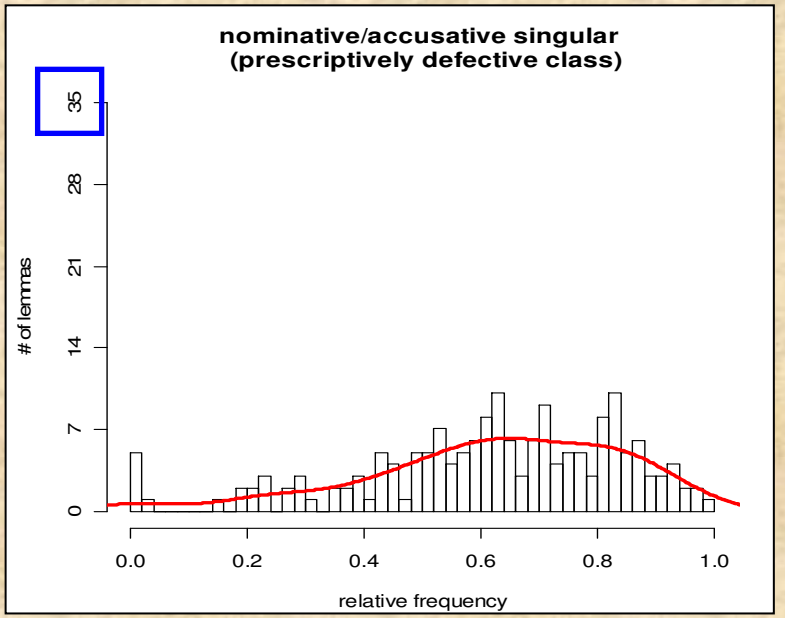
η θάλασσα 'sea'	**sing**	**plural**
nom	θálass-a	θálass-es
acc	θálass-a	θálass-es
gen	θálass-as	θalass-ón
voc	θálass-a	θálass-es

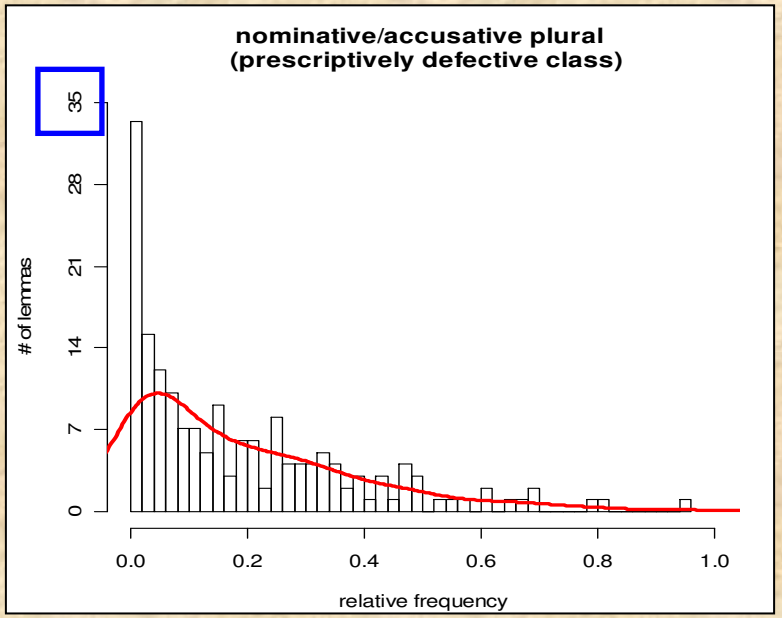
η κοπέλα 'girl'	**sing**	**plural**
nom	kopél-a	kopél-es
acc	kopél-a	kopél-es
gen	kopél-as	*
voc	kopél-a	kopél-es

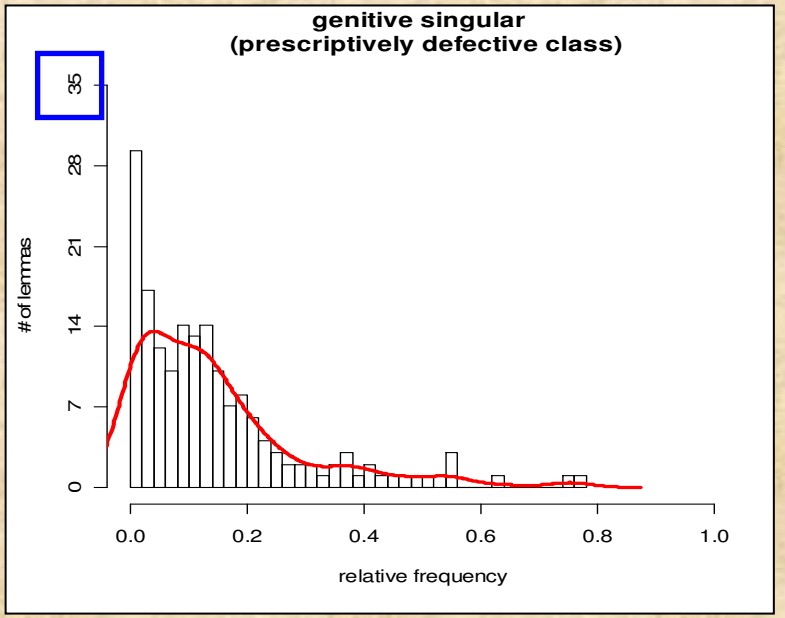
Modern Greek genitive plural gaps

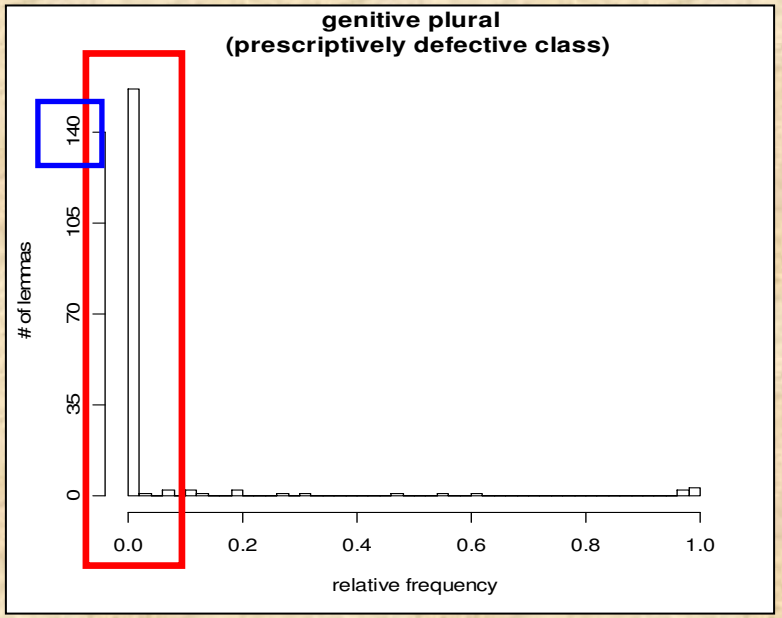
- Genitive plural gaps attested in...
  - Dictionaries & grammars (e.g., *Lexiko tis koinis neoellinikis* (1998), Holton et al. (1997))
  - Production experiment data (Sims to appear)
  - Corpus data

Modern Greek genitive plural gaps









Modern Greek genitive plural gaps

- Notable properties of the genitive plural
  - Same segmental form across all inflection classes (-*on*)
  - However, stress placement varies according to class
    - In some, no effect on stress placement (=always lexical)
    - In some, genitive plural stress always placed on a particular syllable (either always penultimate or always final)
    - In some, genitive plural stress may, or may not, shift towards end of the word. Particularly variable for words with penultimate stress elsewhere in the paradigm.

η ελπίδα 'hope'	**sing**	**plural**
nom	elpíđa	elpíđes
acc	elpíđa	elpíđes
gen	elpíđas	elpíđon
voc	elpíđa	elpíđes

η ντομάτα 'tomato'	**sing**	**plural**
nom	domáta	domátes
acc	domáta	domátes
gen	domátas	domatón
voc	domáta	domátes

Modern Greek genitive plural gaps

- Notable properties of genitive plural gaps
  - Not randomly distributed among inflection classes
    - 88.5% belong to class of feminines with nominative sing /-a/
    - 10.8% belong to class of feminines with nominative sing /-i/
    - 0.07% belong to all other classes
  - Classes with gaps are those for which genitive plural stress sometimes, but not always, shifts towards the end of the word
  - Not randomly distributed within class

Lexemes with nom sg /-a/	**antepenult stress in nom**	**penult stress in nom**	**final stress in nom**
# defective gpl	206	1,132	0
# non-defective gpl	1,234	3,661	818
% defective	**14.3%**	**23.4%**	**0%**

Modern Greek genitive plural gaps

- Obvious analysis seems to be that uncertainty regarding stress placement causes paradigmatic gaps (e.g., via avoidance).
- But experimental evidence indicates that Greek speakers treat high frequency defective lemmas as a distinct category not directly tied to variable stress placement (Sims to appear).
  - The status of low frequency defective lemmas is unclear.
- Suggests that defectiveness among (at least) high frequency lemmas represents a (partially) lexicalized generalization.

- Question: If we assume no synchronic explanation or other motivation beyond patterns of usage, can the Modern Greek genitive plural gaps be learned?

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Morphosyntactic learning as Bayesian estimation

kopéla	**Raw #**	**Relative freq**	**All lemmas: Relative freq**
N/Asg	980	62.7%	56.6%
Gsg	200	12.8%	21.1%
N/Apl	383	24.5%	17.5%
Gpl	0	0%	4.7%
Sum	1563	100	100

Learner infers the probability distribution over inflectional property sets (IPS's) for each lexeme (cf. Baayen 2007)

Application to KOPELA

- –Learner hears many KOPELA tokens, but no or few tokens of KOPELA+GEN.PL
- –Learner infers that relative absence of KOPELA + GEN.PL is a property of KOPELA

Morphosyntactic learning as Bayesian estimation

- Learning a gap in a high frequency lexeme involves inferring deviation from expected probability. Expectations are set by lexical neighbors.

- However, the relative frequency of a lexeme + IPS cannot be reliably estimated from a small sample

- Learner looks to lexical neighbors as need to fill in the missing information
  - If learner hears many tokens of lexeme (e.g. KOP'ELA 'girl'), the distribution of those tokens is more influential
  - If learner hears few tokens of lexeme (e.g. ATIM'IA 'vice, dishonest trick'), the distribution of lexical neighbors is more influential

Morphosyntactic learning as Bayesian estimation

- Hypothesis: Two ways to learn gaps
  - Word-specific learning for highly frequent lexemes
    = potential deviation from expectations; conforms to observed data
  - Analogically-driven learning from lexical neighbors for lower frequency lexemes
    = conforms to expectations; potential deviation from observed data
- For lower frequency lexemes, gaps are predicted to be learnable to the extent that they (a) are significantly well represented within the relevant class, and/or (b) form a morphophonologically coherent group.

- Question: How well represented do paradigmatic gaps need to be? How morphophonologically coherent do they need to be?

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target:
kopéla

1) Lexical nbhd

aveltiría
avlepsía
angelía
ageláda
ángira
agorá
agorafovía
ágra
agrotiá
agonía
adekaría
aerámina
aerogéfira
aerometaforá
azaléa
anása

2) Average relative freq for lexical neighborhood

neighborhood	w	N/Asg	Gsg	N/Apl	Gpl
avlepsía	**1**	54.7	11.3	30.2	3.7
ángira	**0**	70.5	28.6	0.9	0
ágra	**1**	58.0	23.0	0	18.9
agrotiá	**0**	34.2	65.7	0	0
anása	**1**	86.5	2.6	10.9	0

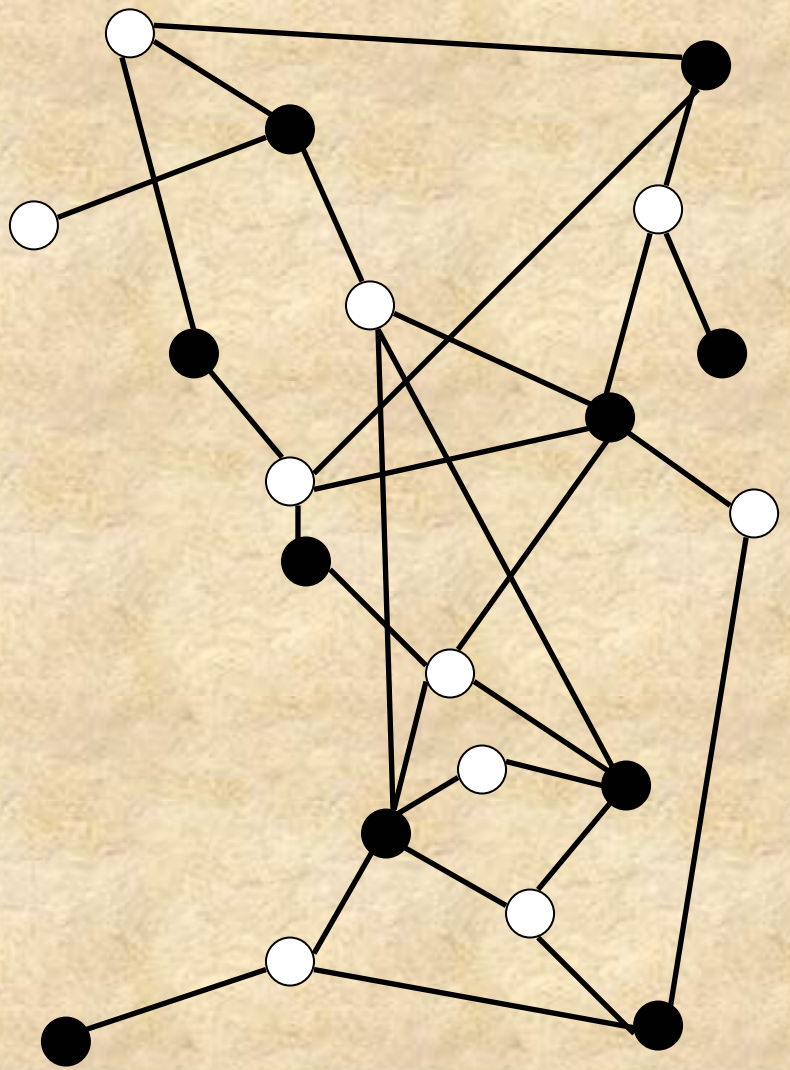
Average relative freq (lexical neighborhood)	60.8	26.2	8.4	4.5

3) Mix attested relative freq & nbhd relative freq

Raw tokens (kopéla)	980	200	383	0
Attested relative freq (kopéla)	62.7	12.8	24.5	0
Predicted relative freq (kopéla)	**62.6**	**13.4**	**24.0**	**0.02**

Testing our account

- Adults talk (100,000 nouns each), children listen
- End of generational cycle: adults die off, children learn grammar, mature, reproduce
- Speech of new adults based on the grammar that they learned
- 10 generations
- 50 adults and 50 children per generation
- Each child connected to 10 adults on average (random network)
- First generation seeded by random sampling of –a nouns from ILSP Hellenic National Corpus



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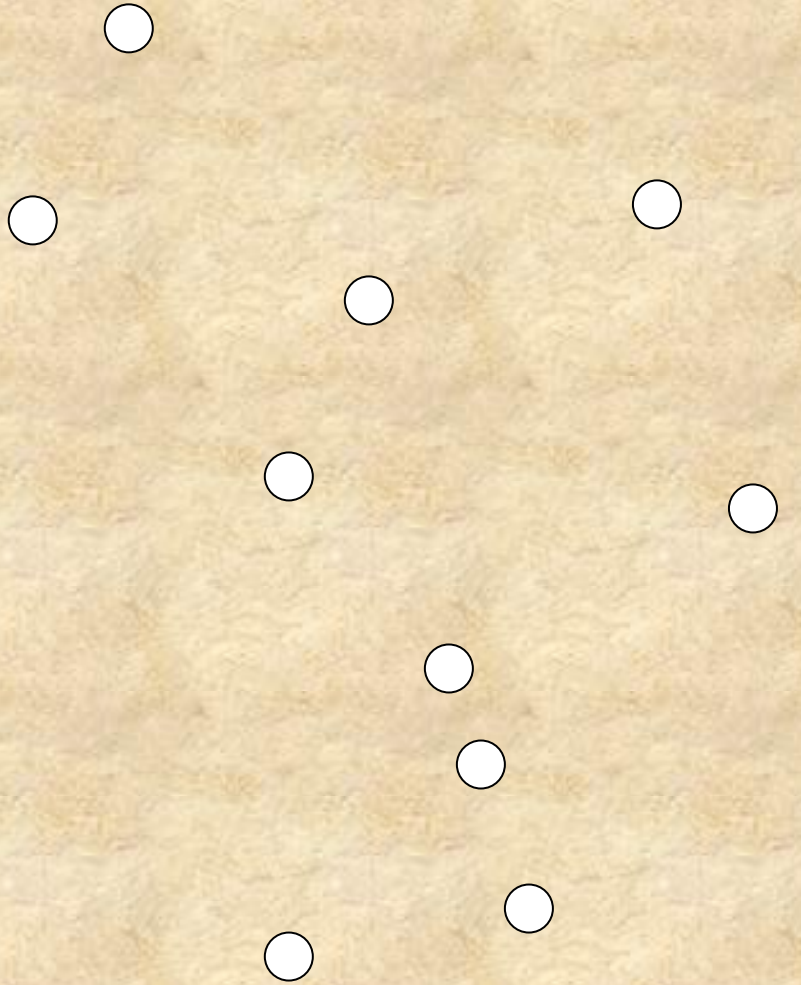

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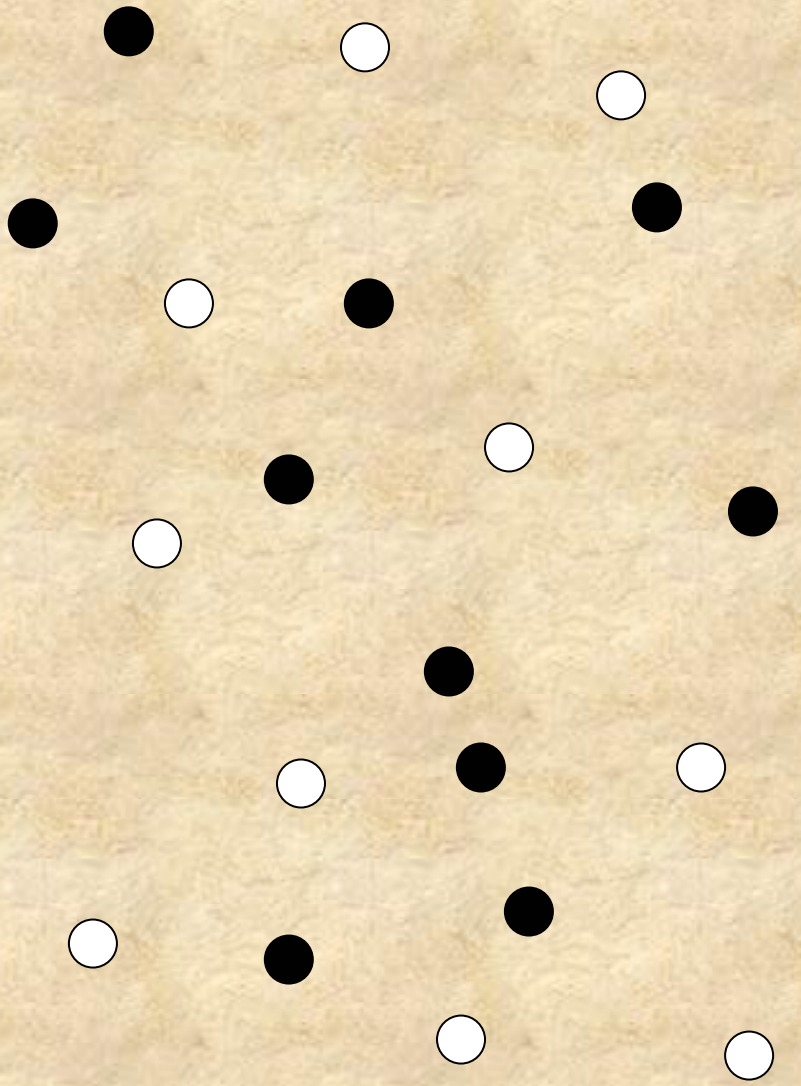

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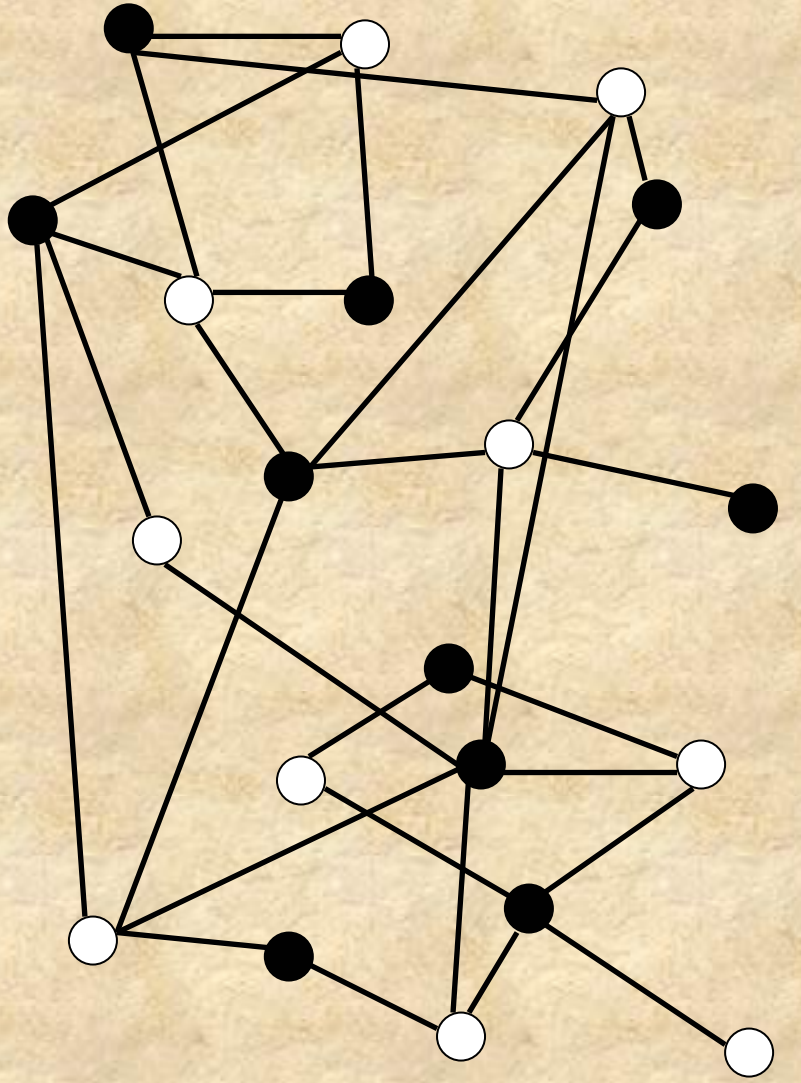

Testing our account

- Evaluation questions
  - Do existing gaps persist for multiple generations?
  - Does the overall number of gaps remain (relatively) constant for multiple generations?
- Conditions
  - Two types of analogical influence from lexical neighborhood: unweighted vs. morphophonologically-weighted
  - Four levels of analogical influence

A corpus-based definition of gaps

kopéla	**Raw #**	**Relative freq**
N/Asg	980	62.7%
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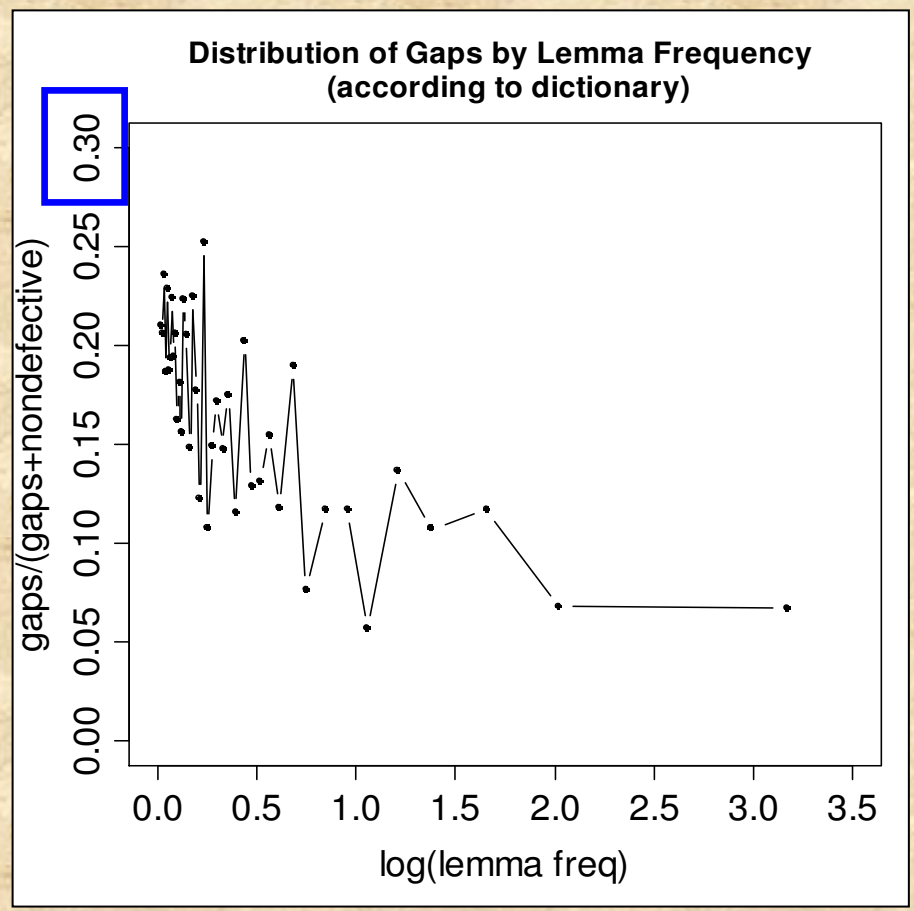
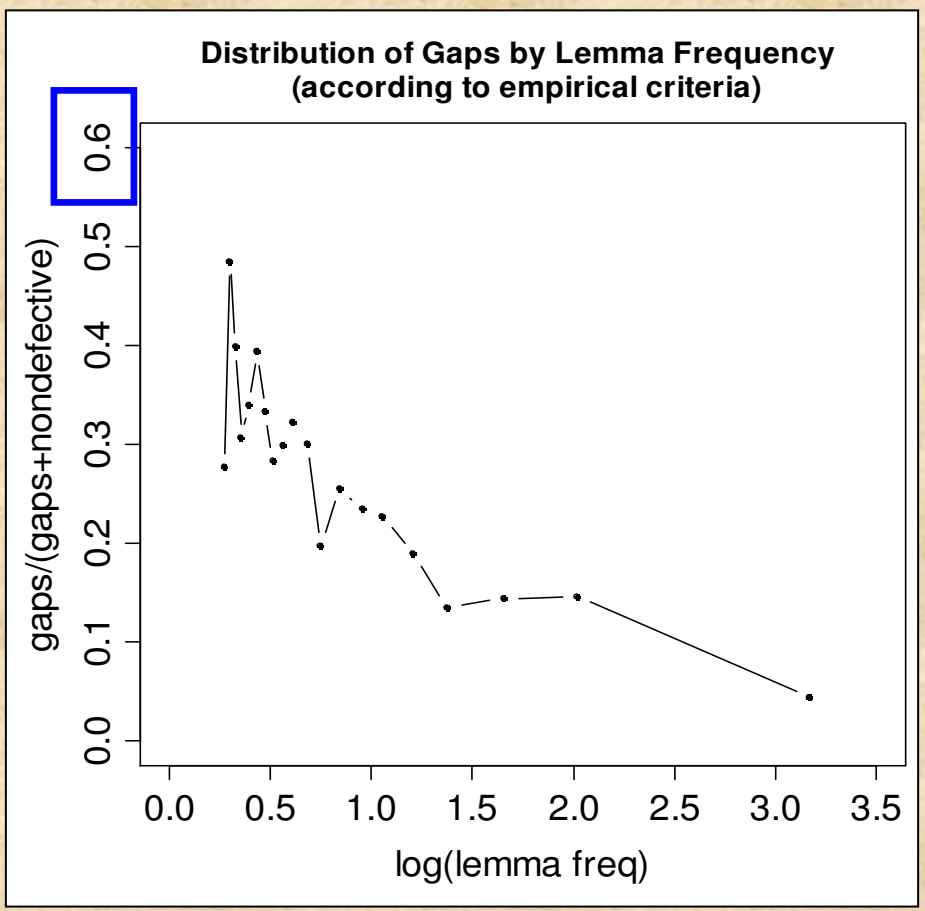
N/Apl	383	24.5%
Gpl	0	0%
Sum	1563	100

- Corpus data (HNC)
  - 4,995 noun lemmas in class O25-O28 (*Lexiko tis koinis neoellinikis*)
  - 12,600 wordforms with at least 1 occurrence
  - 1.92 million tokens
- Gap criteria
  - Remove sampling errors:
    raw lemma occurrences > 36 (0.75 tokens per million words)
  - No singularia tantum nouns:
    N/Apl > 2% relative frequency
  - Gpl < 0.05% relative frequency
- 545 gaps in seed
  - 1,914 "candidate" lemmas

Validity of a corpus-based definition of gaps

- Corpus-based criteria (right) capture overrepresentation of dictionary-defined gaps (left) among low frequency lemmas.





Validity of a corpus-based definition of gaps

- Corpus-based criteria for gaps correctly reject almost all lexemes that dictionaries consider to be non-defective, and correctly include the majority of lexemes that dictionaries consider defective, (but overgeneralize a bit).

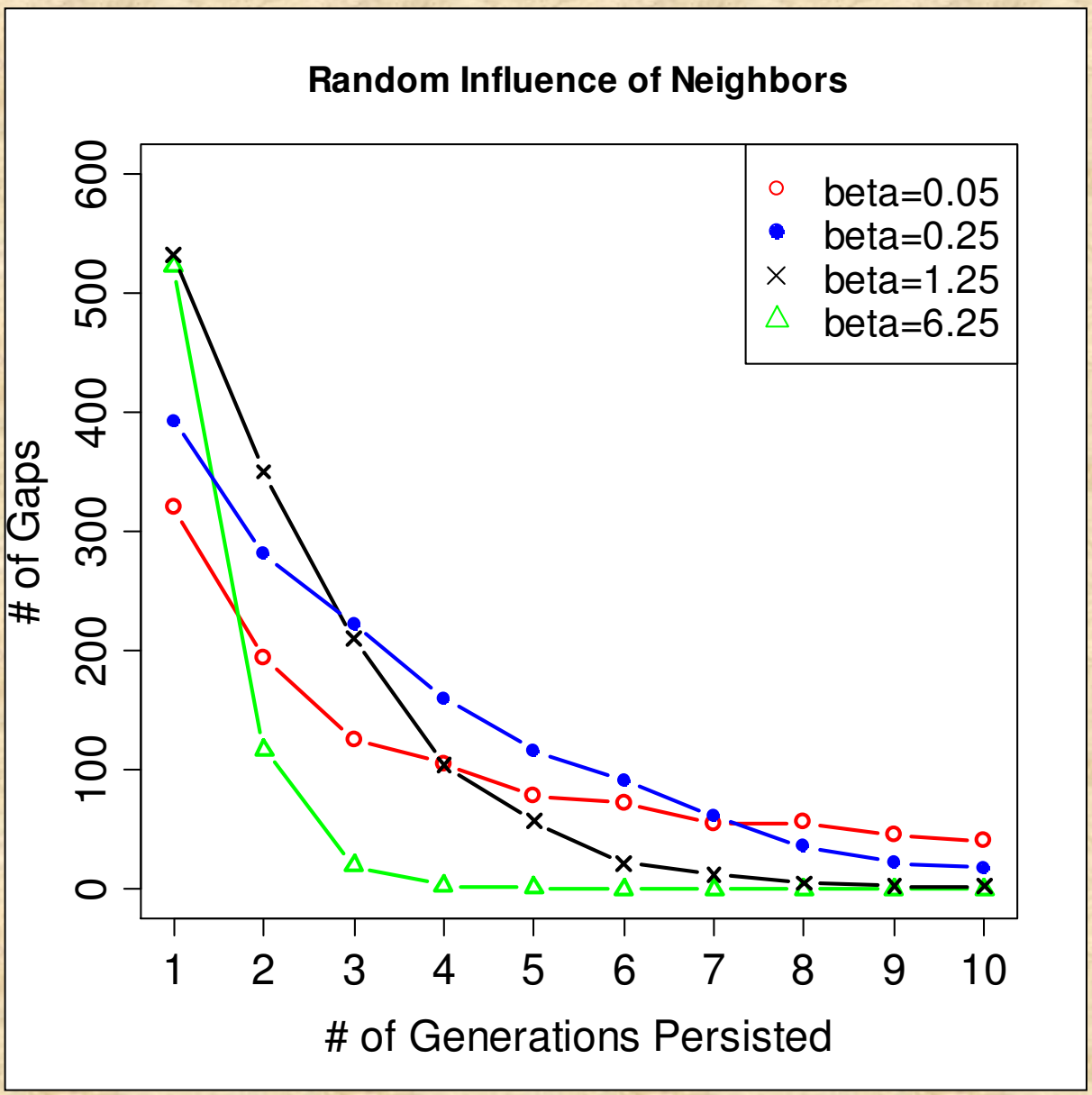
Dictionary

Corpus

	Defective	**Non-defective**	**Precision**
Defective	N=113	N=306	**27%**
Non-defective	N=60	N=4517	**98.7%**
Recall	**65.8%**	**93.7%**	

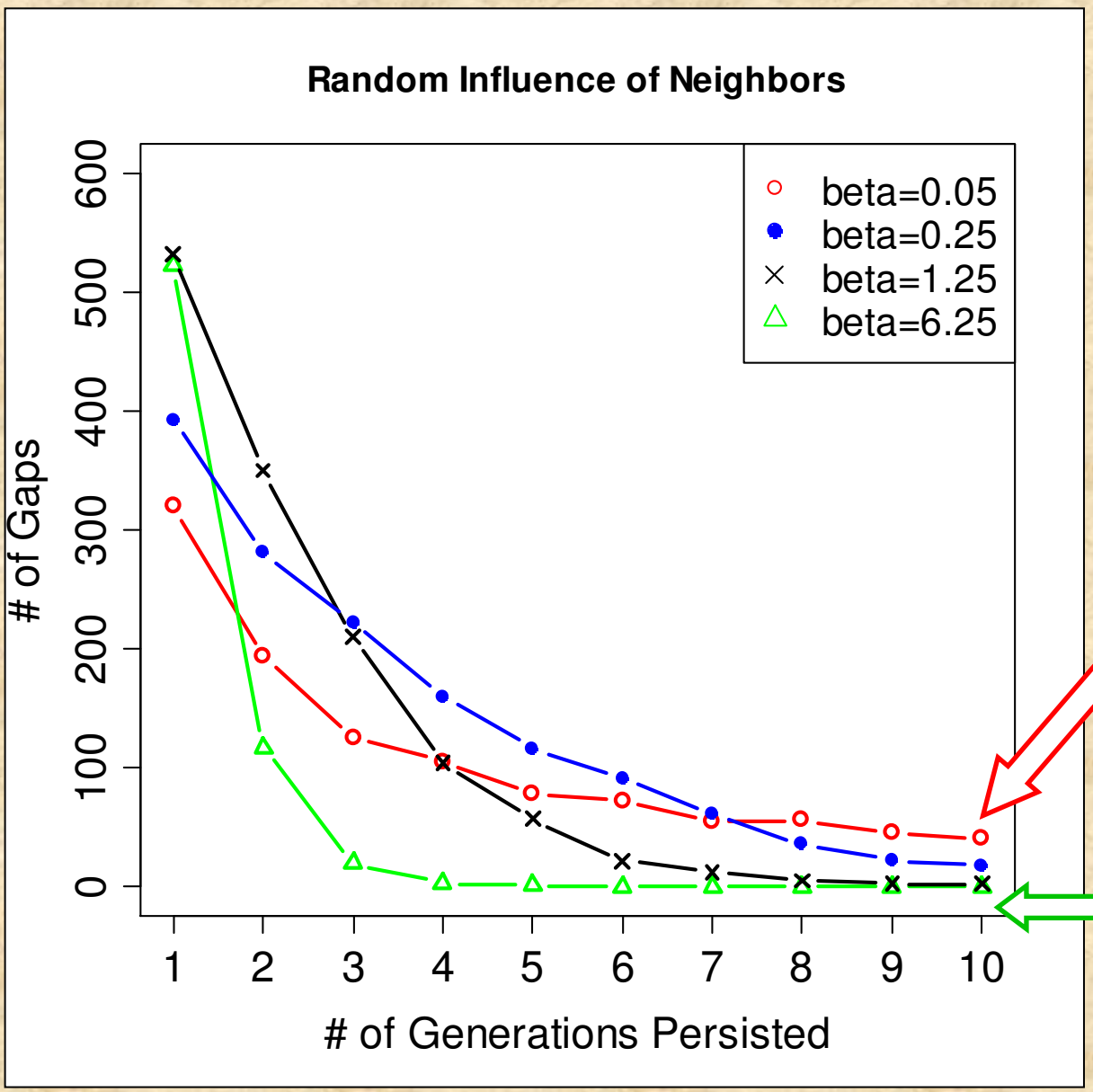
- Recall: How many of the dictionary-defined gaps were also gaps according to our corpus-based criteria
- Precision: How many of our empirically-defined gaps are identified as gaps by dictionary

Persistence of gaps



- The "lifetime" of a gap
- Histogram: For each lemma, the number of generations in which that lexeme had a GenPl gap (out of 10 possible)
- Higher beta = more analogical influence

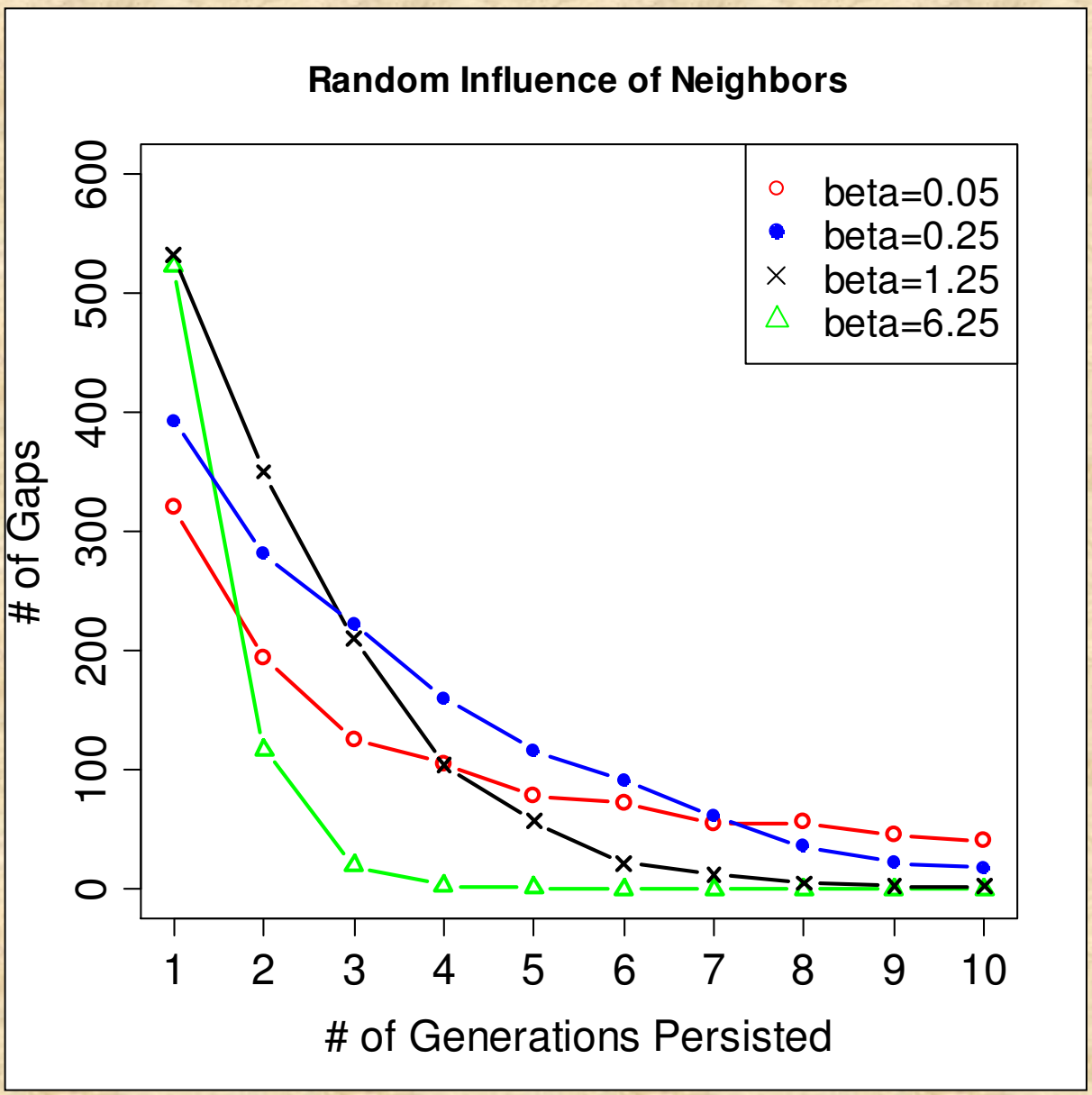
Persistence of gaps



Least analogical force of lexical neighborhood

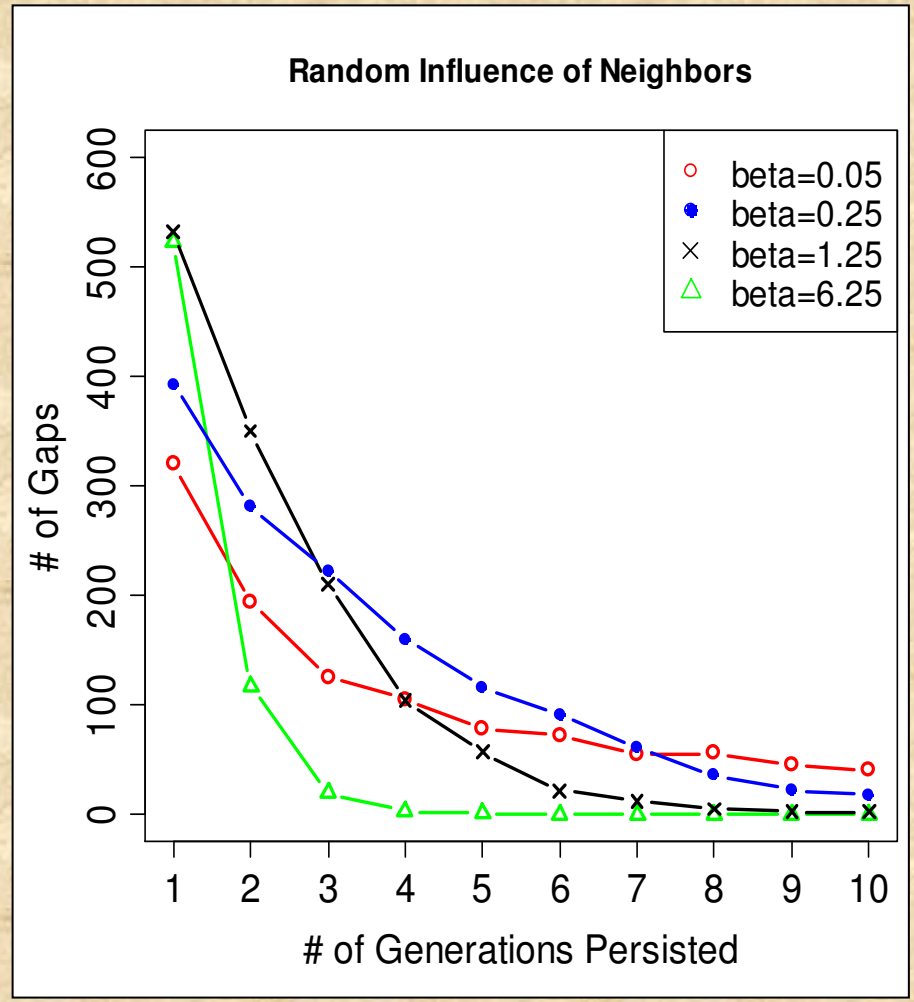
Most analogical force of lexical neighborhood

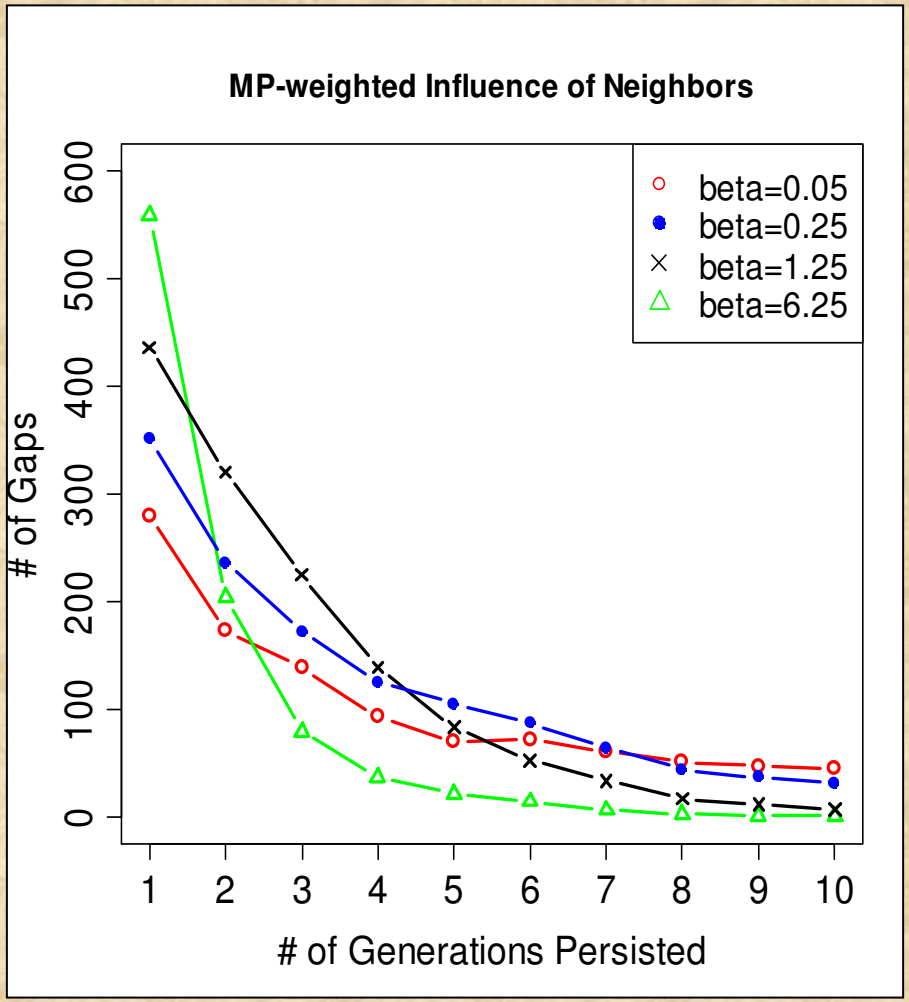
Persistence of gaps



- The less the analogical influence, the better gaps persist.
- Weak / moderate analogical influence → some gaps will persist for all 10 generations (word-specific learning)
- Strong analogical influence → gaps quickly "die out".

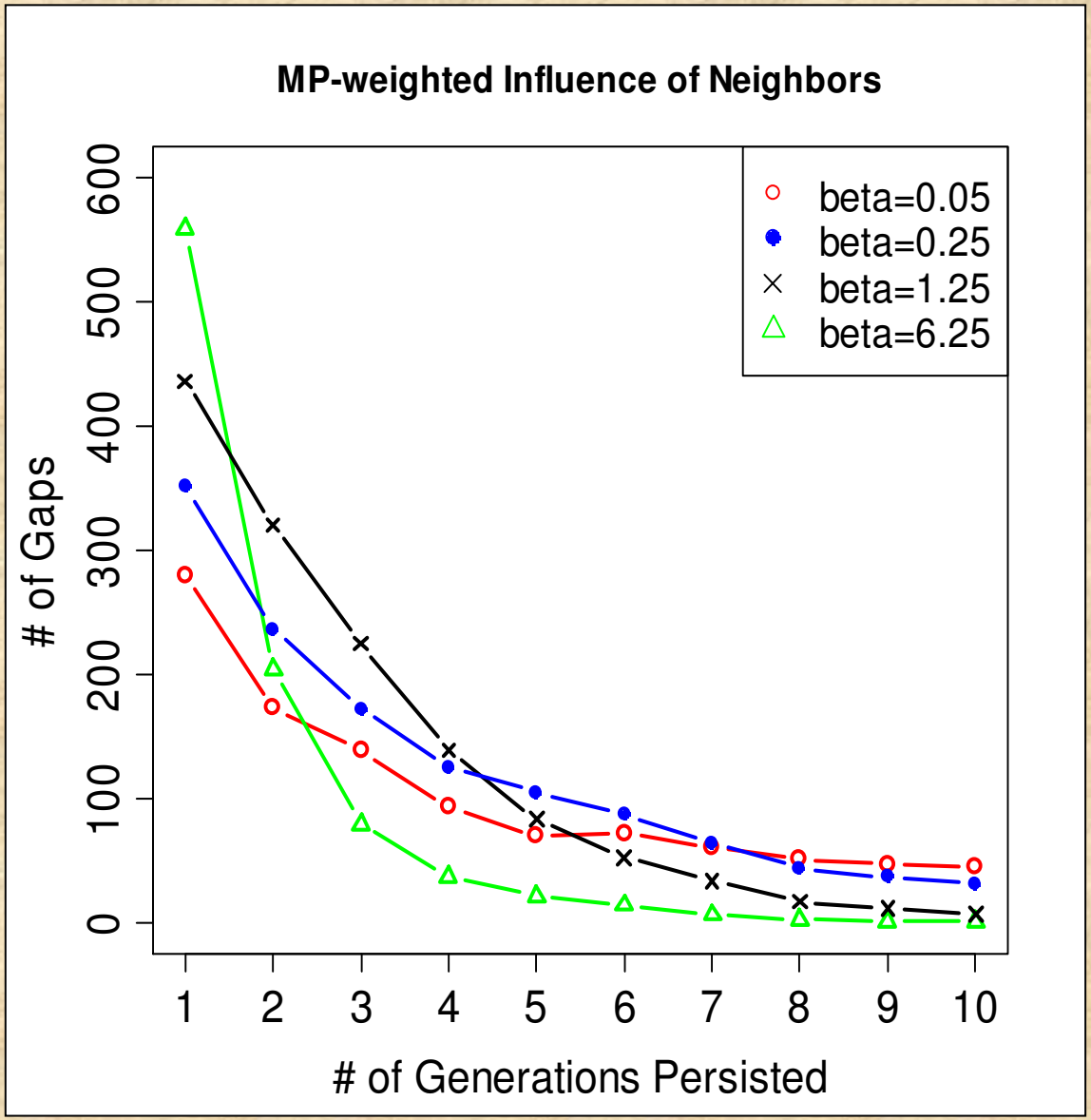
Persistence of gaps



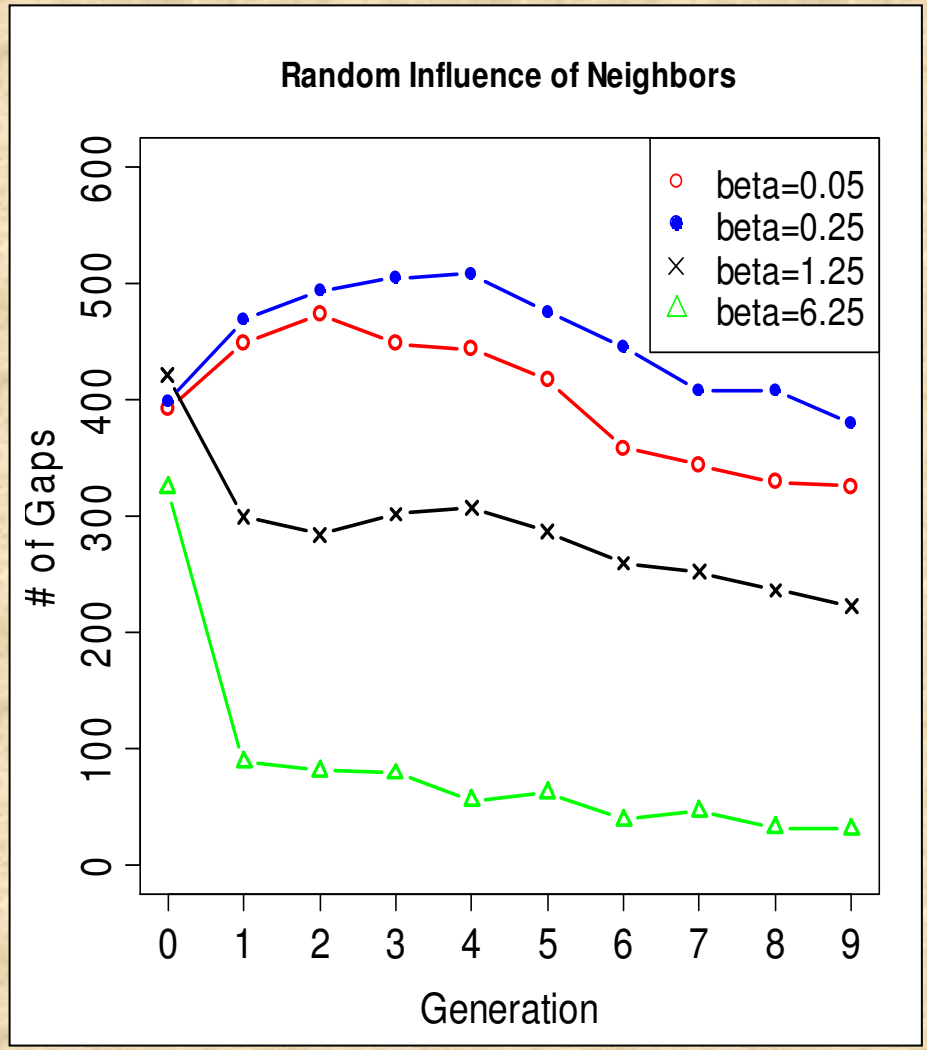


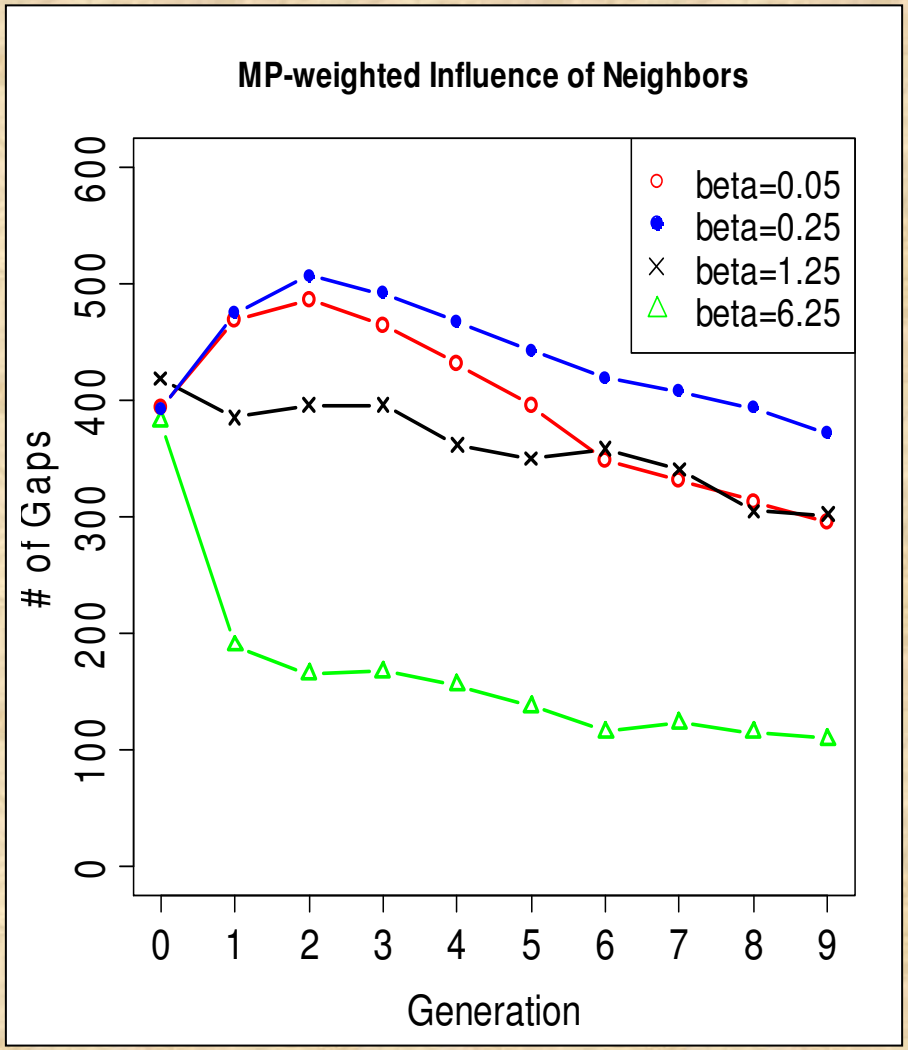
Persistence of gaps

- Weighting by morphophonological similarity increases the lifetime of a given GenPl gap, particularly when there is heavy analogical influence.
- With weak analogical influence, gaps reach a point of stability.
- Relationship between penultimate stress and gaps is to some degree self-reinforcing.



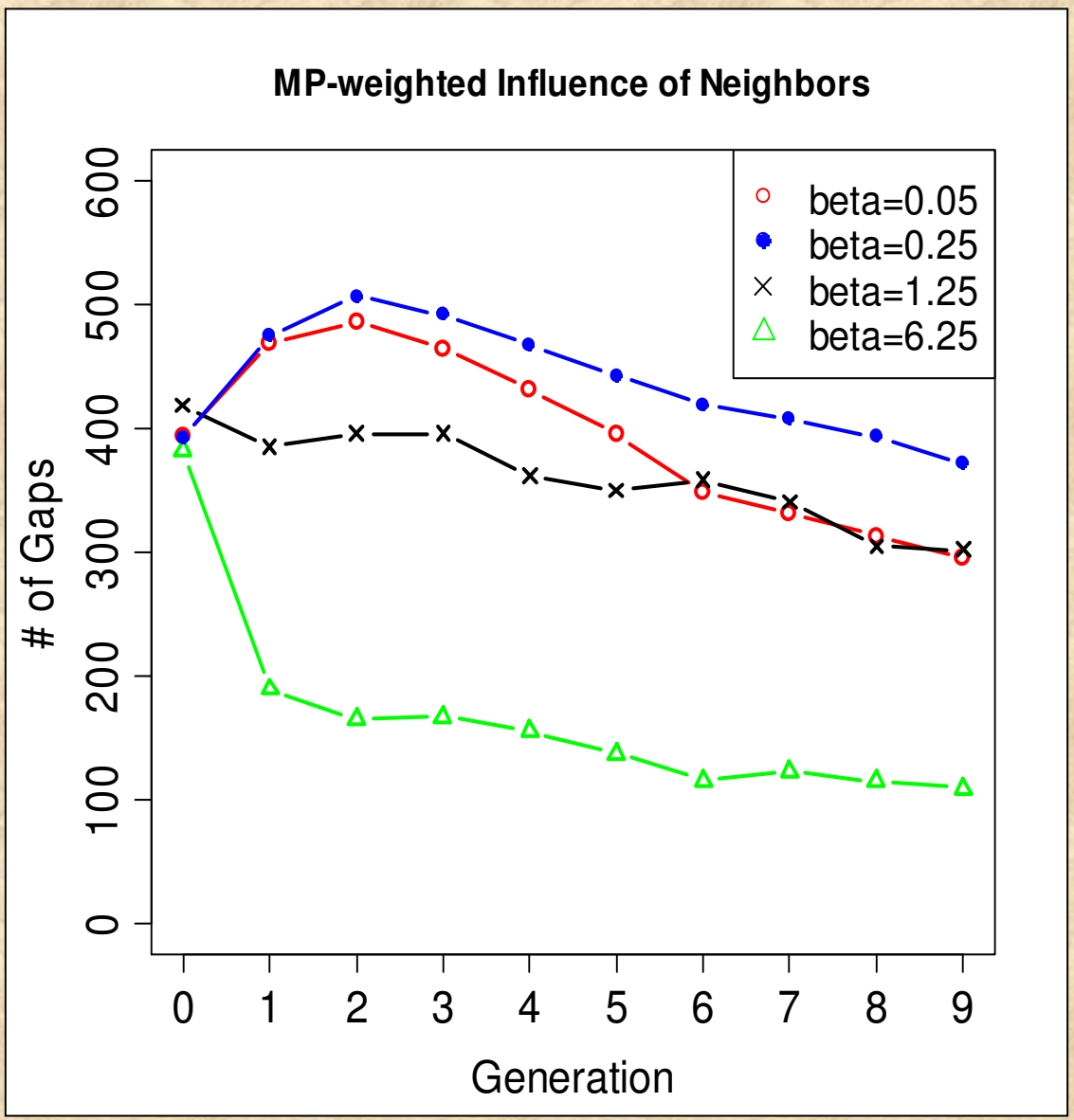
Gaps per generation





Gaps per generation

- Weighting by morphophon. similarity bolsters the number of gaps in a generation when analogical influence is strong
- Some new gaps are created. Still, an overall pattern of loss
- Suggests that weak clustering (penultimate stress) and relatively large proportion of gaps may be insufficient by themselves for gaps to be stable in the language



Lessons from Modern Greek

- Assuming no synchronic explanation or other motivation for the gaps beyond patterns of usage, we had partial success in modeling the persistence of genitive plural gaps from one generation to another.
- As predicted, there is evidence for both word-specific and analogical learning of gaps.
  - Persistence of gaps across all generations under weak analogical influence indicates word-specific learning of defectiveness for high frequency lemmas.
  - Weighting the influence of other lexemes by morphophonological similarity greatly improved the learnability of gaps among low frequency items.
- However, the relatively large number of genitive plural gaps and weak clustering among penultimate stress nouns were not sufficient conditions to produce a generationally stable pattern.
- Overall, the results suggest that these conditions likely facilitate learning, but for all but high frequency items, they are not by themselves sufficient.

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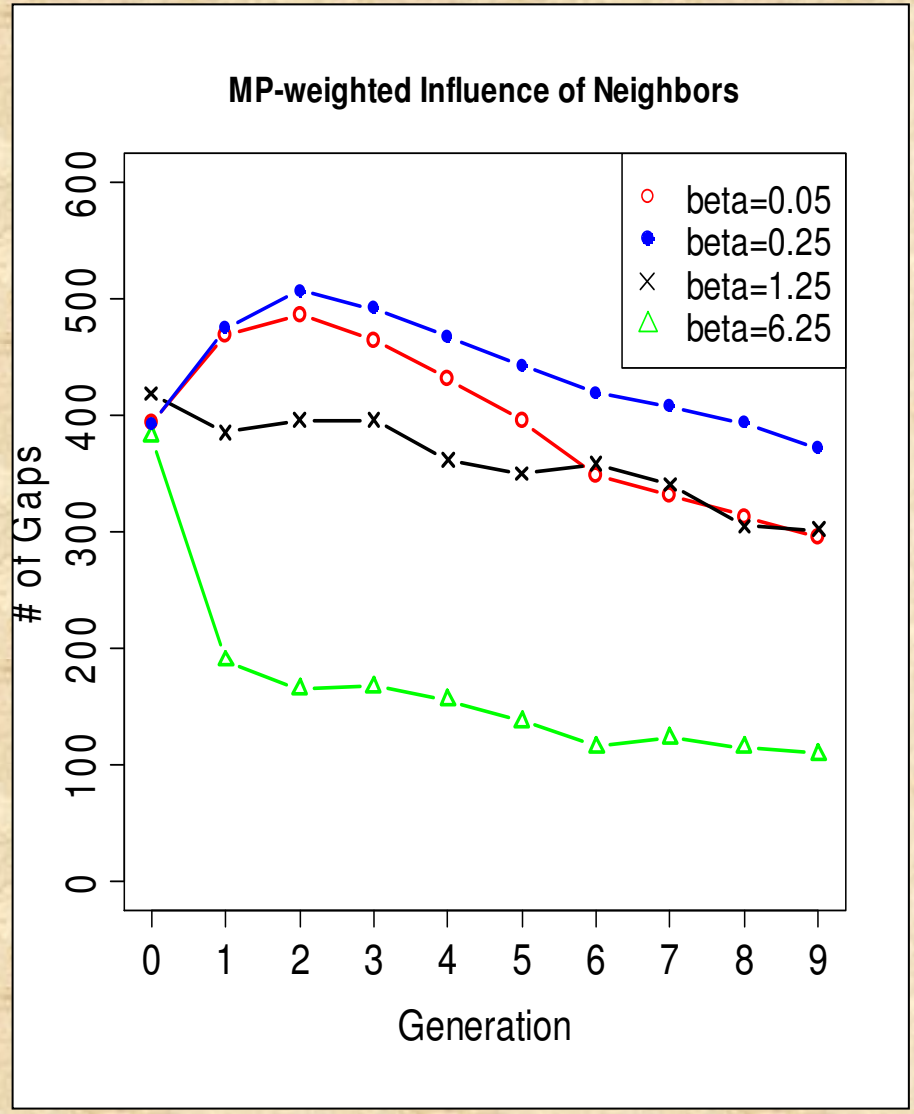
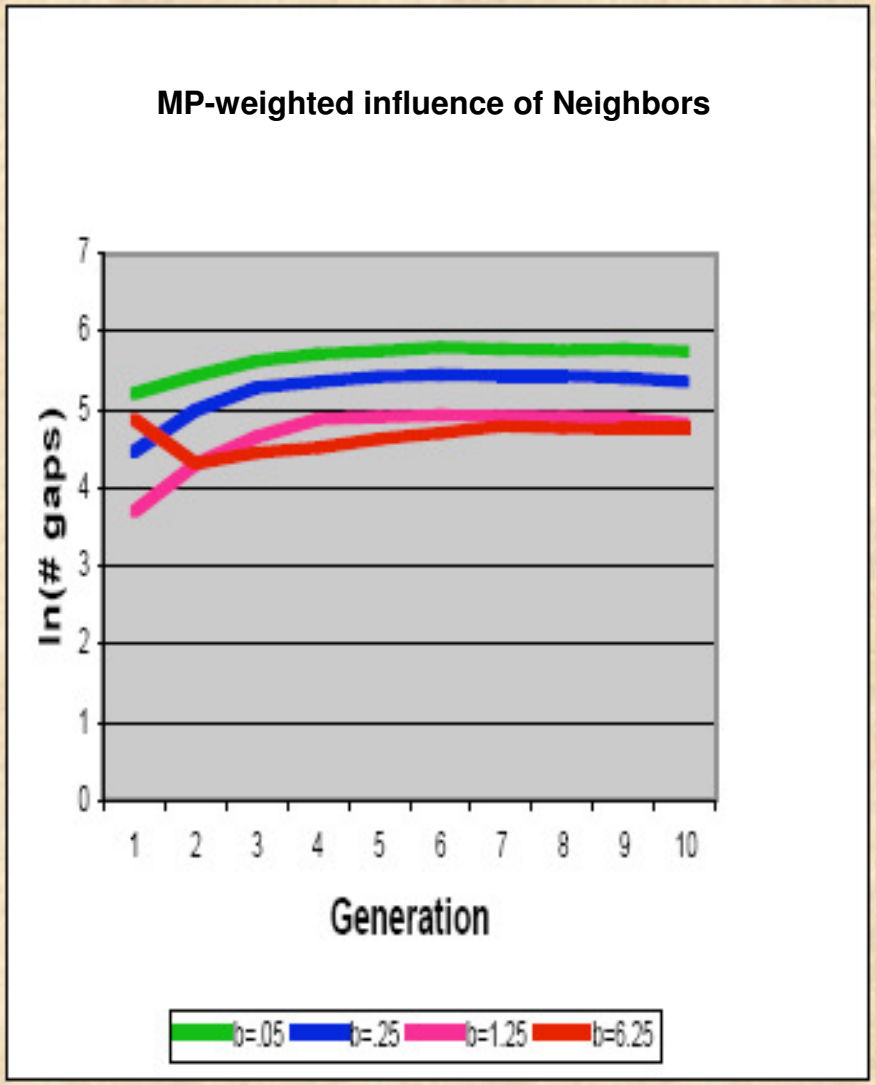
A quick comparison with Russian

Gaps per generation: Greek



Gaps per generation: Russian



Implications of the Russian data

- What makes Russian different from Modern Greek?
  - Russian has fewer defective lexemes (both in absolute and proportional terms), but more tightly clustered within the lexicon.
  - Modern Greek gaps skew infrequent.
- Speculation on the implications of these differences
  - Morphophonological clustering of gaps in the lexicon may be a prerequisite for learning gaps in the absence of synchronic grammar-internal motivation, and thus a prerequisite for lexicalization of gaps. The more tightly clustered, the better.
  - For learning gaps among low frequency lemmas, degree to which defective lexical neighbors deviate from mean usage may be more important than the number of defective lexical neighbors.
    - Gaps in high frequency lemmas represent greater magnitude deviation from mean behavior, and therefore individually exert greater analogical force

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Overall Conclusions

- Sampling problem is true problem for a usage-based account if and only if the expected behavior of a low frequency lemma is to be non-defective.
  - While perhaps counterintuitive, a **confluence of well-established principles** (e.g., analogical influence, sensitivity to probability distributions within the paradigm) can, under some circumstances, lead to the **expected behavior being defectiveness**.
- This confluence of factors also helps us (in principle) to resolve the minority behavior problem
  - In Modern Greek, and even more so in Russian, a balance between expected and observed behavior, and a lexeme-by-lexeme definition of expectations, allowed us to identify a small subclass as defective.
- All factors are not created equal.
  - Degree of morphophonological clustering, whether defective lexemes skew frequent or infrequent (=the magnitude of influence of a given gap on neighbors), and proportion of defective to non-defective lemmas are all hypothesized to influence expected behavior.
  - However, the results of modeling Greek suggest that the last of these may be least important.

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Modern Greek paradigmatic gaps (or could it be periphrasis?)

- Widespread variation between synthetic genitive forms and prepositional phrases containing accusative nouns/bare accusative nouns/appositional constructions
  - Known relevant factors: register, semantics, definiteness, morphology (e.g., inflection class), morphophonology (e.g., morphologically-governed stress placement), frequency (Sims to appear a), social(?)
  - Sample description: "Από [Apó]+accusative is often used as a colloquial alternative to the genitive, particularly, the possessive genitive, the genitive of type, the genitive of content, or the partitive genitive…" (Holton et al. 1997:383).
  - Examples:

(a) mia seirá dialékseon
a series.nomsg lecture.**genpl**
'a series of lectures'

(b) mia seirá piđímata
a series.nompl leap.**nompl**
'a series of leaps'

(c) mia seirá apó terástia piđímata
a series.nompl **from** huge leaps.**accpl**
'a series of huge leaps'

Modern Greek paradigmatic gaps (or could it be periphrasis?)

- But there are indications that, e.g., **kopelón* 'girl.genpl' should be treated as a paradigmatic gap, not as (morphological) periphrasis.
  - Non-systematicity of genitive "replacements"
  - Lack of cumulative exponence
  - Genitive replacements available in both singular and plural, although paradigms defective only in the plural
  - Genitive replacements co-exist with synthetic genitive plural forms, where they exist (e.g., *θalassón* 'sea.genpl')
  - Variation governed (primarily) by non-morphological factors (esp. stylistic)
- Our claim: Periphrasis may be related to genitive plural gaps (e.g., availability of periphrastic constructions may help to promote gaps), but they are formally distinct phenomena. Paradigms for nouns like *kopéla* are truly defective.

Comparison to constraint demotion

- Important contrast with constraint demotion accounts of learning defectiveness (e.g., Rice 2003, McCarthy and Wolf 2005, based on Smolensky 1996)
  - Both approaches rely equally on implicit negative evidence
  - Constraint demotion cannot solve the sampling problem
    - CD model rests on the assumption that the sample is always sufficient to reliably estimate morphological behavior of a given lexeme
  - Constraint demotion fairs poorly on the minority behavior problem
    - Both models require lexeme-by-lexeme specification of defectiveness, but in a CD model, gaps which represent a minority pattern are predicted to be randomly distributed. In our model, defective lexemes are predicted to cluster in the lexicon, even if a minority pattern.