Exemplar-Based Linguistics

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A Classical Rule

Indefinite article in English

a __ + C

following word begins with a consonant

a boy, *a university*, *a history*

an __ + V

following word begins with a vowel

an apple, *an honest*, *an historical*

An Exemplar-Based Approach

Use of examples to predict *a* versus *an*

For a given case, hunting for an appropriate exemplar to make a prediction:

___ + coy

the actual occurrence of *coy*
a nearest neighbor: *boy*, *toy*, *decoy*
exemplars further away: *cry*, … , *zebra*

The “Rule” Equivalent

(1) Apply every possible “true” rule:

a if followed by a consonant (ah, the real rule!)
a if followed by an obstruent: *soy*, *pie*, *fried*, …
a if followed by a velar: *goy*, *guy*, *grim*, …
a if followed by a voiceless velar stop: *kite*, *criminal*, *cute*, …
a if followed by a velar and a diphthong: *coy*, *cow*, *kind*, …
etc.

(2) The probability of applying a “true” rule is proportional to its frequency squared.

No “false” rules!

Every subrule of a “true” rule behaves identically:
a “homogeneous” or “correct” rule

Eliminate the “false” (“heterogeneous” or “incorrect”) rules, such as:

90% of the time choose *a*
when the first vowel in the following word is *oi:*

a	*toy*, *boy*, *boycott*, *loiterer*, …
an	*oil*, *oink*, *ointment*

Missing the significant generalization

You flunk beginning linguistics!

The real question is: What are speakers doing?

Everything is analogical, no rules at all.

How could the brain keep track of all possible "true" rules?

And why would the probability of applying a rule equal the square of its frequency?

Doing it with exemplars, not rules

A dataset based on specific occurrences

specifying variables, for example:

phonemes (two before and two after)

consonant-vowel distinction (C versus V)

phrasal break before the article (+ or |)

and the outcome, for each one, *a* or *an*

Sample database

164 instances, 136 with *a* and 28 with *an*
with no exceptions to the “rule”
From an actual text, the first 10:

```
a  CrVu+CgCl through a glass darkly
a  VACs+CmV% across a most interesting book
a  VeCt+CkVA get a copy
a  CnCt|CfCy print. a few years
an VoCr+VICn for an institute class
an VeCt+V*Cr get an early version
a  VaCd+CbV@ had a bound copy
a  VECv+CbVU of a book
an V$Cd+VICm played an important part
a  VeCn|CgCr then, a great honor
```

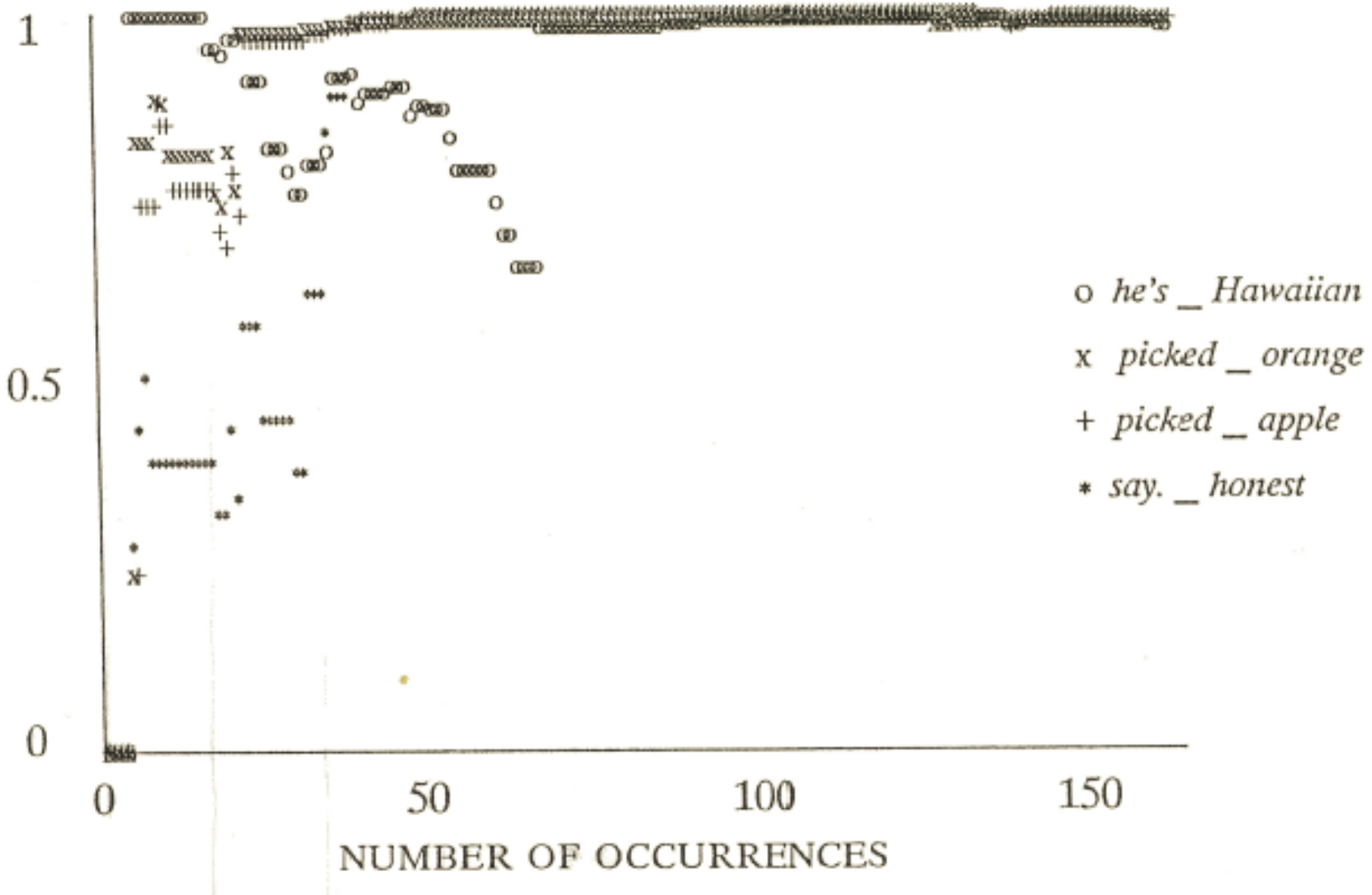
Predictions for given contexts

Here are 8 (one of which is in the dataset):

```
?  CkCt+VaCp picked __ apple
?  CkCt+VoCr picked __ orange
?  CkCt+CpVe picked __ pear
?  VACn+CtV! upon __ time
a  VaCt+CnVa at __ gnat
?  CsV$|VACn say. __ honest
?  CpV$|CyVu pay. __ university
?  ViCz+VECw he’s __ Hawaiian
```

Virtually always 100% if consonant-initial, from the beginning

Four vowel-initial cases



Children's errors

I want it go in *a* upper.

What's *a* alligator?

This *a* end.

No, this *a* engine.

I wanta make *a* egg.

Where's *a* other one?

Reversions in learning, making "progress"

Transition from *a* to *an*

Initial preference for *a*

Gyrations towards *an*

No place at which the traditional rule is learned

Adult behavior is reached after about 80 instances

A residual window of leakage:

one-way (*an* > *a*, not *a* > *an*)

Sapir: “All grammars leak”

“Competence is performance”

No need for a rule independent of usage

No need to find reasons for the one-way leakage

markedness

open syllables versus closed syllables

pronunciation

harder to pronounce *an boy* than *one boy*?

Robustness

The rule is fragile:

What to do when the initial segment is overlaid with noise?

Influence of a particular word:

we can recognize the intended word

Certain sequences of sounds are expected:

if the second segment is an *s*,

the first is undoubtedly a vowel in English

Need for redundant variables;

not just the crucial ones

A different database

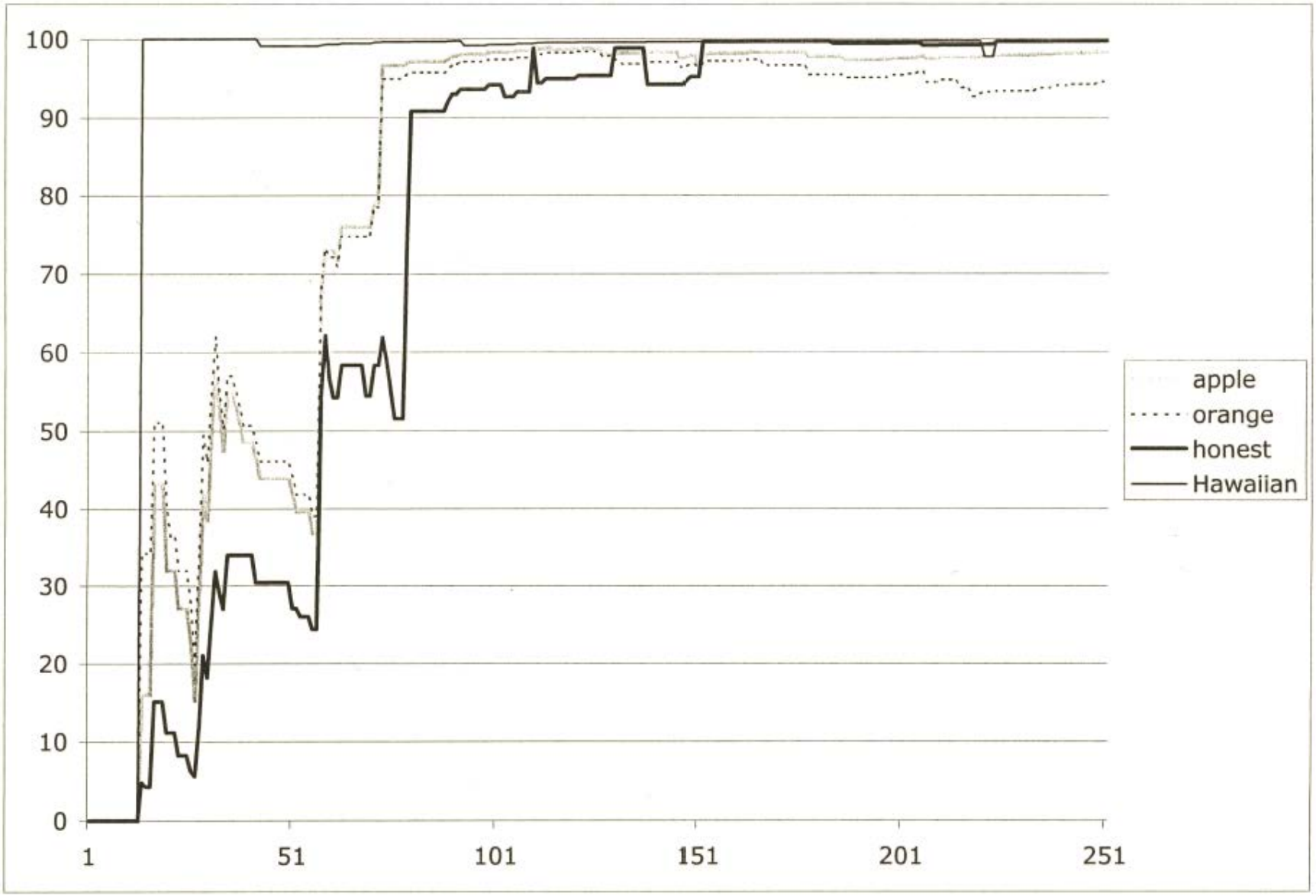
251 instances, 211 with *a* and 40 with *an*

no exceptions to the “rule”

from an actual text, the second 10:

```
a  , V I  C th + C b  V e  , with a better
a  , V a  C z  + C k  V E  , as a conjectural
a  , V a  C z  + C r  V I  , as a result
an , V E  C z  + V o  C f  , was an awful
a  , V e  C m  | C r  V i  , them | a reading
a  , V I  C n  + C d  V I  , in a difficult
an , V I  C ng + V e  C s  , missing an s
a  , V *  C r  + C sh V o  , after a short
a  , V I  C th + C s  V i  , with a single
a  , C p  C t  | C n  V E  , manuscript | a number
```

The same basic results!



Historical or Dialectal Drift

First iteration: from no exceptions to a few

Second iteration: put the exceptions in the data set

A few more leaks!

Continuing with further iterations,

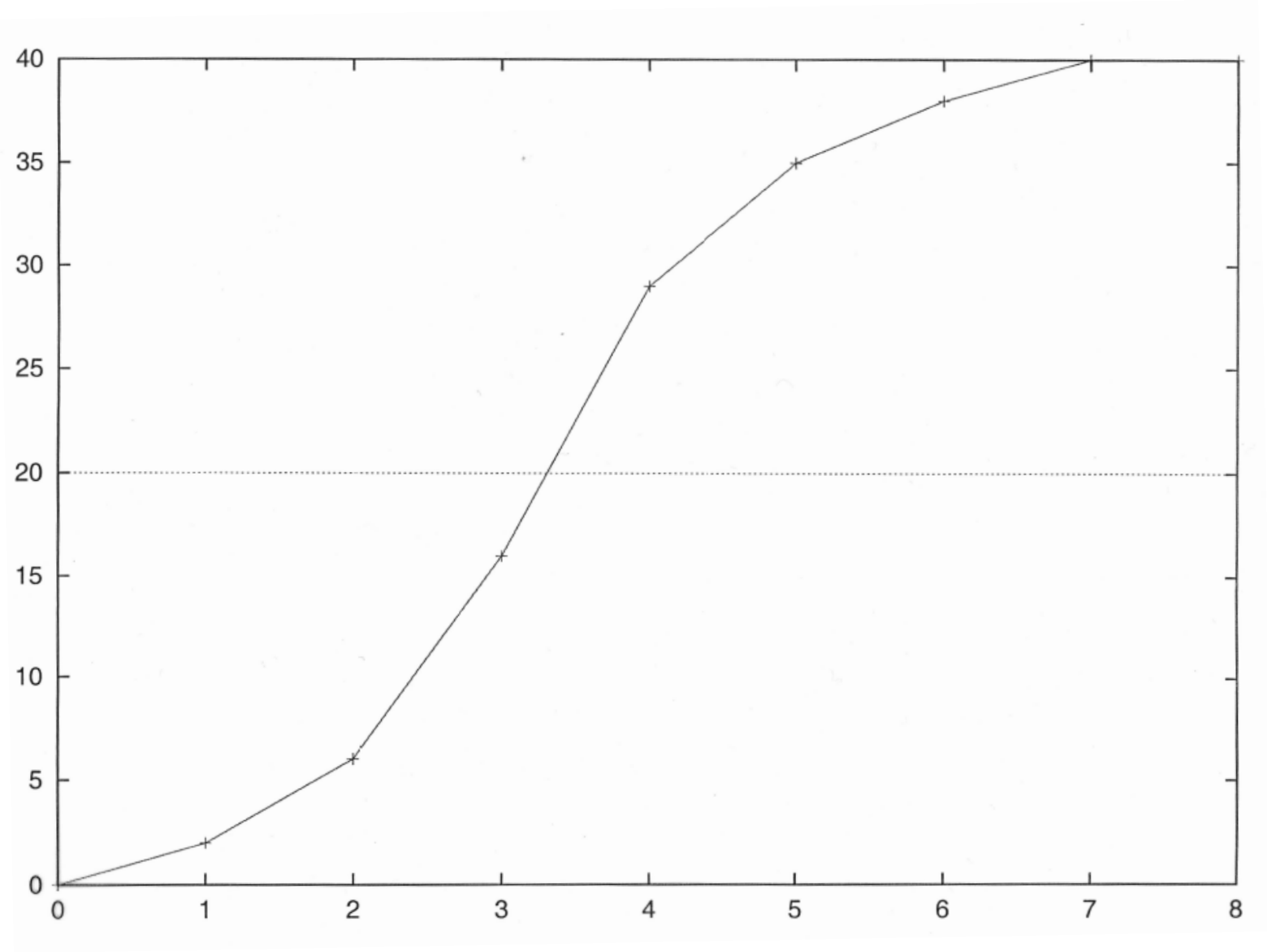
we get a few relics of *an*

Eventually, all instances of *an* go to *a*

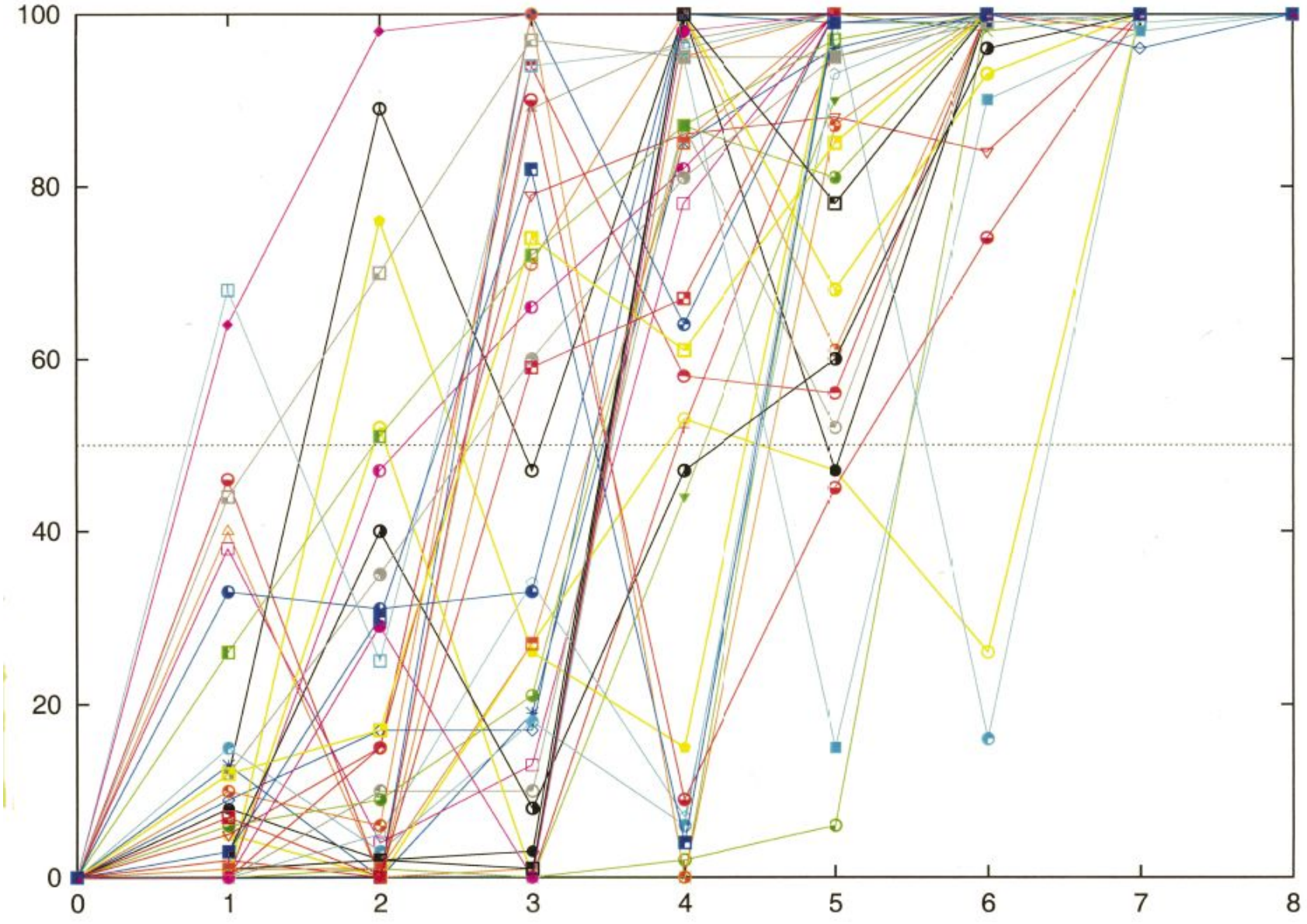
A Neogrammarian-like shift without exception,

but with Sapir's drift

The traditional *s*-curve!



Turbulent drift!



William Labov

"The Social Motivation of a Sound Change"

Martha's Vineyard Island, 1961

ai > əi

au > əu

effect of linguistic and social variables

turbulent drift for individual speakers

at varying rates for individual words

probabilistic throughout

North Tisbury Fisherman GB

	0	1	2
right	▪▪	▪▪▪▪	▪▪▪▪▪▪
night	▪▪	▪▪	▪
white			▪
like		▪▪	
sight	▪▪▪	▪	
quite	▪		
striped	▪▪		
swiped		▪	
wife	▪▪		
life	▪▪	▪▪▪	▪
knife	▪		▪
spider			▪
side	▪▪▪▪▪▪▪	▪	
tide	▪▪▪▪▪	▪	
applied	▪		
characterized	▪		

	0	1	2
Ivory			▪
live	▪		▪
five		▪	
I’ve		▪	
by		▪	
fly in			▪
high	▪		
fryin’	▪		
why		▪	
my	▪▪		
try		▪	
I’ll	▪		
piles	▪		
while	▪▪▪		
mile	▪		
violence	▪		

North Tisbury Fisherman (cont.)

	0	1	2
shiners	▪		
kind	▪		
iodine		▪	
quinine	▪		
time	▪▪		
line		▪	
I	▪	▪▪▪▪▪	▪▪▪▪▪▪▪▪▪▪
fired	▪		
tire	▪		

	0	1	2
out	▪▪▪▪▪	▪▪	▪▪▪▪
about	▪	▪	
trout	▪	▪	
house		▪	
south	▪▪	▪	
mouth	▪	▪▪▪	
couch	▪	▪	
now	▪▪		
how	▪▪		
sound	▪▪		
down	▪▪▪▪▪▪▪▪▪▪		
round	▪▪▪▪		
hound	▪		
ground	▪		

Linguistic variables

Not favoring centralization	→	*Favoring centralization*
sonorants	zero final	obstruents
nasals		orals
voiced		voiceless
velars	labials	apicals
fricatives		stops

Centralization by Age

	ai > əi	au > əu
over 75	0.25	0.22
61 to 75	0.35	0.37
46 to 60	0.62	0.44
31 to 45	0.81	0.88
14 to 30	0.37	0.46

Centralization by Geography

	ai > əi	au > əu
Down-island	*0.35*	*0.33*
Edgartown	0.48	0.55
Oak Bluffs	0.33	0.10
Vineyard Haven	0.24	0.33
Up-island	*0.61*	*0.66*
Oak Bluffs	0.71	0.99
North Tisbury	0.35	0.13
West Tisbury	0.51	0.51
Chilmark	1.00	0.81
Gay Head	0.51	0.81

Centralization by Occupation

	ai > əi	au > əu
fishermen	1.00	0.79
farmers	0.32	0.22
others	0.41	0.57

Centralization by Ethnic Group

	ai > əi	au > əu
English	0.67	0.60
Portuguese	0.42	0.54
Indian	0.56	0.90

Centralization by Attitude

	ai > əi	au > əu
positive	0.63	0.62
neutral	0.32	0.42
negative	0.09	0.08

Combinations of probabilities?

Probabilistic rules?

David Sankoff approach:

- an underlying probability for each variable,
  - linguistic and social
- a logistic formula combines the probabilities
  - for any given collection of variables
- one free factor determined by the data

A static approach:

- does not predict drift nor movement towards exceptionality

Neogrammarian tendencies

Dealing with exceptions?

ignore, set aside, due to dialect contamination

Strong evidence for drift towards completion

Possibility of different states of final completion, found in related languages and dialects

Gemination in Finnish dialects

Southwest dialects: special gemination

obstruent > long / __ VV

p, *t*, *k*, *s*

no restriction on the preceding syllable

now historical, no longer productive

Another form of gemination

Eastern dialects: general gemination

consonant > long / [stressed V] __ VV

obstruents and sonorants

preceding syllable has some stress

currently productive

Extension of eastern gemination

Eastern dialectal special gemination

consonant > long / __ VV

no restriction on the preceding syllable

spreading independently outward

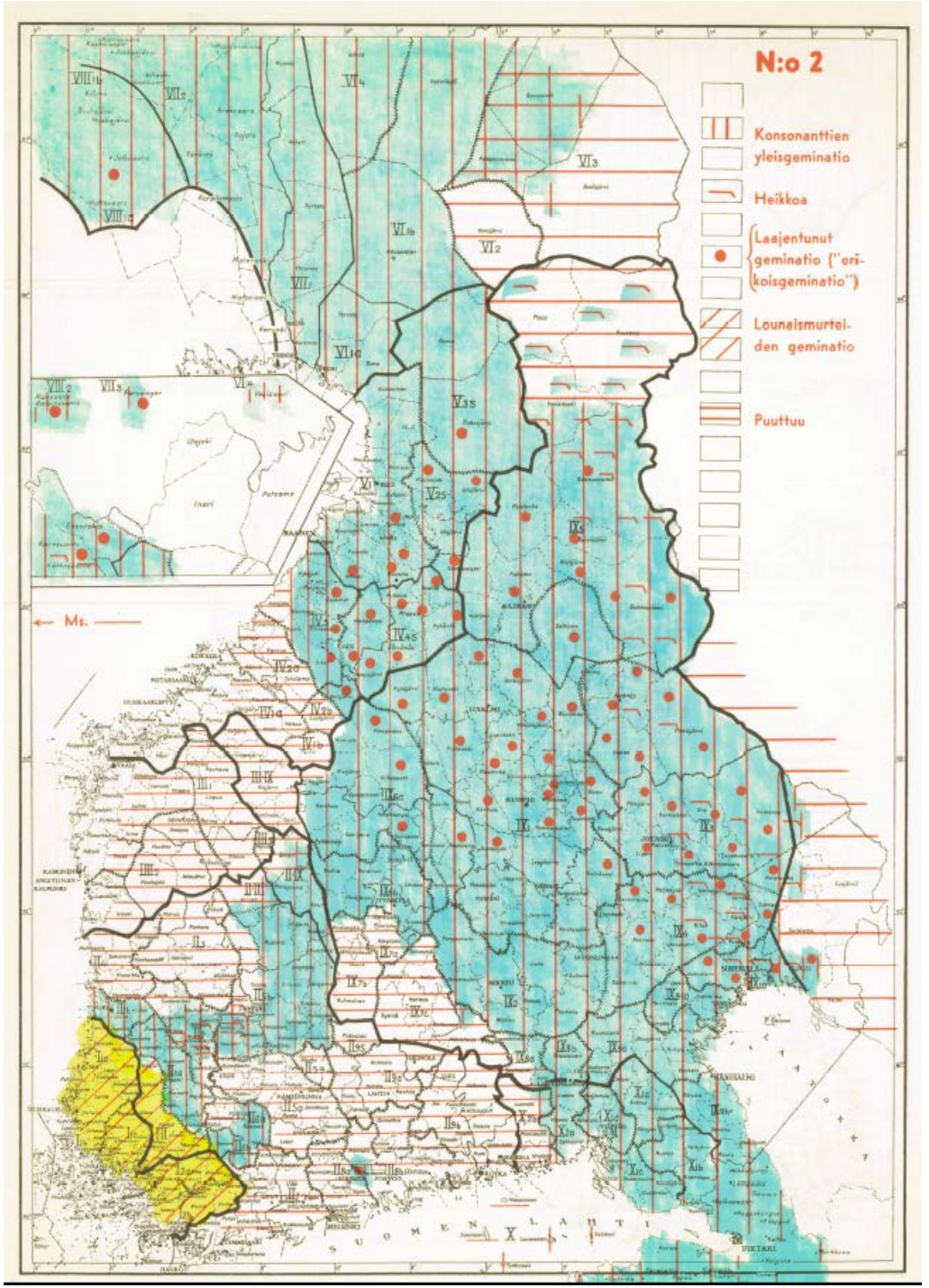
on the edges of general gemination

Kettunen, Rapola earlier reported as idiosyncratic;

now complete in many places

Analogy works towards regularization

Dialect Map of Gemination



Complex Morphological Systems

Children's errors:

regular verbs > irregular

"Yesterday it snew." (my son Lawrence, 6 years, 10 months old)

"He succame to it." (a teenager, reported by Bruce Derwing)

Analogical modeling: A single-route system

Regular verbs must be discovered among the mass of all the verbs, irregular and regular

Past-tense database for English

Based on actual past-tense forms (all verbs are familiar);
from speech and writing of children (3rd through 6th grades)

Six stages, exponentially increasing (doubling),
from the most frequent to the least:

stage 1	30	1 – 30	be, have, … , know, like
stage 2	60	31 – 60	write, sit, … , grow, pull
stage 3	122	61 – 122	fly, win, … , miss, invite
stage 4	244	123 – 244	wonder, last, … , count, shed
stage 5	488	245 – 488	arise, sign, … , arrange, brag
stage 6	976	489 – 976	split, trade, … , unite, value

snew

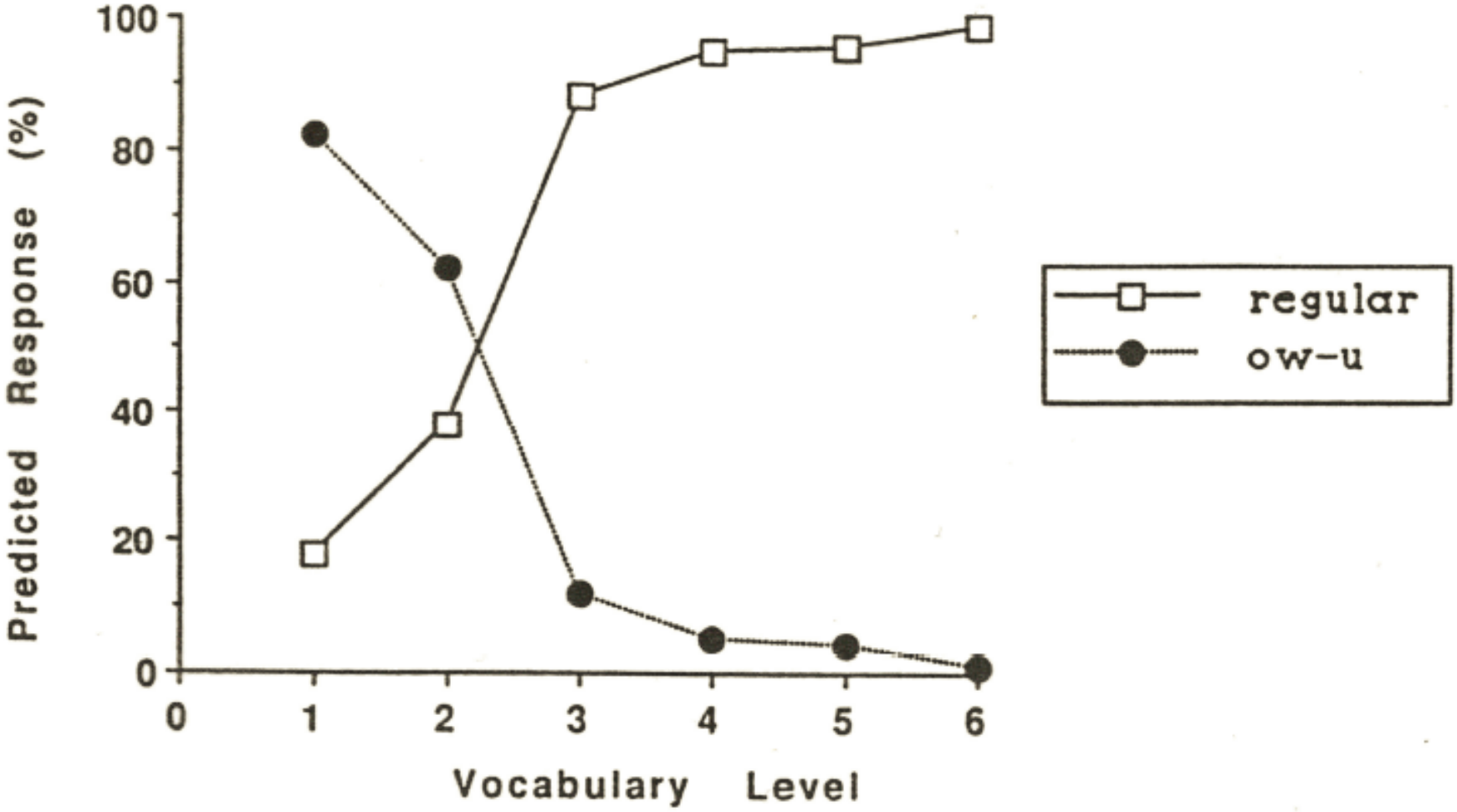


Figure 1. Predicted past tense forms for the verb 'snow'

overflew

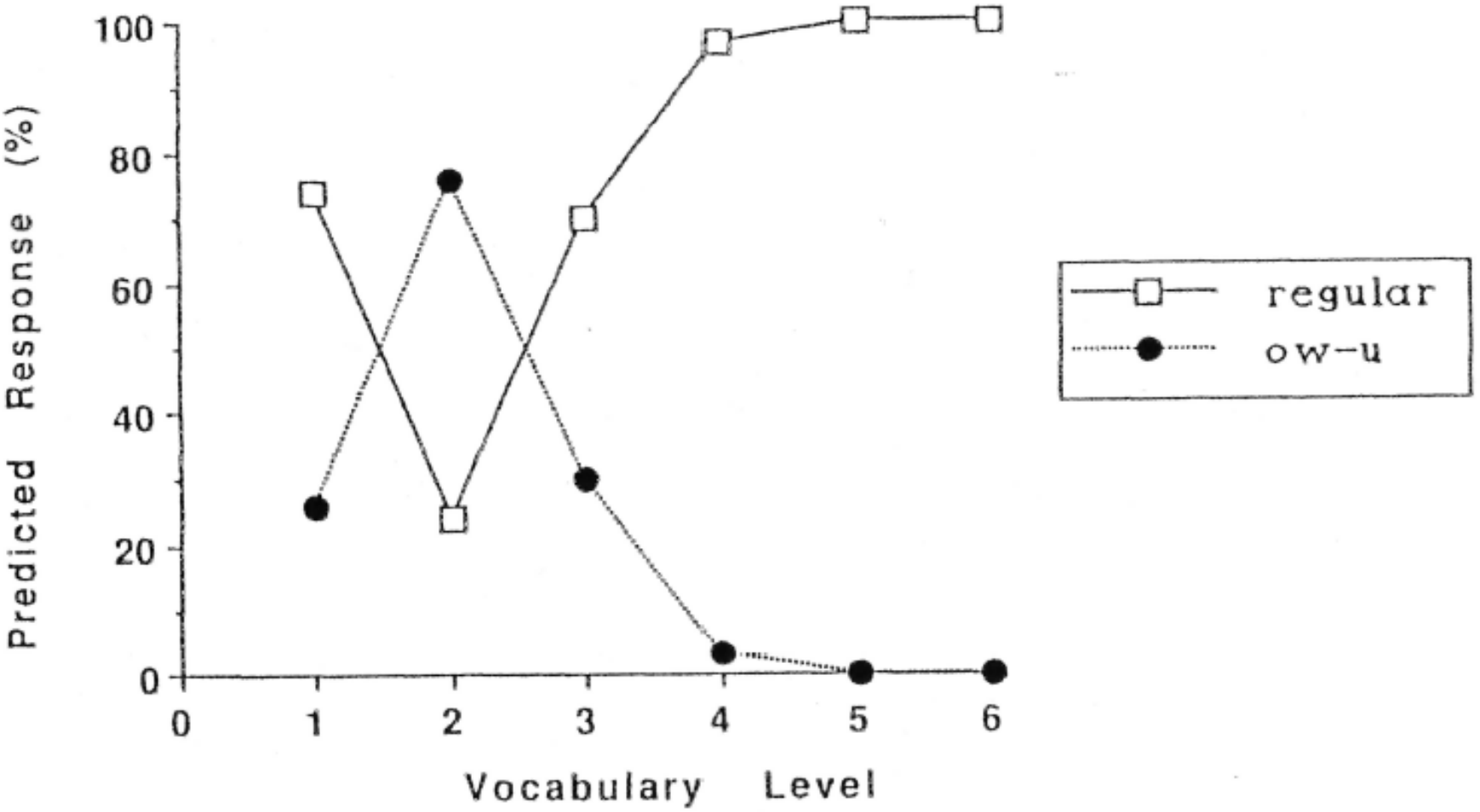


Figure 2. Predicted past tense forms for the verb 'overflow'

succame

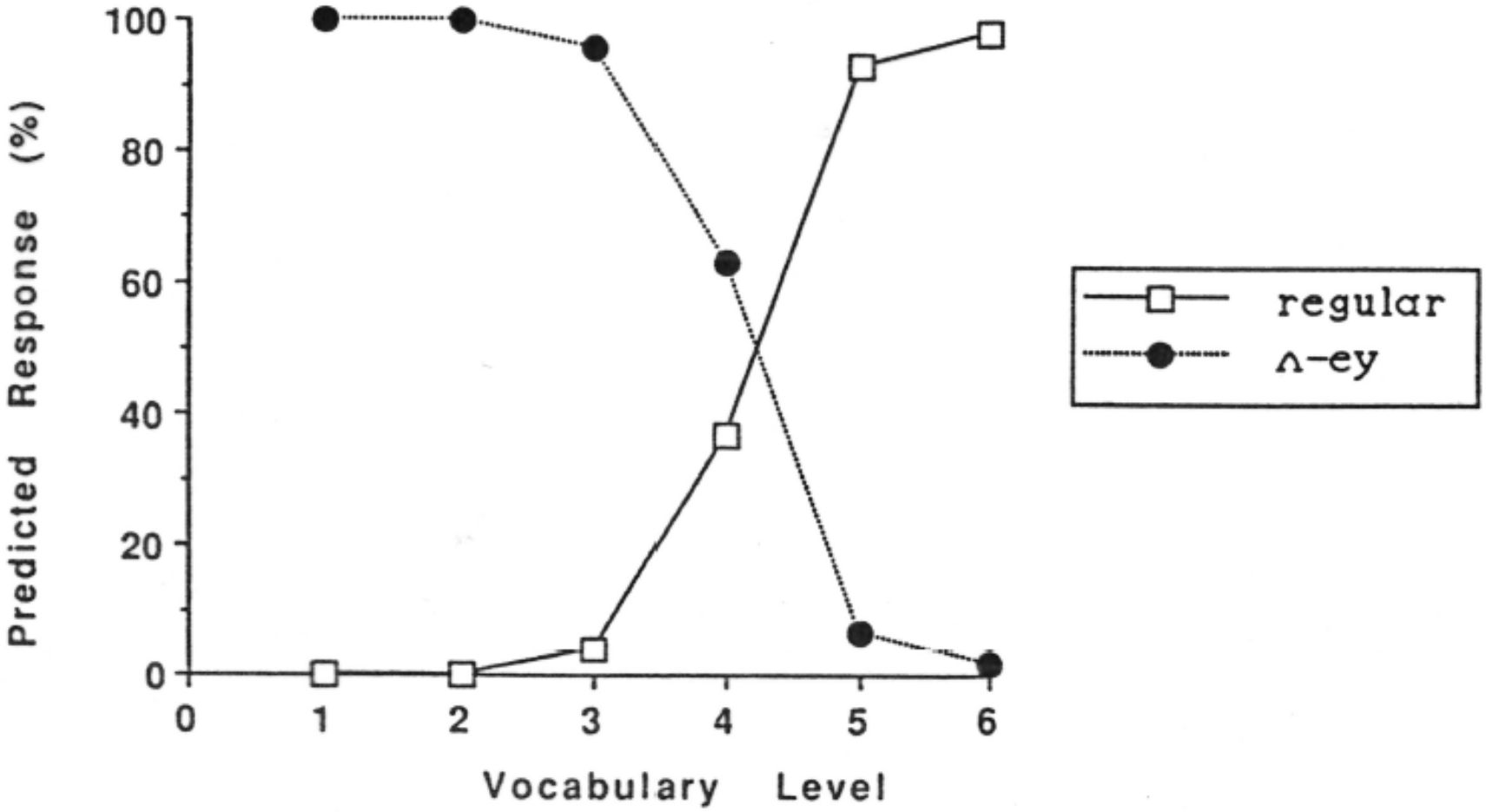


Figure 3. Predicted past tense forms for the verb 'succumb'

Scatalogical past-tense forms

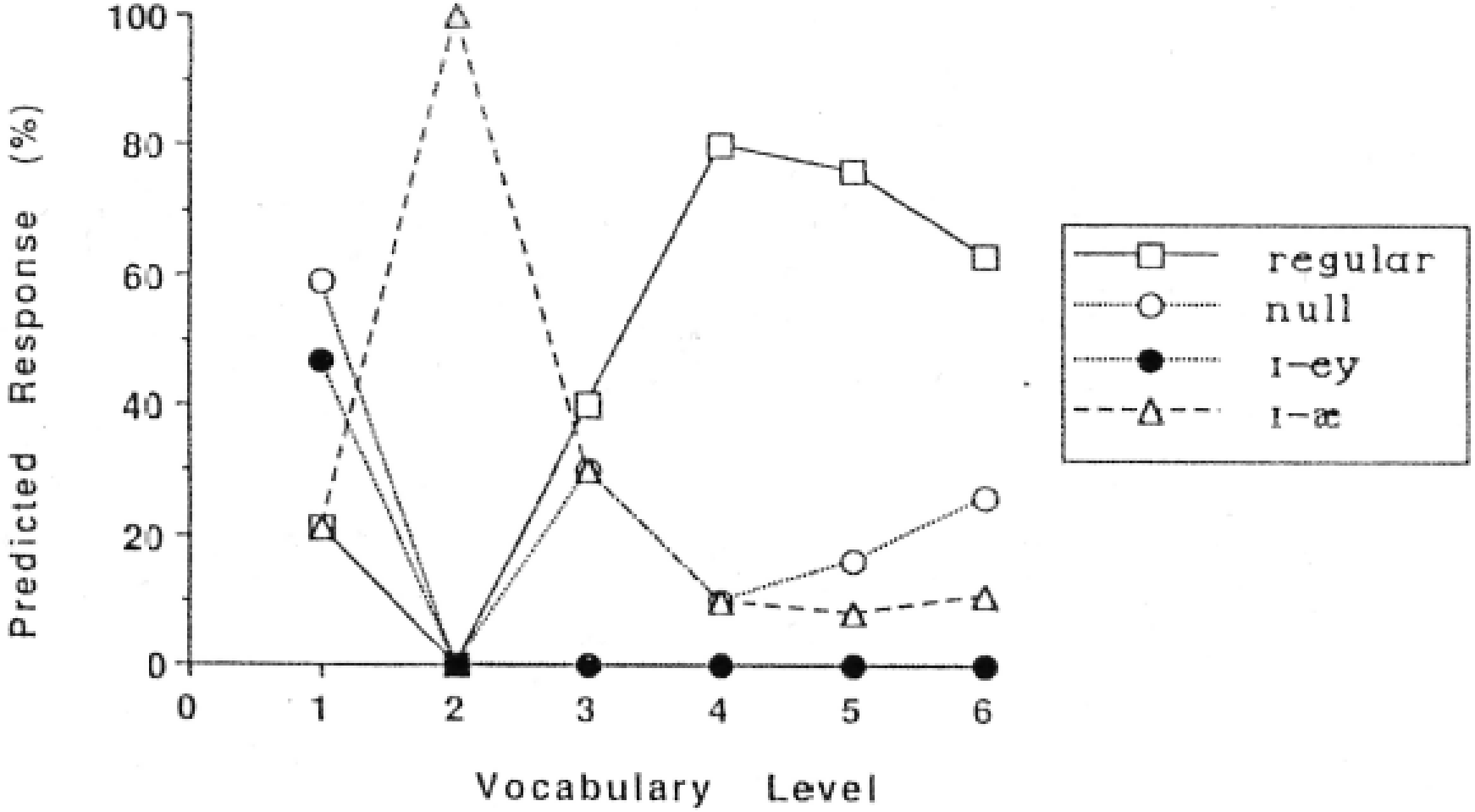


Figure 4. Predicted past tense forms for the verb 'shit'

Behavior near exceptions

ox ~ oxen

fox ~ foxes, box ~ boxes, tax ~ taxes

effect of nearest neighbors:

nonce test: *ux* ~ *uxen* (about 20%)

exceptional plural: *ax* ~ *axen* (NPR radio)

Names of the days

Monday: /məndei/ ~ /məndi/

and all other names for days of the week

From older speakers:

Wendy's as /wɛndeiz/

Sandy as /sændei/, corrected to /sændi/

Exceptional misspellings

Frequent misspelling by school children

GREAD for *grade* (cf. *great*)

Historical change

WHO, WHOSE, WHOM: /h/ exceptionally spelled as *wh*

/hwo:/ > /ho:/ (late Middle English)

as in /two:/ > /to:/ for *two*

WHOLE, WHORE, WHOOP

all spelled earlier with *h*, historically not /hw/

Other words misspelled in Early Modern English (1400s – 1600s)

WHORD *hoard*

WHOLY *holy*

WHOME *home*

WHOOD *hood*

WHOTE *hot*

Pronunciation effects

consonantal /ɛnt/, not /ænt/

<< *continental*

nuclear /kjələr/, rather than /kliər/

<< *particular*, *spectacular*, *circular*, *molecular*, *secular*, *perpendicular*, *muscular*, *vernacular*, *jocular*, …

standard *nuclear* << *cochlear* (*transplant*)

Will nearest neighbors work?

Effects of regular, strong gangs
    further away than the nearest neighbors

Past tense of *sorta-* ‘to oppress’ in Finnish

tV-si	*sorta-* ~ *sorsi*	cf. *murta-* ~ *mursi* ‘break’
V-I	*sorta-* ~ *sorti*	cf. *souta-* ~ *sousi* ‘row’

Historically, supposed to be *sorsi*
Nearest neighbor is *murta-*
Inexplicable until explained by analogical modeling

Evidence for *sorti*

Nykysuomen Sanakirja

sorta- listed under its own morphological type

citations: 10 *sorti*, 1 *sorsi*

Suomen Kielen Perussanakirja

sorti listed as normal, *sorsi* as rare

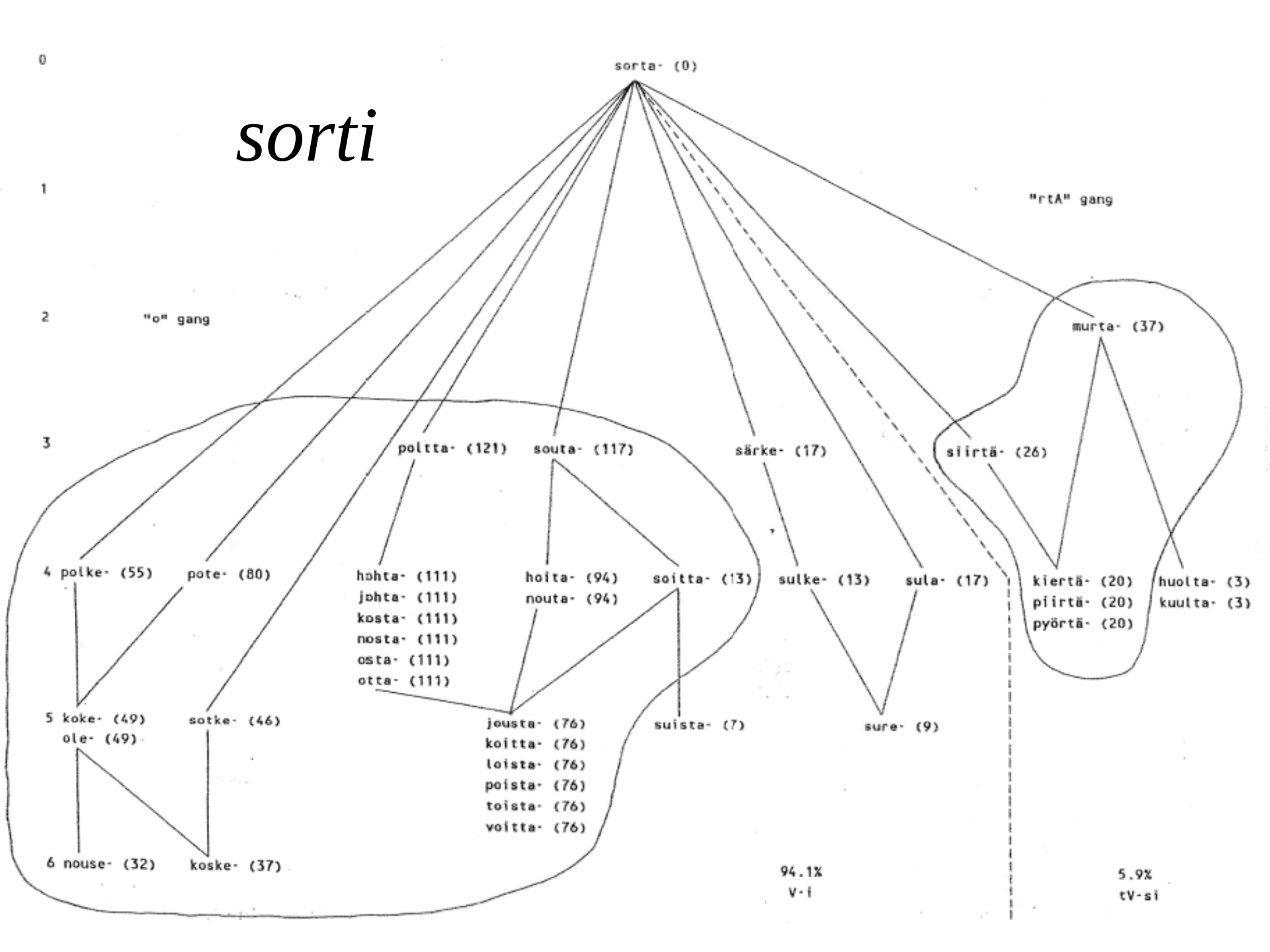
citations: 2 *sorti*, 0 *sorsi*

Looking for the answer

The regular *V-i* rule just took over
(nearest neighbor doesn't work)

Dissimilation: avoidance of two *s*'s in a row
sisään 'in', *sisu* 'courage', *sorsa* 'wild duck', *susi* 'wolf', *sisältä-* 'to contain'

The answer: it's the *o* vowel


sorti
0
1
2
3
4
5
6
sorta- (0)
"o" gang
"rtÄ" gang
murta- (37)
poltta- (121)
souta- (117)
särke- (17)
siirtä- (26)
polke- (55)
pote- (80)
hohta- (111)
johta- (111)
kosta- (111)
nosta- (111)
osta- (111)
otta- (111)
hoita- (94)
nouta- (94)
soitta- (13)
sulke- (13)
sula- (17)
kiertä- (20)
piirtä- (20)
pyörtä- (20)
huolta- (3)
kuulta- (3)
koke- (49)
ole- (49)
sotke- (46)
jousta- (76)
koitta- (76)
loista- (76)
poista- (76)
toista- (76)
voitta- (76)
suista- (7)
sure- (9)
nouse- (32)
koske- (37)
94.1%
V-i
5.9%
tV-si

Learning probabilities

Analogical Modeling has no probabilistic rules

Predictions are made “on the fly”,

made in terms of the given context

All we have are exemplars

Hypothetical probabilistic rule for *dived ~ dove*

Mark Davies' *Corpus of Contemporary American English* (COCA), 1990-2012

52.9% *dove*, 47.1% *dived*

A random sequence of *d*'s and *o*'s:

29 instances of *dove*, 21 of *dived*

dodooooooooodooooooooddoooddddooodddddddoodd
oddodooddo …

Storing and accessing exemplars

Problems with probabilistic rules:

- problems learning a probability from data
- problems using a probability to predict an occurrence

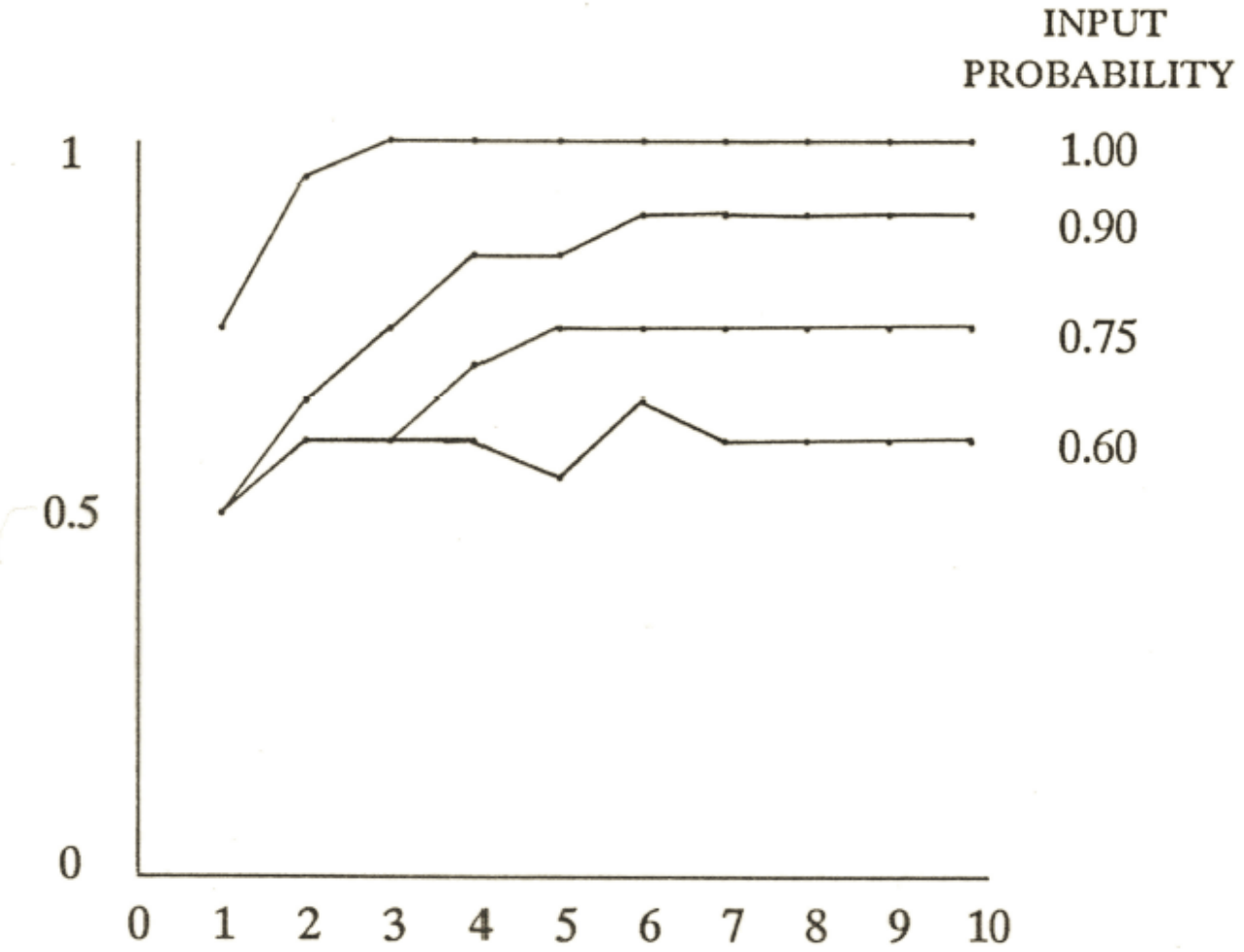
The exemplar approach (analogical modeling):

- store exemplars
- randomly select an exemplar

Difficulties replicating random probabilistic behavior:

- artificial neural nets, parallel distributed processing, connectionism

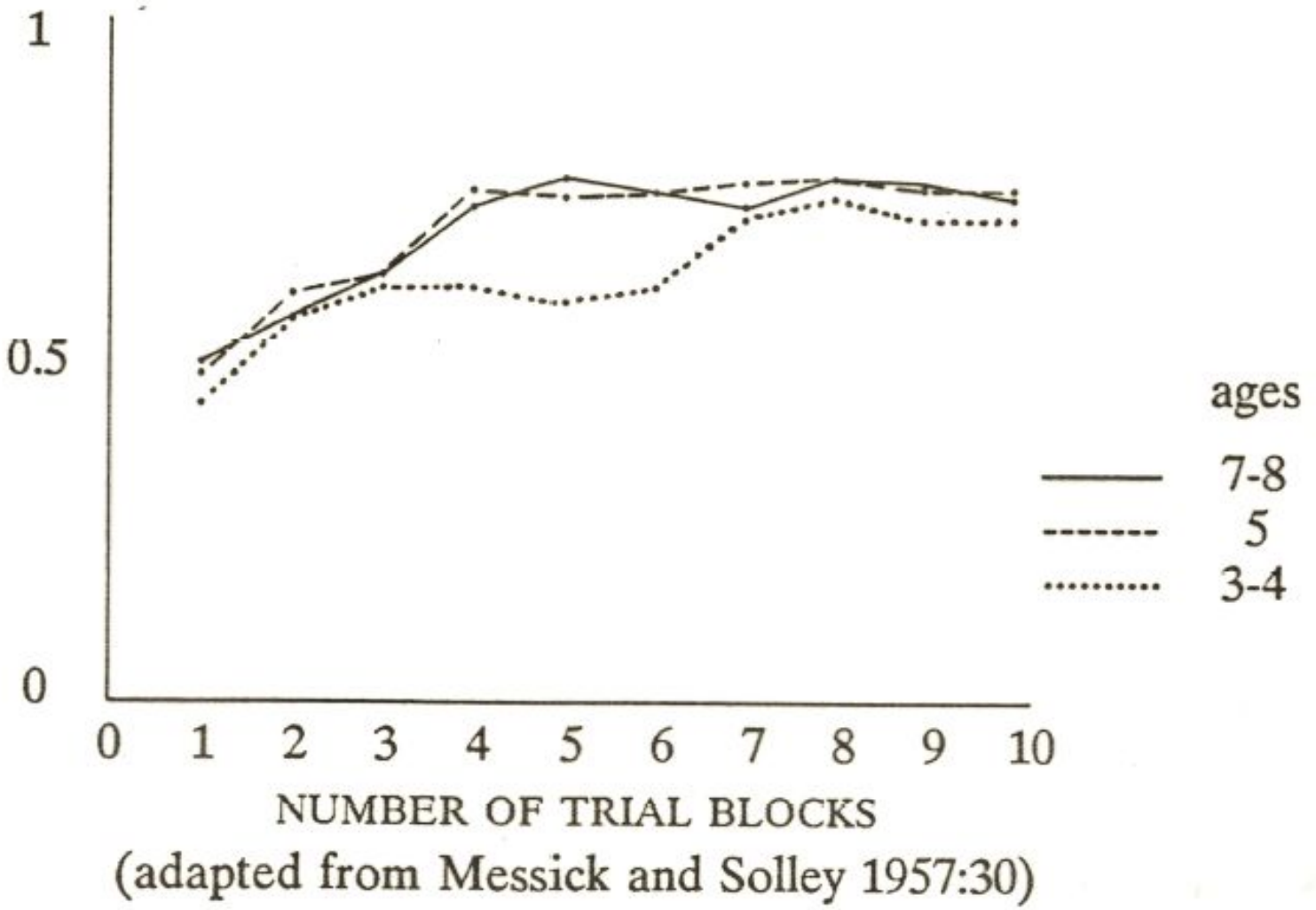
Adults learning probabilities



(adapted from Messick and Solley 1957:26)

Kids learning probabilities

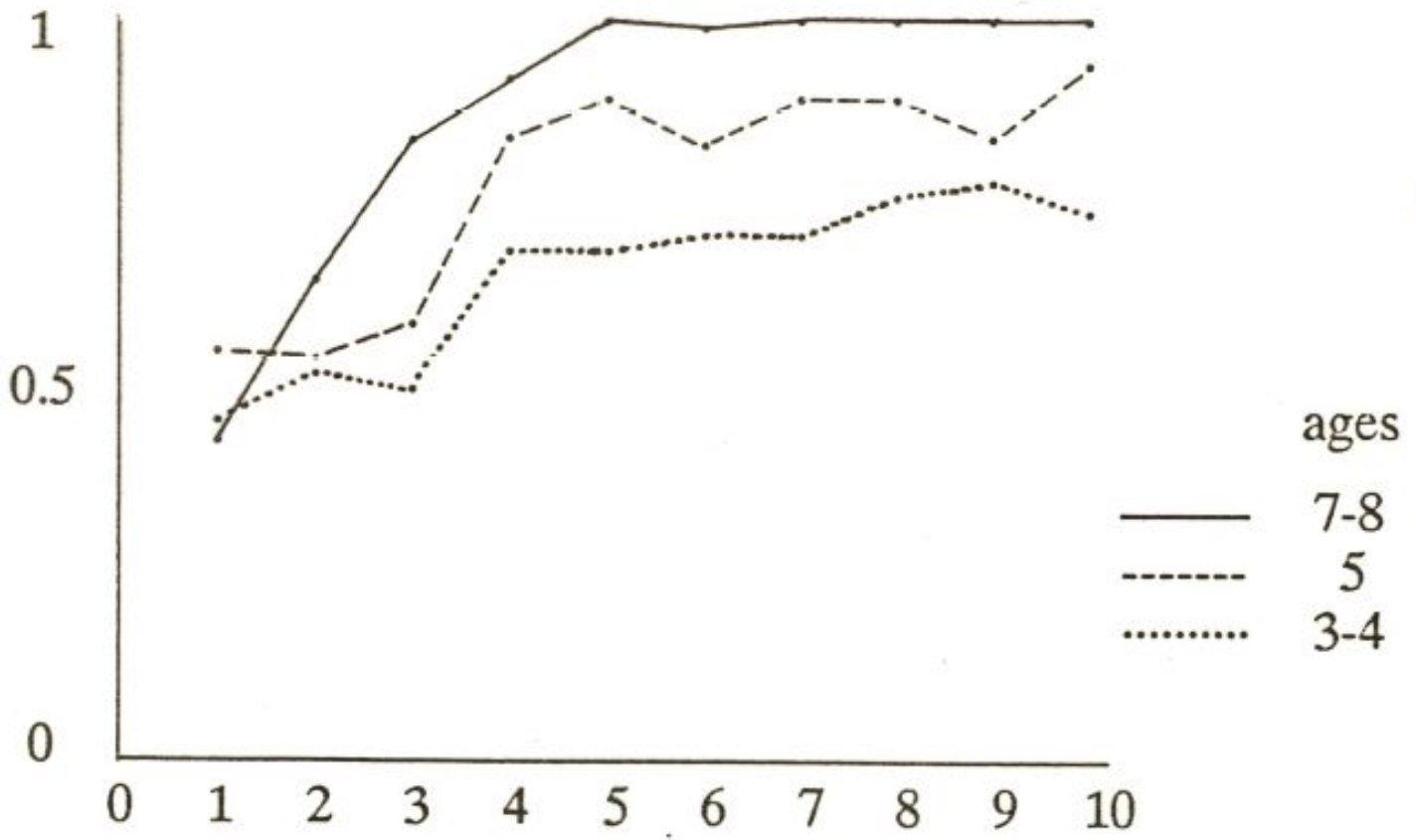
no-reward experiment (random selection for all ages):



(adapted from Messick and Solley 1957:30)

Adding a reward

reward experiment (selection by plurality for older ages):



(adapted from Messick and Solley 1957:30)

Analogical Modeling Literature

1989, *Analogical Modeling of Language*

Kluwer: Dordrecht, Netherlands

1992, *Analogy and Structure*

Kluwer: Dordrecht, Netherlands

2002, *Analogical Modeling: An Exemplar-Based Approach to Language*

edited with Deryle Lonsdale and Dilworth Parkinson

John Benjamins: Amsterdam, Netherlands

The AM Website

http://humanities.byu.edu/am/

Articles by various scholars using analogical modeling

The AM computer program,
available for download in various formats

The Exponential Explosion

Every new variable added:

- doubled the running time
- doubled the memory requirements

Can currently run up to 70 variables

- basically in linear running time
  - after 70 variables, exponentiality sets in
- space requirements are consistently exponential

The “rule” equivalent to AM

All possible rules are considered,
but the heterogeneous ones are removed

The probability of using one of the homogeneous rules is proportional to its frequency squared

Frequency squared describes language behavior most accurately

The squaring also follows from a statistical rule of always minimizing uncertainty (a quadratic measure)

Quantum Computing of Analogical Modeling

Quantum mechanics (QM)
- all possible paths
- interference wipes out conflicting paths
- observe one of the remaining paths
  - probability is the amplitude squared

Quantum analogical modeling (QAM)
- all possible variable combinations
- remove all cases of heterogeneity
- observe one of the remaining homogenous cases
  - probability is the frequency squared

Richard Feynman's observation

Quantum computing quote from Richard Hughes

Note that input data must typically be carried forward to the output to allow for reversibility. Feynman showed that in general the amount of extra information that must be carried forward is just the input itself.

QAM Literature on arXiv.org

2000, “Analogical Modeling and Quantum Computing”
arXiv:quant-ph/0008112, 28 August 2000
the arguments for why AM is quantum mechanical

2005, “Quantum Analogical Modeling: A General Quantum Computing Algorithm for Predicting Language Behavior”
arXiv:quant-ph/0510146, 18 October 2005
the general quantum algorithm for analogical modeling
runs in linear time and linear space

2010, “Quantum Analogical Modeling with Homogeneous Pointers”
arXiv:1006.3308, 16 June 2010
the simplest conceptual version of QAM
runs in quadratic time and quadratic space