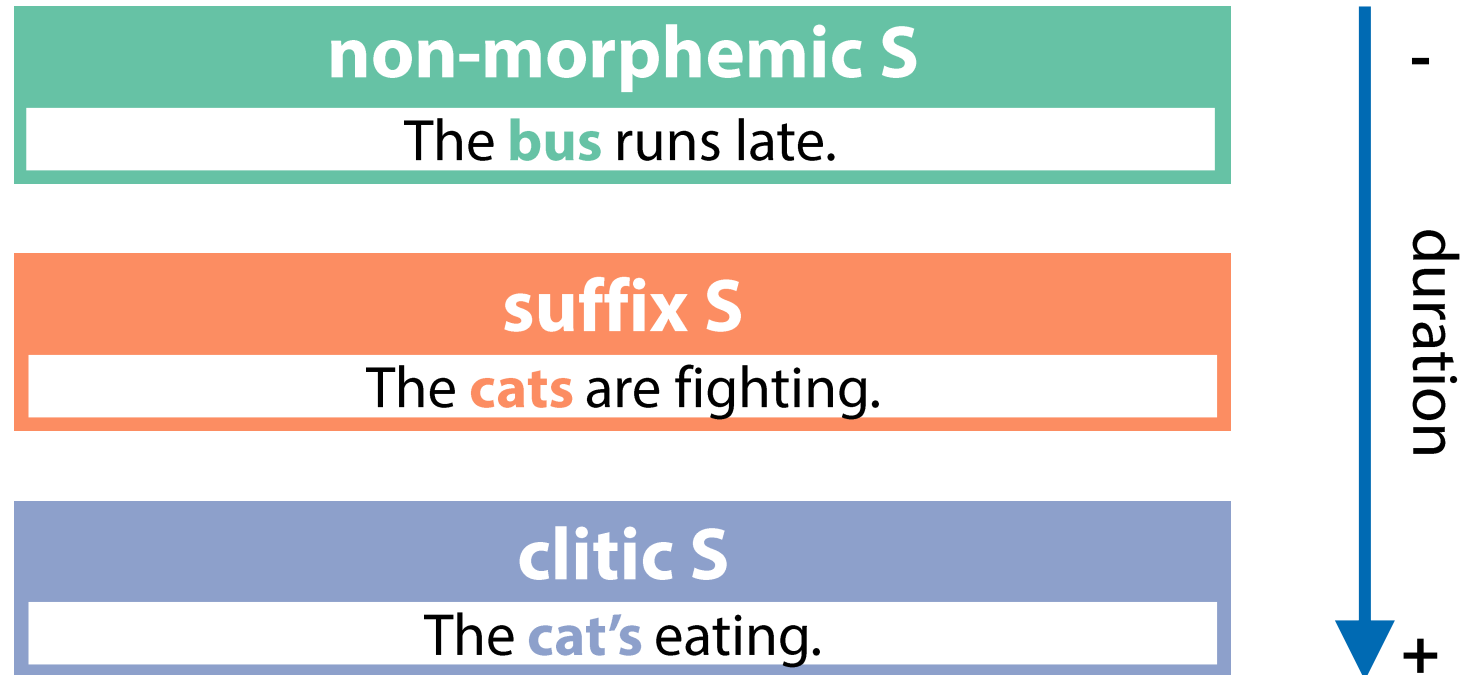


Modelling word-final /s/ duration in pseudowords with LDL

Dominic Schmitz, Ingo Plag, Dinah Baer-Henney

Previous findings on /s/ duration



- ▶ Zimmermann (2016); Plag et al. (2017); Tomaschek et al. (2019); Schmitz et al. (2020)
- ▶ but also: Walsh & Parker (1983); Hsieh et al. (1999); Seyfarth et al. (2017); Plag et al. (2020)

Previous findings on /s/ duration

non-morphemic S

The **glaips** calls his mum.

plural S

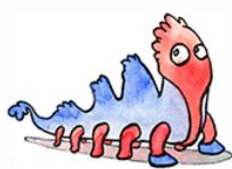
The **glaips** called their mum.

clitic S

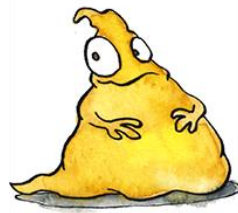
The **glaip's** called his mum several times.



a glip



a pleets



a clook



a prufs



a bloup



a glait

Previous findings on /s/ duration

non-morphemic S

The **glaips** calls his mum.

plural S

The **glaips** called their mum.

clitic S

The **glaip's** called his mum several times.

-
duration
+

How to explain such differences?

- ▶ standard feed-forward theories of morphology-phonology interaction (e.g. Chomsky & Halle, 1968; Kiparsky, 1982)
 - ▶ bracket erasure: simplex and complex word forms are the same to production
- ▶ psycholinguistic models of speech production (e.g. Levelt et al., 1999; Roelofs & Ferreira, 2019)
 - ▶ phonological forms without morphological info are used in speech production

Alternative: Discriminative Learning

- ▶ Can we use measures derived from discriminative networks to model /s/ duration?
 - ▶ Yes: Tomaschek et al. (2019) reproduce the differences in /s/ duration found by Plag et al. (2017) by means of NDL measures
- ▶ Can we use pseudowords?
 - ▶ Yes: Chuang et al. (2020) successfully implement LDL with real and nonce words; pseudowords resonate with the lexicon = show semantics

Can we implement LDL with real and nonce words and use measures derived from such an implementation to model /s/ durations? If so, how can we interpret these LDL measures?

Can we **implement LDL with real and nonce words** and use measures derived from such an implementation to model /s/ durations? If so, how can we interpret these LDL measures?

LDL Basics

▶ lexome

basic semantic units corresponding to words or morphological functions

$$\text{cat} = \overrightarrow{\text{cat}} \quad \& \quad \text{cats}_{\text{plural}} = \overrightarrow{\text{cat}} + \overrightarrow{\text{plural}}$$

▶ cue matrix C

encodes the forms of words in a binary fashion, giving information on which triphones are part of which word

	#k{	k{t	{t#	#bV
cat	1	1	1	0

▶ semantic matrix S

contains semantic vectors of word forms on basis of their corresponding lexomes

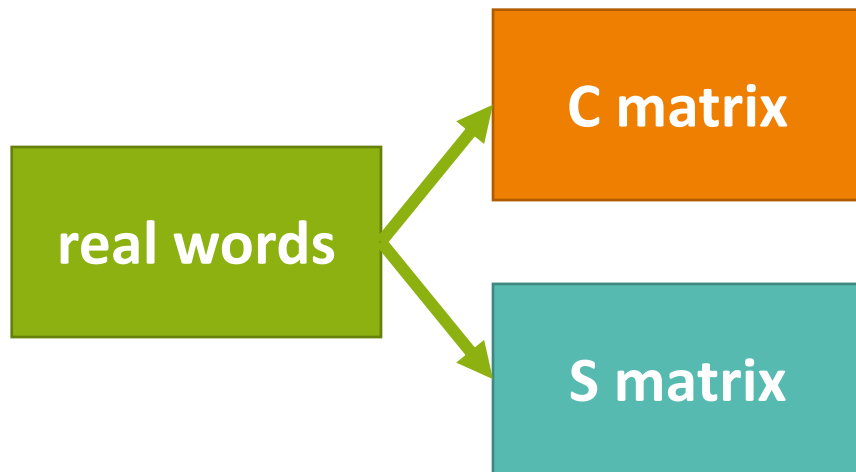
	bus	eel
k{t	0.7	0.2

LDL: Real Words

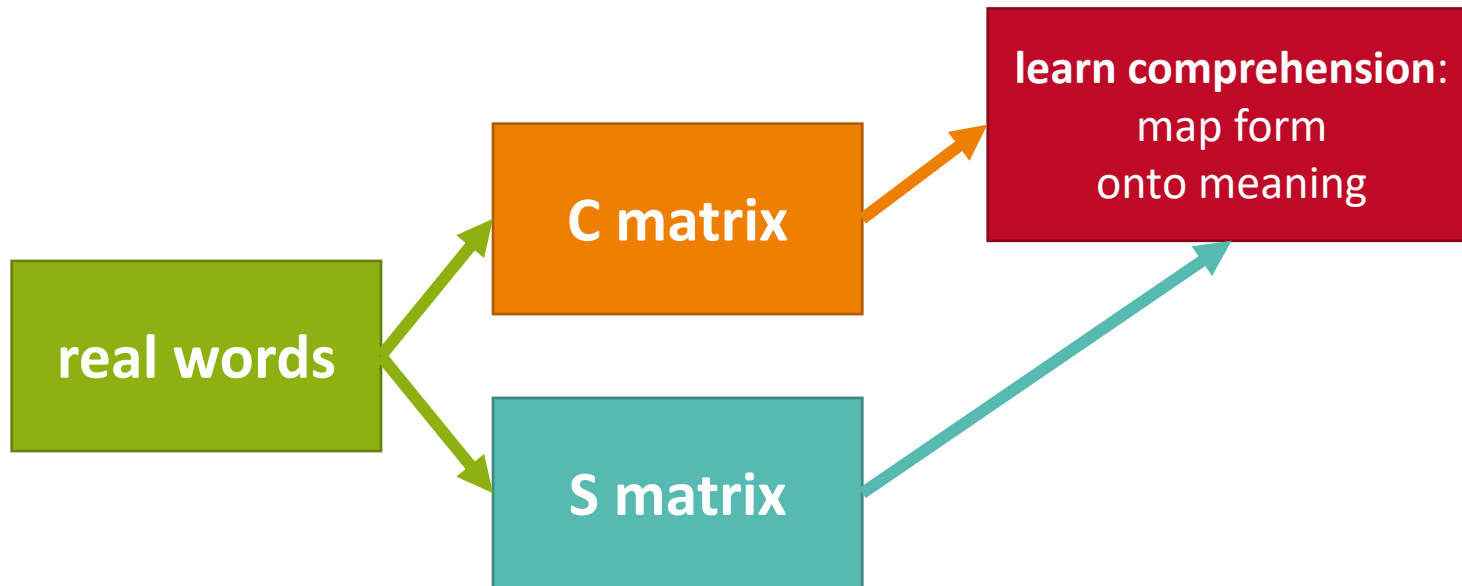
- ▶ C and S matrix are easily created with WpmWithLdl package (Baayen et al., 2019)
- ▶ C matrix:
 - ▶ based on 8362 words taken from MALD corpus (Tucker et al., 2019)
- ▶ S matrix:
 - ▶ based on semantic vectors created based on TASA corpus (Ivens & Koslin, 1991) by Baayen et al. (2019)

LDL: Real Words

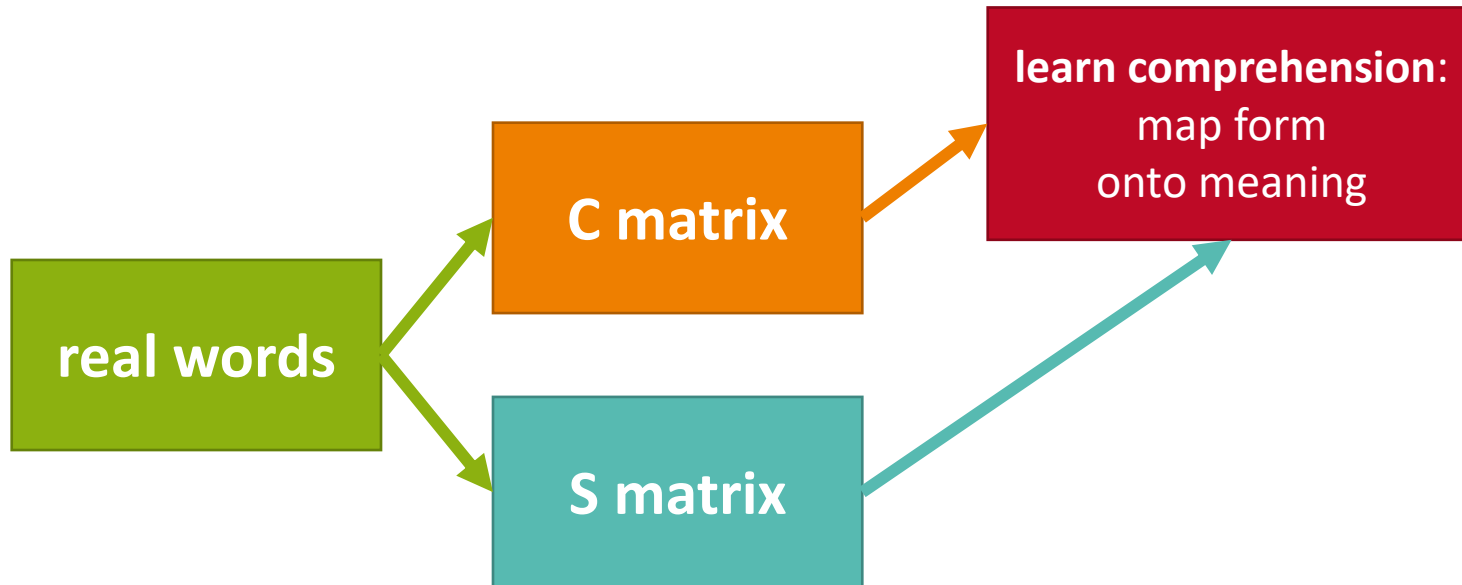
LDL: Real Words



LDL: Real Words

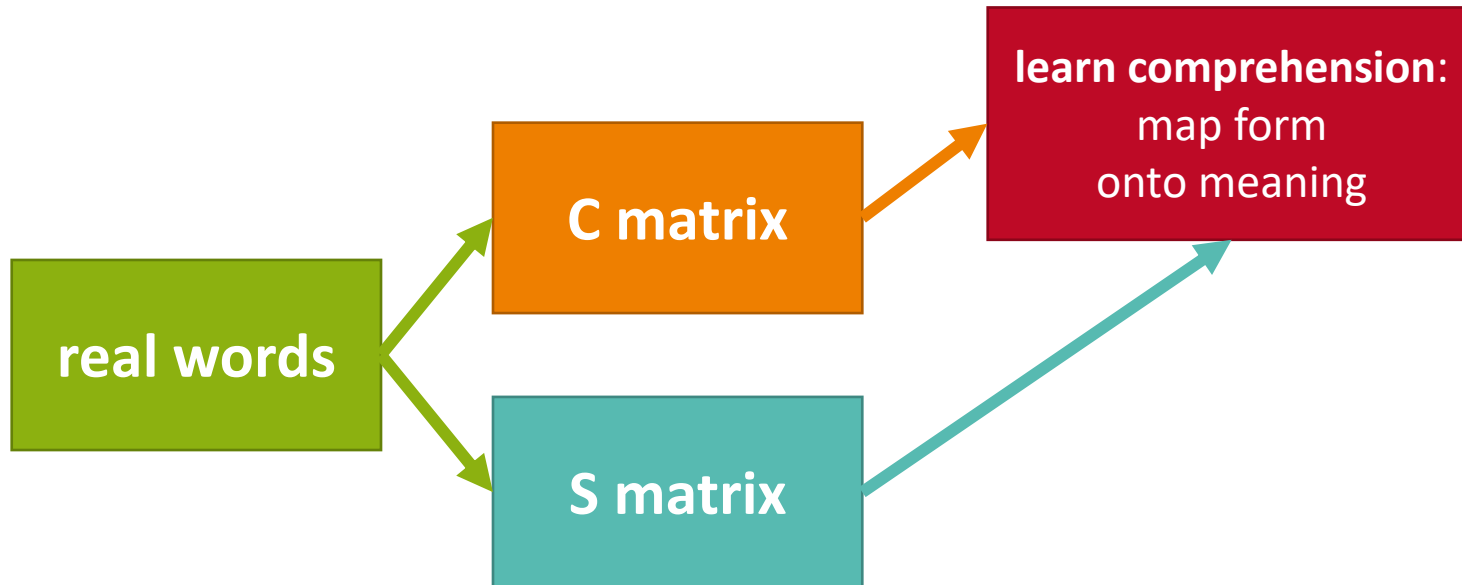


LDL: Real Words



$$CF = S$$

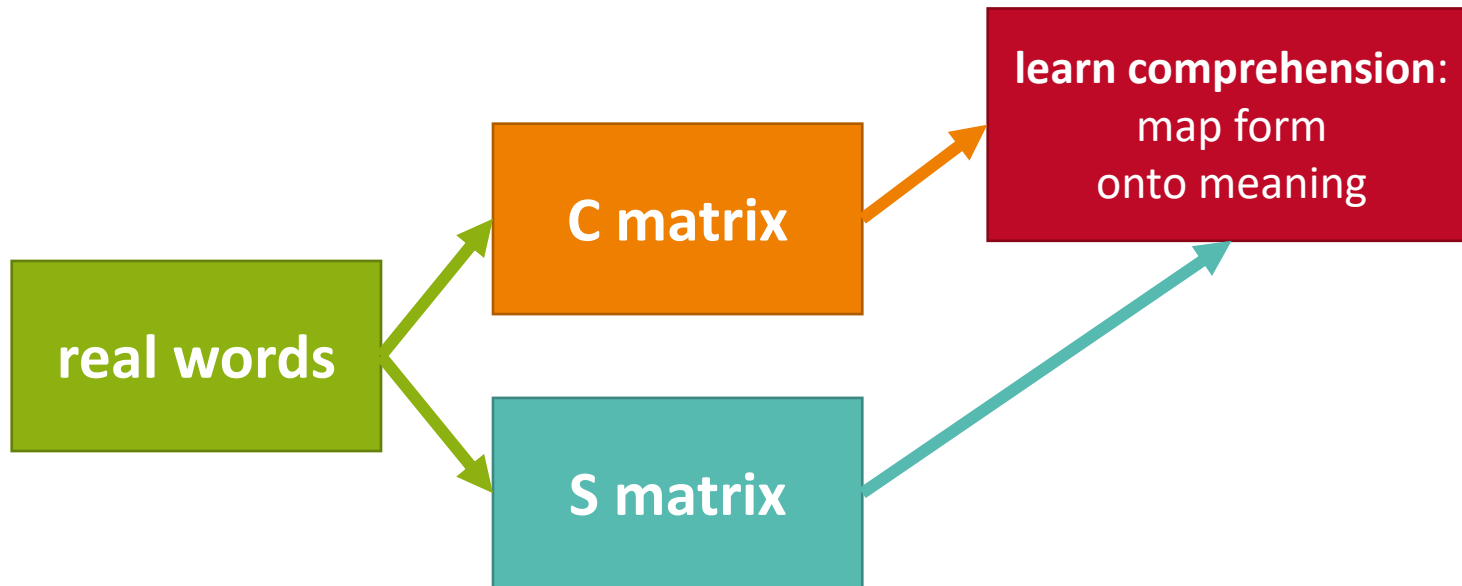
LDL: Real Words



$$CF = S$$

$$F = C'S$$

LDL: Real Words

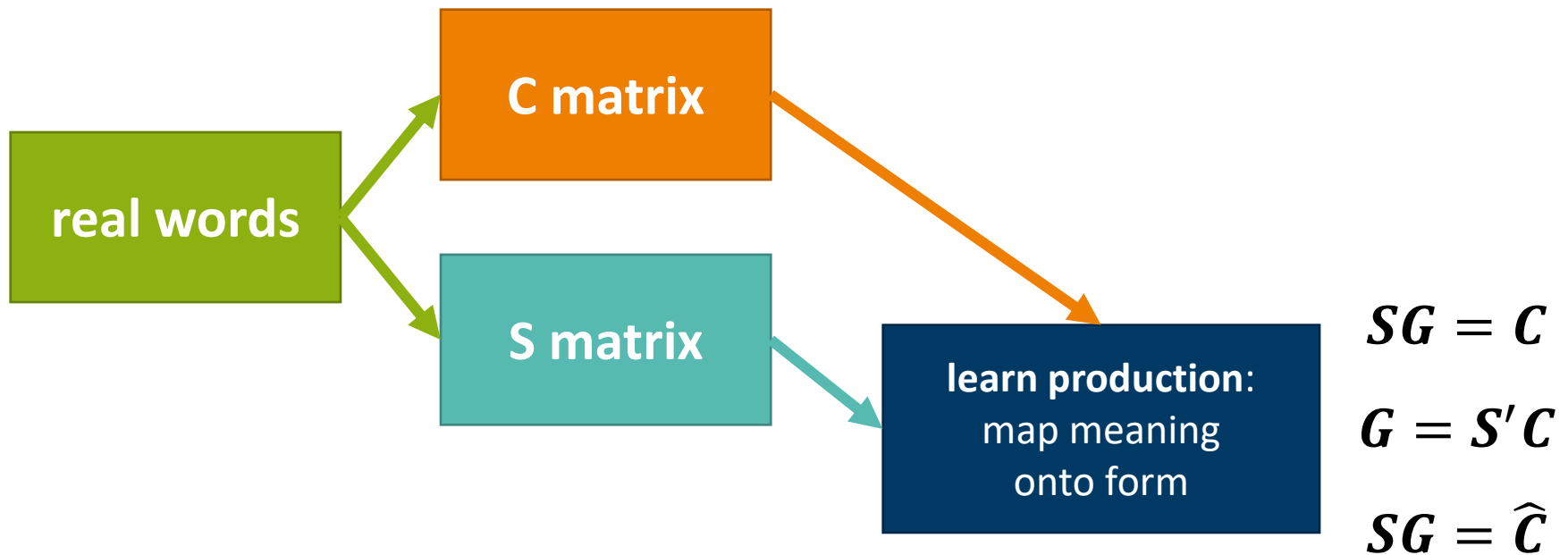


$$CF = S$$

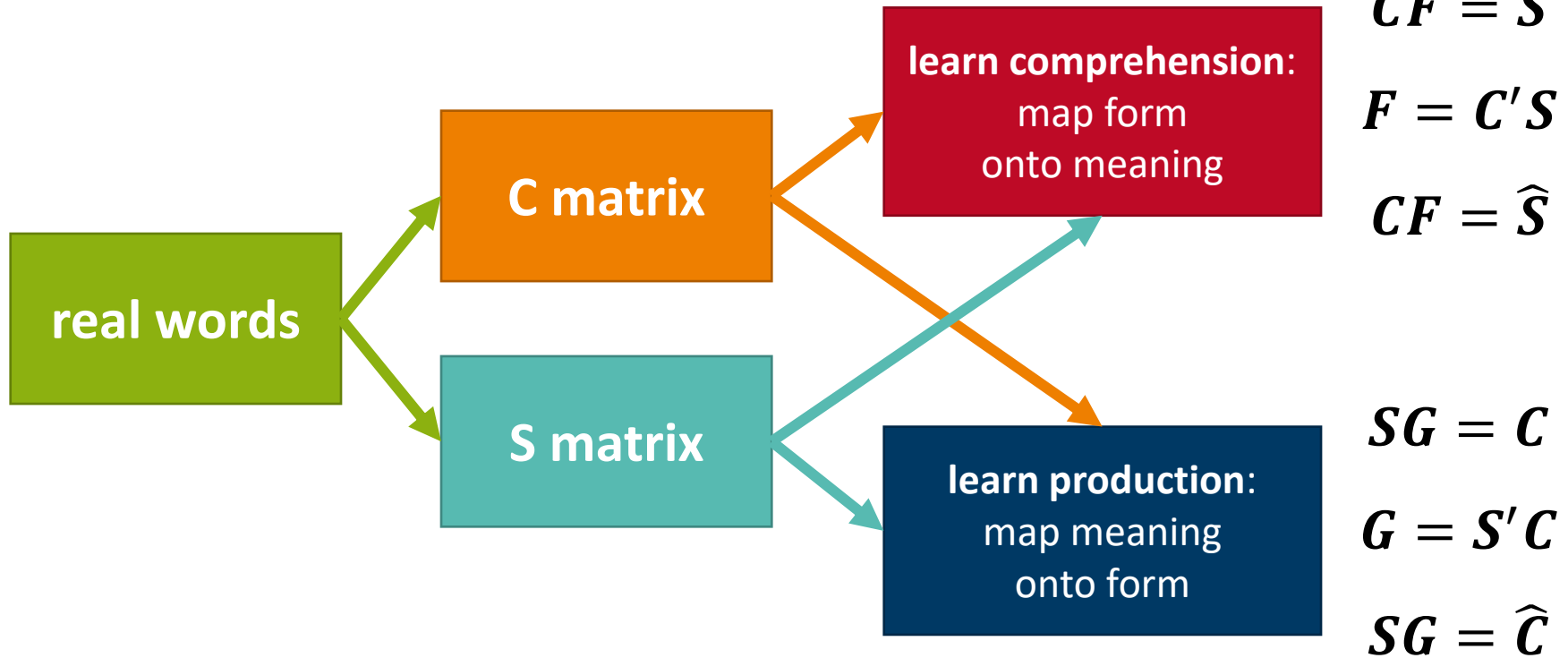
$$F = C'S$$

$$CF = \hat{S}$$

LDL: Real Words



LDL: Real Words

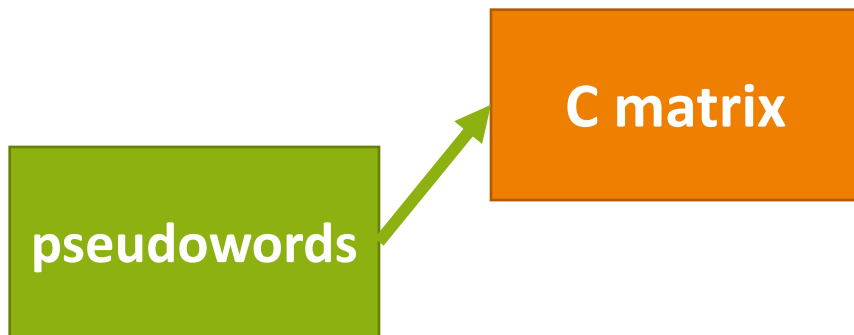


LDL: Pseudowords

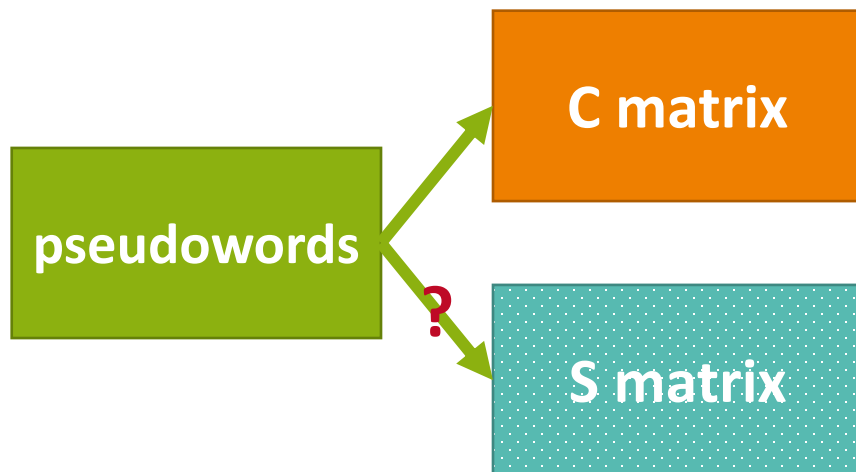
- ▶ C matrix is easily created with WpmWithLdl package (Baayen et al., 2019)
- ▶ C matrix:
 - ▶ based on 48 pseudowords with 72 phonological forms taken from the ENGS production experiment (Schmitz et al., 2020)
- ▶ S matrix:
 - ▶ ...well, what about the S matrix?

LDL: Pseudowords

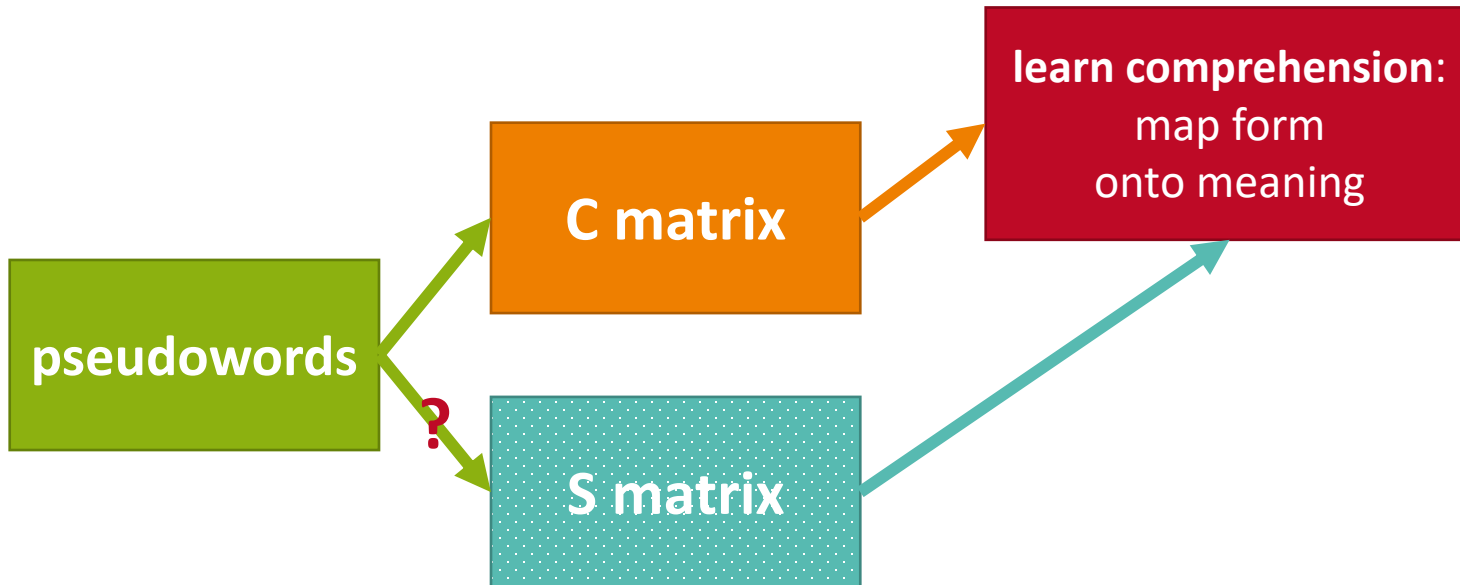
LDL: Pseudowords



LDL: Pseudowords

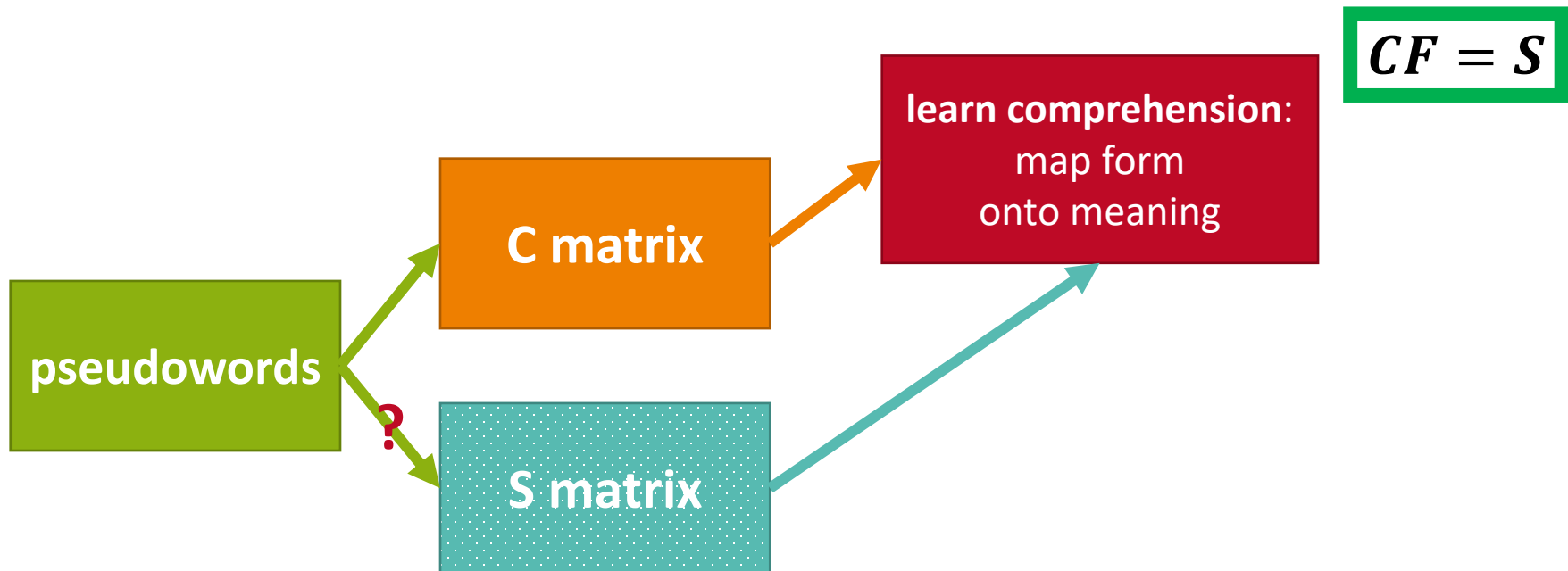


LDL: Pseudowords

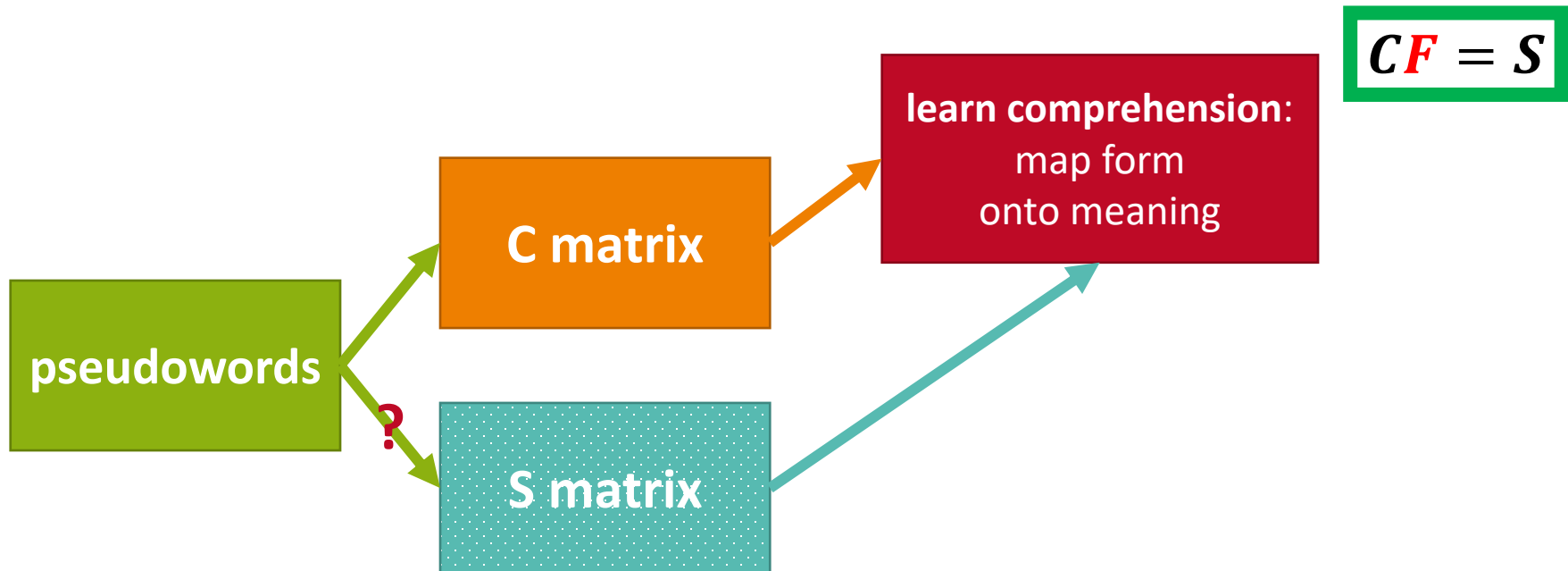


$$CF = S$$

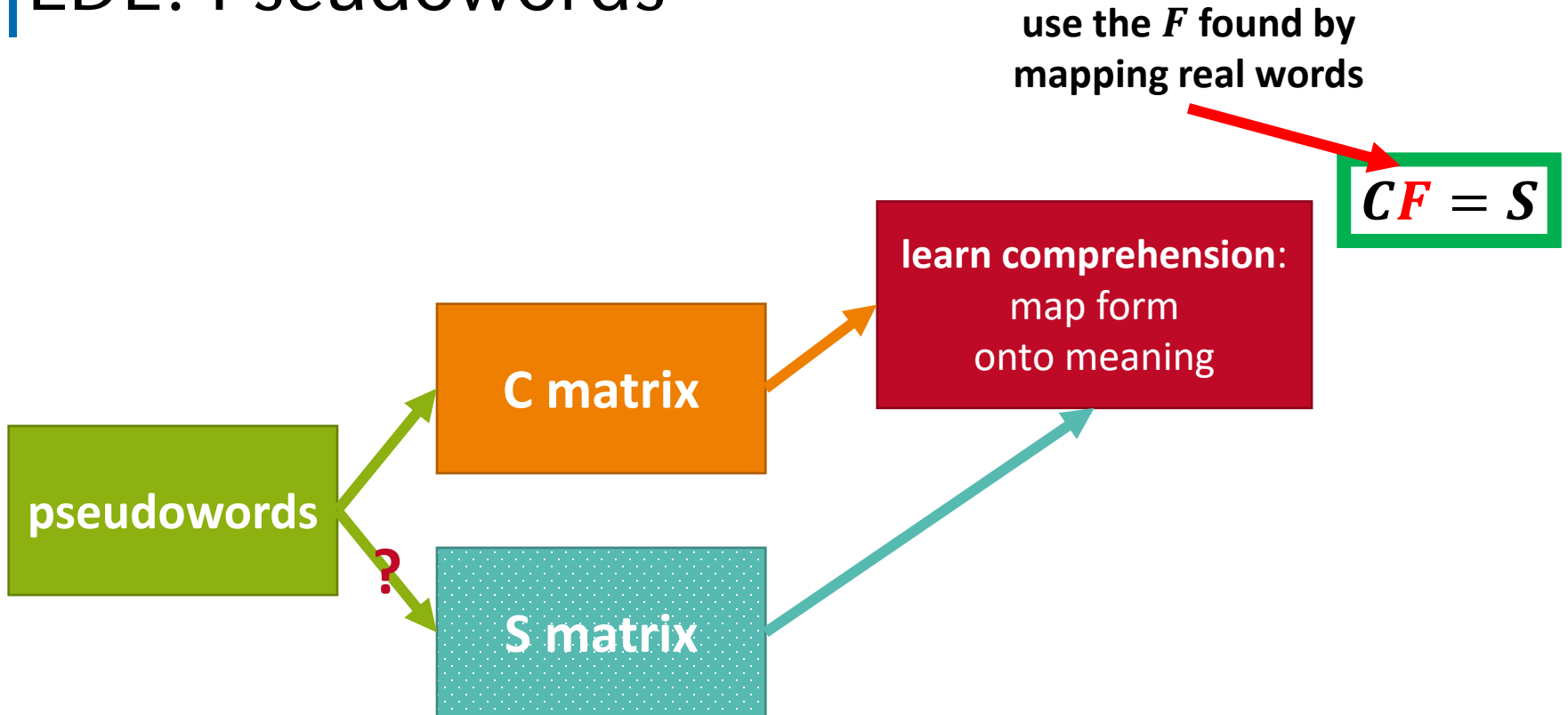
LDL: Pseudowords



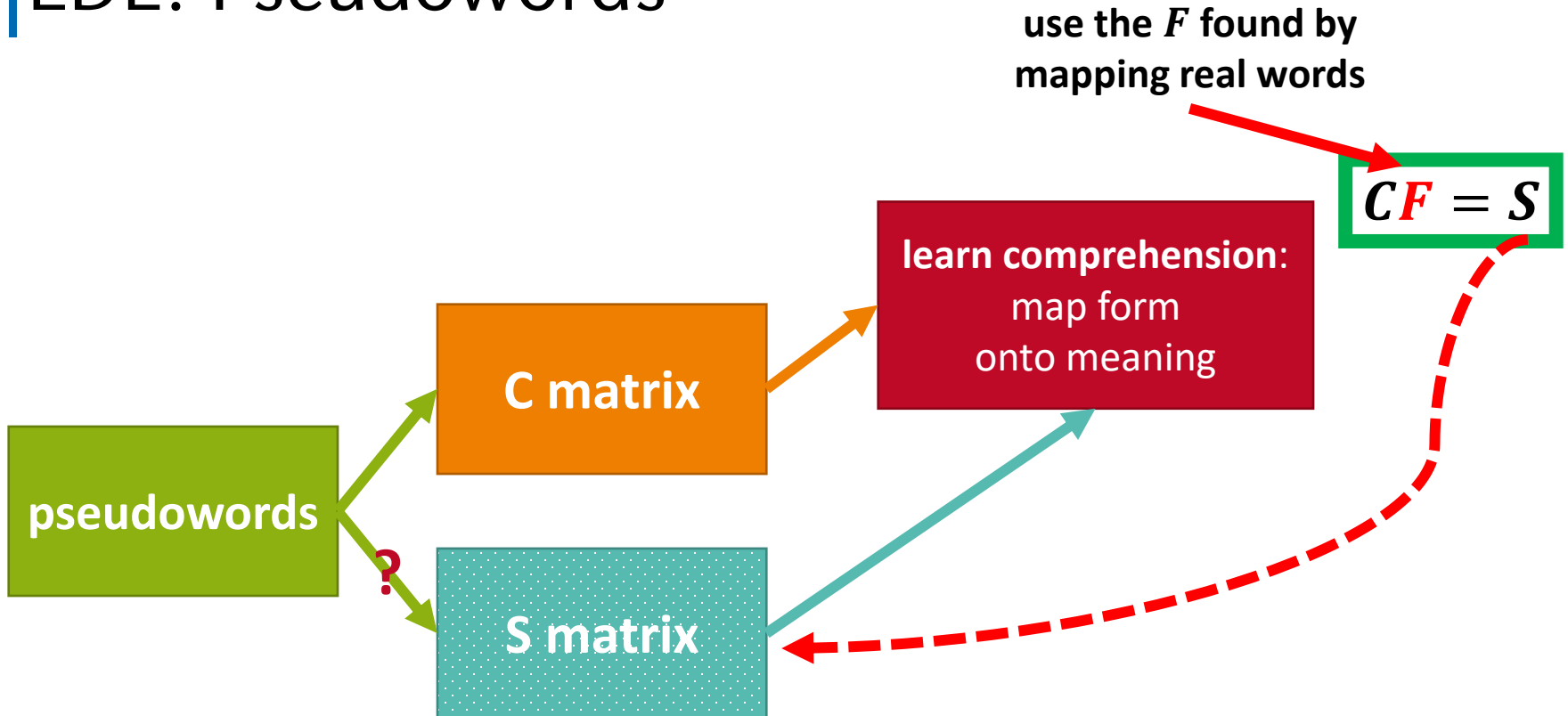
LDL: Pseudowords



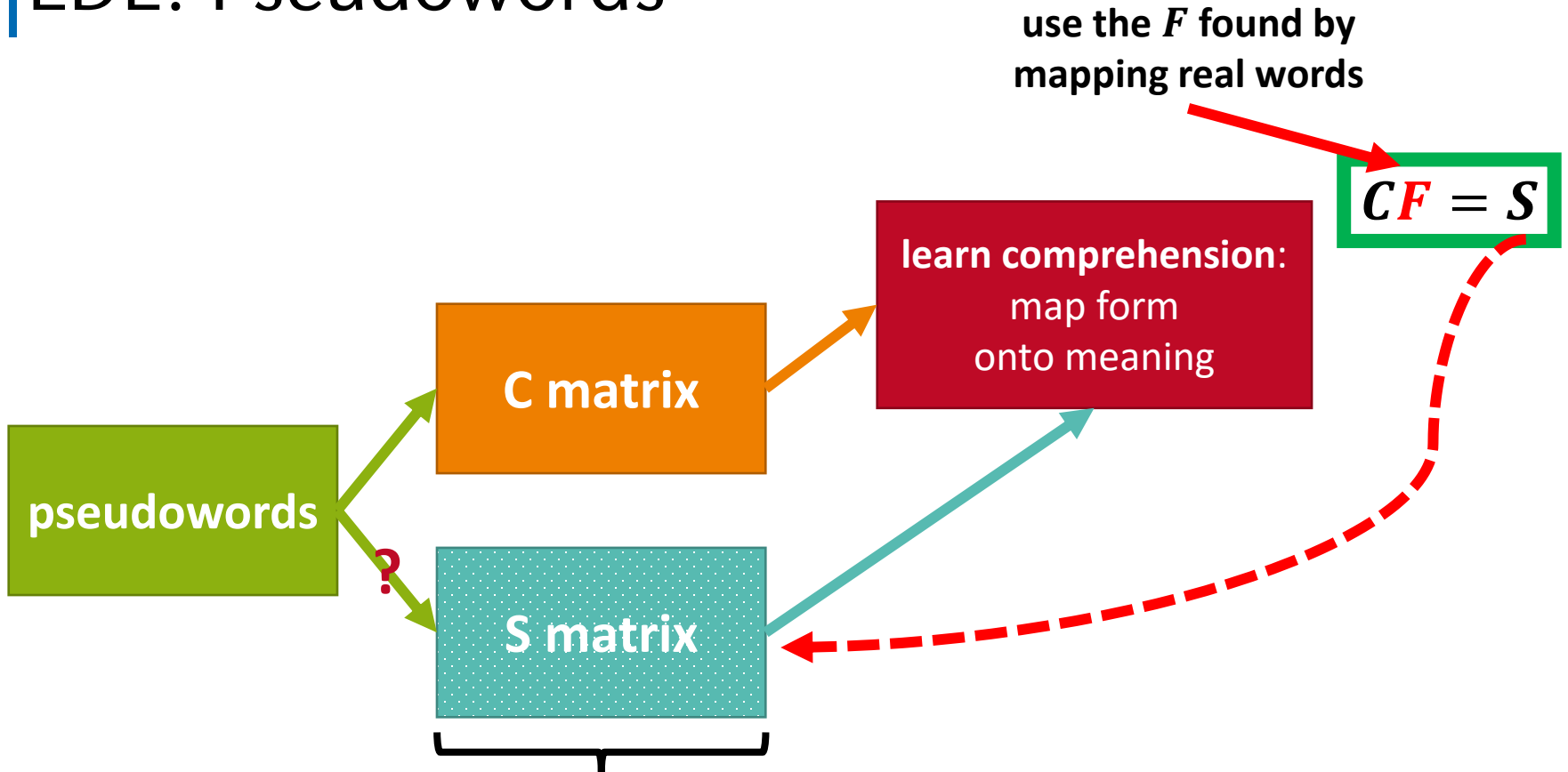
LDL: Pseudowords



LDL: Pseudowords

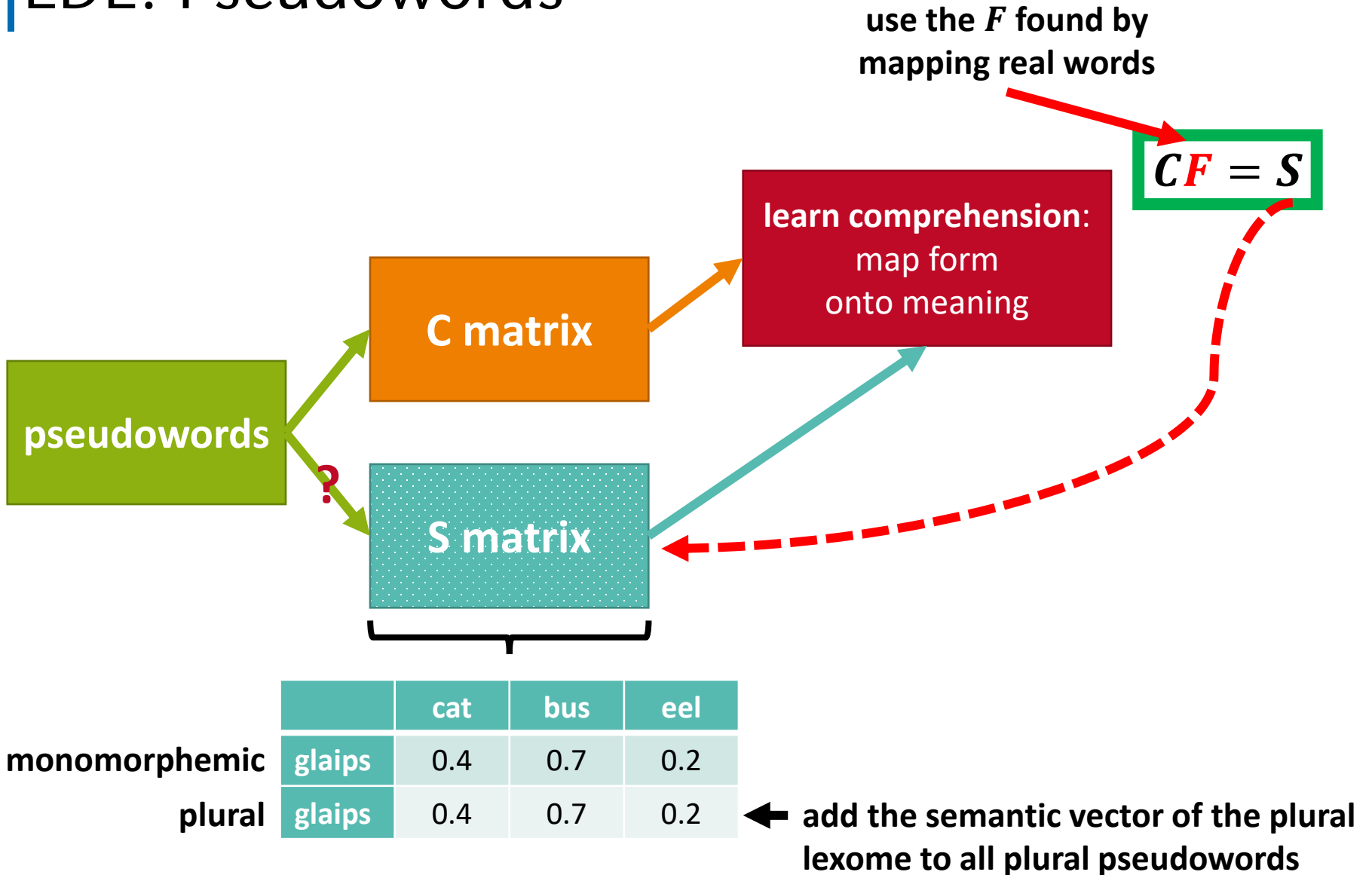


LDL: Pseudowords

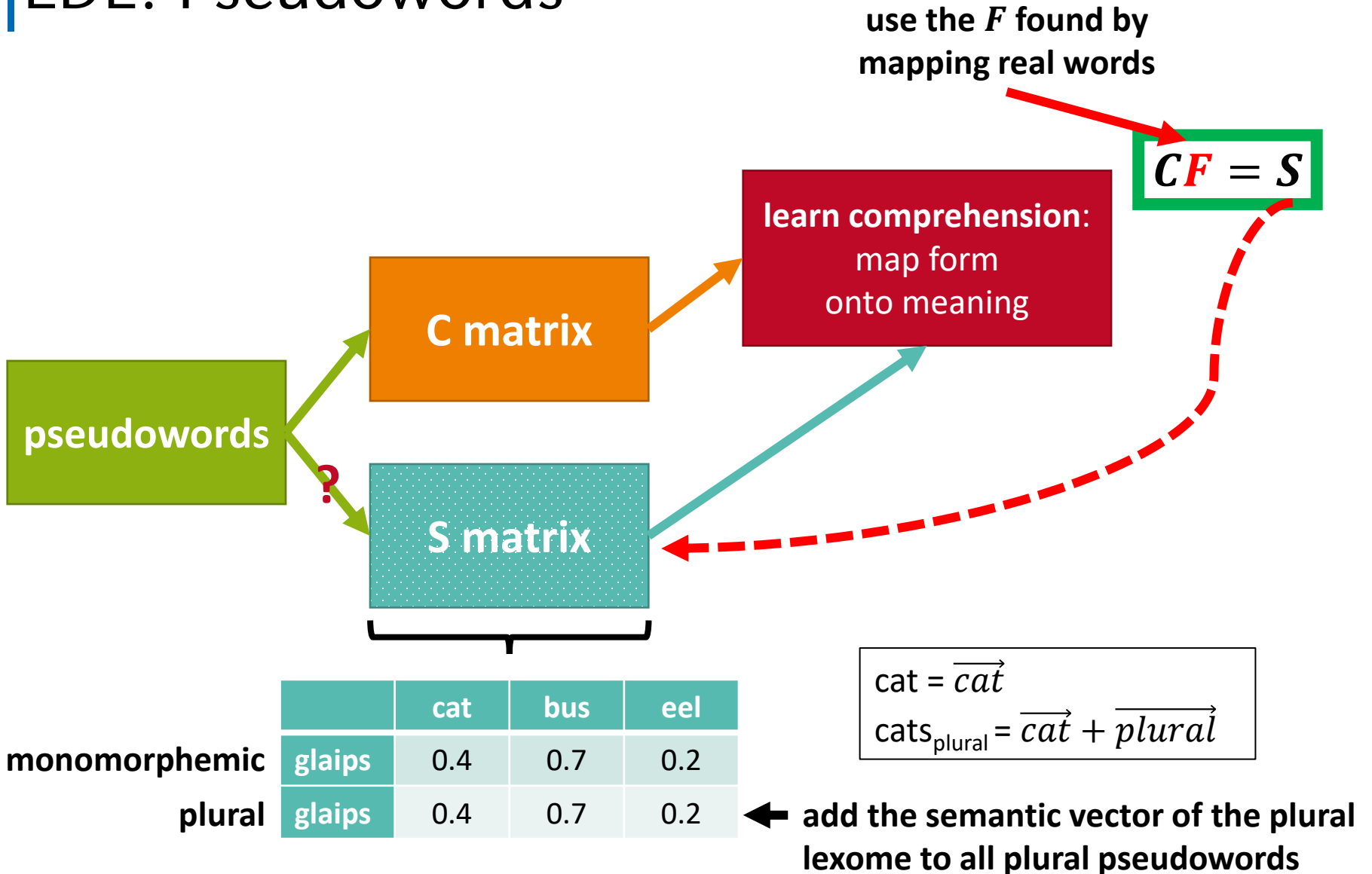


		cat	bus	eel
monomorphemic	glai <u>ps</u>	0.4	0.7	0.2
plural	glai <u>ps</u>	0.4	0.7	0.2

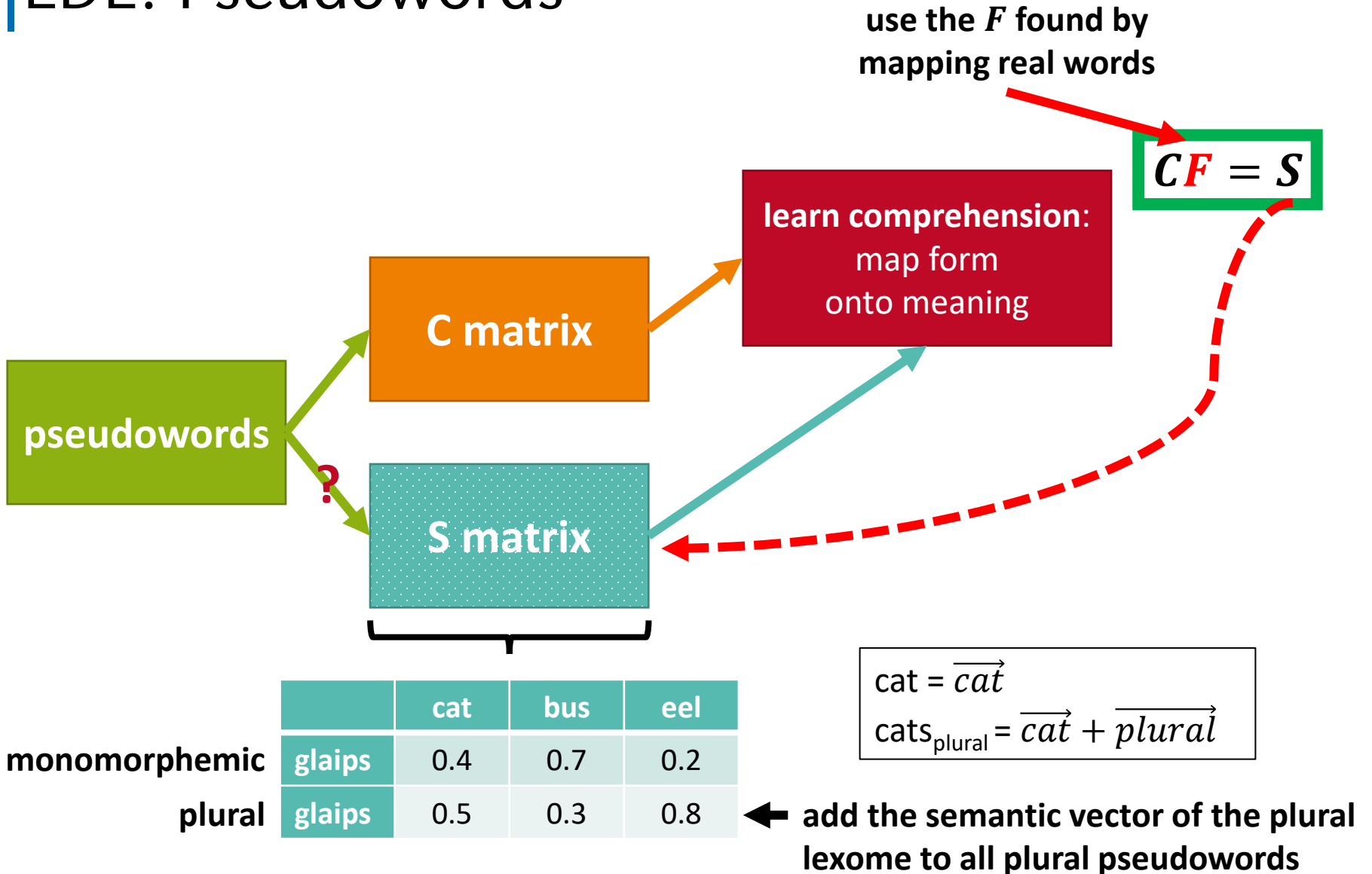
LDL: Pseudowords



LDL: Pseudowords

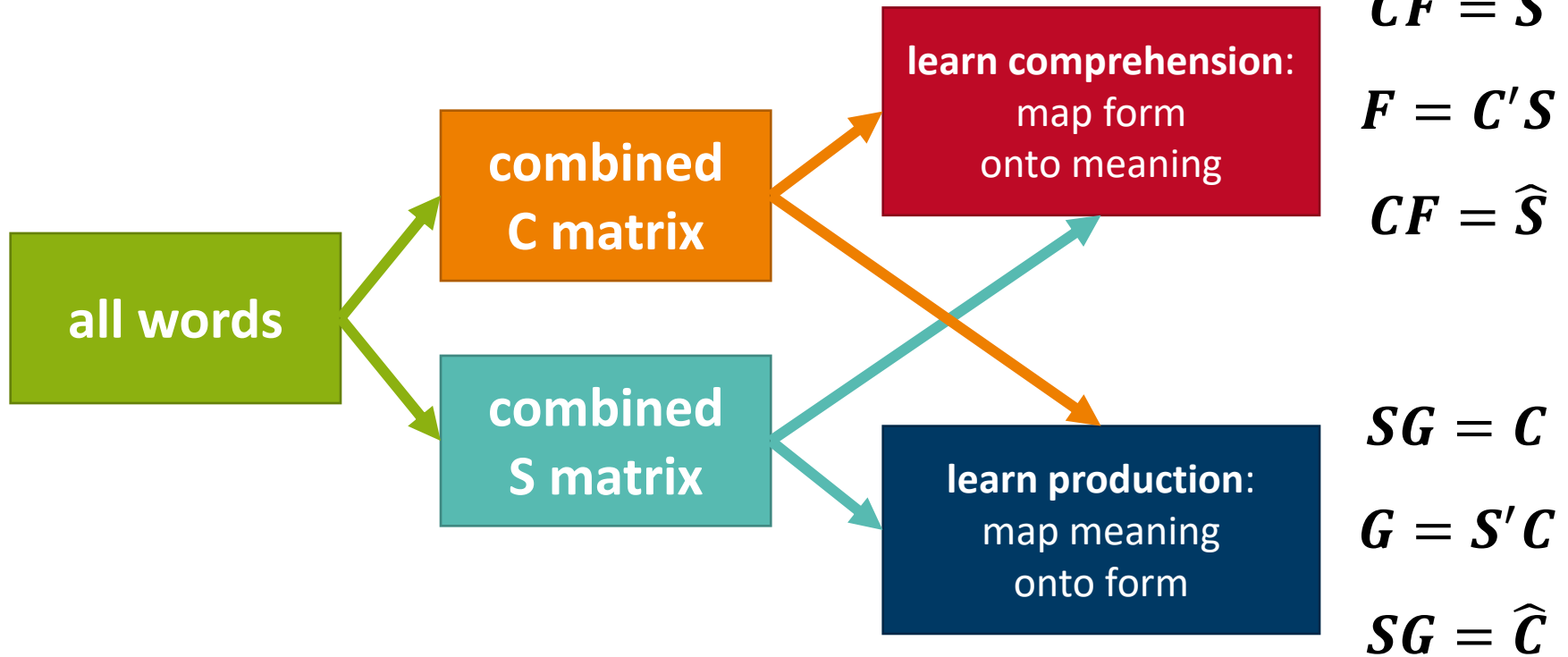


LDL: Pseudowords

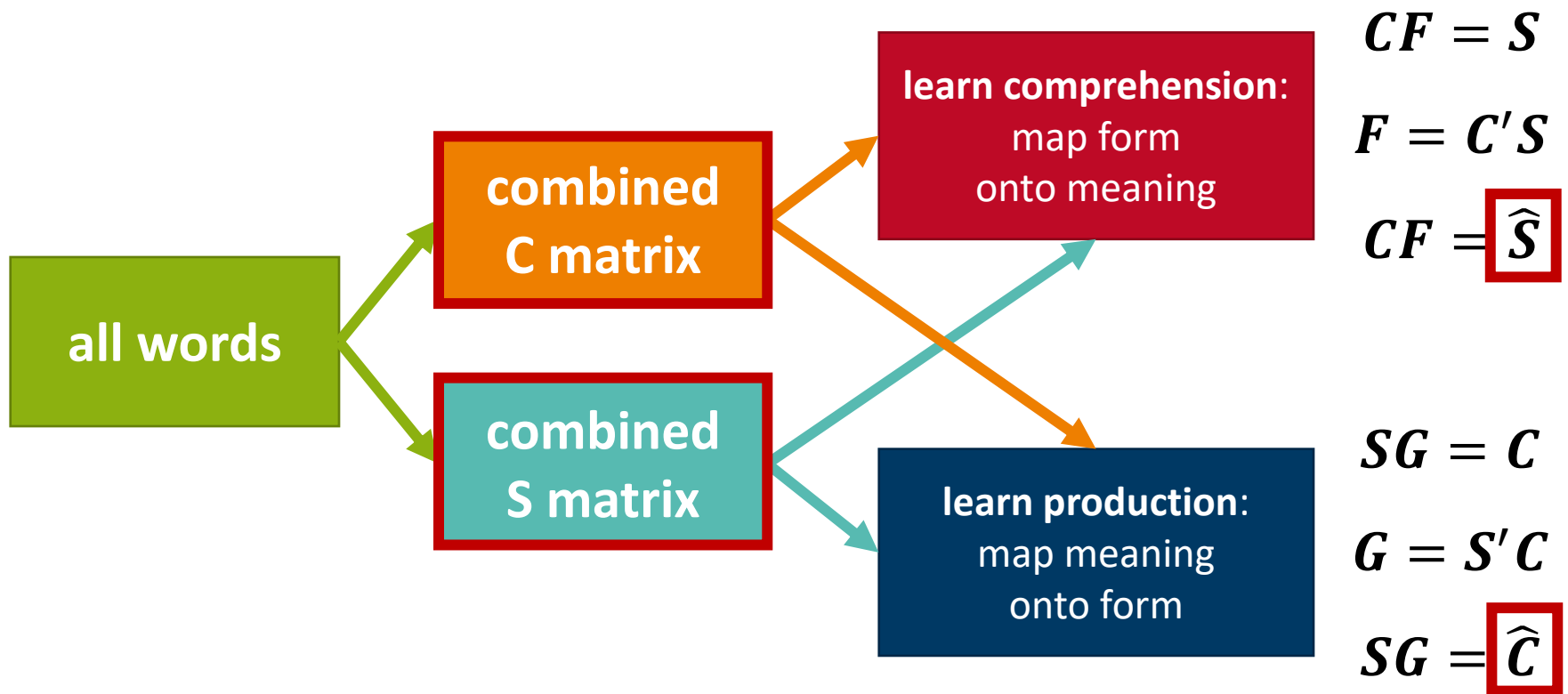


LDL: Real + Nonce Words

LDL: Real + Nonce Words



LDL: Real + Nonce Words



Can we **implement LDL with real and nonce words** and use **measures derived from such an implementation** to model /s/ durations? If so, how can we interpret these LDL measures?

LDL: Measures

- ▶ 17 measures derived from LDL implementation in total
 - ▶ 13 as part of the WpmWithLdl package (Baayen et al., 2019)
 - ▶ 4 of those introduced by Chuang et al. (2020)

- ▶ let's see whether (some of) these measures are useful when modelling /s/ durations

Can we **implement LDL with real and nonce words** and use **measures derived from such an implementation** to **model /s/ durations**?

If so, how can we interpret these LDL measures?

Two Models

- ▶ we use linear mixed-effects regression models, following standard procedures (e.g. log-transformation; stepwise backward model selection; trimming of residuals)
- ▶ all initial models share the same non-lexical covariates, e.g. speaking rate, pause, following segment type
- ▶ **Model 1:**
model containing LDL measures and the categorical variable ‘type of S’
- ▶ **Model 2:**
model containing LDL measures only

Principal Component Analyses

- ▶ the 17 LDL measures & ‘type of S’ show a total of 16 correlations with $r \geq 0.5$
- ▶ two separate PCAs are computed as ‘type of S’ is one of the highly correlated variables
- ▶ Why two PCAs?
 - ▶ remember: we want to create two models, i.e. one with
 - ▶ LDL measures with ‘type of S’
 - ▶ LDL measures without ‘type of S’

Can we **implement LDL with real and nonce words** and use **measures derived from such an implementation** to model /s/ durations?

If so, **how can we interpret these LDL measures?**

Model 1: LDL + 'type of S'

- ▶ variables showing significant effects are
 1. base duration
 2. pause
 3. Component4Bin
 4. segmental class of the following segment
 5. speaking rate
 6. Component3
 7. consonant preceding the /s/

Model 1: LDL + 'type of S'

▶ variables showing significant effects are

1. base duration

2. pause

3. Component4Bin

4. segmental class of the following segment

5. speaking rate

6. Component3

7. consonant preceding the /s/

Model 1: LDL + 'type of S'

Component4Bin

- ▶ strongly correlated with
 - ▶ type of S
 - ▶ ALC

Model 1: LDL + 'type of S'

Component4Bin

- ▶ strongly correlated with
 - ▶ type of S
 - ▶ categorical variable: non-morphemic vs. plural /s/
 - ▶ ALC

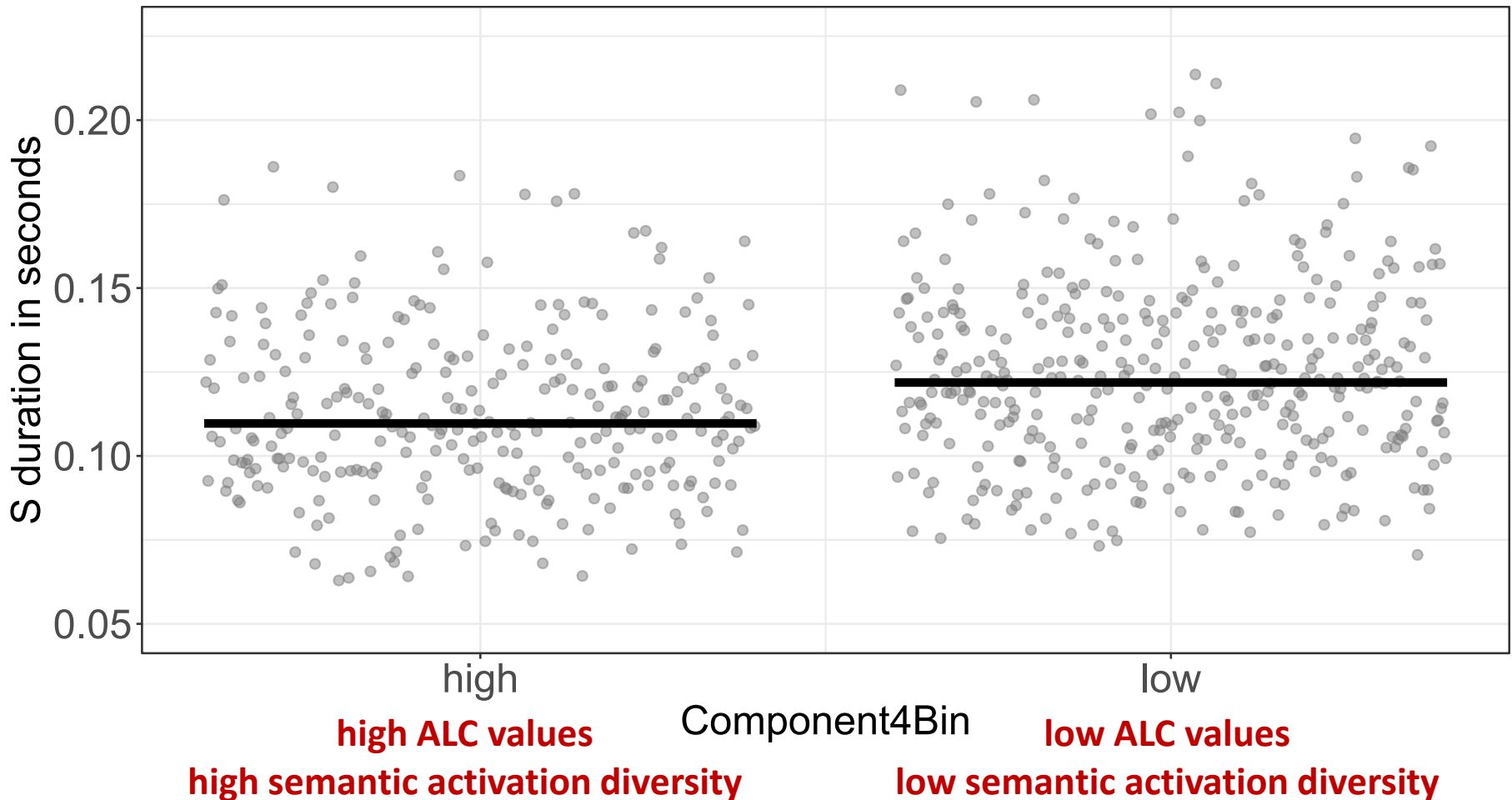
Model 1: LDL + ‘type of S’

Component4Bin

- ▶ strongly correlated with
 - ▶ type of S
 - ▶ categorical variable: non-morphemic vs. plural /s/
 - ▶ **ALC – Average Lexical Correlation**
 - ▶ mean value of all correlation values of a pseudoword’s estimated semantic vector with each of the real word semantic vectors
 - ▶ higher values indicate that a pseudoword vector has “landed” in a denser semantic neighbourhood
 - ▶ may be interpreted as a measure of semantic activation diversity for pseudowords

Model 1: LDL + 'type of S'

Component4Bin



Model 1: LDL + 'type of S'

▶ variables showing significant effects are

1. base duration

2. pause

3. Component4Bin

4. segmental class of the following segment

5. speaking rate

6. Component3

7. consonant preceding the /s/

Model 1: LDL + 'type of S'

Component3

- ▶ strongly correlated with
 - ▶ l1norm
 - ▶ l2norm

Model 1: LDL + 'type of S'

Component3

- ▶ strongly correlated with

- ▶ **l1norm**

- ▶ the sum of the absolute values of vector elements of a given word's predicted semantic vector, i.e. its city-block distance

- ▶ **l2norm**

Model 1: LDL + 'type of S'

Component3

- ▶ strongly correlated with

- ▶ **l1norm**

- ▶ the sum of the absolute values of vector elements of a given word's predicted semantic vector, i.e. its city-block distance

- ▶ **l2norm**

- ▶ the square root of the sum of the squared values of a given word's predicted vector, i.e. its Euclidian distance

Model 1: LDL + 'type of S'

Component3

- ▶ strongly correlated with

- ▶ **l1norm**

- ▶ the sum of the absolute values of vector elements of a given word's predicted semantic vector, i.e. its city-block distance

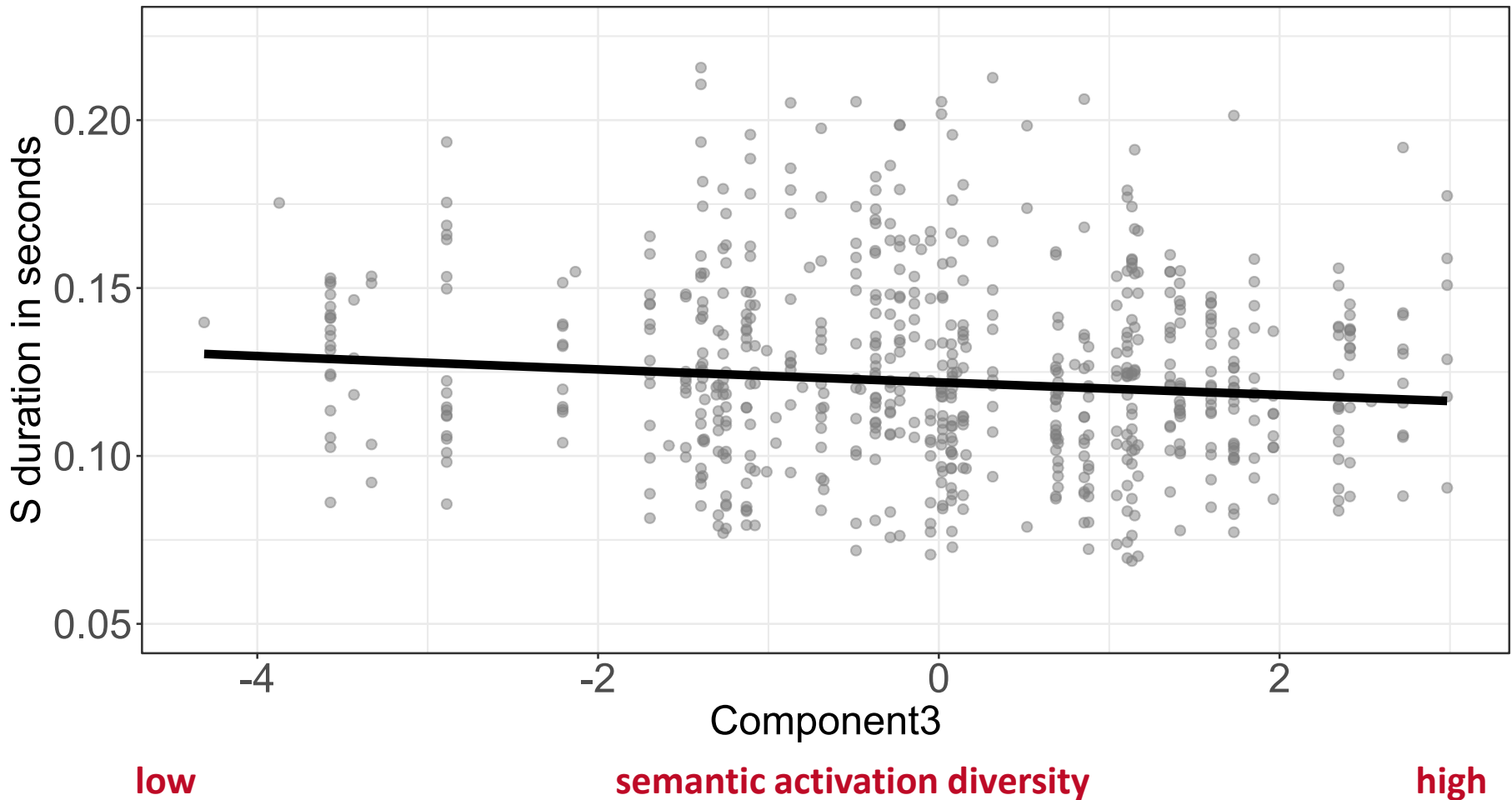
- ▶ **l2norm**

- ▶ the square root of the sum of the squared values of a given word's predicted vector, i.e. its Euclidian distance

- ▶ higher values imply more strong links to many other lexomes
 - ▶ both measures may be interpreted as semantic activation diversity

Model 1: LDL + 'type of S'

Component3



Model 1: LDL + 'type of S'

Component3

- ▶ strongly correlated with
 - ▶ l1norm
 - ▶ l2norm
 - ▶ both measures may be interpreted as semantic activation diversity,
- ▶ some sort of general semantic activation diversity effect:
 - ▶ higher activation diversity leads to shorter /s/ durations

Model 2: LDL only

- ▶ variables showing significant effects are
 1. base duration
 2. pause
 3. segmental class of the following segment
 4. speaking rate
 5. Component.woA.4
 6. consonant preceding the /s/

Model 2: LDL only

▶ variables showing significant effects are

1. base duration
2. pause
3. segmental class of the following segment
4. speaking rate
5. Component.woA.4
6. consonant preceding the /s/

Model 2: LDL only

Component.woA.4

- ▶ strongly correlated with
 - ▶ density
 - ▶ ALC
 - ▶ ALDC

Model 2: LDL only

Component.woA.4

- ▶ strongly correlated with
 - ▶ density
 - ▶ mean correlation to eight closest semantic neighbours
 - ▶ higher values indicate a denser semantic neighbourhood
 - ▶ may be interpreted as a measure of semantic activation diversity
 - ▶ ALC
 - ▶ ALDC

Model 2: LDL only

Component.woA.4

- ▶ strongly correlated with
 - ▶ density
 - ▶ may be interpreted as a measure of semantic activation diversity
 - ▶ **ALC – Average Lexical Correlation**
 - ▶ mean value of all correlation values of a pseudoword’s estimated semantic vector with each of the real word semantic vectors
 - ▶ higher values indicate that a pseudoword vector has “landed” in a denser semantic neighbourhood
 - ▶ may be interpreted as a measure of semantic activation diversity for pseudowords
 - ▶ **ALDC**

Model 2: LDL only

Component.woA.4

- ▶ strongly correlated with

- ▶ density

- ▶ may be interpreted as a measure of semantic activation diversity

- ▶ ALC

- ▶ may be interpreted as a measure of semantic activation diversity for pseudowords

- ▶ **ALDC – Average Levensthein Distance of Candidates**

- ▶ the mean of all Levenshtein distances of a word and its candidate forms

target	candidates	distance	ALDC
prVps	prVts	1	1

Model 2: LDL only

Component.woA.4

- ▶ strongly correlated with

- ▶ density

- ▶ may be interpreted as a measure of semantic activation diversity

- ▶ ALC

- ▶ may be interpreted as a measure of semantic activation diversity for pseudowords

- ▶ **ALDC – Average Levenshtein Distance of Candidates**

- ▶ the mean of all Levenshtein distances of a word and its candidate forms

target	candidates	distance	ALDC
prVps	prVts	1	1
pli:ps	pli:ts	1	1.5
	pri:ts	2	

Model 2: LDL only

Component.woA.4

- ▶ strongly correlated with

- ▶ density

- ▶ may be interpreted as a measure of semantic activation diversity

- ▶ ALC

- ▶ may be interpreted as a measure of semantic activation diversity for pseudowords

- ▶ **ALDC – Average Levenshtein Distance of Candidates**

- ▶ the mean of all Levenshtein distances of a word and its candidate forms

- ▶ conceptual similar to classical measures of phonological neighbourhood density

- ▶ may be interpreted as a measure of phonological certainty, i.e.

- higher values = less similar neighbours = higher degree of certainty

Model 2: LDL only

Component.woA.4

- ▶ strongly correlated with

- ▶ density

- ▶ may be interpreted as a measure of semantic activation diversity

- ▶ ALC

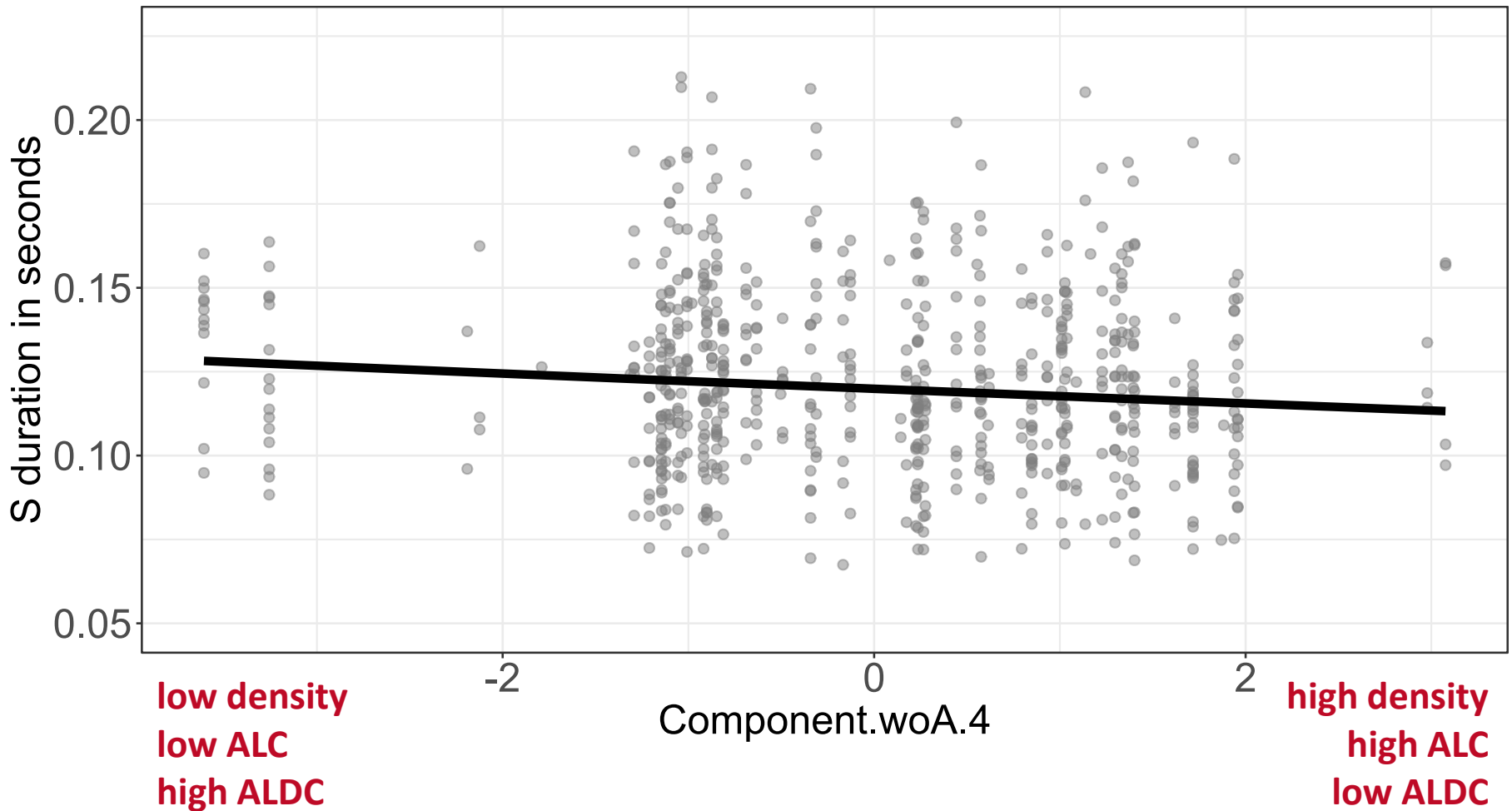
- ▶ may be interpreted as a measure of semantic activation diversity for pseudowords

- ▶ **ALDC – Average Levensthein Distance of Candidates**

- ▶ may be interpreted as a measure of phonological certainty

Model 2: LDL only

Component.woA.4



Model 2: LDL only

Component.woA.4

- ▶ strongly correlated with
 - ▶ density & ALC
 - ▶ may be interpreted as a measure of semantic activation diversity
 - ▶ ALDC
 - ▶ may be interpreted as a measure of phonological certainty
- ▶ some sort of general semantic activation diversity effect:
 - ▶ higher activation diversity leads to shorter /s/ durations
- ▶ more phonological certainty = longer /s/ durations

Can we **implement LDL with real and nonce words** and use **measures derived from such an implementation** to model /s/ durations?
 If so, **how can we interpret these LDL measures?**

Discussion

- ▶ higher activation diversity leads to shorter /s/ durations
 - ▶ a prolongation of the acoustic signal is dysfunctional if the prolongation maintains or increases the discrimination problem instead of contributing to resolving it (Tomaschek et al., 2019)
- ▶ more phonological certainty = less similar neighbours = longer /s/ durations
 - ▶ in line with results on pseudoword word durations modelled by LDL measures (Chuang et al., 2020)
 - ▶ such effects of phonological neighbourhood density on articulation were found before (e.g. Gahl et al., 2012)

Thank you!



References I

- Baayen, R. H., Chuang, Y.-Y., & Heitmeier, M. (2019). *WpmWithLdl: Implementation of Word and Paradigm Morphology with Linear Discriminative Learning* (1.3.17.1).
- Chomsky, N., & Halle, M. (1968). *The Sound Pattern of English*. Harper and Row.
- Chuang, Y.-Y., Vollmer, M. L., Shafaei-Bajestan, E., Gahl, S., Hendrix, P., & Baayen, R. H. (2020). The processing of pseudoword form and meaning in production and comprehension: A computational modeling approach using linear discriminative learning. *Behavior Research Methods*, 49. <https://doi.org/10.3758/s13428-020-01356-w>
- Gahl, S., Yao, Y., & Johnson, K. (2012). Why reduce? Phonological neighborhood density and phonetic reduction in spontaneous speech. *Journal of Memory and Language*, 66(4), 789–806. <https://doi.org/10.1016/j.jml.2011.11.006>
- Hsieh, L., Leonard, L. B., & Swanson, L. L. (1999). Some differences between English plural noun inflections and third singular verb inflections in the input: The contributions of frequency, sentence position, and duration. *Journal of Child Language*, 26(3), 531–543. <https://doi.org/10.1017/S030500099900392X>
- Ivens, S. H., & Koslin, B. L. (1991). *Demands for Reading Literacy Require New Accountability Methods*. Touchstone Applied Science Associates.
- Kiparsky, P. (1982). Lexical morphology and phonology. In I. Yang (Ed.), *Linguistics in the morning calm: Selected papers from SICOL1* (pp. 3–91). Hanshin.
- Levelt, W. J. M., Roelofs, A., & Meyer, A. S. (1999). A theory of lexical access in speech production. *Behavioral and Brain Sciences*, 22(1), 1–75. <https://doi.org/10.1017/S0140525X99001776>
- Plag, I., Homann, J., & Kunter, G. (2017). Homophony and morphology: The acoustics of word-final S in English. *Journal of Linguistics*, 53(1), 181–216. <https://doi.org/10.1017/S0022226715000183>

References II

- Plag, I., Lohmann, A., Ben Hedia, S., & Zimmermann, J. (2020). An <s> is an <s'>, or is it? Plural and genitive-plural are not homophonous. In L. Körtvélyessy & P. Štekauer (Eds.), *Complex Words*. Cambridge University Press.
- Roelofs, A., & Ferreira, V. S. (2019). The architecture of speaking. In P. Hagoort (Ed.), *Human language: From genes and brains to behavior* (pp. 35–50). MIT Press.
- Schmitz, D., Baer-Henney, D., & Plag, I. (2020). The duration of word-final /s/ differs across morphological categories in English: Evidence from pseudowords [Manuscript submitted for publication].
- Seyfarth, S., Garellek, M., Gillingham, G., Ackerman, F., & Malouf, R. (2017). Acoustic differences in morphologically-distinct homophones. *Language, Cognition and Neuroscience*, 33(1), 32–49. <https://doi.org/10.1080/23273798.2017.1359634>
- Tomaschek, F., Plag, I., Ernestus, M., & Baayen, R. H. (2019). Phonetic effects of morphology and context: Modeling the duration of word-final S in English with naïve discriminative learning. *Journal of Linguistics*, 57, 1–39. <https://doi.org/10.1017/S0022226719000203>
- Tucker, B. V., Brenner, D., Danielson, D. K., Kelley, M. C., Nenadić, F., & Sims, M. (2019). The Massive Auditory Lexical Decision (MALD) database. *Behavior Research Methods*, 51(3), 1187–1204. <https://doi.org/10.3758/s13428-018-1056-1>
- Walsh, T., & Parker, F. (1983). The duration of morphemic and non-morphemic /s/ in English. *Journal of Phonetics*, 11(2), 201–206. [https://doi.org/10.1016/s0095-4470\(19\)30816-2](https://doi.org/10.1016/s0095-4470(19)30816-2)
- Zimmermann, J. (2016). Morphological status and acoustic realization. In C. Carignan & M. D. Tyler (Eds.), *Proceedings of the Sixteenth Australasian International Conference on Speech Science and Technology (SST-2016)* (pp. 201–204). ASSTA. <https://assta.org/sst-2016-proceedings/>