Linguistic stability increases with population size, but only in stable learning environments

Does demographic structure affect linguistic evolution? An SDE approach.

Andreas Baumann | University of Vienna | Evolang XII, Toruń

Population size and linguistic evolution

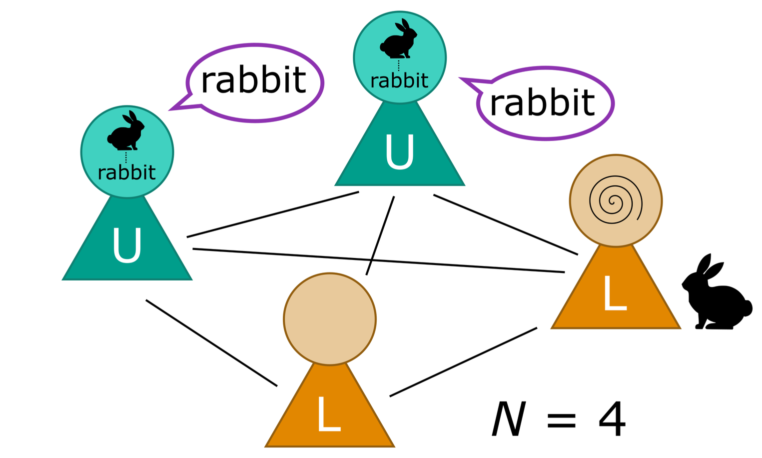
- **Population size** has been proposed to affect linguistic **structure** (e.g. review by Nettle 2012)
- Large populations accommodate large **phoneme** inventories
- Small populations show more complex **morphology**
- **Rates of lexical loss** are higher in small populations
- Similar effects are well known in **biological evolution** (drift, population bottlenecks, founder effects,...)
- Can we study the relationship among population size an language by using **basic models of linguistic spread**?

R_0 as a measure of linguistic stability: deterministic finite population model

- Population composed of **learners L** and **users U** with $L + U = N$
- Spread of linguistic items modeled by a simple **dynamical system** (Nowak 2000, Cavalli-Sforza & Feldman 1981)
- **Basic reproductive ratio R_0** defined as the expected number of learners that learn a linguistic innovation from a single user
- R_0 is a **standardized measure** of reproductive success and stability in linguistics (Baumann & Ritt 2018)

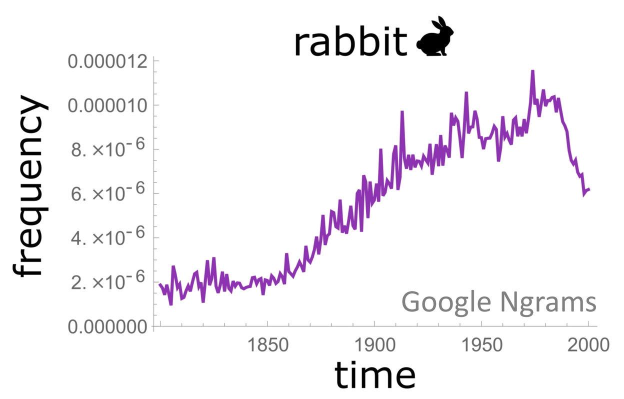
$$R_0 = \frac{\lambda N}{1+\gamma}$$

$$\begin{aligned} dL/dt &= \overbrace{-\lambda LU}^{\text{learning}} + \overbrace{\gamma U}^{\text{unlearning}} - \overbrace{L}^{\text{death}} + \overbrace{N}^{\text{birth}} \\ dU/dt &= \underbrace{\lambda LU}_{\text{learning}} - \underbrace{(1+\gamma)U}_{\text{death and unlearning}} \end{aligned}$$



What if transmission during learning is not constant? The stochastic model:

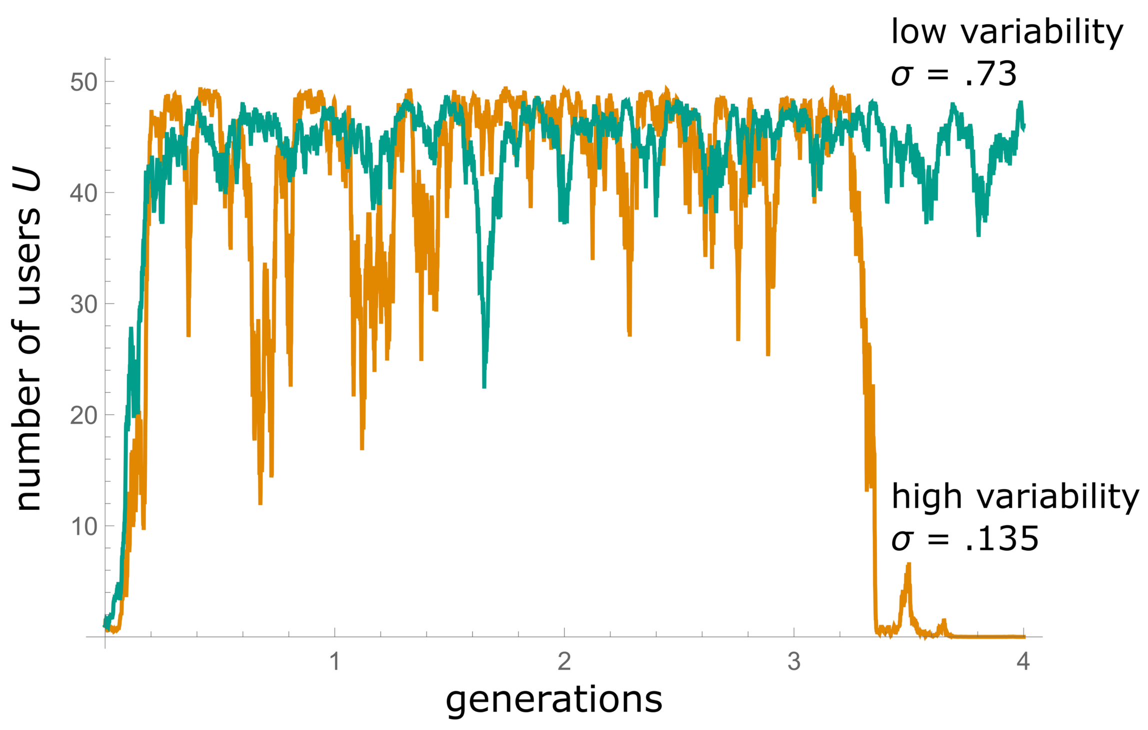
- Transmission during **learning** is **not** always **constant**:
- E.g. changing network density, fluctuation in use (→ left) ...
- Extension of the model: allowing for **variable learning rate**
- This yields a **stochastic differential equation** with parametric noise (SDE; → top right). *NB*: this is not demographic noise!
- R_0 is **diminished by variability** (→ middle)
- If variability is too high, items can go extinct (→ bottom right)



$$R_0 = \frac{\lambda N}{1+\gamma} - \frac{\frac{1}{2}\sigma^2 N^2}{1+\gamma}$$

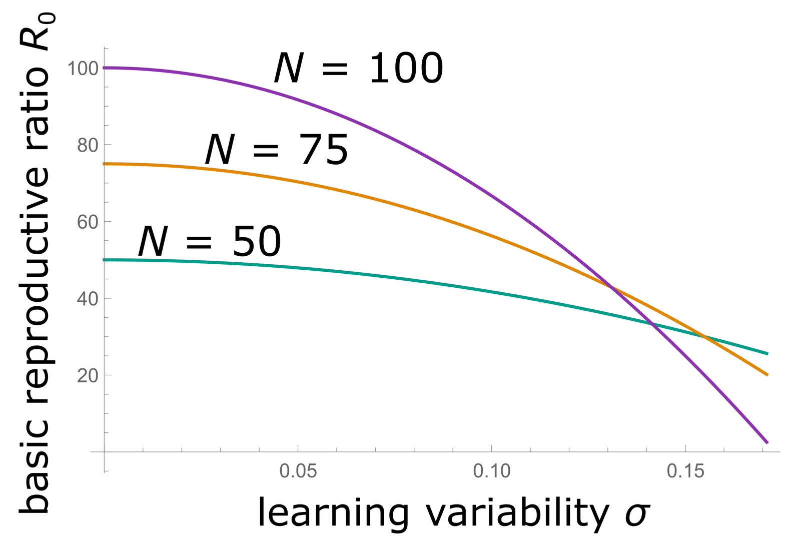
(Gray et al. 2011)

$$\begin{aligned} dL &= (-\lambda LU + \gamma U - L + N)dt - \sigma LU dW(t) \\ dU &= (\lambda LU - (1+\gamma)U)dt + \sigma LU dW(t) \end{aligned}$$



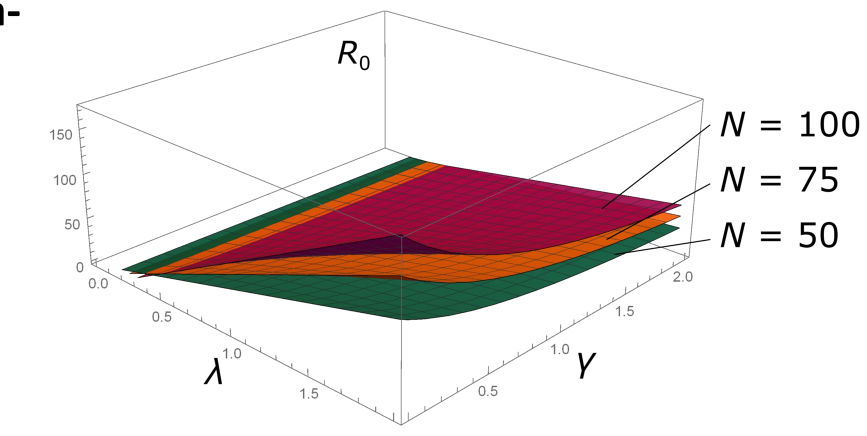
Effects of learning variability on R_0

- Basic reproductive ratio **R_0** is **affected negatively by** learning **variability**
- This applies even if populations are large
- Linguistic stability increases with population size, but only if learning **variability** is **not too high**



Effects of learnability and usability

- Items benefit from **increasing learnability** and **usability**
- **Adaptive effects are stronger** the larger the population
- However, increasing learnability λ always pays off; effects of **increased usability** (lower γ) may be **small** in the presence of noise



Variability as a factor in language evolution: answers and (more) questions

! **Linguistic stability** increases with population size, but only if variability during learning is low

! **Adaptive effects** are stronger in large populations

! **High variability** causes loss and mitigates gains in usability, also for large N

? Are linguistic items showing high fluctuation difficult to acquire? (cf. Newberry et al. 2017, Baumann & Ritt 2018)

? Are linguistic items more optimized in large populations? (cf. Fay & Ellison 2013)

? Are linguistic items rather optimized for learnability than for usability? (cf. Fay & Ellison 2013; Bybee 2010)

Variability during learning decreases stability of linguistic items.

andreas.baumann@univie.ac.at

https://anglistik.univie.ac.at/staff/staff/baumann/

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R_0.... expected number of learners learning an item from a user ('R nought')

α ....rate of switching from L to U (learning rate)

γ .....rate of switching from U to L via unlearning in addition to death

W ...Wiener process (random noise)

σ ....strength of variability during learning (variance of Wiener process)

Atkinson, Q. D. (2011). Phonemic diversity supports a serial founder effect model of language expansion from Africa. Science, 322(6027), 346–349.

Baumann, A.., & Ritt, N. (2018) The basic reproductive ratio as a link between acquisition and change in phonotactics. Cognition 176: 174-183.

Bromham, L., Hua, X., Fitzpatrick, T., & Greenhill, S. J. (2015). Rate of language evolution is affected by population size. Proceedings of the National Academy of Sciences, 112(7), 2097–2102.

Bybee, J. (2010). Language, Usage and Cognition. Cambridge: Cambridge University Press.

Cavalli-Sforza, L. L., & Feldman, M. W. (1981). Cultural transmission and evolution: aquantitative approach. Princeton: Princeton University Press.

Fay, N., & Ellison, T. M. (2013). The cultural evolution of human communication systems in different sized populations: usability trumps learnability. PloS one, 8.

Gray, A., Greenhalgh, D., Hu, L., Mao, X., & Pan, J. (2011). A stochastic differential equation SIS epidemic model. SIAM Journal on Applied Mathematics, 71(3), 876–902.

Lupyan, G., & Dale, R. (2010). Language structure is partly determined by social structure. PloS one, 5.

Nettle, D. (2012). Social scale and structural complexity in human languages. Phil. Trans. R. Soc. B, 367, 1829–1836.

Newberry, M., Ahern, C., Clark, R. , & Plotkin, J. (2017) Detecting evolutionary forces in language change . Nature 551: 223-226.

Nowak, M. A. (2000). The basic reproductive ratio of a word, the maximum size of a lexicon. Journal of theoretical biology, 204(2), 179–189.

Nowak, M. A., Plotkin, J., & Jansen, V. (2000). The evolution of syntactic communication. Nature, 404(6777), 495–498.