Language Evolution and Diachrony Generation

Research Project Report

Matthieu Boyer

Laboratoire Lattice

CNRS — ENS-PSL — Université Sorbonne Nouvelle

Under supervision of Mathieu Dehouck

Introduction

Few database available in diachrony :

- The Index Diachronica [ind]
- The $\mathcal{E}$vosem [FKD$^+$25]

There is a need for less localized data.

Plan

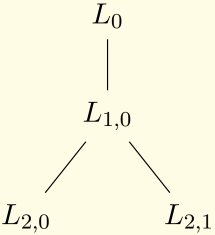
Idea

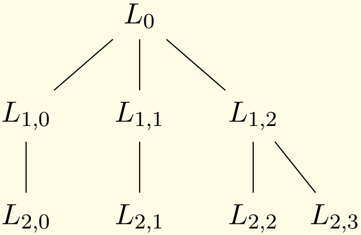
- One Language Evolution
- Two Language Evolution

Results

Evolution as Random Trees I

Consider a language L_0, which we will call our *base language*.





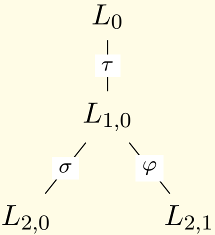
Evolution as Random Trees II

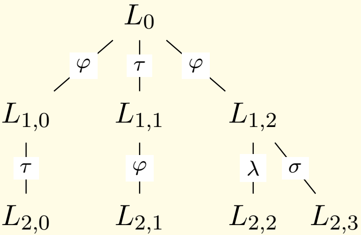
Algorithm One Language Evolution

```
$leaves \leftarrow \{L_0\}$
$\mathcal{T} \leftarrow \mathrm{Tree}\,(L_0, \varnothing)$
for $n \leq$ Epochs do
    for $l \in \mathrm{Leaves}\,\mathcal{T}$ do
        $S \leftarrow \mathrm{Evolve}\,l$
        $l \leftarrow \mathrm{Tree}\,(l, S)$                ▷ Here $\mathcal{T}$ is modified in place.
return $\mathcal{T}$
```

Specification of Evolve I

We want to choose between *evolution types* $(\varphi, \sigma, \tau, \lambda)$ at computation :





Specification of Evolve II

We want Evolve to be *easily revertible* :

$$\mathbb{P}\left(\mathrm{Evolve}\left(l_1\right) = l_2\right) \neq 0 \Leftrightarrow \mathbb{P}\left(\mathrm{Evolve}\left(l_2\right) = l_1\right) \neq 0$$

Plan

Idea

One Language Evolution

Two Language Evolution

Results

Collision Hypothesis I

We assume language interacting create evolutions :

$$\begin{tikzcd}[arrows=dash]
L_{0,1} \arrow[d, "\tau"] \arrow[dr, "\varphi"] & & L_{0,2} \arrow[dl, "\sigma"'] \arrow[d, "\lambda"] \\
L_{1,1} & L_{1,2} & L_{1,3}
\end{tikzcd}$$

Collision Hypothesis II

Algorithm Two Language Evolution

```
$\mathcal{T} \leftarrow \mathrm{Tree}\,(L_0, \varnothing)$
for $n \leq \texttt{Epochs}$ do
    for $l \in \mathrm{Leaves}\,\mathcal{T}$ do
        $S \leftarrow \mathrm{Evolve}\,l$
        $\mathrm{Push}\,(\mathrm{Stack}, l \leftarrow l \cup \mathrm{Tree}\,(l, S))$
    for $l \in \mathrm{Leaves}\,\mathcal{T}$ do
        $l^\dagger \leftarrow \mathcal{P}_l\,(\mathrm{Leaves}\,\mathcal{T})$
        $S \leftarrow \mathrm{Collision}\,(l, l^\dagger)$
        $\mathrm{Push}\,(\mathrm{Stack}, l \leftarrow l \cup \mathrm{Tree}\,(l, S))$
    $\mathrm{Apply}(\mathrm{Stack})$
return $\mathcal{T}$
```

Specification of Collision

Collision should :

- be *easily revertible*.

Specification of Collision

Collision should :

- be *easily revertible*.
- provide a way to choose collision type, for each parent.

Specification of Collision

Collision should :

- be *easily revertible*.
- provide a way to choose collision type, for each parent.
- take *linguistic* proximity of the parents into account.

Specification of Collision

Collision should :

- be *easily revertible*.
- provide a way to choose collision type, for each parent.
- take *linguistic* proximity of the parents into account.
- take the probability distribution $\mathcal{P}$ as the strength of the collisions.

A Manifold of Languages I

$\mathcal{P}_l$ models the probability of interaction with l. Defining a *geographical* embedding gives :

$$\mathcal{P}_l \propto \frac{1}{d_l\left(x\right)}$$

A Manifold of Languages II

- The simplex, that is, $d_l(x) = 1$ for all l, x.
- $\mathbb{R}^3$, with the ℓ^2 distance.
- The 2-sphere $\S^1$ where each language is a pairλ, φ :

$$d_{(\theta_1,\lambda_1)}\left(\theta_2, \lambda_2\right) = \arccos\left(\sin\left(\varphi_1\right)\sin\left(\varphi_2\right) + \cos\left(\varphi_1\right)\cos\left(\varphi_2\right)\cos\left(\lambda_2\right.\right.$$

A Manifold of Languages III

We suppose a language only interacts with languages from the same epoch, for now. We could add a new dimension to the manifold to modelize time.

Moreover, we are not required to use a metric but simply a positive separated function.

Implemented I

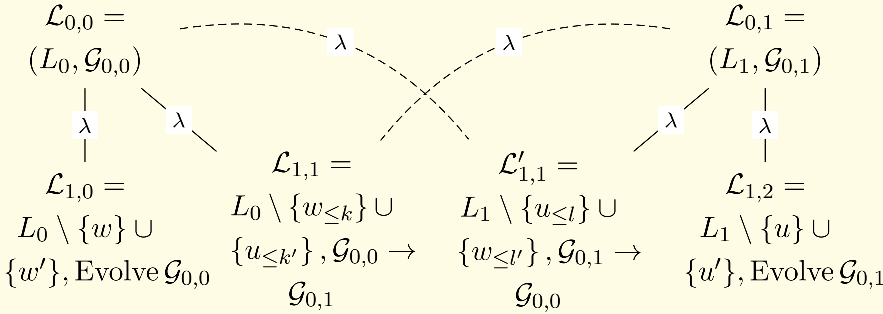
We worked using a modular structure :

- A tree generation module
- A *linguistical* observable
- A *geographical* observable

We have implemented all 3 previously defined *geographical* observable.

Implemented II

We only have a lexicon observable :



$\mathcal{L}_{0,0} = (L_0, \mathcal{G}_{0,0})$

$\mathcal{L}_{0,1} = (L_1, \mathcal{G}_{0,1})$

$\mathcal{L}_{1,0} = L_0 \setminus \{w\} \cup \{w'\}, \text{Evolve}\,\mathcal{G}_{0,0}$

$\mathcal{L}_{1,1} = L_0 \setminus \{w_{\leq k}\} \cup \{u_{\leq k'}\}, \mathcal{G}_{0,0} \to \mathcal{G}_{0,1}$

$\mathcal{L}'_{1,1} = L_1 \setminus \{u_{\leq l}\} \cup \{w_{\leq l'}\}, \mathcal{G}_{0,1} \to \mathcal{G}_{0,0}$

$\mathcal{L}_{1,2} = L_1 \setminus \{u\} \cup \{u'\}, \text{Evolve}\,\mathcal{G}_{0,1}$

Implemented III

For our probabilities, we set thresholds :

- $1 - \alpha$ representing our random evolution probability ;
- $1 - \beta$ representing our collision generation probability.

Our problem is then to find *optimal* parameters
$\alpha, \beta, \mathrm{Evolve}, \mathrm{Collision}$ and distribution $\mathcal{P}$.

Performance Checking I

We use the $\mathcal{E}$vosem project [FKD$^+$25] as a lexical bank :

- Our base languages are two proto-families, Germanic and Indo-European which derived in modern French, German, English, Dutch, Spanish, Italian and Danish.
- Accuracy is computed by the ℓ^2 distance between subsets of the dialexification matrices.
- Limitation of randomness is done by repetition of the experiments, though there are $\mathcal{O}\left(3^{7d}\right)$ submatrices.

Performance Checking II

However, our algorithm is quite slow. Assuming :

- Evolve is done in constant time (false for phonetics, for example).
- $\mathrm{Collision}$ is done in constant time.
- Computing $d\left(x, y\right)$ is done in constant time.
- Loss computation is in constant time.

we get a complexity in $\mathcal{O}\left(3^{2d}k\right)$ for d epochs and k base languages, to multiply by the number of repetitions and parameters.

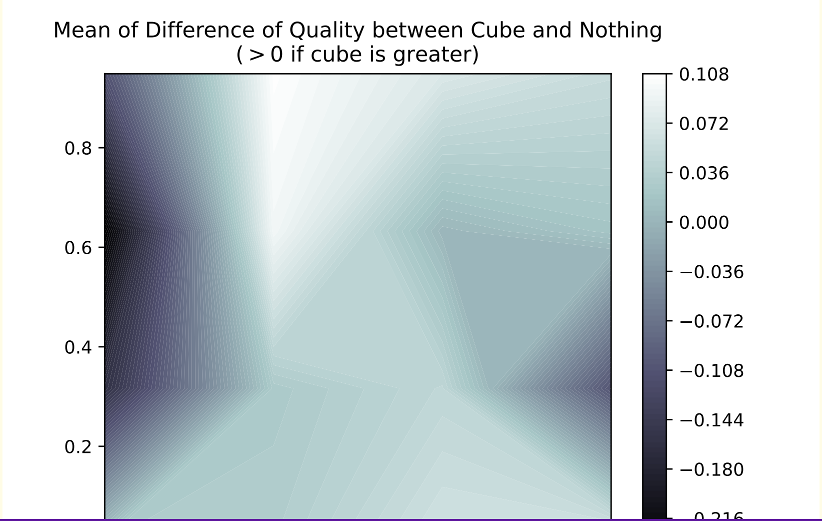
Results I

We take for base languages for the euclidean space :

$$\left(\begin{pmatrix}1\\0\\0\end{pmatrix},\begin{pmatrix}0\\1\\0\end{pmatrix}\right)$$

and for the sphere $\S^1$ we take the GPS coordinates of Paris and Berlin.

Results II


Mean of Difference of Quality between Cube and Nothing
(> 0 if cube is greater)
0.8
0.6
0.4
0.2
0.108
0.072
0.036
0.000
−0.036
−0.072
−0.108
−0.144
−0.180
−0.216

References

- Alexandre François, Siva Kalyan, Mathieu Dehouck, Martial Pastor, and David Kletz.
  Evosem : A database of dialexification across language families.

  Online database., 2025.
- Index diachronica.
  `https://chridd.nfshost.com/diachronica/`.