An Asynchronous Cellular Automaton Model For Language Shift

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Abstract

The phenomenon of language extinction is a major social problem affecting millions of people worldwide. This is primarily due to language shifts, which occur when a community of speakers ceases to utilise their traditional language and instead employs a new language in all communication settings. Understanding language shifts, especially as a way of predicting the extinction or survival of subordinate languages, should therefore be an essential challenge for social science research. In this paper we present a model of language shift using a two dimensional asynchronous cellular automaton. This model simulate linguistic change in a multilingual context. The model uses an initial matrix reflecting the linguistic diversity of a region. Each element or cell of the matrix is representing an individual speaking at least two languages. A local rule is then applied to each cell with an adjustable update probability and the desired values of the maintenance parameters which represent a threshold that determines the resistance of an individual speaking a subordinate language to the influences of the neighbourhood speaking the dominant language. The survival or extinction of subordinate languages is dependent upon the level of engagement exhibited by individuals with their respective languages. The model provides a simulation tool that we hope will prove useful to study this sociological aspect. During simulation we applied our model to the case of Algeria. The simulation results show that the survival of subordinate languages in our model is very sensitive to the initial conditions and the values of the maintenance parameters. This sensitivity shows how small changes can have a big impact on language evolution. It helps us understand how languages change over time.

keywords : Asynchronous Cellular Automata, Computational Simulations, Sociodynamics

1 Introduction

Languages, like living organisms, undergo a dynamic evolution over time, experiencing subtle yet continuous changes in vocabulary and expression. This linguistic evolution reaches a crucial crossroads, one of the most profound being the transition from everyday use to the brink of extinction.

The phenomenon marking a significant change in linguistic usage patterns within a community is described as "language shift". This phenomenon is distinctive to multilingual societies.

The phenomenon begins as a community gradually adopts a new language, often enticed by perceived economic, political, or social benefits. This shift, influenced by factors such as globalization, urbanization, or government language policies.

Within communities boasting two or more languages, a discernible hierarchical structure invariably takes shape, designating one language as dominant and relegating others to subordinate roles. This linguistic hierarchy, while capable of prolonged coexistence, remains vulnerable to disruptions.

In scenarios where this equilibrium is disrupted, speakers of the subordinate language find themselves under heightened pressure, inducing shifts in their speech behavior. This transformative change materializes as speakers of the subordinate language recognize a perceived devaluation of their linguistic expression vis-à-vis the dominant language. In response to this shift in dynamics, individuals may come to the realization that their language has lost practicality and, as a consequence, make a conscious decision to cease its usage across all communicative domains.

While language shift signals a significant change in usage patterns within a community, language maintenance represents a resilient counterforce. It is a phenomenon wherein speakers, groups, or speech communities steadfastly continue to use their language across various spheres of life, resisting the encroachment of dominant or majority languages vying for prominence.

In the context of simulating language shift, asynchronous cellular automata provide a versatile computational framework to capture the dynamic evolution described in the previous paragraphs. Asynchronous cellular automata model individual cells, representing speakers or communities, with states corresponding to their language use. Unlike synchronous models, where all cells update simultaneously, asynchronous CA allows for independent updates, reflecting the nuanced and individualized nature of language adaptation. This approach is particularly relevant for simulating language shift, a process intricately linked to individual and localized responses to external influences. By incorporating the principles of language hierarchy and the pressures leading to shifts in speech behavior, an asynchronous cellular automata model can simulate the intricate interplay of linguistic dynamics and external influences, offering insights into the fluid nature of language evolution

within diverse, multilingual communities.

2 Research aim

In this article we aims to present an approach using Asynchronous Cellular Automata to simulate linguistic change in multilingual communities, with a particular focus on the Algerian context, taking into account social pressure, in particular that exerted by the neighbourhood, as well as the parameter of language maintenance. A theoretical framework will be developed that includes various social, cultural and economic factors that influence this change. Simulations will be carried out to assess the impact of the dynamics of the neighbourhood and the degree of attachment of the individuals to the subordinate languages on the linguistic behaviour. By executing these simulations, we aim to observe how different scenarios, such as migration and language policies, affect the linguistic dynamics within the country.This study aims to address key questions such as how to model language interactions and the significant impact of socio-economic factors, including pressure from one's environment, on these dynamics. We suggest that these factors can be effectively represented by our model, and thus it offers a new perspective on the understanding of sociolinguistic issues in Algeria.. The results of this research have the potential to inform policymakers on language and educational policies, thus enriching the debate on linguistic practices in the country.

3 litterature review

Multilingualism generally refers to the use of at least two languages by an individual, the term has several meanings depending on the area of specialisation.
The questions that often asked about multiilinguals are:

- what happens when they stop using one of their languages due to a change in their linguistic needs, due to immigration, for example?
- What are the indicators of language shift, and what causes it?

The process of language shift is complex and not fully understood. For this reason, researchers have developed theoretical models. These models provide a structured framework for analysing the various factors that contribute to language shift.

3.1 Language Contact

Language contact is the use of more than one language in the same place at the same time. It does not mean multilingualism, but some communication between

speakers of different languages. According to Apple and Mysken (1987), language contact automatically leads to bilingualism. One of the ways in which language contact can happen is through migration.
Migration which means the movement of people from one region to another has a major impact on the language people speak, because it puts two languages into contact. This can lead to a number of linguistic implications such as language shifting and language death.

3.2 Language Dynamics: Shift and Maintenance

"Language Shift" is a phenomenon that describes the transition of a community from using their native language to adopting a new one across all communication domains. Factors such as globalisation, urbanisation or government language policies often influence this shift.

While language shift signals a significant change in how communities communicate, "language maintenance" stands as a powerful counterforce. It's a phenomenon where people, groups, or entire communities actively choose to keep using their native language in all aspects of their lives, even when faced with the pressure of a dominant language. It's a way of preserving their cultural identity and heritage.
Think of it this way: globalization, urbanization, and even government policies often favor certain languages, pushing others to the sidelines. But language maintenance shows that a language's vitality can endure, even in the face of these pressures. This resilience adds another layer of complexity to the dynamic interplay of languages within diverse communities.

In a multilingual society, the interplay between the mother tongue and a foreign language is of particular importance. The mother tongue, which is the first language acquired by children, is like the foundation of their identity and culture. It connects them deeply to their roots and provides a comfortable space for sharing and understanding, often within the family and community.

Simultaneously, a foreign language acts as a powerful tool for communication across cultures. It opens doors to new experiences and allows people to engage in conversations with others from different backgrounds. This beautiful interplay of languages in a bilingual society brings a unique richness. It's a reminder that diversity is a strength, and that embracing different ways of speaking and thinking can lead to a more vibrant and understanding world. But it also presents challenges, like finding the right balance between expressing ourselves authentically in our native tongue and adapting to the diverse linguistic landscape around us.

3.3 Language situation in Algeria

The language situation in Algeria is a reflection of its history and geography. The country has various language varieties ranging from Tamazighth to foreign languages that have more or less influenced it including Arabic which refers to spread of Islam, and the influence of Arabic culture and language in North Africa.

In Algeria, the multilingualism is structured into three linguistic spheres: the Arabophone sphere, Tamazightophones sphere and the sphere of foreign languages.

Arabic and Tamazight are the two predominant mother tongues for most Algerians.

Arabic occupies a dominant place in the daily lives of Algerians, both in the private and public spheres. It is the cradle of emotions, thoughts and family exchanges, embodying the first language that many learn from childhood. Algerian homes often echo with the melodies of *Dialectal Arabic*, used warmly in informal conversations, stories and anecdotes passed down from generation to generation. In a more formal context, *Academic Arabic* is used in schools, institutions and the media, where the standard variant is used for teaching, drafting official documents and communicating in the national media.

The Tamazight languages, an integral part of Algeria's rich cultural and linguistic heritage dating back thousands of years, have faced historical challenges during the colonial and Arabisation periods. Although often undervalued and considered inferior in Algerian society, especially in rural areas, recent years have seen a resurgence of efforts to preserve and promote Tamazight culture. These initiatives include the establishment of language schools, the development of Tamazight media and the official recognition of Tamazight alongside Arabic, demonstrating a commitment to celebrating the linguistic diversity that contributes to Algeria's identity.

Approximately 8.8 million Algerians, or almost 27.4% of the population, belong to the Amazigh community, mainly concentrated in the Kabyle region of eastern Algeria. Another significant Amazigh community, which speaks a distinct Tamazight dialect called Chaoui, resides in the eastern region of Aures.

Although there are other communities of Tamazight speakers, they remain minorities, mainly isolated in the southern part of the country. As the map below shows, these communities contribute to the linguistic tapestry of Algeria.

In Algeria, French and English are the two main foreign languages, each officially recognised and each playing a different role. The country is a linguistic crossroads where French retains a deep historical influence dating back to the colonial era and continues to shape various aspects of Algerian society, particularly in government, education and cultural life.

Despite a decline in the use of French in some areas, its imprint remains deep-seated and is evident in everyday conversation, where French lexical items are often integrated. English has gained some ground, especially in education and certain professional sectors, but its influence is not as pervasive as that of French.

Nevertheless, there is an emerging trend of some individuals choosing English as a second language, reflecting a dynamic shift in linguistic preferences and an adaptation to contemporary global realities. This evolving linguistic landscape in Algeria highlights the complex interplay between languages, historical legacies and the ongoing impact of globalisation on language choice.

Explore how different languages are used in Algeria through the following table, highlighting their official roles and common usage.

Languages	**Official Use and Domains**	**Common Usage**
Arabic	Official language, government, education and media	Everyday communication and formal documents
Tamazight	Constitutional recognition, education and media representation	Daily life, cultural expression and rural communities
French	Historical influence, administration education and media	Administrative contexts some media and formal settings
English	Increasing presence education, and some professional sectors	Academia, international business interactions

To understand the linguistic dynamics in Algeria, it is imperative to adopt an approach of partitioning the country based on the dominance of mother tongues, integrating both Arabophone and Amazighophone regions.

It is important to note that the dominance of foreign languages may vary depending on the context. For instance, in a professional setting, English may prevail, while in informal interactions among friends, French might take precedence. This contextual approach reflects the diversity of linguistic influences in different aspects of daily life in Algeria.

3.4 Models of language Shift

Different models have been put forward by different scholars to explain for language shift and language maintenance. However, some of the proposed models are too specific or rigid, making it difficult to apply them to other populations, only some selected models seems to be more general such as Kloss's Model, Conklin and Lourie's Model and the Fishman's one.
Different social factors that influence language change can be simulated by different configurations and rules in cellular automata. For example, they can model language contact, where speakers adopt words from neighbouring languages, or show how social position affects dialect use. By considering individual speakers as cells that interact with their neighbors it possible to explore how local influences can lead to major shifts in language. There are many uses to which an asynchronous cellular automaton can be applied, but their use in studying language change is relatively unexplored. There are several research projects that explore linguistic change using models based on cellular automata. Here are some examples:

1. William A. Kretzschmar and Ilkka Juuso 's model (2014) : They provide a model which describe the diffusion of dialect features as an adaptive aspect of the complex system of language. The shows how a feature, once established, can spread across an area, and how the distribution of a dialect feature, as it appears in the Linguistic Atlas data, can either propagate or decline.

2. Francesc S. Beltran & all 's model(2009): they present the properties of a cellular automaton which incorporates some of the assumptions of the Gaelic-Arvanitika model of language change and the findings on the dynamics of social effects in the field of social psychology. They show that the survival or extinction of Catalan in Valencia depends on individuals' engagement with their language.

Our research is to the our knowledge, the first comprehensive application of asynchronous cellular automaton to this field.

3.5 Asynchronous cellular automata

A cellular automaton is a mathematical model consisting of a grid of cells each cell assumes a specific state, and interactions with neighboring cells determine its future state through local rules. This dynamic evolution occurs iteratively, with each cell updating its state based on the current conditions of surrounding cells.

In two-dimensional cellular automata two well known neighborhoods are possible. The Von Neumann neighborhood involves cells directly adjacent horizontally

and vertically to a central cell, forming a cross-shaped configuration. In contrast, the Moore neighborhood encompasses cells horizontally, vertically, and diagonally relative to the central cell, creating a grid-like configuration. The selection between these neighborhoods depends on the desired spatial sensitivity in the simulation.

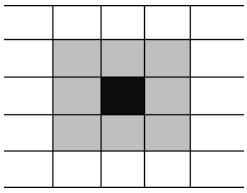


Figure 1: Moore neighborhood

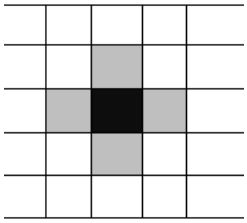


Figure 2: Von Neumann neighborhood

Temporal considerations in cellular automata usually involve discrete time and synchronous state updates. However, asynchronous cellular automata introduce independent cell updates, allowing a cell's new state to influence the calculation of states in neighboring cells.

Asynchronism, often perceived as an external and uncontrolled phenomenon, is frequently modeled as a stochastic process. Two primary stochastic updating schemes are employed: fully asynchronous updating, where the local rule is applied to only one randomly chosen cell at each time step, and asynchronous updating, where each cell has a probability a of applying the rule and a probability $1 - a$ to stay in the same state.

The asynchronous updating of cells in asynchronous cellular automata can effectively simulate the gradual shifting of language use over time, capturing the influences of migration, social interaction, and other factors that impact language spread.

During simulation we chose to use periodic boundary conditions . Periodic conditions imply that the edges of the lattice are cyclically connected, creating a continuous topology. In practical terms, this means that cells on the edges also interact with those on the opposite side of the grid, ensuring continuity in the model. This approach eliminates artificial boundaries that might otherwise affect the behavior of the system.

4 Research methods

Consider a scenario in which a community uses four languages, consisting of two dominant languages: a mother tongue and a foreign language, and two subordi-

nate languages: a mother tongue and a foreign language Each individual in the community has a distinct mother language and uses a foreign language as a second language. In our conceptual framework, the classification of an individual's language behaviour into one of four main states depends on factors such as the strength or weakness of his or her connection to subordinate languages, the social pressure to use the dominant language, and the number of neighbours who actively use the dominant language.
Here's a look at each of the states in more detail:

- State "00": Individuals speak a subordinate language and use another subordinate language as their second language.
- State "01": Individuals speak a subordinate language and use a dominant language as their second language.
- State "10": Individuals speak a dominant language and use a subordinate language as their second language.
- State "11": Individuals speak a dominant language and use another dominant language as their second language .

Each state "mn" is coded by an integer p such that $p = n * 2^0 + m * 2^1$. The four states are encoded in the following way:

State	00	01	10	11
Code	0	1	2	3

In our model, the community of speakers resides within a finite-sized, two-dimensional cellular automaton. The simulation program is designed to process a finite matrix that represents a specific segment of the community. Each cell in this matrix corresponds to the linguistic state of an individual, denoted by values 0, 1, 2, or 3. During each time step, the cells undergo updates with a probability $alpha$.

As in [5] we introduce two parameters of maintenance: the first (Pm) concerns the maintenance or abandonment of the subordinate language as a mother tongue, and the second (PF) concerns switching from one foreign language to another.

The maintenance parameter, in the context of language shift, can be seen as a threshold that determines the resistance of an individual speaking a subordinate language to the influences of the neighbourhood speaking the dominant language. This threshold represents the strength of the individual's attachment to his or her mother tongue and the effort required by the neighbourhood to induce a shift towards the dominant language.

When the neighbourhood exceeds this threshold, the individual may be more inclined to make a linguistic shift, gradually abandoning their mother tongue in favour of the dominant language. The pressure exerted by the neighbourhood, combined with other social and cultural factors, may influence the individual's decision to change language.

It is important to note that this maintenance threshold can vary from one individual to another depending on various factors but it is applied uniformly in this model.

Consider a particular cell at position (i, j) the sum of all coefficients of 2^0 of neighbor cells indicates the social pressure to speak a dominant mother language . We will denote such sum by Sm.

$$Sm_{i,j} = \sum_{r=-1}^{1} \sum_{s=-1}^{1} [\frac{c_{i+r,j+s}}{2}]$$

where [] is the integer part.

The sum of all coefficients of 2^1 of neighbor cells indicates the social pressure to speak and transmit the dominant Foreign language. We will denote such sum by Sf.

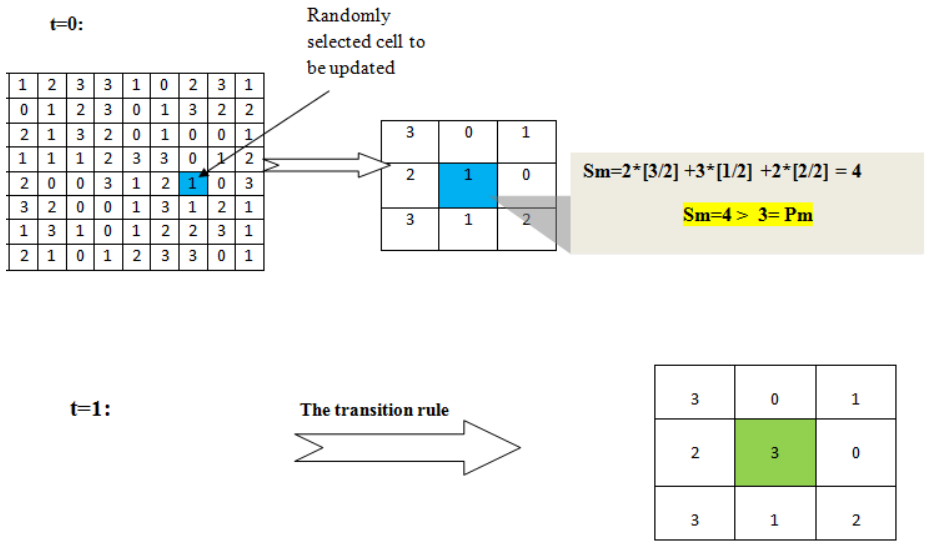
$$Sf_{i,j} = \sum_{r=-1}^{1} \sum_{s=-1}^{1} (c_{i+r,j+s} - [\frac{c_{i+r,j+s}}{2}].2)$$

where [] is the integer part.

Calculating the new state involves calculating the two sums Sm and SF of the cell's neighbourhood, which includes the target cell itself. These sums are then compared with pre-established thresholds (Pm and Pf respectively) to determine the next state. The potential range of these two sums is from 0 to 9. The transition rule is described in detail in the following table:

↓ initial state	0	1	2	3
0	$Sm \leq Pm$ and $Sf \leq Pf$	$Sm \leq Pm$ and $Sf > Pf$	$Sm > Pm$ and $Sf \leq Pf$	$Sm > Pm$ and $Sf > Pf$
1	...	$Sm \leq Pm$	...	$Sm > Pm$
2	...	...	$Sf \leq Pf$	$Sf > Pf$
3	...	...	...	$\forall Sm, Sf$

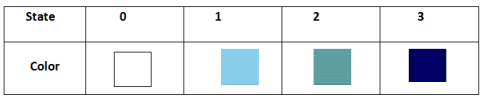
Example 1 *Using the transition rule that simulates language shifts, we will update the state of a randomly selected cell.We suppose that Pm=3 and P f* = 8.



4.1 Model simulations

We applied our program to matrices representing different regions of Algeria. The program then visually displays the evolution through an animation, providing an overview of the linguistic dynamics within the selected region.
The program generates also a detailed graph showing the percentage of each language state of individuals in the region from the initial time (t=0) until the cellular automaton stabilises. This dynamic graph allows the user to observe how language preferences evolve within the population over iterations. The inclusion of this graphical representation provides a visual perspective, making it easier to understand linguistic trends and transitions between dominant and subordinate languages.

Color codes are as follows:



To study linguistic stability, we analyze how different parameter configurations influence the persistence of native and foreign languages over time. Some parameters or scenarios may favor the stability of a language, while others lead to significant changes.

In order to validate and test our asynchronous cellular automaton model of language shift in Algeria, we conducted a survey of 100 students, doctoral candidates and faculty members at the University of Bejaia. This initiative was prompted by the lack of reliable statistics on this specific topic. The survey included key questions designed to gather relevant information about the participants' language preferences.

Participants were asked about their mother tongue as well as the language they use in different contexts, such at university (among friends), at work or to study. These questions were designed to provide valuable insights into the language dynamics within the university population.

The survey results are detailed in the table below :

Mother tongue	Tamazighth 72%	Arab 28%
The foreign language used among friends	French 60% | English 12%	French 18% | English 10%
The foreign language used to study	French 32% | English 40%	French 14% | English 14%

This results in two initial matrix states to be studied, each characterized by a unique percentage distribution:

among friends: state 0 = 10% , state 1 = 18% , state 2 = 12% and state 3 = 60%.
at work or study: state 0 = 14% ,state 1 = 14% , state 2 = 32% and state 3 = 40%.

5 Results and discussion

Simulation results of our model highlights a form of sensitivity to initial conditions. This sensitivity manifests in distinct behavioral patterns, even when identical maintenance parameters are applied to the two initial matrices representing these contexts.

Example 2 *For an update probability $alpha$ of 0.7 and maintenance parameters $Pm = Pf = 6$, the cellular automaton shows a remarkable sensitivity to initial*

conditions. This observation is particularly evident when examining two different initial matrices representing the social context (among friends) and the professional context, as shown in Figures 3 and 4, which detail the evolution of the percentages of each state until the cellular automaton stabilises.

In particular, the frequencies of state 2, which represents individuals who speak a dominant mother tongue and use a subordinate foreign language, behave differently in these two contexts. In the social context, these frequencies decrease before stabilisation, suggesting an early dynamic of linguistic change. In the professional context, on the other hand, they follow a different trajectory, increasing before stabilising. This difference in behaviour underlines the dependence on initial conditions and highlights the complexity of linguistic dynamics within specific contexts.

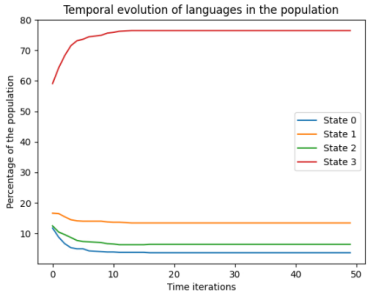


Figure 3: Social context (among friends)

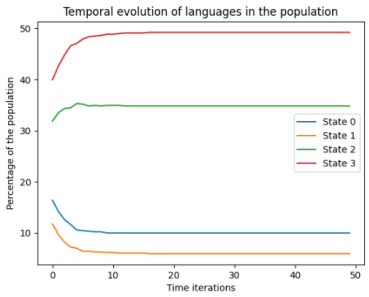


Figure 4: Professional context

Example 3 *For an update probability alpha of 0.7, a series of experiments were carried out varying the parameters related to the maintenance of subordinate languages Pf and Pm. The results show significant dynamics in the survival and extinction of subordinate languages, as shown in Figures 6 and 8.*

In the case where Pf is set to 3 and Pm to 2, low maintenance of subordinate languages leads to their extinction.

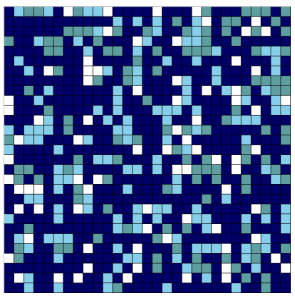


Figure 5: t=0

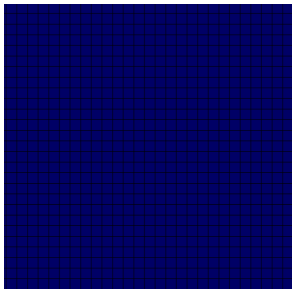


Figure 6: The automaton stabilizes, subordinate languages =0%

Conversely, when the parameters are set for strong preservation of the subordinate language (Pm=6 and Pf=5), the survival of the subordinate language is ensured. Figure 8 shows cells representing individuals adopting subordinate languages, indicating their persistence after the stabilisation of the cellular automaton.

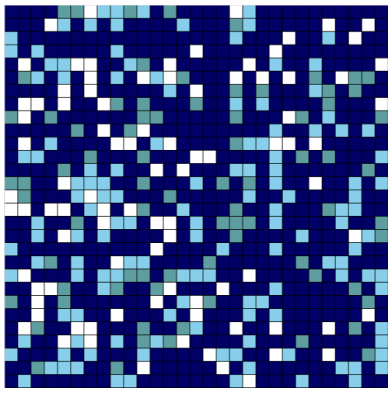


Figure 7: t=0

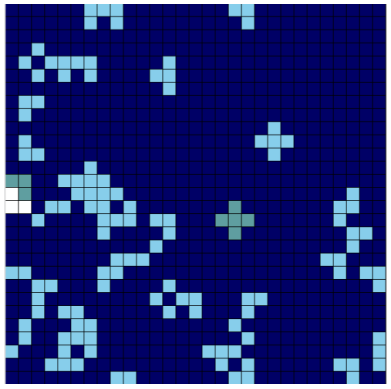


Figure 8: The automaton stabilizes

In general, values of Pm and Pf below 5 lead to the extinction of subordinate languages after the stabilization of the cellular automaton. Conversely, values equal to or greater than 5 promote the persistence of these languages, as depicted in Figures 9 and 10.

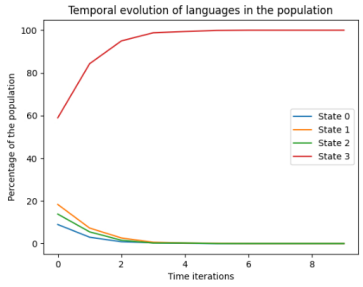


Figure 9: Pm=Pf=4

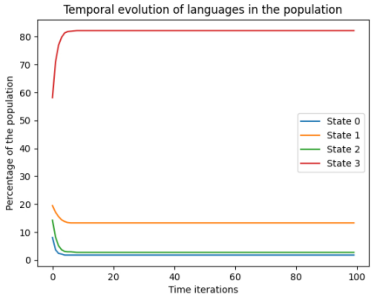


Figure 10: Pm=Pf=5

An extreme scenario, characterized by an exceptionally strong language maintenance policy $Pm = Pf = 8$, was incorporated into our simulation. The outcomes indicate that in such conditions, each initial configuration remains fixed, implying a state where no changes occur in the languages adopted by individuals throughout the iterations. See Figures 11 and 12.

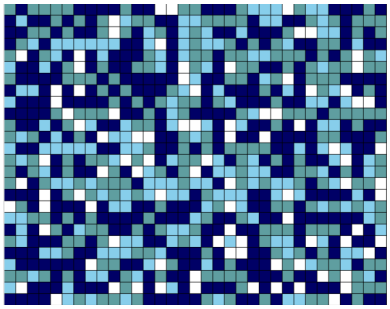


Figure 11: random initial configuration

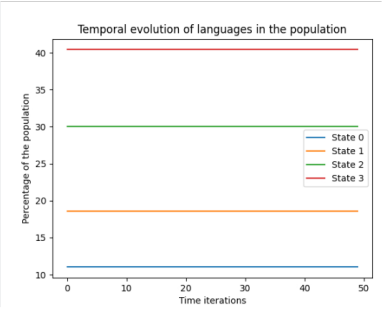


Figure 12: fixed temporal evolution of languages in the population

6 Conclusion and perspectives

In this article, we presented a simulation model based on asynchronous cellular automata to investigate linguistic changes in multilingual contexts, using Algeria as an illustrative example. Our approach based on asynchronous cellular automata provides an interesting perspective by delving into linguistic dynamics at a microscopic scale.

One direction for refining and extending this model is to explore individual variability in the maintenance of subordinate languages. This means that threshold

parameters will be dependent on cell states.

We would also be happy to collaborate with sociologists working on this topic to obtain suitable data to calibrate our model. For now the model was calibrated using only small scale data and random generated data.

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