Computational Model of Cultural Preservation based on Cellular Automata

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Abstract. The competition and integration of cultures is an unavoidable trend in the context of globalization, and immigration behavior has significantly accelerated the process of cultural transmission and integration. Cultural change is an evolutionary process in a complex social system. At present, scholars in this field mainly use the complex network model, Axelrod's cultural communication model, and cellular automata model to simulate the evolution of culture. The process of cultural retention is a mathematical model with discrete time, space, and variables. Based on the above characteristics of the model, the affected population can be divided into small rectangular units, and time can be divided into units at the same time. Effectively simplified the simulation process.

1. Introduction
The competition and integration of cultures is an unavoidable trend in the context of globalization, and immigration behavior has significantly accelerated the process of cultural transmission and integration. Cultural change is an evolutionary process in a complex social system. At present, scholars in this field mainly use the complex network model, Axelrod's cultural communication model, and cellular automata model to simulate the evolution of culture.

In order to study the retention degree of migrating civilizations, after calculating the similarity degree of civilizations, we used cellular automation to fit the 15-year decreasing cultural retention degree of three groups of different civilizations.

2. Model establishment
The cellular automaton model is mainly composed of four parts: the scope and definition of the cell, the state of the cell, the selection of the cell neighborhood, and the evolution rules of the cell. In view of the specific situation of question 1.2, this article will explain these four parts in detail.
2.1. The scope and definition of a cell
In the model constructed in this paper, we assume a matrix as the spatial scope of a cell. Each cell represents an individual with a certain culture.

The cultural characteristics of individuals are described by Hofstede's cultural dimensions theory, which is a framework for cross-cultural communication, developed by Geert Hofstede. This theory shows the influence of social culture on the values of its members and how these values relate to members' behavior, and it uses 6 dimensions to describe the national culture of a country.

The 6 dimensions are: Power distance index (PDI); Individualism vs. collectivism (IDV); Uncertainty avoidance (UAI); Masculinity vs. femininity (MAS); Long-term orientation vs. short-term orientation (LTO) and Indulgence vs. restraint (IND). We can draw the differences between the values of the residents of different countries in these 6 dimensions. Since the values of the residents were formed under the influence of their own culture, we can draw the differences between the cultures of different countries.

After consulting relevant data, we can obtain specific data of the above 6 dimensions in different countries, so that we can calculate the degree of difference between the cultures of the two countries. Suppose there are two countries, A and B, where the 6 dimension values of country A are \( A_{\text{PDI}}, A_{\text{IDV}}, A_{\text{UAI}}, A_{\text{MAS}}, A_{\text{LTO}}, A_{\text{IND}} \), and the 6 dimension values of country B are \( B_{\text{PDI}}, B_{\text{IDV}}, B_{\text{UAI}}, B_{\text{MAS}}, B_{\text{LTO}}, B_{\text{IND}} \). In order to avoid the influence of the actual value of dimension, the degree of difference between the same dimensions between the two countries is defined as

\[
DIF_{\text{dim}} = \frac{|A_{\text{dim}} - B_{\text{dim}}|}{A_{\text{dim}} + B_{\text{dim}}} \times 100\% 
\]

Then we can get the degree of cultural difference between the two countries as

\[
DIF = \frac{1}{6} \left( \frac{|A_{\text{PDI}} - B_{\text{PDI}}|}{A_{\text{PDI}} + B_{\text{PDI}}} + \frac{|A_{\text{IDV}} - B_{\text{IDV}}|}{A_{\text{IDV}} + B_{\text{IDV}}} + \frac{|A_{\text{UAI}} - B_{\text{UAI}}|}{A_{\text{UAI}} + B_{\text{UAI}}} + \frac{|A_{\text{MAS}} - B_{\text{MAS}}|}{A_{\text{MAS}} + B_{\text{MAS}}} + \frac{|A_{\text{LTO}} - B_{\text{LTO}}|}{A_{\text{LTO}} + B_{\text{LTO}}} + \frac{|A_{\text{IND}} - B_{\text{IND}}|}{A_{\text{IND}} + B_{\text{IND}}} \right) \times 100\% 
\]

2.2. State of the cell

In the model established in this article, each cell has 3 states, which are:

1. Local culture: Define LC as the original culture in a certain spatial range, assuming it’s initial.
2. Immigration culture: Set the value of the culture of immigration as IC. Since the degree of difference between the two cultures is already known, the degree of similarity between the two cultures can be calculated as \( SIM = 1 - DIF \). So we can get the initial value of the Immigration culture:

\[
IC = LC \times SIM = LC(1 - DIF) 
\]

3. Evolving culture: Cultural exchanges and integration are mutual, including the impact of immigrant culture on the original culture in the region and the impact of local culture on immigrant culture. So define FC as the culture that is being affected.

2.3. Cell Neighborhood Selection

The common neighborhoods of cellular automata are Von Neumann Neighborhoods, Moore Neighborhoods, and Margolus Neighborhoods. In this paper, Von Neumann Neighborhoods is selected as the cell neighborhood of this model.
2.4. Cell evolution rules
The evolution rule is expressed as the state of a certain cell at the next moment, which is determined by
the state of this cell and surrounding cells at the current moment.

Specifically in the model, let the state evolution rule be $S_{i,j}^{t+1} = f(S_{i,j}^t, S_{n,m}^t)$, where $\eta$ represents
the state transition function, and $S_{n,m}^t$ represents the value of the neighbor cell of the cell $(i, j)$ at time $t$. Considering that the fusion of cultures is mutual,
that is, the local culture affects the immigrated culture while it itself will be affected by the immigrated
culture. At the same time, considering the cell neighborhood selected by this model, define $\eta$ as the
following functional expression:

$$S_{i,j}^{t+1} = SIM \times \frac{\sum_{n,m} S_{n,m}^t}{4} + DIF \times S_{i,j}^t$$

(4)

3. Additional notes on the model

3.1. Determination of the scope of immigration
From the model of question 1.1, we can define the number of environmental migrants moving into a
country as $P_{EM}$, collecting data to obtain the population of the local country, then we can calculate the
ratio of immigrants to the total population of the country. Use this ratio to calculate the number of cells
representing the immigrants at the initial moment, that is

$$N_{in} = \frac{P_{EM}}{P_{OR}} \times N, N = 700 \times 700$$

(5)

Because the location of immigrants is uncertain, this article calculates the value of the immigration
culture and randomly assigns this value to $N_{in}$ cells in the cell range to simulate the process of immigration.

3.2. Evaluation of cultural retention
The degree of cultural retention $\eta_{re}$ is defined as the degree to which the original characteristics are
retained in the process of the affected culture being affected by the local culture. Let $sum_0$ be the sum of
all data in the initial matrix, $sum_{end}$ be the sum of all data in the matrix after the simulation is over, and
$sum_{10}$ is the sum of all values in the matrix when all the values in the matrix are 10. (all local cultures).
The calculation formula that defines $\eta_{re}$ is
\[ \eta_{re} = \frac{\text{sum}_{\text{end}} - \text{sum}_0}{\text{sum}_1 - \text{sum}_0} \times 100\% \]  

(6)

Thereby, the degree of retention of the immigrant culture can be determined.

4. Model solving and result analysis

This paper uses MATLAB to construct the cellular automata model of the above cultural evolution. Three migration scenarios are simulated:

1. Brazilian immigrants to the United States
2. British immigrants to Germany
3. Malaysians immigrate to Russia

Find the data to get the Hofstede's cultural dimensions data of the corresponding country (see the table below) and insert it into the model.

| Country     | PDI | IDV | UAI | MAS | LTO | IND | Degree of difference (%) |
|-------------|-----|-----|-----|-----|-----|-----|--------------------------|
| Brazil      | 69  | 38  | 49  | 76  | 44  | 59  | 22.79892524              |
| USA         | 40  | 91  | 62  | 46  | 26  | 68  |                          |
| UK          | 35  | 67  | 66  | 65  | 83  | 40  | 15.76477762              |
| Germany     | 35  | 89  | 66  | 35  | 51  | 69  |                          |
| Malaysia    | 100 | 26  | 50  | 36  | 41  | 57  | 27.63050233              |
| Russia      | 93  | 39  | 36  | 95  | 81  | 20  |                          |

Taking the data obtained in the case of "Brazilian immigrants to the United States" as an example, a part of the cell data is extracted, and a schematic diagram of the process of cultural decline is drawn below.

Fig 2. Cell evolution process diagram.

Finally, we can calculate the degree of cultural retention after moving into the following table.
Table 2. The degree of cultural retention.

| Cycle Times | UK  | Germany | Brazil & USA | Malaysia & Russia |
|-------------|-----|---------|--------------|-------------------|
| 0           | 1   | 1       | 1            | 1                 |
| 1           | 0.99| 0.99    | 0.99         | 0.99              |
| 2           | 0.95| 0.96    | 0.94         | 0.99              |
| 3           | 0.88| 0.89    | 0.85         | 0.99              |
| 4           | 0.85| 0.81    | 0.74         | 0.99              |
| 5           | 0.82| 0.72    | 0.62         | 0.99              |
| 6           | 0.81| 0.62    | 0.49         | 0.99              |
| 7           | 0.77| 0.52    | 0.37         | 0.99              |
| 8           | 0.72| 0.42    | 0.23         | 0.99              |
| 9           | 0.62| 0.32    | 0.18         | 0.99              |
| 10          | 0.57| 0.21    | 0.13         | 0.99              |
| 11          | 0.37| 0.16    | 0.14         | 0.99              |
| 12          | 0.27| 0.12    | 0.09         | 0.99              |
| 13          | 0.22| 0.13    | 0            | 0.99              |
| 14          | 0.16| 0.09    | 0            | 0.99              |

The image drawn based on the obtained data is as follows

Fig 3. Schematic diagram of cultural retention.

5. Model to assess the potential impact of the proposed policies

5.1. Model analysis
National development is a complex system composed of five sub-systems: population, economy, resources, environment, and resident life. Measuring the potential impact of a policy must be analyzed from these five sub-systems. In order to better describe their changes, we select 18 indicators corresponding to these five sub-systems, and establish a comprehensive evaluation index system.
Considering the high-dimensional, non-linear and non-normal characteristics of the system’s data, we decide to use the projection pursuit method to analyze the data. Specific steps are as follows:

1. Construct the projection eigenvalue $Z_j$

$$Z_j = \sum_{i=1}^{m} x_{i,j} \times a_i$$  \hspace{1cm} (7)

In the formula, $x_{i,j}$ represents the value after the i index of sample j is normalized; $a_i$ represents the component of the projection direction vector $a$, and $a_i \in [-1, 1]$.

2. Construct the projection index function $Q(a)$

Define distance between classes

$$s(a) = \left[ \sum_{j=1}^{n} (Z_j - \bar{Z})^2 / n \right]^{1/2}$$ \hspace{1cm} (8)

Define inter-class density

$$d(a) = \sum_{j=1}^{n} \sum_{k=1}^{n} (R - r_{j,k}) \times f(R - r_{j,k})$$ \hspace{1cm} (9)

Constructing a projection indicator function

$$Q(a) = s(a) \times d(a)$$ \hspace{1cm} (10)

In the formula, $a$ represents the projection direction, $a = (a_1, a_2, ..., a_m)$; $\bar{Z}$ represents the average value of the comprehensive projection eigenvalues $Z_j$ of n samples, that is, $\bar{Z} = \frac{1}{n} \sum_{j=1}^{n} Z_j$; $r_{j,k}$ represents the distance between the comprehensive projection eigenvalues $Z_j$ and $Z_k$ of samples j and k, that is
\[ r_{jk} = ||Z_j - Z_k||, \quad (j, k = 1, 2, ..., n) \]

\( R \) is the window width of the density, the range is \( r_{\text{max}} + \frac{m}{2} \ll R \ll 2m \), where \( r_{\text{max}} \) is the maximum value of \( r_{jk} \), and \( m \) is the number of indicators. Generally, \( R = m \) is acceptable; when \( R > r_{jk} \), \( f(R - r_{jk}) = 1 \); when \( R < r_{jk} \), \( f(R - r_{jk}) = 0 \).

3) Optimize the projection direction

From the above analysis, it can be known that the direction corresponding to the maximum value of the projection index function \( Q(a) \) is the optimal projection direction. Objective optimization function:

\[
\max Q(a) = s(a) * d(a) = \left[ \frac{1}{n} \sum_{j=1}^{n} \frac{(Z_j - \bar{Z})^2}{\bar{Z}} \right]^{1/2} \times \sum_{j=1}^{n} \sum_{k=1}^{n} \left[ (R - r_{jk}) \ast f(R - r_{jk}) \right] \quad \text{s.t.} \quad ||a|| = 1 \tag{11}
\]

There are many ways to optimize the projection direction, and we use genetic algorithms to optimize it.

4) After we obtain the optimal projection direction \( a \), we can calculate the weight of each index in the subsystem to which it belongs based on the sample.

\[
w_i = x_{i,j} \times a_i \tag{13}
\]

5.2. Model solving

Assume that the four refugee-receiving countries are Australia, Canada, Sweden, and the United States, and look up the data to obtain the values corresponding to the 18 indicators of the four countries. By substituting these data into the model, we can get the total Potential Impact Evaluation Index and the corresponding Potential Impact Evaluation Index values for the four countries in the absence of environmental migration, as shown in the figure.

![Image of Potential Impact Evaluation Index and its criterions](image-url)

Our proposed policy will change one of these 18 indicators: Policy 1 “Increase Employment” will increase the country’s employment rate, Policy 2 increases the proportion of social security in government expenditures, and Policy 3 changes the number of doctors owned by a thousand people.

Therefore, we calculated the changed values and substituted them into the model after the immigrants moved in to get the total Potential Impact Evaluation Index and the Potential Impact Evaluation Index...
values for the four countries corresponding to the three proposed policies. See the appendix for specific pictures. Compare the Potential Impact Evaluation Index of 4 countries in the above 5 cases, and draw a comparison diagram as shown below.

![Comparison of Potential Impact Evaluation Index values in 5 cases](image)

**Fig 6.** Comparison of Potential Impact Evaluation Index values in 5 cases.

### 6. Analysis of simulation results

It can be seen from the line chart that the degree of retention of the moved-in culture and the degree of difference between the two cultures are related. The degree of cultural difference between Britain and Germany is small, and the corresponding culture declines slowly, while the difference between Malaysian and Russian cultures is large, and the degree of cultural retention has been reduced to 0 by the 12th cycle. That is, the culture moved into is completely replaced by local culture.

In addition, the rate of cultural decline is also related to the proportion of immigrants to the local population. The proportion of immigrants determines the initial number of cells representing the immigrant culture. Therefore, the larger the proportion of immigrants, the higher the degree of retention of immigrant cultures.

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