Salzburg Residential Mobility Model

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Abstract

In order to study the mobility of households in Salzburg, an agent-based model was developed in NetLogo to simulate residential mobility. A number of predefined parameters such as income, rent, and income distribution were derived from existing statistics. These parameters were used to tune the model to real-world data. However, it is not possible to build an agent-based model (ABM) that coincides perfectly with the real world. The purpose of an ABM is to break down complexity and emphasize the role of certain events in a phenomenon. The model presented in this paper highlights the role of income and rent/housing costs in deciding the spatial location of an agent within a city. The model also stresses the possibility of finding segregation within Salzburg. Segregation is the clustering of similar agents based upon characteristics such as ethnicity, race, or income. The model finally shows that at least within this modeling approach, tolerance towards neighbors does not play a major role within the process of segregation, while rent and income have a major influence on the housing behavior.

1 Introduction

A complex environment like a city consists of rapidly changing factors and a variety of agents. Some commonly known city-wide phenomena such as congestion, urban sprawl, and segregation are examples of how necessity drives human behavior and influences their decisions within a geographic space (CROOKS et al. 2008). However, as complex environments are built bottom-up, complexity can be reduced by breaking down and decentralizing the environment into simpler parts. This permits the focus to remain on the specific factors responsible for decision-making within the cities. Agent-based modeling (ABM) simulates such complex environments by simplifying the interaction between the agents in a model. An agent is a heterogeneous object, which may be independent, or a part of a group.

The use of GIS in agent-based modeling has been trending for a decade. Embedding or integrating GIS packages into simulation systems (and vice versa) forms seamless GIS-centric modeling software (CROOKS & CASTLE 2012). This allows the agents to be linked to a geographic location, thereby allowing their interaction to be observed on both spatial and temporal scales. Furthermore, such interaction can lead to the emergence of certain patterns like segregation.

According to MASSEY & DENTON (1988, 282), the term "residential segregation" can be defined as "the degree to which two or more groups live separately from one another, in different parts of the urban environment". There are different factors that cause segregation

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of agents within a system (such as income, age, gender, etc.). SCHELLING's (1969) segregation model showed the emergence of strong segregation patterns caused by an agent's mild preference to be surrounded by agents of a similar social and economic status. Indeed walking through the residential areas of a city reveals clusters of various neighborhoods differing from one another on the basis of ethnicity and/or social status. According to BATTY et al. (2004), it is almost impossible to observe this segregation as it occurs because it is only apparent once the segregation is over and can rarely be traced back. AGUILERA & UGALDE (2007) studied the correlation of housing prices to socio-economic status (based on income). The housing prices were strongly dependent on the location of the house and were frequently changed. The individuals displayed a tendency to move to a neighborhood that matched their socio-economic status in response to the changing housing prices.

Agent-based models (ABM) have long been used to predict social and demographic patterns as they tend to simplify complex systems by translating social preferences into rules for agents. The agents act like independent objects with a certain purpose and their interaction often shows emergent patterns over time. It is, however, not possible to include all characteristics of the agents as this would result in an overly complex system. Therefore, a few selected agent characteristics are chosen depending on their relevance to the model's purpose.

The city of Salzburg covers an area of 65.678 km^2 and currently has a population of 146,631 inhabitants (STATISTIK AUSTRIA 2014b). In the past, approximately 7% of the inhabitants of the whole Federal State of Salzburg have relocated to a new residence (STATISTIK AUSTRIA 2014d). Assuming that the same statistics hold true for the city of Salzburg, this implies that around 10,000 households move to a new location every year. The aim of this paper is to develop a model of residential mobility within the city of Salzburg, Austria using agent-based modeling. The objectives of this model are:

- To simulate the movement of different agents within the city to see if any patterns of residential segregation emerge.
- To find the extent to which the model can be tuned to actual data.
- To define tolerance thresholds for agents to observe the effects of minor changes in preferences.

The purpose of this ABM is mainly empirical in nature because it studies the behavior of agents within an analyzed environment. Such combinations are usually used to explain, project, or perform an analysis of a scenario. First, a conceptual model was developed. Then it was tuned to the empirical data of Salzburg (see Section 3) in order to analyze scenarios that can arise from such a simulation.

2 Methods

The ABM presented in this paper was created using NetLogo (WILENSKY 1999), an open-source simulation software. This model is based on Schelling's segregation model as programmed by WILENSKY (1997). The original segregation model considers only two populations of red and green agents, which are randomly placed in the modeling environment. A slider that can be controlled by the user defines the "happiness" parameter that is the percentage of similar agents needed for a single agent to be happy in a neighborhood. As the model starts, the preference of the agents to be in a similar neighborhood emerges and the model ends when each agent has at least 30% of similar neighbors. The end results of Schelling's segregation model shows clusters of red and green agents. As the model progresses, a graph shows the percentage of happy and unhappy agents after each time step (tick). This model was modified and extended to simulate the movement of residents in Salzburg based on rent and income of the districts. It uses four sub-populations with different incomes and varying tolerance levels (towards members of another sub-population) to represent the inhabitants of Salzburg. This version of Schelling's segregation model is then used to decide the movement of residents based on their income and the rent of their residential district. Depending on the rent in a district, an agent can either afford to stay or decide to move due to low tolerance towards his neighbors.

2.1 Agents

In order to place agents within Salzburg, a map of the districts of Salzburg was loaded using a GIS extension for NetLogo. This extension allows the software to read vector data in the form of ESRI shapefiles. In NetLogo, the software specific terms "turtles" and "patches" are used to define two types of agents. Turtles are the agents that move around the modeling environment. They are attributed a set of characteristics that define the manner of their movement. Turtles can also be used to define "breeds" or sub-populations within a population. The presented model has four sub-populations of agents: red, blue, green, and yellow. Each sub-population represents a household and has been categorized according to the income of that household. Each household has the following set of attributes:

- happy? – an indicator that expresses if an agent is happy in its surroundings
- similar-nearby – number of neighbors of the same color
- other-nearby – number of neighbors of a different color
- total-nearby – total number of neighbors
- income – the income earned by the agent

Patches are agents that form the modeling environment for the turtles to move on. Patches do not move, but remain stationary. They can, however, be attributed a set of characteristics that change over time. The patches in the presented model form the districts of Salzburg. Each district belongs to a cluster based on its location, which in turn defines the extent of the rent in the district. Every patch has the following characteristics:

- id – the ID of the district (used to keep agents from hopping outside Salzburg)
- name – the name of the district
- cluster – the cluster number (decides how expensive the rent in a district is)
- rent – the rent of a district

2.2 Parameters and Procedures

The model is highly dynamic and consists of many parameters that can be set by the user with the help of sliders in the user interface. These parameters and the procedures used in the model are summarized in Figure 1. The setup procedure initializes the model according to the chosen parameters. The patches are color-coded to their respective clusters and assigned a rent based on their location. The different sub-populations are randomly placed within the confines of Salzburg. The Go procedure starts the simulation process and the agents start looking for more suitable residences to move to.

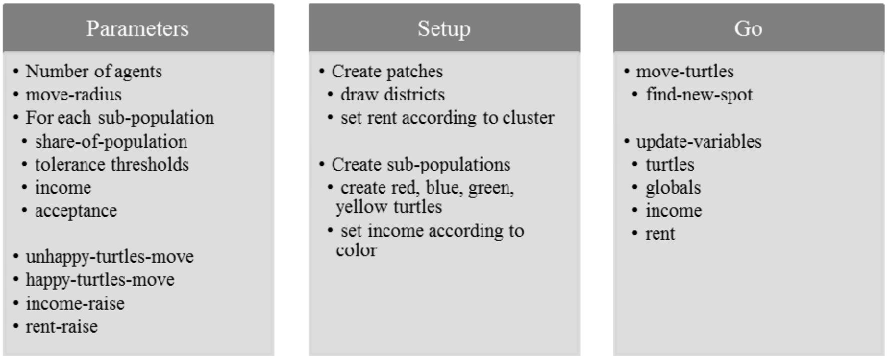

Fig. 1: Parameters and procedures in the residential mobility model

A more detailed description of the simulation procedures is delivered in the next section:

To setup: Initializes the patches within the confines of Salzburg and prepares the different agents. It ensures that none of the agents are too poor for the environment.

To setup-patches: Reads the shapefile and draws the districts of Salzburg. The rent of each patch is set depending on which cluster the district belongs to. There are 6 clusters and each has a rent assigned to it (based on annual statistics). The cheaper areas of a district are given a lighter color than the more expensive ones.

- To setup-reds/to setup-blues/to setup-greens/to setup yellows: Creates the respective sub-population, places them on empty patches within Salzburg, and assigns a random income with a normal distribution.
- To update-variables: Calls all the update procedures
    - To update-turtles: Each agent judges its neighbors based on their income. Neighbors with an income that is more than or the same as that of an agent will count as similar and desirable neighbors, while those with a lower income will be classified as undesirable neighbors. Each sub-population also has a percentage threshold of how many similar neighbors are required to keep an agent happy.
    - To update-globals: Calculates the percentage of similar neighbors along with the percentage of unhappy agents (total and sub-populations).
    - To update-income: Revises the annual income to account for increments.
    - To update-rent: Revises the rent to accommodate annual increases.
- To go: Stops the model after 25 ticks or if all the agents are happy.
- To move-turtles: After each tick, the agents in this model move under three conditions. Firstly, if the rent of a patch is too expensive, the agent has to find a new place to live. Secondly, agents that are not satisfied with their neighborhood move to a more suitable residence. Thirdly, some agents are happy with the location of their home but may still decide to shift to a new home.

- To find-new-spot: This is a recursive procedure that calls itself until a new spot has been found. In order to find a new spot, an agent moves in a random direction within a certain radius. The procedure reiterates until the agent finds an empty patch with an affordable rent.

Each iteration of the model is called a “tick” and represents one year in this model.

3 Model Description

The parameters for the presented model were based on income and rental statistics derived from those of the Federal State of Salzburg. The annual income for the State of Salzburg in 2013 is given in Table 1. This was used as a rough estimate to assign normally distributed random incomes to the four sub-populations in the model. As the wealthiest sub-population, the annual income of the red agents is roughly around €34,000, while the income of the blue agents is about €7,000. The user has the freedom to change these values using the sliders provided. The increase in annual income since 2008 has been between 0.8% and 3.6% (PREISIG 2012).

Another important distribution is the share of each group, i.e. the estimated number of agents in each group. Although there are no statistics showing the direct distribution, the share of people with a “high, middle or low” income based on several parameters could be estimated (STATISTIK AUSTRIA 2014c). According to these statistics, about 10% of the population fall under the high-income category (red agents), 15% have a low income (blue agents), and 75% are in between. For this model, the 75% have been split into two sub-groups (higher middle (green): 35% and lower middle (yellow): 40%).

Salzburg has 32 districts and each district belongs to one of 6 clusters (Figure 2). These clusters define how expensive the rent in a district is. According to IMMOBILIEN RATING BEWERTUNG & ANALYSE (IRG) and AUCON INDEX (2013), the lowest price per square meter was at €7, while the highest was around €16. Assuming that cheaper apartments are smaller than those that are more expensive, the cluster with the lowest cost has an average price of €4200 per year for about 50 m² (cluster 1), while the prices for the most expensive apartments are around €28,800 for about 150 m² (cluster 6).

Table 1: Annual Income for State of Salzburg, 2013 (STATISTIK AUSTRIA 2014a)

Annual Income in Federal Province of Salzburg, 2013	**Annual Income before Tax Reduction (in Euros)**	**Annual Income after Tax Reduction (in Euros)**
Number of people in the labor market	268,347	268,347
1st Quartile	€11,172	€9,084
Median	€24,653	€18,328
3rd **Quartil**e	€38,430	€26,392
Arithmetic Mean	€28,912	€19,998

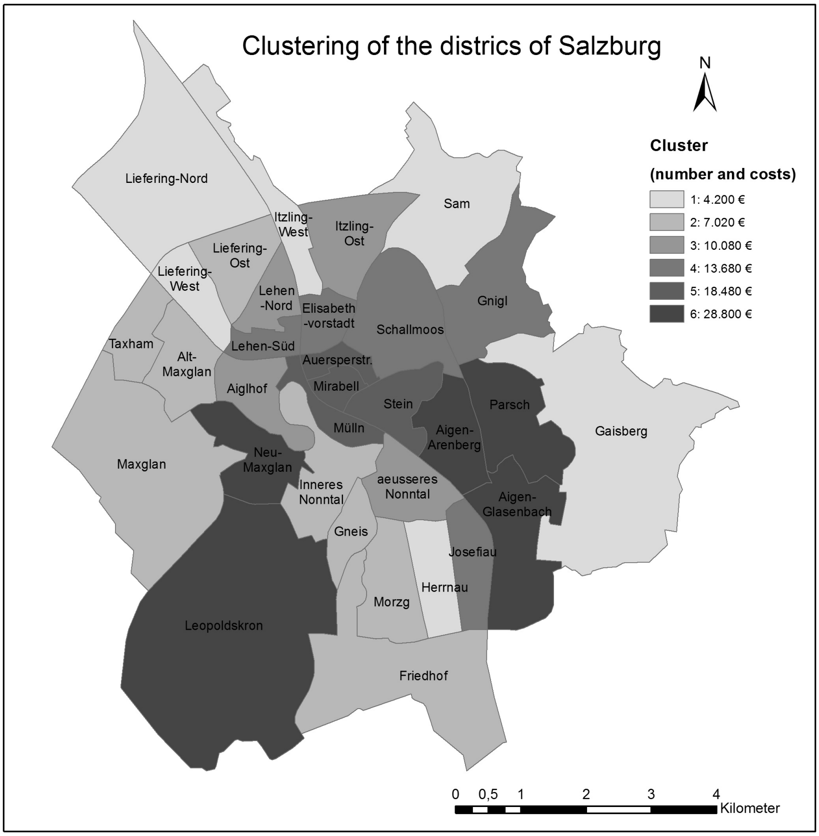

Fig. 2: The districts of Salzburg divided into clusters based on rent

4 Analytics

The model description gave the reader an insight into the empirical data that was used to create the residential mobility model. This section analyzes the results of the model. Four different scenarios are presented based on varying tolerance levels. These tolerance levels assign estimated percentages to immeasurable feelings like a person's reaction to his immediate surroundings. The scenarios are tested against each other to see if the results match our expectations. Each scenario was run over a period of 25 years using the same parameters. This gave the agents enough time to move and settle in different neighborhoods. The average percentage of different agents in every cluster was plotted after each year. As the results of each simulation run are bound to differ due to the individualistic nature of agents in an ABM, it was necessary to run the model a number of times in order to validate the result. The consistency of each scenario was tested by repeatedly running the model 10 times in a row (behavior space analysis in NetLogo). In other words, once the model finished a running for 25 years, it was repeated 9 more times. With the parameters described in the Model Description, the analysis will comprise of 4 different scenarios:

- Scenario 1: All agents are equally tolerant towards other agents. Every group only requires 10% of similar neighbors to be happy.
- Scenario 2: The red agents (richest sub-population) are the least tolerant, while the blue agents (poorest group) are the most tolerant. The red sub-population seeks a similarity of 80%. The green and yellow agents are satisfied with a similarity of 60% and 40% respectively. The blue agents seek for a similarity of only 20%.
- Scenario 3: The red and blue agents (i.e. extremes on a social class scale) are less tolerant than the others. They prefer a similarity of 80%, whereas the green and yellow agents are satisfied with a similarity of 20%.
- Scenario 4: All agents are equally intolerant towards others. Every group of agents seeks for 80% similar neighbors.

The assumption is that the agents will show the least segregation in Scenario 1. Scenario 2 is expected to result in a segregation of the richest agents (red), while the other clusters have higher social diversity. Scenario 3 is predicted to produce an outcome where rich (red) as well as poor agents (blue) are segregated, while the middle class agents (green and yellow) intermingle with their neighbors. The highest level of segregation is expected in Scenario 4, as the agents are extremely intolerant towards members of a different type.

In **scenario 1**, the blue agents are predominantly found in clusters 1 and 2. The yellow agents prefer cluster 1 above all others. The rich agents move from cluster 1 to other clusters and are mostly found in cluster 6. Cluster 2 consists to about 80% of green and blue agents and, only 20% of red and yellow ones. Despite the fact that the green agents can afford to live in cluster 6, a large number of them move to cluster 2. As this scenario has the highest tolerance level, the rent and income of the agents play a larger role in decision making than finding similar neighbors.

Scenario 2 introduces increasing levels of tolerance into the model. Here the rich red agents prefer having similar neighbors, while the poorer (yellow) agents are most likely to accept foreign agents into their neighborhood. Once again, the red agents gradually move to cluster 6. The green agents, which previously showed a preference for cluster 2, can now be seen moving out of cluster 2 and into clusters 3 and 4. This is likely due to the increase in the number of blue agents within cluster 2. The yellow agents show a consistent affinity to stay in cluster 1.

Scenario 3 considers an intolerant attitude from the richest (red) and poorest (blue) agents, while the agents belonging to the middle class (green and yellow) are very tolerant of other agents. The result is almost exactly the same as Scenario 1 (where all agents were extremely tolerant towards one another). The reason for this is because the extremely intolerant rich and poor agents together form only 25% of the entire population, while the remaining 75% of the population is highly tolerant.

Scenario 4 considers all agents to be highly intolerant towards dissimilar agents. In this case, the number of blue agents is lower in cluster 1 than in the other scenarios. This change can be explained by their extreme intolerance towards the other agents. The blue agents move to cluster 2 because a number of yellow agents migrate to cluster 1. This influx of blue agents to cluster 2 causes the displacement of green agents to clusters 4 and 5.

The diagrams in Figure 3 show the exact distribution of each group of agents for every scenario in cluster 6. The outputs of this cluster show the most significant differences. In scenario 1, the two richest groups of agents (reds and greens) are clearly dominant, whereas the percentage of the two poorer groups (blue and yellow) is lower and approximately at the same level. The red and green agents are dominant in scenario 2, but the green ones have a larger share. Moreover, the blue agents clearly have a greater share than the yellow ones although they represent the group with the lowest income. Scenario 3 delivers similar outcomes as scenario 1. The results of scenario 4 again are similar to those of scenario 2. However, here the percentage of green and blue agents is clearly higher than in scenario 2.

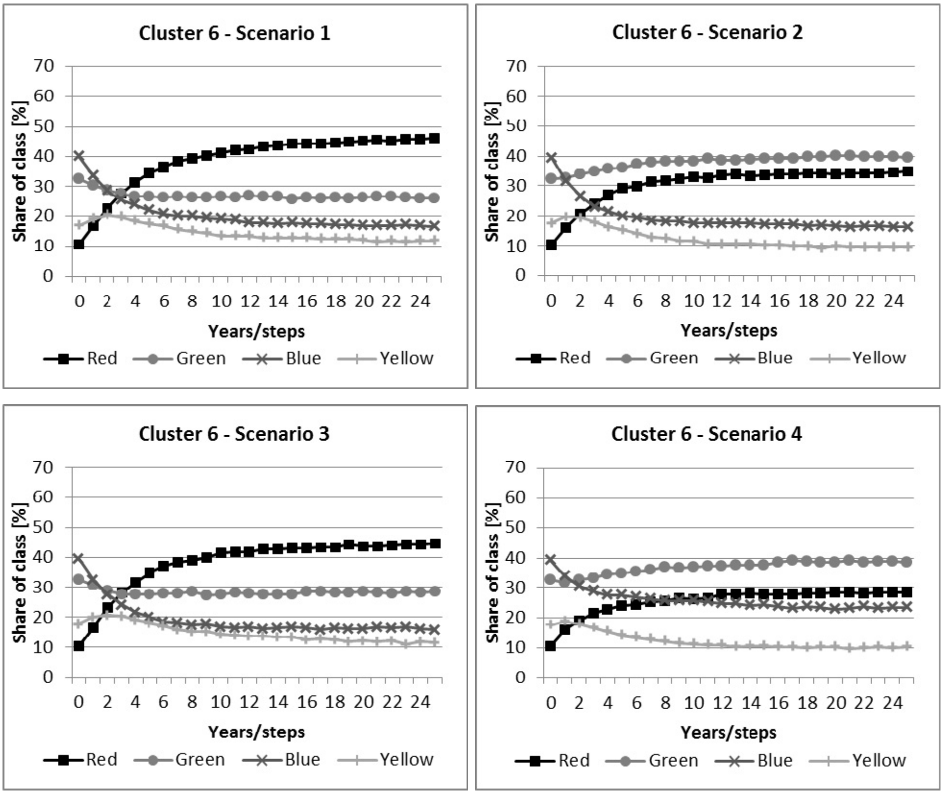

Fig. 3: Behavior of agents in cluster 6

Comparing the scenarios for the agents instead of the clusters reveals interesting outcomes. The red agents prefer cluster 6, which consists of the most expensive districts. This was expected, as rich folk tend to reside in costly areas. However, they also move to districts within cluster 2. In every scenario, about 20% of the red agents moved to cluster 2. Green agents do not prefer cluster 4 or 5 as expected, but instead move to cluster 2. The more tolerant the agents are, the more likely they are to move to cluster 2. So for scenario 4, the share of green agents is about 30%, while it is about 40% for scenario 1. The blue agents prefer the cheapest clusters, but more and more change to cluster 2 in scenario 4. The distribution of the yellow agents stays the same during all the scenarios.

5 Discussion

The model shows almost immediate segregation of the different sub-populations as the agents move to a district that is more suitable to their income or to a neighborhood that matches their tolerance thresholds. The segregation seen in the model is not as strong as Schelling's segregation. However, the model definitely shows that the agents move in and out of the districts. Therefore, this ebb and flow of agents is highly dependent on the social and economic status of the agent making the decision.

One of the other objectives of this model was to find the extent to which the model could be tuned to actual data. An ABM cannot be stopped in the middle of a run. This means that the initial parameters stay the same for the duration of the entire model run (25 years). Consequently, the model results in incredibly high rents and extremely rich agents. However, as the model is based on price proportions and not actual prices, this does not affect the accuracy of the model. One problem that needs to be explained is the model's emphasized focus on the economic aspect of Salzburg, more than the geospatial aspect. Residential mobility definitely influences the spatial tendencies within the city. The addition of more geospatial aspects would take place at a higher level. However, the purpose of this model is to show spatial tendencies with respect to economic status.

The model showed some expected results, such as the fact that poor agents cannot afford the high rents within cluster 6, so they are generally not able to settle down in this location. Other outcomes were unexpected, for example that so many upper middle-class agents prefer the cheaper clusters to the more expensive ones even if they could afford them. Most interesting is that even if there were minor differences, the behavior of the agents did not change significantly throughout the four different scenarios. The reason for this could be that agents accept all other agents with a higher income, but don't accept those that have a lower income, leading to no clustering of the poorest agents as they accept every other agent. Another explanation could be that the tolerance level has no major effect, or only a lower effect on the moving pattern than the income and the rent. The tolerance levels could not be derived from literature and are almost impossible to calculate based on personal preferences. This is the reason sliders were used to define different tolerance thresholds. Since there is no data available for tolerance level, this cannot be validated.

References

AGUILERA, A. & UGALDE, E. (2007), A Spatially Extended Model for Residential Segregation. Discrete Dynamics in Nature and Society, 2007, 1-20.

BATTY, M., BARROS, J. & JUNIOR, S. A. (2004), Cities: Continuity, Transformation and Emergence. Complexity and Co-evolution: Continuity and Change in Socioeconomic Systems, 61-76.

CROOKS, A. T. & CASTLE, C. J. E. (2012), The integration of agent-based modelling and geographical information for geospatial simulation Agent-based models of geographical systems. Springer, 219-251.

CROOKS, A., CASTLE, C. & BATTY, M. (2008), Key challenges in agent-based modelling for geo-spatial simulation. Computers, Environment and Urban Systems, 32 (6), 417-430.

IMMOBILIEN RATING BEWERTUNG & ANALYSE (IRG) & AUCON INDEX (2013), Wohnimmobilien Salzburg Stadt (Information poster online). http://www.aucon.at/immopreise/salzburg/130316_Index_SALZB.pdf (2015-01-10).

MASSEY, D. S. & DENTON, N. A. (1988), The Dimensions of Residential Segregation. Social Forces, 67 (2), 281-315.

PREISIG, F. (2012), Einkommen 2012 der Arbeiter und Angestellten in Salzburg. Analyse statistischer Daten aus der Sozialversicherung, Kammer für Arbeiter und Angestellte für Salzburg (AK Salzburg).

SCHELLING, T. (1969), Models of segregation. American Economic Association Papers and Proceedings, 59 (2), 488-493.

STATISTIK AUSTRIA (2014a), Brutto- und Nettojahreseinkommen der unselbständig Erwerbstätigen 2013 nach Bundesländern (online). http://www.statistik-austria.at/web_de/statistiken/soziales/personen-einkommen/jaehrliche_personen_einkommen/019352.html (2014-12-15).

STATISTIK AUSTRIA (2014b), Einwohnerzahl nach Politischen Bezirken 1.1.2014 (online). http://www.statistik.at/web_de/klassifikationen/regionale_gliederungen/politische_bezirke/index.html (2014-12-20).

STATISTIK AUSTRIA (2014c), Lebensbedingungen und Erwerbsstatus von niedrigen, mittleren und hohen Einkommensgruppen 2013 (online). http://www.statistik.at/web_de/statistiken/soziales/armut_und_soziale_eingliederung/022862.html (2014-12-15).

STATISTIK AUSTRIA (2014d), Wanderungen innerhalb Österreichs (Binnenwanderungen) zwischen Bundesländern und Umzüge innerhalb der Bundesländer seit 2013 nach Ereignismonat, Bundesland und Staatsangehörigkeit. Umzüge innerhalb der Bundesländer (online). http://www.statistik.at/web_de/statistiken/bevoelkerung/wanderungen/wanderungen_innerhalb_oesterreichs_binnenwanderungen/035362.html (2014-01-07).

WILENSKY, U. (1997), NetLogo Segregation model. Center for Connected Learning and Computer-Based Modeling: Northwestern University, Evanston, IL. Retrieved from http://ccl.northwestern.edu/netlogo/models/Segregation.

WILENSKY, U. (1999), NetLogo. Center for Connected Learning and Computer-Based Modeling: Northwestern University, Evanston, IL. Retrieved from http://ccl.northwestern.edu/netlogo/.