Inner-City Gentrification Simulation Using Hybrid Models of Cellular Automata and Multi-Agent Systems

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Abstract

Gentrification, as one example of complex urban behaviors, has enjoyed the spotlight among researchers in various fields of study such as economics, politics, sociology, and geography for about four decades. Most former research discusses theoretical issues, causes, and consequences of gentrification, but do not typically focus on building models to describe the dynamical process of gentrification.

This thesis reports on an agent based model for simulating the phenomenon of inner-city gentrification using hybrid models of Cellular Automata (CA) and Multi Agent Systems (MAS) design and effort has been put into constructing an exploratory model of gentrification. The model method involves functions of CA and MAS focusing on behavior of agents, which are residential mobility and residents' decision-making processes at micro-scale. The simulation model is applied to the Gateway district and its northern neighborhood in Salt Lake City, Utah. In order to test the model of gentrification, various hypotheses from gentrification theory are posed in simulation. The hypothesis is examined by running the model in different scenarios. The simulation results demonstrate that the model is verified at a theoretical concept level and thus the model shows the capability of using an agent-based model for understanding complex urban dynamics, in particular gentrification.

1. Introduction

Human interactions make the world very complicated, discontinuous, and irregular in its superficial physical form. Often, it looks like chaos, however, underneath this impression, an order, which is regular, unyielding, and infinitely complex exists (Batty 1994). Phenomena of urban systems also have this complex behavior. For example, residential mobility, which consists of individual human activities and behaviors interacting with each other in various circumstances, leads to emergence of interesting phenomena.

Gentrification, as one example of complex urban behaviors, has enjoyed the spotlight among researchers in various fields of study such as economics, politics, sociology, and geography for about four decades. Hamnett (1991) explains several potential reasons why the issue of gentrification has received much attention. He mentions that there is a major challenge to traditional theories of residential location and urban social structure and also theoretical conflicts among researchers about the idea of gentrification. In addition, gentrification has policy and political debates regarding gentrification-related consequences. For example, some city planners may want to renovate and upgrade an area in an inner city. This plan may directly or indirectly lead to gentrification; however, it is accompanied by involuntary displacements of often lower income residents, sometimes causing homelessness. Further, gentrification is one of the major leading edges of contemporary metropolitan restructuring. Considering these reasons, understanding the phenomenon of gentrification in complex urban systems is a very meaningful issue, especially in terms of academic debates and decision-making for urban planners, realtors, developers, and residents.

The objective of this thesis is to simulate the phenomenon of inner-city gentrification using hybrid models of Cellular Automata (CA) and Multi Agent Systems (MAS) design and effort has been put into constructing an exploratory model of gentrification. Most former research discusses theoretical issues, causes, and consequences of gentrification, but not much research focuses on building models to describe the dynamical process of gentrification. This might be because of the fact that gentrification is a very complex phenomenon possessing various factors from economics, politics, sociology, psychology, geography, and urban studies. Nevertheless, an approach to building simulation models is needed in order to understand behaviors of gentrification. Simulating gentrification requires concepts of bottom-up approach and multi-scale dynamical simulation since under the context of gentrification dynamical individual level interactions among households, business tenants, and developers trading in properties at a micro-scale in various circumstances might emerge as a particular spatial clustering phenomenon, gentrification, at macro- or regional-scale.

The simulation model is applied to the Gateway district and its northern neighborhood in Salt Lake City, Utah. In order to test the model of gentrification, various hypotheses from gentrification theory are posed in simulation. The hypothesis is examined by running the model in different scenarios.

This paper is organized as follows. The first section introduces the research and objectives. The second section is a literature review of gentrification. The third section defines the methodology of our gentrification model, and the fourth section presents the simulation process and result applying to a real city. The last section draws some concluding statements.

2. Literature Review of Gentrification Theories

To put it shortly, gentrification is a gradual process of changing a particular area in an inner city from an area in impoverished condition to one affluent condition by the restoration and upgrading of deteriorated urban property by more affluent middle- to higher-class people; often this results in the involuntary displacement of original working- or lower-class people. The cause of gentrification can be due to many various factors across socioeconomic, cultural, political, and spatial issues. As consequences of gentrification, there are many impacts for affected neighborhoods, cities, and metro areas. In some cases, consequences are clearly positive or negative, whereas, in other cases, the nature of the consequences have both positive and negative impacts depending on the perspective of the stakeholder (Kennedy and Leonard 2001). Some examples are involuntary or voluntary displacement of households and business tenants, raising of housing and neighborhood values, increasing local and state tax revenue, changing street flavor and new commercial activity, conflicts between old and new residents, and changing community structure.

Theoretically, the phenomenon of gentrification has been largely discussed in the field of urban geography. In previous works, there were two mainstreams of gentrification theory. Hamnett (1991) mentions these as "… the liberal humanists who stress the key role of choice, culture, consumption and consumer demand, and the structural Marxists who stress the role of capital, class, production and supply. Gentrification is one of the main arenas of conflict between the proponents of culture, preference and human agency, and the proponents of the imperatives of capital and probability." (p.174)

As one of the former representatives, Ley (1980) explained a phenomenon of gentrification in terms of economics with reference to the theory of postindustrial urbanism (Bell 1973 and 1976, Habermas 1970, 1971, and 1975). In an economic sense, a city transitions in society from industrial (early capitalism) to postindustrial (advanced capitalism) due to technological developments accompanied by shifts in the employment type from blue collar to white collar and in the industrial type from manufacturing to services. Ley's paper in 1986 clearly stated the link between the theory of postindustrial urbanism and gentrification. "The production of professionals, managers, and other quaternary employees working downtown … provide the demand base for housing re-investment in the inner city. … This population, as it gives political and economic expression to its own predilection to urban amenity, will restructure the built environment and accelerate the gentrification process" (Ley 1986, p.532). Discussing the important role of structure changes in postindustrial society, Ley argued for the importance of cultural concepts, "The neighbourhoods themselves include a measure of life-style, ethnic and architectural diversity, valued attributes of middle-class movers to the central city. … these desiderata of the culture of consumption should not be under-estimated in interpreting the revitalization of the inner city" (Ley 1981. p.128). As Ley discussed, gentrifiers, as a demand-side factor, play an important role in the gentrification process because of the fact that they have a desire to live in the inner-city and accelerate the gentrification process. When modeling gentrifiers, discussions of their characteristics and behaviors, which are later argued in this chapter, are exceedingly important since different types of gentrifiers as a demand-side factor have different roles for the process of gentrification.

By contrast, Smith and his rent gap hypothesis explained gentrification as "supply-side" rather than "demand-side." The concept of his theory is that "a broader theory of gentrification must take the role of producers as well as consumers into account, and when this is done, it appears that the needs of production – in particular the need to earn profit – are a more decisive initiative behind gentrification than consumer preference" (Smith 1979, p.540). Based on this, Smith has developed his rent gap theory, which is the disparity between the potential ground rent level and the actual ground rent capitalized under the present land-use. The rent gap is produced primarily by capital depreciation and by continued urban development and expansion. Only when this gap emerges can redevelopment be expected since if the present use succeeded in capitalizing all or most of the ground rent, little economic benefit could be derived from redevelopment. Gentrification occurs when the gap is wide enough that developers can cheaply purchase shells, physical housing structures, can pay the builders' costs and profit for rehabilitation, can pay interest on mortgage and construction loans, and can then sell the end product for a sale price that leaves a satisfactory return to the developer (Smith 1979).

Both theoretical approaches of gentrification have been largely discussed in the field of urban geography (Ley 1987, Smith 1987, Smith 1992, Bourassa 1993, Hamnett 1991, Hamnett 1992, Clark 1992, Bondi 1999, Bridge 1994, Lees 2000). Hamnett argues that both of theses are partial attempts to explain gentrification; therefore, an integrated explanation for gentrification must involve both explanations of the production of devalued areas and housing and the production of gentrifiers and their specific consumption and reproduction patterns (Hamnett 1991). Specifically, he mentioned four requirements for gentrification to occur on a significant scale; 1) the supply of suitable areas for gentrification, 2) the supply of potential gentrifiers, 3) the existence of attractive central and inner city environment, and 4) a cultural preference for inner city residence by a certain segment of the service class. In this study, these requirements are examined by running the gentrification model in different scenarios.

3. Methodology

Studying complex systems is a relatively new approach to science, and deals with how fragmented parts of a system give rise to the collective or aggregated behaviors of the system and how the system interacts with its environment, often in a non-linear way. This approach has a significant advantage when simulating urban systems: its emphasis on detailed, non-linear, and bottom-up approach to understanding urban dynamics. In the real world, urban systems, including gentrification, are composed at a local scale of individual level behaviors, such as residential mobilities, that interact with each other dynamically and manifest emergent properties at multiple scales. Torrens (2003) mentions that much research in social science is challenged by a dichotomy between the individual and the aggregate, and traditional models of top-down approach such as reductionism, which analyzes problems by breaking them down to their constituent components, might cause problems of ecological fallacy (Wrigley et al. 1996) and modifiable areal units (Openshaw 1983). Therefore, the bottom-up approach or so-called generative approach is a considerably important methodological concept in order to understand complex urban systems.

The model methodology involves demand and supply factors of gentrification using hybrid models of CA and Multi-Agent Systems. The focus is on the dynamic simulation of gentrification processes with fine local scale, which is the household level, and also on agent-based model development considering agents' mobility and their decision-making processes.

3.1 CA, MAS, and Hybrid Model

Among Agent-Based Models (ABM), CA are very simple discrete dynamic spatial systems based on a particular class of automata and their local rules. The function of an automaton is to process internal information, which is contained within the automaton itself, as well as external information that is input to it (Torrens 2003). CA, based on the concept of automata, can be used to build models in which contiguous or adjacent cells, such as those that might comprise a rectangular grid, change their states, in other words their attributes or characteristics, through the repetitive application of simple rules (Batty 1997). CA are comprised of five major components, cells, states, lattice, neighborhoods, and transition rules. MAS are one type of ABM and they are comprised of components that are similar to CA such as states, neighborhoods, and transition rules. However, the distinguishing characteristic of MAS is that agents in MAS have free mobility in the space with certain movement rules. In terms of modeling urban systems, each of them has a different strong point. CA include the capability of designing with attention to detail, characteristics of inherently spatial and decentralized form, dynamic behavior, a mechanism of multi-scale approaches, and having a natural affinity with raster data and GIS, whereas MAS have a great capability of representing mobile entities in urban environments, such as dynamical flows of population, households, and vehicles because of the characteristic of the freedom for true spatial mobility (Torrens 2003).

CA and MAS are, however, often used separately in models of urban systems and that may cause shortcomings in depicting real urban systems since real cities consists of both immobile entities such as urban infrastructures and mobile entities such as human. In addition, "the characteristics of urban infrastructure change over time because of human intervention within and around them. Similarly, cities are more than the people that inhabit them. There is a built environment that they influence and are shaped by" (Torrens 2001, p.9). Therefore, interactions between urban infrastructure and mobile entities are necessary to represent real urban systems. Thus, the hybrid model, which is composed of CA and MAS, is a more appropriate method for urban modeling since it possesses both CA and MAS advantages.

3.2 Gentrification Model

3.2.1 Agent Type

In our gentrification model using the hybrid model, there are two types of agents, 1) fixed agents, which act as CA, representing individual properties and 2) mobile agents, which act as MAS, representing residents in the space. The space is defined on a regular lattice of square cells. Since we would like to focus on the micro-scale level, the cell size is small enough to represent individual buildings and properties. However, there is a difficulty in treating the size of property because properties' sizes differ from each other in a real city, whereas cells' sizes in a regular grid CA model are uniform. To deal with this problem, each cell owns a size value, and the model simulation considers the value but not cell size.

In our model, we consider four types of fixed agents and one mobile agent. The four classes of fixed agents are, 'Market', 'Sub-area', 'Property', and 'Fixed Land'. 'Market' describes meso-scale status in the market that is simply an aggregation of smaller scale agents in it, which corresponds to a property sub-market. Therefore, as smaller scale agents change their state variables in every time step, 'Market' statuses are also updated dynamically. A market is further divided into small areas called 'Sub-area', which is between meso- and micro-scale. Likewise market sub-areas are also an aggregation of smaller scale agents. 'Property' and 'Fixed Land' are micro-scale fixed agents. The major difference between the two is that 'Property' is an active automaton, its state variables are changeable through transition rules like property type, property value, and vacancy status, while 'Fixed Land' is a fixed automaton, its state variables are not changeable but have influence on other transitions. For 'Fixed Land', there are two types, road and access point. Road shows road networks and access point is a location that residents will travel to. I consider four access points, downtown, highway entrance/exit, shopping mall, and grocery. Since 'Fixed Land' is a passive agent, it does not own any state variable.

'Resident' is a mobile agent in my model, units of which are a household. A 'Resident' owns state variables that include economic status, ethnicity, his preferences for housing choice, and sense of his neighborhood's environment. State variables for agents are as follows.

Market (m) / Sub-area (s)

Total number of properties: T_{Pl}

Total number of residents: T_{Rl}

Median property value: M_{Pl}

Median residents' economic status: M_{El}

Median accessibility to downtown: MA_{DTl} (0 to 1)

highway: MA_{HWl} (0 to 1)

mall: MA_{Ml} (0 to 1)

grocery: MA_{Gl} (0 to 1)

Vacancy rate: V_{Rl} (%)

(l refers to a number of market or sub-area: 1 to n)

Property (unit: parcel)

Property price: P_j

Property value: P_{Vj} (0 to 1)

Property size: S_j

Property size value: P_{Sj} (0 to 1)

Land use: L_{Uj} (Vacant, Residential, Commercial, Industrial)

Housing type: H_{Tj} (Single house, Duplex, Condominium, 3-4 units apartment, 5-9 units apartment, 10 or more units apartment)

Tenure: Te_j (rent/own)

Household capacity: Cp_j

Number of occupied or rented residents: NR_j

Vacancy rate: V_j (0-100 %: V = O / Cp * 100)

Accessibility to downtown: A_{DTj} (0 to 1)

highway: A_{HWj} (0 to 1)

mall: A_{Mj} (0 to 1)

grocery: A_{Gj} (0 to 1)

Neighborhood median property value: MP_{Vj} (0 to 1)

Neighborhood median residents' economic status: E_{SMj} (0 to 1)

Neighborhood ethnic rate: E_{Rkj}

(k refers to a number of ethnic identity: 1 to n)

(j refers to a number of property's identity: 1 to n)

Resident (unit: household)

Economic status: E_{Si} (0 to 1)

Ethnic status: E_{ki}

Settled status: S_{Si} (Stay, Move)

Resident's preferences: R_{Pi}
Probability for a resident i choosing a property j: Pb_{Cij}
Probability for a resident i leaving i's property j: Pb_{Lij}
Threshold for resident i's probability of choosing a property: TH_{Ci}
Threshold for resident i's probability of leaving i's property: TH_{Li}

(k refers to a number of ethnic identity: 1 to n)
(i refers to a number of resident's identity: 1 to n)

State variables that have a value range from 0 to 1 are normalized values, which are converted from actual values to 0-1 scale values using the following calculation.

$$\frac{V_i - V_{\min}}{V_{\max} - V_{\min}} \qquad (1)$$

where, V_i is an actual value for agent *i* (e.g. property price, property size, accessibility, or economic status (annual income)). V_{min} is an actual minimum value in all agents, and V_{max} is an actual maximum value in all agents.

3.2.2 Simulation Process

The fundamental simulation process is shown in Figure 1. First of all, initial information for fixed agents and a mobile agent is distributed. When the initial distribution has completed, state variables for 'Market' and 'Sub-area' are calculated as aggregated information. At each time step in a model simulation, there are three main processes, new residents' inflow/current residents' decision to move, housing choice, and update values. The first process consists of the inflow of new residents and decision to leave made by current residents. In this process, current residents will calculate the probability for leaving their property. If the probability of resident i leaving his property j is greater than the threshold, the resident will decide to leave. As the second process, new residents and current residents who decide to leave their property will calculate the probability for choosing a market and house. Here, we introduce the concept of hierarchical nested choice.

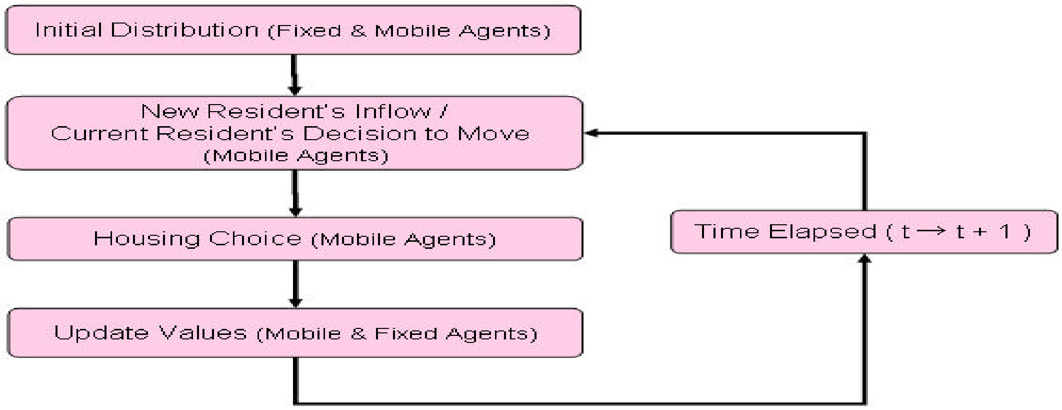

Figure 1. Flow chart of the fundamental simulation process

As described in Figure 2, there is a hierarchical choice for residential mobility, that is, first a resident selects one market as a meso-scale choice, and then, as a micro-scale choice, the resident will select one property having the highest utility among available properties in the selected market. If the probability is greater than the threshold (TH_{Ci}), the resident will settle in the property.

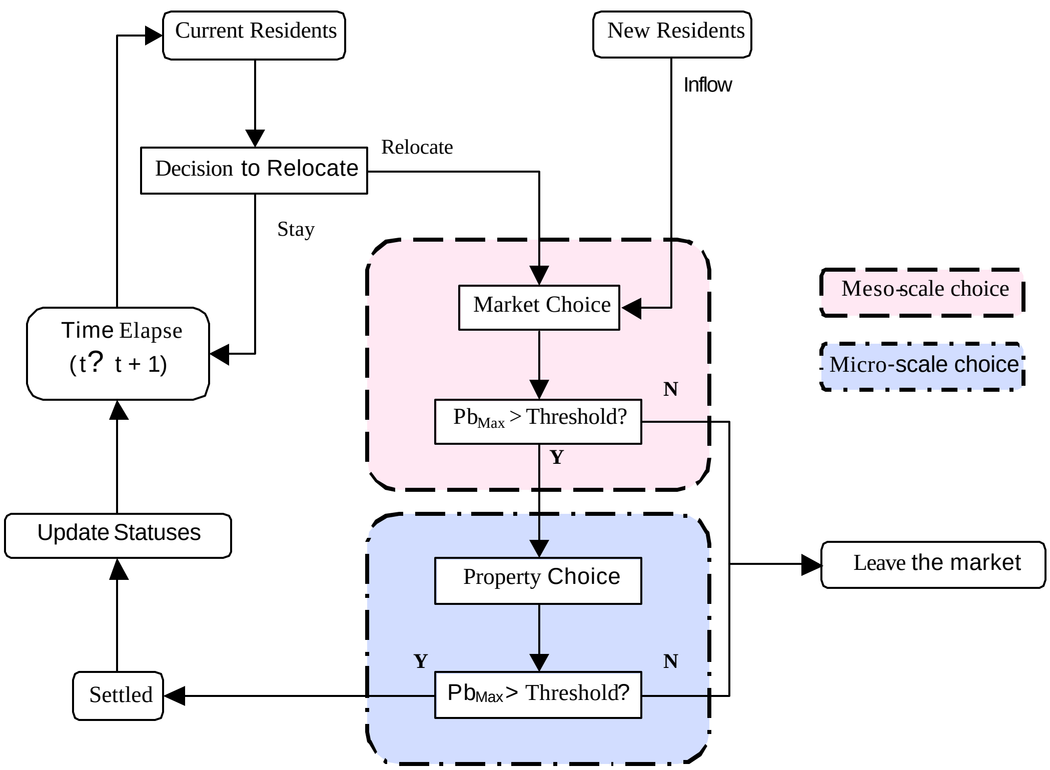

Figure 2. Diagram of residential housing choice process

At each hierarchical level of choice, a resident considers the composite attribute to evaluate a market or property in a selected area (see Fig. 3).

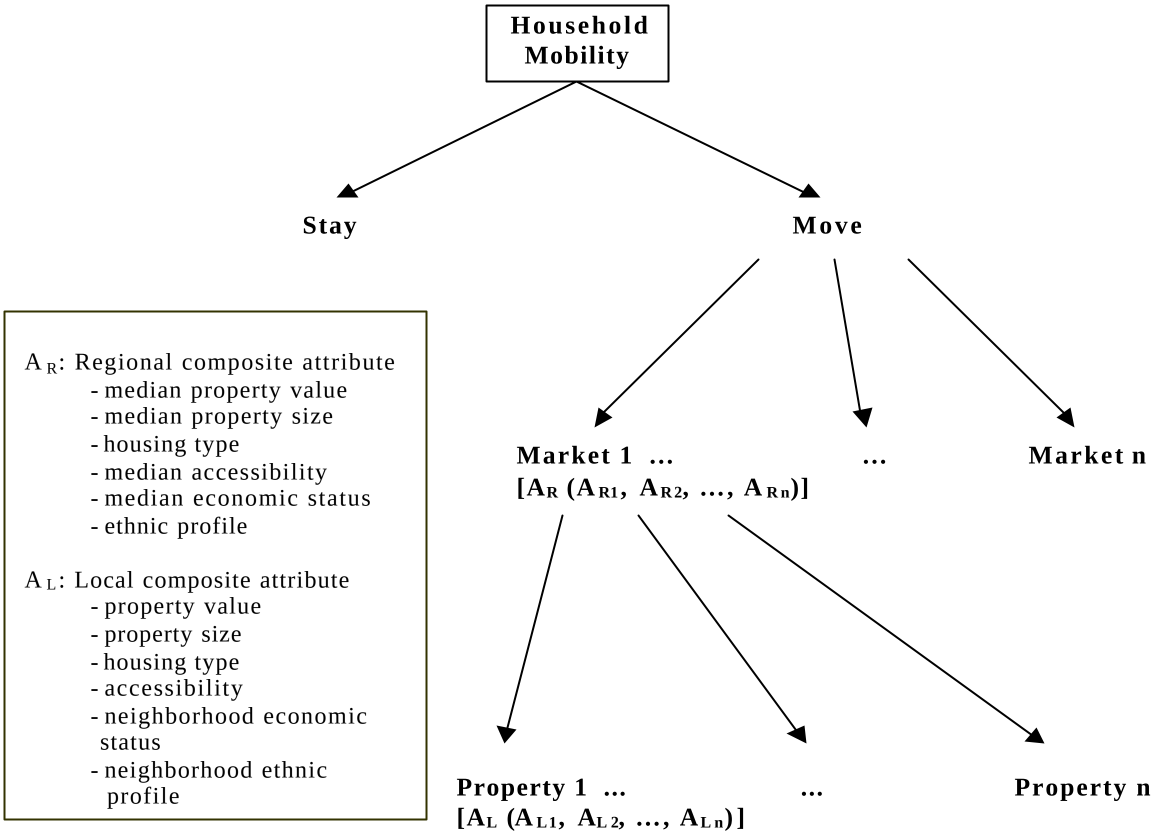

Figure 3. Hierarchal nested tree of household mobility, regional and local choice

Mathematically, this hierarchical nested choice can be described by a utility function. We assume that the probability for a resident i choosing a property j (Pb_{Cij}) will be described as a function of each attribute of a resident i. Attributes are individual's preferences for selecting a house consisting of two major characteristics, house and neighborhood environment. Thus, the utility function is defined as follows.

$$Pb_{Cij} = \sum (b_{HE} * H_E) + \sum (b_{NE} * N_E) \qquad (2)$$

where,

$\sum (b_{HE} * H_E)$: sum of characteristic values for house environment

$\sum (b_{NE} * N_E)$: sum of characteristic values for neighborhood environment

b_{HE} : coefficient on each value for house environment

b_{NE} : coefficient on each value for neighborhood environment
H_E : values for house environment
N_E : values for neighborhood environment

In our model, we consider four factors of housing characteristics that influence residential housing choice, property value suitability, house type preference, house size preference, and accessibility preference and two factors of neighborhood characteristics, neighborhood's economic status and ethnicity.

As a last simulation process, a vacancy adjustment function updates property value by examining the vacancy rate of property. It introduces the idea that properties' value will be adjusted by the vacancy status of the properties. The mathematical form, which is adapted from UrbanSim Beta Version (University of Washington 1998), is described as follows.

$$P_{v(t+1)} = P_{v(t)}\left[\frac{(1+a_b - V_{bl(t)} + l(1+a_b - V_{bl(t)}))}{1+l}\right]^b \qquad (3)$$

where, $P_{V(t)}$: an individual property value in time t, $V_{bl(t)}$: the vacancy rate for space in a building type b in location l in time t, a_b: the normal vacancy rate for building type b, ß: a scaling parameter for the property value adjustment, initially set to 1,?: a parameter for weighting the regional and zonal influence.

4. Simulation

Based on the theory and methodology mentioned in the prior section, the phenomenon of gentrification is simulated with a hybrid model of CA and MAS form.

4.1 Study Area

The study area is a part of the Gateway district and its northern neighborhood in Salt Lake City, Utah. Since Salt Lake City has been developing the Gateway district along the Gateway specific plan, the area has enjoyed the spotlight. Moreover, the area and surroundings have a great potential to be redeveloped because of some the tentative plans. Simulating urban infrastructure dynamics with residential mobility in this area is, therefore, an interesting issue for examining city planning and urban geography as it relates to developers and residents. The study area is located between Interstate 15 (I-15) on the west, 200 West on the east, 500 North on the north, and 300 South on the southern end (see Fig. 4).

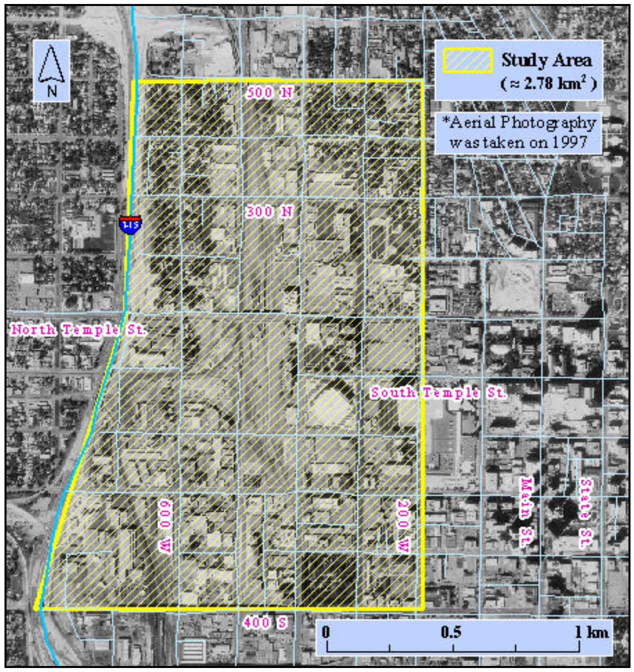

Figure 4. Study area

4.3 Data Resources

Table 1 shows data resources that have been used to build the simulation. Property data are at parcel scale; therefore they can be put into the model directly. However, resident data are not at household scale, but at regional scale. Therefore, we created a synthetic population at micro-scale, estimated from higher scale data or assigned random values.

Table 1. Data resources

Data Type	Year	Scale	Resources
Property			
Value ($)	2004	Parcel	Salt Lake County Assessor's office
Size (ft^2)	2004	Parcel	Salt Lake County Assessor's office
Type	2004	Parcel	Salt Lake County Assessor's office
Location	2004	Parcel	Salt Lake County
Road network	2000	1:100,000	The Census2000 TIGER/Line data
Resident	2000	Census Block	The Census2000 Summary File1
	2000	Census Block Group	The Census2000 Summary File3
	1990	Census Block Group	The Census1990 Summary File 3

4.4 Simulation Assumptions

The simulation applied to the study area is based on some underlying assumptions as follows.

1 – No land use transition or residential properties' expansion
2 – Considering owner-occupied properties
3 – Considering single house unit and condominium unit
4 – Considering Non-Latino and Latino as ethnicity
5 – Maximum utility for residents' housing choice

The first four assumptions on the above list are due to data limitations and model simplification. The first assumption is that we consider only residential properties, and the process of land-use transition is eliminated since the main aim is not to represent land-use transitions but to represent a gentrification phenomenon. However, the transition probability for 'Property' can be implemented from the model developed by White and Engelen (1993, 1997), which is basically the probability calculation for transition from one land-use type to another. In addition, for simplicity there is not new properties construction in the simulation. The second and third assumptions are that we consider owner-occupied single house unit or condominium unit as a property type. The fourth is that residents are either Non-Latino or Latino since these two are major ethnicities in the study area. The last assumption is the maximum utility for resident's housing choice indicating that residents will choose a house, such that it has the highest utility.

Based on the assumptions and data from resources and synthetic population, the gentrification simulation model was developed using NetLogo 2.0, which is an agent-based programmable modeling environment for simulating natural and social phenomena (Wilensky 1999). At the initial distribution, we define three markets based on reasonable delineation of property submarkets (see Fig. 5). Market-1 is located between Interstate 15 (I-15) on the west, 500 West on the east, 500 North on the north, and South Temple St. on the southern end. Market-2 is located between 400 West on the west, 200 West on the east, 500 North on the north, and North Temple St. (100 North) on the southern end. Market-3 is located between 400West on the west, 200 West on the east, 100 South on the north, and 400 South on the southern end. All of Market-1 and most of Market-2 are occupied by single housing units, however, the railroad divides two markets creating different environments. By contrast, Market-3 has only condominium units as residential properties. Figure 6 shows the model at the initial distribution in the NetLogo environment.

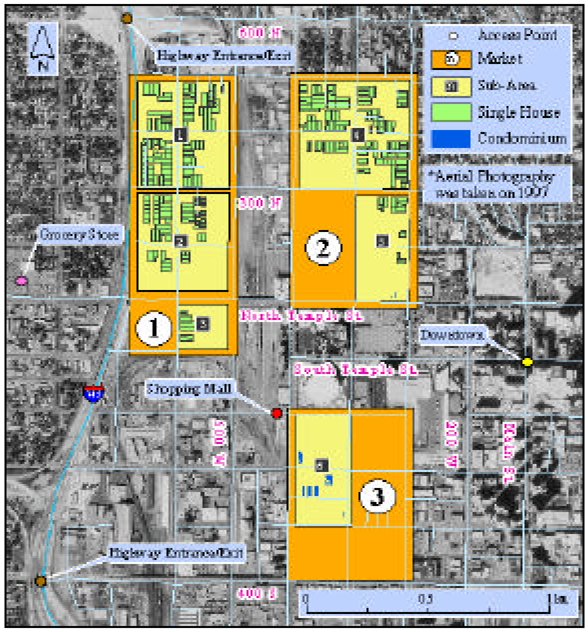

Figure 5. Area divisions and access points

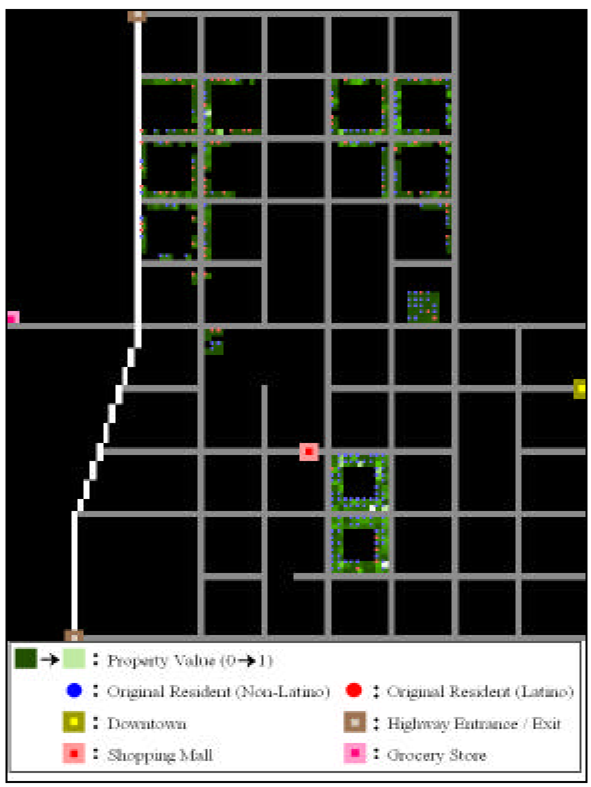

Figure 6. Agent-based model at initial distribution

4.5 Simulation Scenario

To test the gentrification model, we established a hypothesis that the introduction of both demand and supply factors of gentrification, which are gentrifiers and gentrifiable properties respectively, drives the gentrification phenomenon. In order to test the hypothesis, I set four scenarios as follows.

1: Base simulation

2: Introducing potential gentrifiers

3: Introducing potential gentrifiable properties

4: Introducing both potential gentrifiers and gentrifiable properties

The first scenario is the base simulation and user-defined parameters are shown in Table 2. The value of G_{POP}, which is population growth in each simulation time step, could be estimated from Census data, however, it is not a true population growth because it is the number of household who will look for a property but not all will decide to settle in. Therefore, in this study, it is assigned to 3% of the initial household population estimated from Census data, which shows that the average monthly household population growth from 1990 to 2000 is 3.217% in the study area. Other parameter values are empirically assigned since sufficient data are not available.

Table 2. Initial parameter settings for each scenario

Category	Parameter	Definition	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Population	G_{POP}	Population growth	10	10	12	12
	D_{POP}	Population decrease	2	2	2	2
Agents	N_{CELL}	Neighborhood cell	10	10	10	10
Property	V_{Rm1}	Vacancy rate for market 1	0.15	0.15	0.15	0.15
	V_{Rm2}	Vacncy rate for market 2	0.15	0.15	0.15	0.15
	V_{Rm3}	Vacancy rate for market 3	0.15	0.15	0.15	0.15
Resident	TH_{Ci}	Threshold for resident i`s probability of choosing a property	0.82	0.82	0.82	0.82
	TH_{Li}	Threshold for resident i`s probability of leaving i's property	0.48	0.48	0.48	0.48
Vacancy adjustment function	α_S	Normal vacancy rate for single house unit	0.15	0.15	0.15	0.15
	α_C	Normal vacancy rate for condominium unit	0.15	0.15	0.15	0.15
	β	Scaling parameter	1.00	1.00	1.00	1.00
	λ	Weight for regional and zonal influence	0.025	0.025	0.025	0.025
Gentrifier	G_{nt}	Gentrifier parameter	-	3.00	-	3.00

The second scenario considers the demand side factor of gentrification theory. The scenario poses questions relating to the implications of potential gentrifiers inflow to the study area. In order to model the concept of gentrifiers' inflow, simply the economic status for new residents is raised. The third scenario considers the supply side factor of gentrification theory. In this scenario, potential gentrifiable properties are introduced between Market 1 and Market 2. Finally, the fourth scenario considers both demand and supply side theories. Thus, the scenario combines scenario 2 and 3.

4.5 Simulation Results

In order to examine simulation results in terms of testing hypotheses, we consider the simulation dynamics for property value and economic status as well as the residential displacement process. In each scenario, the model was run for 500 simulation time steps and market average values of total household, property value, economic status, original resident profile, and Non-Latino ethnicity profile are outputted and examined. It is assumed that one simulation time step equals a month since the household population growth (G_{POP}) is monthly growth; therefore, 500 simulation time steps correspond to approximately 40 years. For the output values, dynamics of a single typical run and the average of 10 simulations in each scenario are examined.

As a result of a typical single simulation run, the dynamics of scenario 4 successfully show the gentrification process due to the impact from introducing gentrifiers and gentrifiable properties (see Fig. 7 to 11). Specifically, as property values increase, an increment of economic status can be seen, the dynamics of which cannot be seen in scenario 1 and 3. Also, the introduction of both supply and demand factors lifts up Market 1 and 2, while the dynamics cannot be seen in scenario 2. Moreover, compared with scenario 2, the property value in each market is much higher at the end of simulation. This indicates that only when both factors are introduced, does Market 4 play a role as a mediator for developing neighborhood markets.

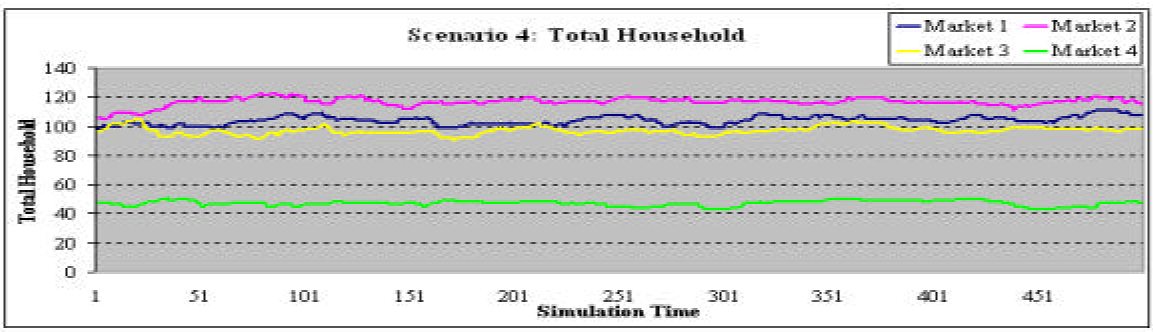

Figure 7. Simulation result: Total household, scenario 4 (demand and supply)

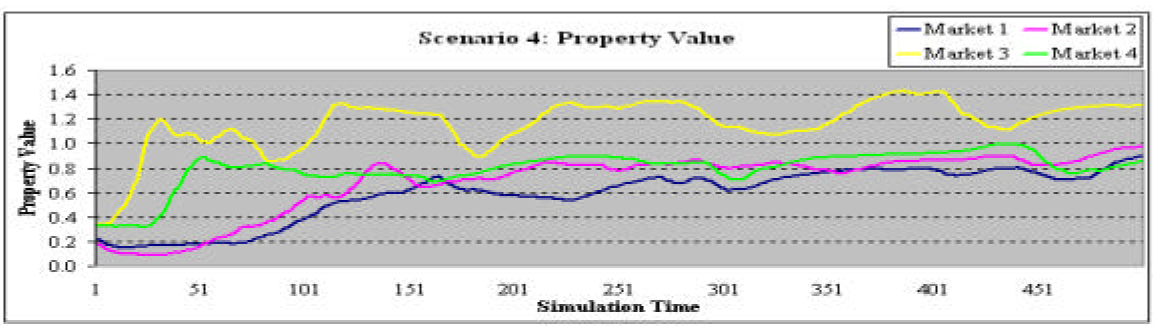

Figure 8. Simulation result: Property value, scenario 4 (demand and supply)

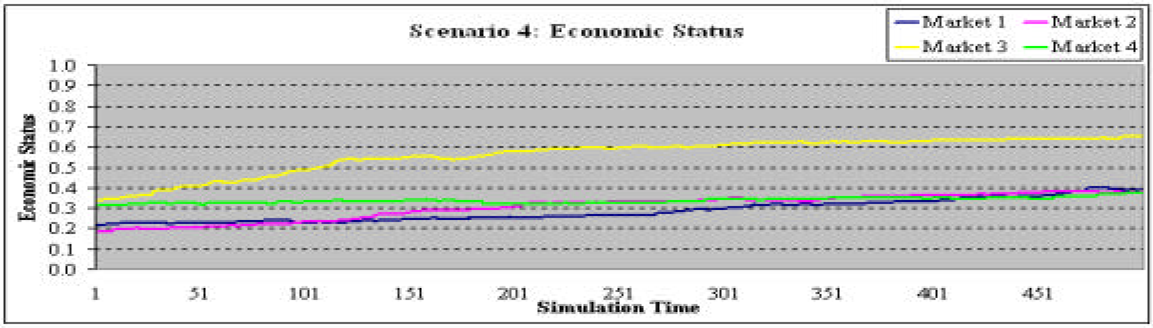

Figure 9. Simulation result: Economic status, scenario 4 (demand and supply)

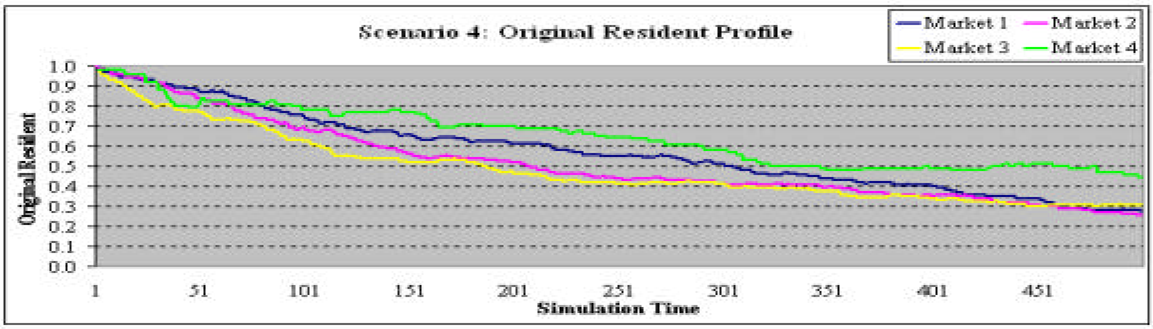

Figure 10. Simulation result: Original resident profile, scenario 4 (demand and supply)

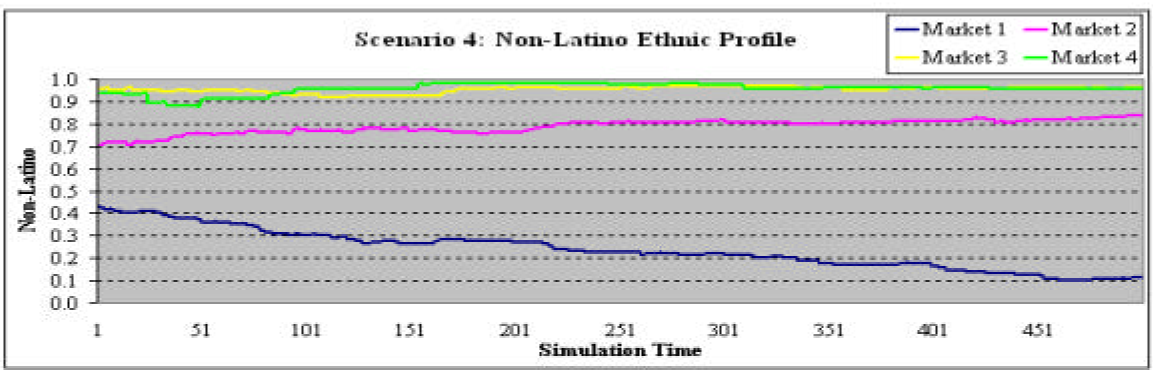

Figure 11. Simulation result: Non-Latino ethnic profile, scenario 4 (demand and supply)

5. Conclusion

This paper reports on an agent-based model for simulating the phenomenon of inner-city gentrification using hybrid models of Cellular Automata (CA) and Multi Agent Systems (MAS) design. Gentrification, a term that was first coined by Ruth Glass (Glass 1964), has been largely discussed especially in the field of urban geography. However, most former research discusses theoretical issues, causes, and consequences of gentrification, but not much research focuses on building models to describe the dynamic aspects of gentrification. An approach of building simulation models helps to understand dynamical behaviors of gentrification. The model method involves functions of CA and

MAS focusing on behavior of agents, which are residential mobility and residents' decision-making processes at micro-scale. The simulation results demonstrate that the model is verified at a theoretical concept level and thus the model shows the capability of using an agent-based model for understanding complex urban dynamics, in particular gentrification.

This study demonstrates the capability of using an agent based-model for understanding complex urban dynamics, in particular gentrification. Although the model is only verified on a theoretical level, it can be a springboard to explore more sophisticated agent-based models for simulating gentrification as well as other urban simulations and ultimately supporting decision-making for policy-makers, urban planners, developers and residents. In addition to this, the model helps researchers in further understanding the mechanism of gentrification, which is accomplished by examining parameter effects.

As a future research direction, in terms of model improvement, there are several considerations to achieve more realistic urban simulation. One of the key issues is that it is necessary to gain micro-scale data for applying simulation in the context of real urban dynamics as well as for model validation. The lack of accurate micro-scale data may introduce artifacts. In order to prevent such artifactual results, sufficient micro-scale data is necessary, which may be obtained through market survey or using a more sophisticated synthetic population method to estimate realistic data. Moreover, the acquisition of historical data would be useful to validate a simulation result and also to determine appropriate simulation time and scale. In particular, with historical data, the validity of simulation dynamics as well as simulation time and scale should be tested by running the model and examining goodness-of-fit. In this study, some of the model assumptions also constrain the simulation's ability to represent real urban dynamics, which is due to data limitations and model simplification. This could be improved by adding additional agents and rules to represent complex behaviors in the model.

Further exploration into more of the mechanisms of gentrification, residential mobility, and property upgrading is another future research direction. In this study, the phenomenon of gentrification is understood in terms of demand- and supply-side theories, and this concept is implemented in simulation scenarios by simply introducing gentrifiers and gentrifiable properties. However, gentrification in the real world is much more complex in its urban dynamics. For example, top down-concepts such as issues of urban planning and political zoning should be taken into consideration, while this study focused on bottom-up approaches. In terms of the mechanism of residential mobility, this work used a utility function, which is derived from the idea of a hedonic approach, and residential mobility is determined by six variables. It is important to empirically determine the significant variables for housing choice behavior, for example, which variables are critical and relevant components for housing choice behavior in the utility function. This could be examined by statistical methods or simply adding or removing some of factors and testing simulation. For the mechanism of property upgrading, the mathematical form is adapted from UrbanSim Beta Version (University of Washington 1998), which functions in such a way that properties' value is adjusted by the vacancy status of the properties. This could be improved by further investigating the mechanism.

As for modeling implementation, the gentrification model was implemented in NetLogo 2.0, which is an agent-based programmable modeling environment for simulating natural and social phenomena (Wilensky 1999). Although the platform has advantages such as a simple language and ease of use, a more user-flexible platform that is object-oriented would be appropriate for improving efficiency of building a model as well as simulating processes.

The model described here has potential for application to other urban dynamics dealing with residential housing choice such as issues of urban development, sprawl, and socio-spatial segregation. This will be the subject of further work to extend the research.

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