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Modeling Human Migration Dynamics in Netlogo

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Modeling Human Migration Dynamics in Netlogo

A Project

Presented to

The faculty of Department of Computer Science

San José State University

In Partial Fulfillment

Of the Requirements for the Degree

Master of Science

By

Vikram Deshmukh

May 2018

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The Designated Project Committee Approves the Project Titled

MODELING HUMAN MIGRATION DYNAMICS IN NETLOGO

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ABSTRACT

Human Migration has often been the catalyst for the rise and fall of civilizations. It is imperative to study human migration dynamics if one is to gain insights into migratory behavior among human beings and how migration affects societies. There has been considerable research to study migration. This has given rise to some popular migration theories like the neoclassical approach, network migration, pull-push migration, etc. These theories shed light on some peculiar behaviors that influence the migration decision of an individual or a group, while also trying to predict the outcome of such actions.

The goal of this project is to build and study agent-based models (ABM) of these existing migration theories using NetLogo. This project also aims to develop and propose an operational model that could potentially be used by policy makers to aid them in rational policymaking.

Key Terms — **Agent-Based Modelling, Human Migration, Migration Simulation, NetLogo, Migration Theory.**

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1. INTRODUCTION: MIGRATION IN THE REAL WORLD

Historically, human migration has played a pivotal role in shaping the world. It is this ongoing churn of immigrants that will shape future human societies. There is a plethora of reasons that may explain why some people migrate. In recent times, conflicts and communal turmoil have continued to displace people in some parts of the world. Case in point being the Syrian war and the Rohingya refugee crisis among others. People fleeing persecution in their homeland look for asylum or safer sanctuaries in other parts of the world. While the needs of such displaced asylum seekers constitute as basic human right to live a dignified life, the sheer numbers of such people seeking refuge in a foreign land does put an undeniable strain on the economic and other resources of the host country. In some cases, this also triggers an anti-migration backlash. Owing to mounting pressure from some sections of the society, lawmakers have resorted to making policies to regulate this migration flow and, in some cases, blocking access to foreign immigrants altogether, be it for refugees seeking asylum (displaced due to war, communal violence, natural disasters, etc.) or blue-collar workers looking for menial jobs (like seasonal farm workers), or highly skilled foreign workers (e.g. H1-B workers in US).

In such an environment, one needs to ask questions like: What's the right way to control migration? What are the different types of migrants? Is there a way of identifying impact of policymaking in advance, before the policy is implemented?

This project aims to propose a solution that tries to answer most of these questions to varying degrees. Over the course of this project, we identified various pain-points that

plague today's immigrant, and influence her decision to migrate to another part of the world. Agent-based modeling was chosen as the tool of choice to create a human migration model that could simulate real world migration as closely as possible.

2. EXISTING MIGRATION THEORIES AND THEIR LIMITATIONS

It is common knowledge that the volume of human migration between two locations is directly proportional to the population sizes of these locations and inversely proportional to the distance between them [1]. This is also called the gravity model of migration [1]. Klabunde and Willekens [2] also suggest considering Circular Migration. This is the phenomenon where the individual feels the benefits of living in the host country are no longer as lucrative as before and decides to migrate back to the country of origin instead of, say, the second-best migration destination.

To understand migration better, Bauer and Zimmermann [1] classified migration under two heads: internal and international migration. Migration within the same country is considered internal migration, and migration to another country is called international migration. There is one exception though: the European Union (EU) functions as a single entity with free trade and movement of people within the member countries [1]. Hence, migration within the EU is also considered internal migration. The main criterion to classify migration as internal and international is the legal restrictions that come with international migration [1]. The simulation created as part of deliverables for this project include a model for studying internal as well as international migration. In later chapters, we'll study the effects of internal migration as well as the change in system behavior when legal restrictions are imposed on migrating to a certain region in our simulation environment.

What follows is a summary of most widely known migration theories:

2.1 The Neoclassical Approach

The main assumption behind the neoclassical approach is that individuals try to maximize their gains given their constraints [1]. Owing to the wage differential between the country of origin and the host country, migration occurs from the low wage country to the high wage country [1]. Due to this migration, the supply of labor in the low wage country decreases leading to an increase in wages. The flow of migration tapers out when the system reaches an equilibrium with respect to the wages (the wage differential has diminished considerably enough to match the cost of migration from the low wage country to high wage country). This theory has undergone refinement over the years by dropping the assumption of full employment in the host country in favor of a probability of employment. This approach, however, has received a lot of criticism on conceptual and empirical grounds [3, pp. 7-8]. Its reduced complexity is attributed to omission of major migration determining factors and assuming homogenous migrants.

It is also worth noting that, when we created a human migration model based on the neoclassical approach, equilibrium is achieved, not when the wages offered in the destination country become equal to wages offered in the country of origin, but, instead, the system achieves equilibrium when the cost of migrating to a higher wage region wipes out any gain from migrating to that region.

2.2 Human Capital Theory

The human capital theory is one of the most widely used approaches for studying human migration. It considers migration as an investment decision of an individual [1].

Individuals decide by factoring various points like their skill levels, cost of learning a new skill, expected returns, etc. This theory reveals some peculiar observations about migration behavior.

For example, according to this theory [1]:

- Likelihood of migration decreases with age: Older people are more apprehensive about migrating to a different country unless necessary.
- Individuals with higher education exhibit a higher tendency to migration. This is due to knowledge about the opportunities present in other countries. Also, often, it is the lowest or the highest skilled individuals who opt to migrate.
- Risk and cost of migration increases with distance. In recent times, this claim has been disputed in the light of availability of cheaper means of travel.

The human capital model of migration is also useful to model both permanent and temporary migration [1]. However, Kurekova [7] observed that while there is correlation between wage differentials and migration flows, it was hardly the most defining factor of the model. It must be noted here that this theory considers migration decision as a purely individual behavior.

2.3 Family Migration

Unlike the human capital theory, family migration theory argues that migration is often not a decision of an individual but of a family. According to this theory, a family will only migrate if the migration leads to an overall gain for the entire family. For example,

the financial gain due to migration to one individual of the family should make up for the loss of income to other individuals of the family due to migration [1].

Like the human capital theory, family migration theory also focusses primarily on the ‘gain’ (usually in financial terms) from migration as the only factor influencing migration decision.

2.4 Network Migration

Network migration theory states that migration is not just a one-off phenomenon. Instead it should be considered as a network behavior. These networks maybe composed of family, friends, relatives, etc. The first person in a network who migrates, faces the highest costs and risks. This financial and emotional cost involved in migration is significantly reduced for any subsequent individual in the network who decides to migrate [1].

In the network migration theory, any person (or node) that migrates exerts a relative pressure on all its connected nodes in the network. This theory sheds light on an interesting observation that a person belonging to a family of immigrants or with relatives or friends who’ve migrated to other parts of the world, will exhibit a strong tendency to herself migrate.

2.5 Push-pull Migration

Of all the migration theories discussed so far in this report, the push-pull migration theory is the most comprehensive one. It tries to take a holistic view of migration by considering

the factors in the place of origin that lead the individual to consider migration (termed push factors) as well as the perceived benefits of migrating to a destination (termed pull factors). For example, the positive economic conditions and higher wages in the receiving country can be considered as pull factors while political instability or a natural disaster in the country of origin can be considered as push factors [3].

This approach of considering push as well as pull factors enables this theory to encompass all the behavioral attributes of other theories: the tendency to migrate depending upon how many immigrants any person is connected to can be considered a pull factor, the *wage differential* mentioned in the neoclassical approach can also be classified as a pull factor, the emotional inertia of considering migrating with an entire family unit as discussed in family migration theory can be considered as a push factor.

$$MD_i = push_i + pull_i + intervening_i$$

Where,

MD_i : Migration Decision of individual/agent i

$push_i$: push factor of agent i

$pull_i$: pull factor of agent i

$intervening_i$: intervening factor affecting migration decision of agent i

This theory considers the sum of all push factors and pull factors to determine the *migration decision* of a person. However, it still treats *migration decision* as essentially a scalar value. This results in loss of valuable insights that could be gained by retaining categorical preferences of a person and the degree to which these categories influence the person's *migration decision*. Some of the categorical preferences of a person that can be considered are economic benefits of moving to a specific region, level of safety,

infrastructure, standard of living, etc. This project builds on this theory to study migration dynamics by considering the migration decision as a vector instead of a scalar value.

3. SCOPE OF THE STUDY

Vezzoli et al. [5] in their paper suggest a novel approach to migration forecasting. They cite the restrictive approach taken by existing models that focus on a limited set of factors like demographic trends. The paper instead proposes taking into consideration larger macro factors like changing geopolitical scenarios (like the European refugee crisis, Brexit, etc.), climate change, etc. that are more difficult to predict but are undeniably crucial to migration flows. It suggests that by doing so a more complex but holistic model can be built that can yield more accurate forecasts. Vezzoli et al. [5] call this approach the Global Migration Futures (GMF) scenario methodology.

While this project does try to accommodate a wide range of factors (like the push, pull, and intervening factors mentioned earlier), it does not dive into the intricacies of the GMF approach. The onus is left on the reader to take up the challenge to explore the GMF approach and its possibilities.

4. AGENT-BASED MODELING AND NETLOGO

Agent-based modelling (ABM) is a branch of computer science that deals with building systems to mimic real-world swarm behaviors in a simulated environment [6]. It enables the modeler to build peculiar behavior of individual agents in the system and then study the emergent behavior of the system as a whole. These agents maybe stationary or mobile, simplistic or complex. The collective behavior of this swarm of agents is called emergent behavior, when the behavior of the whole is more complex than the behavior of the parts [11].

Some of the most popular ABM use-cases are summarized below:

1. Modelling an Ant Colony Optimization (ACO) simulation to study the behavior of a swarm of ants or evolution of ethnically segregated communities.
2. Building a model to study biological phenomenon like the spread of epidemics in a region, threat of biowarfare, vegetation ecology, murmuration of starlings, and biodiversity [6].
3. In business and technology, ABMs have been used for modeling organizational behavior, supply chain optimization and logistics, among others. They've have also been used for analyzing traffic congestion.
4. In November 2016, Nasrinpour et al [9] created an ABM to study spread of a message on Facebook.

There are many tools available for creating agent based models. Some of the most popular ones are: AnyLogic, Behavior Composer, DigiHive, JADE, MASON, NetLogo,

and Swarm [10]. In this project, we have used NetLogo to create an agent-based model (ABM) and study human migration dynamics.

NetLogo is a computational, multi-agent programmable modelling environment as well as a programming language. It was developed by Uri Wilensky at the Center for Connected Learning (CCL) at Northwestern University [11] and is available as open source downloadable software [12]. The NetLogo programming language is based on an earlier Logo programming language.

The agent-based models created using NetLogo 2.0 onwards consist of 3 important parts: the interface, info, and code. The interface is the visual interface of the model where the simulation is rendered. The info section contains detailed information about the model, instructions on how to use it, and observations. The onus of completing the info section also lies on the modeler. This section helps other modelers and users of the model understand the model better. The code section is where the modeler writes logic for updating the ‘world’ and its entities. It also contains information about how every agent in the system updates itself after every tick (i.e. every model update cycle).

4.1 NetLogo world, patches, and turtles

Any NetLogo model is a simulation of the world containing agents. The agents are classified into 2 types: patches and turtles.

Patches are the stationary blocks that make up the world. Like turtles, patches can interact with other patches as well as with other turtles depending upon their behavior

programmed by the modeler. The major difference between turtles and patches is that patches are stationary.

Turtles, on the other hand, may or may not be stationary. Hence, they are also referred to as mobile agents. A model may contain only one type of agents. There can be a model with only patches (e.g. ABM to simulate spread of forest fire) or a model with only turtles (e.g. a model to simulate stampede in a closed room). Both patches and agents can have custom procedures and attributes. Every patch has five pre-defined attributes while every turtle in the world has 13 pre-defined attributes. (More can be added programmatically).

Table 1. Pre-defined turtle and patch attributes

Patch Attributes	Turtle Attributes	
pxcor	xcor	who
pycor	ycor	breed
pcolor	color	hidden?
plabel	label	size
plabel-color	label-color	pen-size
	shape	pen-mode

In addition to the pre-defined attributes tabulated above, custom attributes can be defined for both, turtles and patches. Here's an example of custom attributes defined for turtles and patches:

```

; livability is a vector, disaster-recovery-stage defaults to 0
patches-own [livability disaster-recovery-stage]
; preferences is a vector, isImmigrant is a boolean, threshold is a num
turtles-own [preferences isImmigrant threshold]

```

Figure 1. Custom attributes declaration for turtles and patches

These patches and turtles together constitute the *world* of the model. In addition to the patches and turtles, there is an additional entity called the observer. The interface contains a command box in which the modeler can enter observer commands to debug or get more information about the model at any step of the simulation.

Figure 2. NetLogo environment showing agents, observer bar, and control buttons.

Any ABM created using NetLogo is run in two steps: Initialization and Iterative update. Most models usually ship with 2 buttons for this purpose. One to initialize the world and second to trigger a continuous iterative update.

4.2 Model Initialization

During the initialization phase, all entities in the model world like global variables, patches, and turtles are initialized to their starting state and the world is rendered. This step usually involves assigning some initial values to patch and turtle attributes and may involve assigning some random or preset locations to turtles.

```

] to init-model
  ca ; clear all
  random-seed new-seed ; randomly seed random number generator
  set-default-shape turtles "person"

  init-globals
  reset-ticks
  init-turtles
  init-patches
end

```

Figure 3. Model Initialization Code

Model initialization, usually happens when the user clicks the initialize button provided by the modeler in the interface.

4.3 Iteratively Updating the model

This is the step that triggers update procedures of all agents in the model via a control loop. Being simulation models, NetLogo models are controlled by an update loop that

can be paused and resumed. Generally, a model is run for a set number of iterations and then its state is observed. Owing to the pseudo-random nature of the models, their complexity, and different initial conditions, every simulation may produce different results. Having said that, these results may appear different but are not necessarily random. The goal of the modeler and the model user is to study these results and identify large-scale patterns. Once such patterns are identified, one needs to formulate theories that better explain the phenomenon observed and the patterns generated [11].

5. USING ABM FOR MODELING HUMAN MIGRATION

Being a computational science tool to build models for studying behavioral patterns, agent-based models (ABM) can also be used to model migration tendencies among humans [4]. This project involves building a set of models that help focus on studying the impact of specific phenomenon like disasters and visa restrictions as well as more general immigration behavior among humans. Over the course of building the model, some specific terms are used that form the ontology of this project. These terms have been explained below.

1. World/ Environment

The simulation area in which patches symbolize geographic regions and turtles that are analogous to humans is collectively called the *world*. At some places, it is also referred to as the environment, which is the NetLogo term for it.

2. Livability

Livability of a patch is a vector quantity that contains information about the desirability of the patch based on the environmental, economic, and other factors at that patch.

Livability is described in more detail in the next chapter. For example, if the livability at a particular patch is represented by the vector [20 30 40], where the dimensions represent environmental, economic, and infrastructure scores, and the highest value for any dimension is 50, then it implies that patch does not have extremely desirable environmental conditions, it is slightly above average when it comes to economic opportunities, but the infrastructure at the patch is quite good.

3. Mobility

Mobility is the area around any agent that the agent can perceive. It is an important factor of the model because every time the agent decides to migrate, it evaluates only the patches in its mobility radius to find the patch that will maximize its happiness.

4. Preferences/ Priorities

Preferences is a vector quantity that determines the agents' preferences for various factors like environmental, economic, etc. Preferences is to an agent what livability is to a patch. When determining a potential patch to migrate to, the agent does not just look for a patch with livability vector of the largest magnitude. It looks for a patch with a livability vector that best suits its own preferences.

For example, some agents might give a higher preference to the environmental conditions at a patch than the economic wages offered at that patch. An example of the preference vector of such an agent would be $[0.5 \ 0.2 \ 0.3]$. As one can see, the first dimension, representing the importance of environmental factors for that agent, is the most dominant dimension of the preference vector of that specific agent.

5. Threshold

Threshold is the minimum required livability value for the agents to not migrate. It is only when the livability at the current patch where the agent resides falls below this value, that the agent starts exploring nearby patches with better livability.

6. LIVABILITY AS A VECTOR

As discussed in the earlier sections, the push-pull migration theory, while considering a wide range of parameters, treated the migration decision of the agent as a scalar value. This project puts forth an idea of instead treating the push-pull factors and the agents' personal preferences as vector quantities. This will ensure that every single aspect of the push-pull factor is taken into consideration when making the migration decision.

Going forward, push and pull factors are addressed as the livability of the agents' current patch and destination patch. Consider *livability* of any patch as the features of that region, expressed as an n -dimensional vector, where every dimension of this vector symbolizes some aspect of the patch. For this project, we express the livability of any patch as a three-dimensional vector e.g. (l, m, n) , where l , m , and n indicate the environmental, economic, and infrastructure rating for that patch. Considering livability as an n -dimensional vector allows for provision to alter the complexity of the model as desired. One may wish to treat livability as a 5-dimensional vector with additional dimensions like: education spending, law and order situation of the patches, and quality of healthcare. Such additions can easily be accommodated by our model.

6.1 Initializing livability, North-South disparities

With the intention to ensure that the model closely mimics the real world, it was decided to add some level of disparity in the livabilities of patches based on their location. Northern patches (i.e., patches with larger y -coordinates) would be initialized to higher values of livabilities and it would gradually reduce for patches lower down the y -axis.

This was supposed to be analogous to the disparities in wages, safety, and general quality of life in north African countries and that of their European counterparts.

When the simulation model is run numerous times, it led to some interesting patterns in the changes in livability of patches in some regions as compared to others. These are discussed in more detail in later chapters.

6.2 Updating livability as a function of population and growth

While the livability of a patch is initialized based on its y-coordinate, every consequent update to patch livability is determined by the population on that patch and the growth rate set. There are 2 variations of this function being used. In one version, livability is calculated as a linear function of population while in another version livability is calculated as a quadratic function of population.

Given below is the graphical representation of the gradient achieved when using a linear function for livability and the formula used to calculate it.

Figure 4. Plot (not to scale) of livability as a linear function of population.

While linear function for livability produces good results, a more realistic relationship between livability and population can be achieved by using a quadratic equation as shown below.

Figure 5. Plot (not to scale) of livability as a quadratic function of population.

As can be seen from the plot in figure 5, initially livability increases as population increases. This is owing to economic growth due to availability of labor. But, for some value of ideal population, livability of that patch peaks and further increase in population leads to a decline in livability of that patch.

6.3 General livability as the length of the livability vector

While livability is multi-dimensional, one can get a sense of the overall livability of a patch by plotting the length of the livability vector. A higher overall livability would imply that the patch must score high on at least one factor comprising the livability vector. A patch with very high values for all 3 of its dimensions would indicate an ideal patch with excellent environmental conditions, lucrative economic opportunities, and

good infrastructure. Similarly, a patch with a very low general livability value would represent a patch that wouldn't be the most desirable patch for most agents.

6.4 Agent priorities as a vector

Just like the real world, every agent in our model also has priorities. These are the agent's level of expectations from the patch where it would like to live. In order to make a holistic comparison with the livability vector of patches, agent priorities are also defined as a vector with every dimension representing the same attribute as the corresponding dimension of the livability vector.

6.5 Agent happiness as a dot product of priorities and livability

Considering agent priorities as a vector also helps in calculating its satisfaction level at the current patch or a potential destination patch. The dot product of agent priorities and patch livability yields a scalar value that makes it easier to compare and find the best suited patch for that particular agent.

Where,

$\mathbf{a}$: agent preferences

$\mathbf{b}$: livability of the patch

Figure 6. Dot product of two vectors

To put it simply, a patch would be most desirable to an agent if both, the livability vector of the patch and the preferences vector of the agent point in the same direction.

```

; compute happiness of agent in a place
to-report happiness [place agent]
  let liv [livability] of place
  let pri [preferences] of agent
  report dot liv pri
end

```

Figure 7. NetLogo code to compute agent happiness at the provided patch.

Here's some code that is used to calculate agent *happiness* at a specific patch.

6.6 Computing Happiness (push & pull)

When correlating with the push-pull migration theory, agent happiness at the current patch can be considered analogous to the push factor and agent happiness at the neighboring patches can be thought of as the pull factors of those patches for that specific agent.

6.7 Agent sensitivity threshold

Every agent in the system has been assigned a *threshold* value based on the max-threshold slider provided on the interface. This is the determining factor for the agent. If the *happiness* level at the current patch falls below this *threshold* value, the agent starts evaluating neighboring patches to find a better migration destination.

6.8 Initializing priorities

Agent priority vectors are set during the initialization phase in such a way that the sum of all priority components is 1. E.g. An agent whose priorities are defined by (0.5, 0.5, 0) vector gives equal importance to environmental and economic factors of the place where it lives, and does not consider quality of infrastructure at that patch when making a migration decision.

6.9 Updating Turtles

During every iteration, after all the patches have updated their livability vectors, every agent in the system recalculates the *happiness* at its current patch. If the *happiness* value has dropped below its threshold value, then the agent calculates *happiness* values for all patches in its radius of mobility. It then selects the best patch among these based on their *happiness* values. If the *happiness* value of the ‘best patch around’ is better than the *happiness* value of the patch the agent is currently on, it migrates to that patch. Figure 8 shows a simplified version of the *update-turtle* procedure.

```

; cool use of max-one-of
to update-turtle
  if happiness patch-here self < threshold [
    let places other patches in-radius mobility
    move-to max-one-of places [ happiness self myself]
    set isImmigrant 1
  ]
end

```

Figure 8 Update Turtle procedure

If we let the simulation run this block of code for numerous iterations, interesting patterns start to emerge.

Figure 9. Flowchart of simulation logic in migration ABM.

6.10 User Interface: How to use the model

Figure 10. UI of the Human Migration Agent-based Model (ABM).

The user interface of this version of the migration ABM provides some basic controls to the user to manipulate some global variables like growth rates, agent sensitivity threshold, and initial population. Later versions also contain line chart plots of agent density in the upper half of the environment and mean livability of each of the four quadrants. This shows the back and forth churn that takes place over time.

Additionally, the interface has controls to set the values for growth rates of the 3 vector components. These are the factors by which individual patch components grow during every iteration.

6.11 Observations

It is noteworthy that no empirical data was used during the multiple simulation runs of this model. All tests were run using stochastic data. After observing the system state at the end of multiple simulations, following behavioral patterns were observed.

1. In the beginning, the northern patches are lucrative. So, you see a spike in the number of agents migrating to northern patches.
2. Given sufficient time, and due to lack of workers, the livability of southern patches improves to the point that some agents in the north find it beneficial to move to southern patches. This is also since an increased population of agents on northern patches has reduced the livability of these patches.
3. Eventually, northern patches get more lucrative again and agents start moving up north. This churn continues for an extended period. Consider the simulation world as being divided into 4 geometrically equal regions (say the four quadrants). The figure below shows a plot of mean livability in these regions over time.

Figure 11. Plot of mean livability of 4 quadrants over time.

7. FINDING EQUILIBRIUM

With regards to studying migration theory, equilibrium can be defined in many ways depending on the perspective of the modeler. One may say that equilibrium is achieved once the simulation stabilizes and no unexpected spikes occur in mean livability or population of a patch. While yet another modeler may consider equilibrium as a state when the livability across all patches in the environment evens out or when the agents stop migrating. While both these definitions may be true, in our case we will consider the former definition.

It needs to be understood that the models created as part of this project may never reach a point where migration in system comes to a standstill. These models expect the population churn to continue to perpetuity. This is more in line with how migration works in the real world. In the real world, migration never really stops. Even if we discount the ongoing wars and other crisis, people will continue to migrate in the hopes of a better future. Thus, migration is an ongoing phenomenon that, at best, can be said to achieve speculative equilibrium.

8. SIMULATING DISASTERS

One of the major problems with the earlier, rather myopic migration theories like the neoclassical approach to migration is that these do not take into account migration as an outcome of a disaster. After all, disasters have hitherto been one of the major drivers of human migration. This chapter talks about the need for studying impact of disasters on human migration, the different types of disasters that a modeler needs to consider, and incorporating disaster simulation in to the model and studying its effects on migration patterns.

8.1 Disasters in the real world and their effect on migration

We live in a rather chaotic world where we get to read about disasters happening all over the world. Case in point the refugee crisis in Europe, the Arab spring, Rohingya crisis in the South and Southeast Asia, numerous African countries ravaged by civil wars, internal migration in tropical and equatorial countries due to floods, droughts, earthquakes, or rising water levels due to climate change.

These disasters have a profound impact on the lives of the people affected by them. It needs to be understood that people don't respond to all disasters in the same way. For example, if people are fleeing persecution in their homeland, their priority is safety and not higher wages. Also, such people usually prefer the nearest, safest place they can reach. This can be seen in the skewed number of refugees fleeing the Syrian war taking refuge in huge refugee camps along the border of Turkey and the Rohingyas of Myanmar fleeing their home country and taking refuge in different parts of Bangladesh and India.

Contrary to this is the case of people living in a drought stricken region. For such people, the threat is imminent but not immediate. Such people usually opt for a place that may provide better economic prospects, and may not score high when it comes to standard of living or infrastructure. Therefore, it is imperative to study the impact of different types of disasters on human migration.

8.2 Modeling Disasters

As we discussed in earlier chapters, the model built as part of this project talks about livability of a patch. Higher the livability of a patch the better the overall quality of life at that patch, and the more lucrative it is to the agents. On similar lines, we can simulate disasters by drastically and suddenly reducing the livability of patches in a particular region.

8.2.1 Types of Disasters

For the purpose of this project, we have classified disasters in 3 broad types:

1. Environmental

Any natural calamity can be considered an environmental disaster: floods, droughts, storms, forest fires, et al. In terms of impact on livability, such disasters would set the environmental component of the livability vector to zero, while leaving other components unchanged. This will help us focus on how the agents in the system respond to environmental catastrophes.

2. Economic

For all intents and purposes, an economic crisis or economic depression can also be considered a disaster. It has been seen that any form of economic crisis forces people to desert regions that were once booming and well populated. For example, the rise and fall of Detroit, Michigan as the home of the U.S. Car industry in the 1940s and 50s to filing for bankruptcy in mid-2013.

Figure 12. Detroit city population growth and decline since 20th century.

3. War

For the better part of last century, war has arguable been the most leading cause for displacing people from their homes. People fleeing war and persecution found shelter elsewhere in the world. This led to major demographic restructuring in some parts of the world.

Back in 1780s-1850, a large number of Irish people fled Europe and settled on the eastern coast of the U.S. These people, having lost their livelihood in Europe, were willing to work at lower wages. This led to a growing anti-immigrant sentiment with people putting up NINA (No Irish Need Apply) signs outside their businesses. But, over time assimilation took place, the eastern coast developed, and now the population of Irish-Americans far outmatches the population of Ireland.

The world wars famously displaced hordes of Jews from Europe to present day Israel and the Americas. The seemingly convoluted conflict in Syria has already displaced millions of people to neighboring countries and different parts of Europe seeking asylum.

Therefore, war is an undeniably important type of disaster that needs to be considered when studying human migration. Unlike an economic disaster, a war has a multi-pronged impact on the livability of the patches. In this simulation model, whenever a disaster of type ‘war’ is triggered, it reduces all the dimensions of the livability of patches in the affected area to zeros.

8.2.2 Disaster Recovery Rates

It is noteworthy that not all disaster takes the same time for recovery. Consider a nuclear reactor leak at Chernobyl, Russia or at Fukushima, Japan. Such disasters take decades for the patch to fully recover. On the contrary, consider the 2007 economic meltdown triggered by the financial institutions on the east coast of U.S. The economy had a relatively speedy recovery since then, and while it may not have bounced back completely, it is arguably in a healthier state thereby making the ‘patches’ in the U.S.

attractive to immigrants from around the world. This goes to show that disaster recovery rates may vary depending on the type of disaster. This model takes this fact into account and provides a slider control to the user to set the disaster recovery rate when creating a disaster in the simulation. Given below is a screenshot of the disaster controls provided in this version of the model.

Figure 13. Disaster controls in the model.

8.3 How to use the disaster feature

As can be seen from figure 13, the user of the model has complete control on the type of disaster she would like to create. The disaster-radius slider allows the user to set the impact radius of the disaster. This helps in studying impacts of smaller, more isolated disasters as well as large scale disasters that drastically impact the overall livability of the region. The on-off switch provided ensures that disaster is only triggered when the user intends to and not every time the user clicks in the simulation *world*. As discussed in the earlier section, *disaster-recovery-time* allows the user to set the number of ticks that the affected region will take to fully recover from the disaster. Finally, the *disaster-type* drop down control allows the user to select the type of disaster viz. Environmental, Economic,

or (for the lack of a better word) War. Figure 14 show the snippet of NetLogo code that triggers the disaster in the model.

```

to trigger-disaster
  let ground-zero patch mouse-xcor mouse-ycor
  set pcolor red

  ifelse (disaster-type = "environmental")
    [ set livability replace-item 0 livability 0 ]
    [ ifelse (disaster-type = "economic")
      [ set livability replace-item 1 livability 0 ]
      [ set livability (list 0 0 0) ]
    ]
  set disaster-recovery-stage disaster-recovery-time
end

```

Figure 14. NetLogo code to trigger disaster of choice.

8.4 Observations

The disaster recovery model was run multiple times for different types of disaster. And, it showed some peculiar behavior based on the type of disaster that was triggered. The observations have been summarized below.

1. If the disaster is triggered in the top-right quadrant, all its neighboring quadrants are affected. But, the greatest impact can be seen on the top-left quadrant (which, incidentally is the second-best quadrant in our simulation, by design).

Figure 15. Plot of mean livability of four regions when disaster is triggered.

As one can see in figure 15, that the mean livability in the first quadrant (show in orange color) takes a hit when the disaster is triggered. The ‘disaster-recovering-time’ set by the user at the time of authoring the disaster determines the width of the gulf created by the orange line in the plot.

2. Another interesting observation that can be made is that even after the patches in the region have recovered completely, many agents choose to *avoid* that region. This leads to a surge in the mean livability of that region (refer fig.14). It is only after the mean livability of that region outstrips the mean livability of other regions do the agents start moving to that region.

9. SIMULATING REGULATED IMMIGRANT FLOW

One very crucial goal of this project was to explore a possibility of creating an agent-based model (ABM) that could help policymakers test the outcome of their policy decisions in a simulated environment. This would enable them to come up with more refined and well-thought-out policies that avoid any kind of unwanted repercussions.

Keeping this goal in mind, the last major feature that was added to the ABM was the ability to restrict immigrant flow into a particular region (for the sake of convenience, the top-right quadrant in the simulation is ear-marked for this feature). The user has been provided with controls to set a cap on the number of agents that can be allowed into this region.

9.1 Nature of Regulations

These regulations were intended to mimic the restrictions imposed by the U.S. government on immigrants who can be classified as blue and white-collar workers in the form of various work visa categories like H1-B, L1-B, etc. This enables the model to simulate the impact of limiting the number of skilled and unskilled workers into a historically high-wage region and its impact on the livability of the region.

This feature provides the possibility of running simulations with immigration datasets provided by the U.S. government. However, simulation with empirical data is currently beyond the scope of this project.

9.2 Observations

Given below are some of the observations of the multiple simulation runs with the migration flow regulated in the top-right quadrant of the simulation ‘world’.

1. When a particular region enforces restrictions on free movement of people, it directly and adversely impacts the region with similar livability conditions first, before having any impact on the regions with not so desirable livability figures. It is only when the livability of this second most popular falls below the livability of the southern regions, that the agents start migrating down south.

Figure 16. World snapshot with migration restrictions imposed.

2. Once restrictions are imposed on movement to a specific region, its livability improves. If the limit on number of immigrants allowed in that region is fair then the livability of this region plateaus at a certain point, well within the range of the livabilities of other regions. But, if the limit on the number of immigrants allowed is extremely low, the livability of the region skyrockets. Also, one interesting observation made here is that the agents already in this region do not migrate to patches outside the region as their livability preferences are met in the current region itself.

Figure 17. Mean Livability plot.

10. CONCLUSION AND FUTURE WORK

In this project, we built an agent-based models (ABM) to study dynamics of human migration. We studied certain peculiar patterns that emerge and how population changes impact the livability of different regions. We also found that livability of any region is strongly influenced by the livability and population in its neighboring regions.

Additionally, we simulated different types of disasters and studied how the agents in the disaster-hit region react to it. Finally, we built a feature to restrict flow of agents in a particular region, and how this restriction affected livability and migration in other regions.

This feature-rich model has great potential to be used by disaster researchers and policy makers to better understand the impact of decisions in a simulated environment.

However, this project relies heavily on using stochastic data over empirical data. This provides an opportunity for interested modelers to take up the mantle to use available migration dataset and fine tune the model by performing validation tests against the observed behavior. It may also interest future modelers to extend the model by increasing the number of dimensions in the livability vector to incorporate attributes like social capital, government transparency, etc.

Finally, the power of NetLogo's network modeling feature [12] can be harnessed to build a strongly associated Network migration model in which every agent that migrations exerts a certain level of pull on all the agents connected to it.

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