

Migration Dynamics in Artificial Agent Societies

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Abstract—An Artificial Agent Society can be defined as a collection of agents interacting with each other for some purpose and/or inhabiting a specific locality, possibly in accordance to some common norms/rules. These societies are analogous to human and ecological societies, and are an expanding and emerging field in research about social systems. Social networks, electronic markets and disaster management organizations can be viewed as such artificial (open) agent societies and can be best understood as computational societies. Members of such artificial agent societies are heterogeneous intelligent software agents which are operating locally and cooperating and coordinating with each other in order to achieve goals of an agent society. These artificial agent societies have some kind of dynamics existing in them in terms of dynamics of Agent Migration, Role-Assignment, Norm-Emergence, Security and Agent-Interaction. In this paper, we have described the dynamics of agent migration process, starting from the various types of agent migration, causes or reasons for agent migration, consequences of agent migration, and an agent migration framework to model the its behavior for migration of agents between societies.

I. INTRODUCTION

An *Artificial Agent Society* [8] can be defined as a collection of agents interacting with each other for some purpose and/or inhabiting a specific locality, possibly in accordance to some common norms/rules. These societies are analogous to human and ecological societies, and are an expanding and emerging field in research about social systems. Social networks, electronic markets and disaster management organizations can be viewed as such artificial (open) agent societies and can be best understood as computational societies. The members of such artificial agent societies are heterogeneous intelligent software agents, which are operating locally and cooperating and coordinating with each other in order to achieve goals of an agent society. Artificial Agent Societies can also be viewed as *normative systems*, as in them, the member agents residing have to obey certain rules/norms which are created and abolished from time-to-time in a society and this process is dynamic in nature. Also, the agents residing in the society, while obeying the norms of the society and in order to achieve their individual as well as societal goals move in/between them, and this movement can be termed as *agent migration*.

A. What is Migration?

A **migration system** can be defined as a set of places linked by flows and counter-flows of people, goods, services and information [12], which tends to facilitate further exchange, including migration between the places. And, according to demographers, every act of migration involves an origin,

destination, and an intervening set of obstacles [15]. The dictionary meaning of word **Migration** according to Oxford on-line dictionary is

Movement of people to a new area or country in order to find work or better living conditions.

Considering its *broader demographic perspective*, the term *migration* [19] can also be defined as temporary or permanent move of individuals or groups of people from one geographic location to another for various reasons ranging from better employment possibilities to persecution. Talking in terms of agents (intelligent/software) in artificial agent societies as mentioned above, *agent migration* can be defined as movement of agents in and between societies to new locations for various reasons ranging from societal, economic, social or personal. Although, this movement is selective, but it forms an integral part of the broader process known as *development* of societies, which itself is a linear, universal process consisting of successive stages [12]. The study of migration is not only confined to social sciences, but it has got with a vast and significant importance in the areas of political sciences, economics, anthropology, biology, psychology and artificial intelligence (computer sciences).

In general, migration is considered as a complex dynamic process and a spatial phenomenon with multi-faceted nature and has its own sophisticated theory and dynamics associated with it. The concept of agent migration has been derived from human or animal migration, because like human or animal migration, it has also got associated with it reasons, circumstances, patterns as well as consequences [19] of/for migration. Therefore, various similarities [3] exist between agent, human and animal migration, which are described below.

1) *Similarities between agent, human and animal migration*: Firstly, both the agent and human/animal migration involve movement in order to migrate, be it in the form of migration in or between societies, and this movement involved in both the cases is linear in nature. Secondly, in the all these type of migrations, a special preparation is initially required for migration, which demands a special allocation of energy from the society. Thirdly, migrating species, whether they are agents, humans or animals, have to maintain a strong commitment to their migration mission or challenge, which is going to keep them undisturbed from all the side temptations. Fourthly, the journey of migration, whether its agent, human or animal migration, has to be continued at all costs.

In the case of human migration, migration can be categorized either as *internal (intra-continental or intraregional)* or *external (inter-continental)* migration [14] [15], talking in

same terms, **Agent Migration** can be categorized [17] either as *internal Migration*, (i.e., Migration of agents between two sites in the same society) or as *external Migration*, (i.e., Migration of agents between two different societies). The human migration is normally referred as *immigration*, which is common term used in *demography*, whereas agent migration should be referred by term, *migration* only. In agent migration, the agent who migrates into a new society will be hence termed as *immigrant agent*, and while it is leaving its society of origin to migrate into another, will be termed as *em-migrant agent*.

In addition, to various similarities between agent, human and animal migration, there exist a number of dissimilarities also, which are described below.

2) *Dissimilarities between agent, human and animal migration*: As explained above, agent and human migration are different with respect to few points also, for instance, agent migration is organized and collective in nature whereas human immigration is disorganized and sporadic. In addition to this, human immigration is downright enigmatic, and this aspect is missing in agent migration in artificial agent societies.

B. Dynamics in Artificial Agent Societies

Artificial agent societies like any other working system have some kind of *dynamics* existing in them, which are in terms of dynamics of *Agent Migration*, *Role-Assignment*, *Norm-Emergence*, *Security* and *Agent-Interaction* [23]. These dynamics are basically changes that occur in the behavioral and emergent properties of the societies due to sensing of a stimulus from an environment as well as due to an external agent, who wants to migrate into the society. Also, these all types of dynamics are in one way or another related to each other as all of them are either directly or indirectly affected by one another.

1) *Migration Dynamics in Artificial Agent Societies*: The member agents residing in these societies keep on moving between these societies from time-to-time in the same manner as human-beings move between human-societies [20]. And, this movement of agents between artificial agent societies is called Agent Migration. And, all the *internal (related to agent)* and *external (societal)* issues related to agent migration are called agent migration dynamics. In this paper, we have described agent dynamics from their each and every aspect as they play a very pivotal role in the shaping of societies throughout their life time.

2) *Why Migration Dynamics*: An agent migration is considered as an integral part of development process [12] involved with the growth of artificial agent societies. Therefore, agent migration is one of very essential part of society dynamics, which has to be studied and worked in thoroughly and very less work has been done in this direction. Also, all the other types of society dynamics, (i.e., dynamics of role-assignment, agent interaction, norm emergence, trust and security) [23] are very closely related to it, as all of them are either directly or indirectly affected by migration of agents in/between societies.

Hence, we have focused our research on agent migration dynamics [27] in artificial agent societies in this paper. Our paper focuses on migration dynamics in artificial agent societies because of agent migration process, specifically external migration process, and we have tried to discuss almost everything

which can be related to external migration dynamics, i.e., its types, reasons, framework, consequences or problems arising because of external agent migration in this article.

This paper is organized as follows. In section 2, we have discussed background work already performed in the area of agent migration. In section 3, we have covered various aspects of migration dynamics in agent societies. In section 4, we focus on the types of agent migration between agent societies. In section 5, reasons for agent migration between societies are stated. In section 6, consequences arising out of this agent migration are presented and in section 7, we have described an agent migration framework to facilitate migration of agents between agent societies. Then, conclusions and future work are covered in sections 8 and 9 respectively.

II. BACKGROUND AND RELATED WORK

In this section, we have tried to summarize various works, which have been performed and are related to agent migration in artificial agent societies. Also, we have illustrated various possible extensions, which can be performed related to them.

The categorization of agent migration has also been performed by Costa et al [17], as *Internal Migration* and *External Migration* where external migration occurs if agent moves between societies and internal migration occurs if agent moves within a society from one site(group) to another. Also, various consequences related to agent migration are discussed by Glaser and Morignot in [9] and Dignum et al in [6], and they are in terms of *reorganization* of societies that takes place, i.e., society in which agent enters, has to modify (means modification of structure of its organization) itself in order to accommodate the agent in society's already existing roles, which are distributed amongst its member agents. Also, the agent which has joined the society needs to adapt itself so as to internalize in the organization of the society, it now lives in. The type of reorganization demonstrated by Glaser and Morignot is *static reorganization* and by Dignum et al is *dynamic reorganization* as in the case of latter, modifications in structure and behavior of an artificial agent society after addition, removal or substitution of an agent are done to the society while it is executing (i.e., without bringing down the system). This particular type of reorganization is in the form of *dynamic adaptation*.

The works presented by above three authors are one of the basic and initial works done in the area of agent migration dynamics, but all these can be expanded also, by adding more aspects and factors to the agent migration dynamics. For instance, the only types of migration presented by Costa et al [17] are internal and external migration, which are categorized taking into consideration only the factor of geographical distance spanned by an agent while moving from one place to another. But, there are many other factors, which can be considered (i.e., circumstances and adaptability) while agent is to move. Similarly, the only consequence of migration is listed by Dignum et al [6] and Glaser and Morignot [9], as reorganization (static and dynamic) of society, which is one of the societal consequences, where as there are many other societal and individual consequences, which can be explored upon, while working with the process of agent migration.

The basic motivation behind the reorganization of society is either increase in the *agent's utility* or the *society's utility*. Utility [9] of society means what society has gained out of reorganization after the new agent has joined the society and in order to evaluate the utility of convention of society, cost of reorganization and utility of existing structure once without the newly migrated agent and then with newly migrated agent is evaluated in the form of a utility function, where convention means distribution of roles between agents of the society. And, if the utility of the society increases with the above agent migration, reorganization and hence agent migration is considered beneficial for the society.

The utility of an agent depends on the roles it desires, the roles it has committed to and the confidence with which it is playing its roles. Normally, an agent chooses to integrate into that society, which increases its utility and in that case agent is beneficiary. And on the other hand, a society chooses to integrate with an agent, that increases the its utility. Initially, an agent joining an agent society will be consulting the institutional layer [5] of the society to commit itself to certain role, which it has to play in a society and in order to see, whether it satisfies the norms and rules enforced in the society by this layer.

The reorganization, which is an after effect of agent migration, (i.e., integration of a new agent with a society), demonstrated by Dignum et al [6] is dynamic in nature. They have classified it into types, i.e., *Behavioral* and *Structural*. *Behavioral Change* occurs when organizational structure remains the same but the agents enacting roles [4] [24], decide to use different protocols for the same abstract interaction described in the structure, in case an agent leaves the society and a new agent joins it. Therefore, it is only the interaction pattern, that has to be modified, but on the other hand in the case of *Structural Change*, a decision is made concerning the modifications of one of the structural elements, i.e., societies adapt to environmental changes due to addition, deletion or modification of its structural elements (i.e. agents, roles, norms, dependencies, ontologies and communication primitives). Therefore, behavioral changes temporary changes in an organization whereas structural changes can lead to permanent modification in the structure of an organization [18].

Two different *issues* related to agent integration to an existing agent society are described by Eijk et al in [7] and they are based upon open-ended nature of agent societies that allows for the dynamic integration of new agents into an existing open system. These issues are distinguished as **Agent Introduction** and **Agent Creation**. *Agent Introduction* is addition of a new agent which is existing outside the society into a society and *Agent Creation* is similar to object creation, i.e., a newly integrated agent constitutes a previously non-existent entity and is created in a society for agents with limited resources who may face an overloading of tasks to be performed by them. Although, this paper significantly contributes to the process of agent migration, by dynamically integrating new agents into an already existing society, by using an abstract framework in concurrent object oriented language called POOL and its various communication constructs, but still the abstract framework present in this paper for agent introduction and agent creation in a society can be expanded by considering various push-pull factors and the behaviors of the agents which are migrating in/between them, and that also, while the society

TABLE I. SUMMARY OF RELATED WORK

Author	Work Direction	Key Points	Possible Extensions
Costa et al.	Migration Classification	Internal and External Migration	Various other categories of migration.
Glaser & Morginot	Migration Consequences	Reorganization (Static)	Various other societal and individual consequences.
Dignum et al	Migration Consequences	Reorganization (Dynamic)	Various other societal and individual consequences.
Eijk et al	Migration Issues	Agent Introduction and Creation	A complete migration framework for agent introduction.
Hafizoglu and Sen	Migration Patterns	Conservative, Moderate and Eager Migration	Various other patterns of migration.

is still in running state, i.e., without bringing it down.

When agents migrate between societies, some patterns emerge for migration and they are illustrated by Hafizoglu and Sen in [13] as *Conservative*, *Moderate* and *Eager* migration. These patterns emerge from opinions or choices of agents to migrate. For experimenting between choices and patterns they have used two-dimensional toroidal grid in which simulation proceeds in discrete time steps with agents having two types of opinions, i.e., binary or continuous. In addition to this, many other types of patterns emerging for agent migration process can be studied, like chain, return or step migration of agents amongst societies/groups.

All the above mentioned related works are summarized in table I, which explains various directions followed by various authors in the area of agent migration dynamics, various findings of these research directions as well as how their work can be extended in order to incorporate new aspects in migration dynamics.

Although, migration of agents between societies is discussed in all the above papers, which we have surveyed in this section from different perspectives, but none of them elaborates on the complete migration framework or protocols, which are required and can be used for migration of agents amongst agent societies, i.e., for organizational migration. Our paper focuses on the elaboration of a complete migration framework, which can be used by agents to migrate from one society to another. In addition to that, various dynamics (as mentioned in table I) and their extended forms, in the process of migration will be discussed one by one, in the coming sections.

III. MIGRATION DYNAMICS IN ARTIFICIAL AGENT SOCIETIES

Agent Migration occurs when an agent moves from one site to another site between a society or an agent moves from one society to another one, that also, physically as well as logically. Agent Migration or the process of entrance of new agent into the society has many issues related with respect to dynamics and structure of an open-agent society (as only in the case of open-agent societies, agents can leave or enter any time). In order to understand properly, all the aspects and

behavior of agent migration subsystem [23], which can be viewed as an interdependent dynamic subsystem with its own dynamics, but is interlinked with other subsystems existing in various societies, feedback and adjustments coming from the migration process itself, a proper detailed study of agent migration dynamics is required and that is the main objective of this paper.

The agent migration can be physical as well organizational, because there is a possibility of agents migrating between platforms and that also may be on different computers or same as well, geographically. Our concern in this paper is, only organizational migration, as in the former case, everything is adjusted by network infrastructure for transportation of mobile agents (which are pieces of software), from one site to another. As, the agents in the case of physical migration (agents are mobile in nature), they find standard environments at every site they visit in addition to standard script interpreters for the execution of code and standard communication constructs. Therefore, they face no such problems during and after the physical migration, which are present in the case of organizational migration. Therefore, our main concentration in this paper is only on *organizational* migration and its dynamics.

Basically, dynamics [25] existing in every system can be classified as either *macro dynamics* (i.e., between various societies or inter-societal dynamics) or *micro dynamics* (i.e., inside a single society or intra-societal dynamics). The aspect of internal migration will be considered under micro dynamics and external migration under macro dynamics in agent societies. External Migration is only possible in open agent societies, i.e., society needs to be open internally as well as externally where as in the case of internal Migration society, it need not be an externally open society. This agent mobility actually facilitates efficient collaboration of an agent with other agents at intra-societal (micro dynamics) or inter-societal (macro-dynamics) level. As, we are concerned only with external migration, therefore, the dynamics studied by us will also be of the type of macro-dynamics only. Related to macro or external agent migration dynamics is the *reasons, types, consequences* and *patterns* adopted for migration. Our paper is dedicated to the illustration of these all dynamics related to agent migration in artificial agent societies, and all of them are covered one by one in the coming sections.

Both internal and external migrations are formally treated as the same kind of processes, since the type of procedures involved are the same. In the case of internal migration, migrating agents will be specialized, non-autonomous agents and in external migration, migrating agents will be fully autonomous agents with full capabilities of their own. The set of external migration dynamics [27] need a multi-dimensional theory and a formulation of proper migration framework. Hence, our main concentration in this paper will be on framework for external migration and study of migration dynamics, because this study have more relevance, when they are considered with respect to external migration. Therefore, all the dynamics related to agent migration, starting from the types, reasons and consequences have been discussed by us in the sections to come. Our next subsection is related to various types of migration, (i.e., migration categorization) in artificial agent societies.

IV. TYPES OF AGENT MIGRATION

Agent migration, as explained above, is similar to human or animal migration because reasons, circumstances, patterns and finally consequences, associated with agent migration are almost same as human/animal migration. Also, Agent migration as inspired from human migration [21] [14] can be classified accordingly into various categories depending upon three factors, i.e., *geographical distance spanned, circumstances and adaptability*. These three factors can be stated as follows, Firstly, from geographical distance spanned, we mean that the actual distance which is covered by agent while migrating from one place to another. Secondly, from circumstances, we mean all the political, economic and environmental conditions which force the agent to move from one place to another in a same society or another society. Lastly, adaptability means ability of agent to cope up with new surroundings and new place, when agent moves there [22]. The society/site of origin from which, agent starts its migration can be termed as **migration source** or **sending society** and the destination society/site to which agent migrates is called **migration sink** or **receiving society**.

The first set of migration categories, which are classified according to *geographical distance* factor are *internal* and *external* migration[1]. Where,

- **Internal Migration** can be defined as migration of agents between two sites in the same society, and
- **External Migration** can be defined as migration of agents between two different societies.

The internal migration in agent societies is similar to intraregional migration in human societies and external migrations in agent societies are analogous to intra-continental and intercontinental (i.e., interregional) migrations in human societies. Therefore, consequences and conflicts arising in agent societies are almost same as consequences and conflicts arising in human societies because of similarities between external and internal migrations in agent societies with inter and intra-regional migrations in human societies.

The second set of migration categories, which are classified according to *circumstances* which lead to migration, they are *forced or involuntary, voluntary* or *imposed* migrations. Where,

- **Forced or Involuntary Migration** can be defined as migration in which agent is forced to migrate from source of migration to another society or site due to certain unfavourable circumstances at the migration source.
- **Voluntary Migration** can be defined as migration in which agent voluntarily migrates to another society or migration sink, due to some favourable circumstances there.
- **Imposed Migration** can be defined as migration in which agent is not forced to migrate to another society but due to persistent unfavourable circumstances at the migration source, agent leaves source.

In the case of forced or involuntary migration, agents are left with no choice, they have to migrate, i.e., leave the society. But, in the case of voluntary migration, which can also be termed as *choice migration*, agents by their own will and wish choose

to migrate from one place to another. In the third case, i.e., in imposed migration, which can also be termed as *reluctant or impelled* migration, agents are not forced to migrate but it is due to persistent unfavourable circumstances, they decide to migrate from migration source. The concept of agent migration is also related to various reasons which are the root cause behind it and hence they become an essential part of agent migration dynamics, therefore, we have dedicated next section of our paper to various reasons leading to agent migration.

V. REASONS FOR AGENT MIGRATION

Agents are also assumed to be residing in communities like human beings that are connected in some known topological structure [13]. There are always certain *reasons* which are responsible for agent migration, for instance, there are always some social functions and resources needed by an agent which are present in some another society [16], different than its source society for performing that particular job. Agents can migrate because of various reasons, i.e., *social/societal, economical or personal/individual*. These reasons are further based on *push and pull factors* leading to migration of agents amongst agent societies [20] [15]. *Push factors are basically positive attributes perceived by agents, existing at the new location*, i.e., new society or new site to which agent is planning to migrate. Whereas, *pull factors are negative home*, i.e., *local site or society conditions that impel the agent's decision to migrate to a new society or site*. These push and pull factors are analogous to push and pull factors that result in human migration and can be categorized according to reasons for agents migration as *societal* push-pull factors, *economic* push-pull factors and *individual* push-pull factors.

The *societal* push-pull factors are combination of negative conditions arising in the atmosphere of source society and positive conditions arising in the destination society, as a consequence of which agents migrate between these source and destination agent societies. They are unequal/unfair role-assignment in the source society and comparatively fair/equal role-assignment in the destination society, ineffective security policies in the source society and effective security policies in the destination society. The unequal role-assignment, in a particular society is one of root causes of net overall migration.

Also, when in a particular society some particular role is required to be played by an agent and the member agents of that society are incompetent to play that role. And, if that society comes to know, that, there is some particular agent in some other society, and it is fully competent to play the required role. In this case, the destination society, which requires an agent, can also request or pull an agent from its source society to play that particular role in the destination society. This pull factor can be considered as societal pull factor from the side of destination society.

The *economic* push-pull factors are combination of economic benefits received in the form of rewards for playing some specific role, which is existing in some destination society to which agent wants to migrate, and they pull an agent from its residential source society to migrate. Also, rewards obtained by agent for playing the same role in its source society will be lesser in amount as compared to rewards for the same role, which it can obtain in destination society. Therefore, this

reward differential will be serving as push factor, which will be pushing an agent to migrate to some other society, where its economic conditions can be better.

The *individual* push-pull factors are combination of individual or personal benefits, which an agent can receive in the destination society to which it migrates. They can be in terms of increased individual agent's utility, autonomy, or role-playing opportunities in destination society as compared to the source society in which it currently resides. This factor is basically related to the favorable conditions, which an agent requires in order to function well in society and in search of these conditions, an agent migrates to that destination society, where these conditions are met.

These push and pull factors, i.e., societal, economic and individual, can also be categorized as *material* and *non-material* incentives related to agent migration, because some of the sub-factors from societal, economic and individual factors [12], result in material benefits/incentives, i.e., can be in terms of economic benefits, whereas others can result in non-material benefits/incentives, which is basically in terms of the chances of self-actualization, for the em-migrant/immigrant agents. After the migration is actualized by an agent or set of agents, (*we are considering here agent or set of agents only because migration is a selective process*), and only those agents who are interested in undertaking this process, participate. The extent of migration amongst agent societies depends upon all these migration push-pull factors listed above.

VI. CONSEQUENCES OF AGENT MIGRATION

There are several *issues, problems* and *consequences* associated with the outcome of agent migration and broadly they can be categorized as issues related to the societies and to the migrating agents. Hence, consequences related to agent migration can be classified as *societal consequences* or *personal consequences*. Here, *Societal consequences* occurring because of agent migration, are *maintenance of functional integrity of a society*, i.e., placing the new immigrant agent in society's already existing social structure [11] whereas personal consequences occurring at the side of *immigrant agent*, are problems of *language and interaction protocols* while conversing with the member agents of the destination society, i.e., the society it has entered into, so that it is considered as a well-behaved agent and problems of *knowledge and performance*, which actually define the ways the agent will behave in order to properly perform the functions (to play the roles) that destination society wants it to perform.

Another set of problems related to an immigrant agent while acting as an em-migrant agent is of helping the society it is leaving, i.e., its source society, to preserve its functional integrity in its absence. An immigrant agent will only be integrating (entering) with a new destination society only if it is sure that it is capable of dealing with the problems that it will face when doing that, i.e., it is prepared to solve problems produced by its entrance or departure. This set of problems can be also considered to fall under personal or individual consequences of agent migration. This section of our paper will be describing all the societal as well individual consequences, related to agent migration.

A. Societal Consequences

Various societal consequences related to agent migration process are:

1) *Reorganization*: The societies of origin as well as destination always have to *reorganize* structurally as well as behaviorally, when the process of agent migration takes between them. These consequences can also be termed as social consequences arising out of agent migration. These consequences result in terms of constructs of *dynamic role-allocation* to immigrant agent in the destination society and *dynamic role-deallocation* and then *reallocation* in the source society in the place of em-migrant agent. This reorganization can be performed using dynamic role-allocation constructs available in the *role-assignment* module or subsystem for source and destination artificial agent societies.

2) *Conflicts*: As a result of agent migration process, conflicts will arise in the destination society, to which immigrant agent has entered, because of its integration. The conflicts arising will be *role-conflicts* and *norm-conflicts*. Role-conflicts arise, if an immigrant agent was allocated some role as em-migrant agent in its society of origin. And, after migration to the destination society, as an immigrant agent, it still wants to play the same role in destination society and in the later, it is not possible. Norm-Conflicts arise, when em-migrant agent moves to some destination society, and there as an immigrant agent, does not want to obey the norms of the destination society, and still wants to remain associated with the norms of its society of origin. These conflicts are only tolerated for immigrant agent, when its integration with the destination society increases the society's overall utility.

3) *Norm Emergence*: As a result of migration of agents between societies, the societies also come closer to each other because, when agents following an altogether different set of norms move between them, then *norm emergence* modules of both these societies will execute their respective *norm recognizer* sub-modules to recognize a new set of candidate norms, which later will be functioning as proper or actual norms in the source and destination societies.

B. Individual Consequences

Various individual consequences related to agent migration process are:

1) *Interaction Language and Protocol Conflicts* : These conflicts arise, when an immigrant agent enters the destination society, and the agent communication language and protocols used in the destination society for agent communication are different from what it was using in its society of origin, and agent is unable to participate in conversations with the member agents of the destination society. In order to resolve such conflicts, language and protocol adaptation at the level of immigrant agent is required in order to adapt already existing communication infrastructure in the destination society. Related to this, very significant amount of work has been performed by Bordini in his doctoral thesis [1] [2], which is dedicated to cultural adaptation being performed at the level of immigrant agents in destination society.

2) *Knowledge and Performance Problems*: These problems arise when immigrant agent in the destination society is unable to perform the role allocated to it in destination society in a proper manner, because of improper knowledge present with it to perform that role. And, if the problem of performance persists for the immigrant agent, the destination society may force an immigrant agent to move back to its society of origin.

The outcome of agent's integration with a society is usually an establishment of a new convention between the members of a society and the newly entered agent, i.e., redistribution of roles, performed by role-assignment module which is assigning or distributing roles amongst various member agents in the society. The end result of migration process is a set of relatively stable exchanges, yielding an identifiable geographical structure [13] that persists across space and time. The details of the behavior of migration process are presented by us in the next section.

VII. AN AGENT MIGRATION FRAMEWORK

Agent Migration is very vital for the development of artificial agent societies, because it is basically agent migration, which will be making the set of existing societies dynamic and in-turn facilitating the movement of agents in/between societies. An *agent migration framework* is vital with respect to facilitation of process of migration of agents amongst agent societies. And, it can be considered to be comprised of a set of societies linked by flows and counter-flows of agents between societies, which tends to facilitate further exchange, including migration between the societies. An agent migration framework in order to facilitate migration in artificial agent societies, requires a migration model [26] which can be used to model the behavior of agents, when they migrate in/between agent societies.

The presentation of migration dynamics [25], is actually involved with modeling migration processes over time, which we have assumed to be comprising of discrete time intervals. An agent migration framework comprises of modeling an agent *migration model*, which in turn uses a *migration function* to facilitate migration of agents from source society or society of origin of agents to destination society. A *migration model* attempts to ascertain the relative importance of various determinants (push-pull factors) leading to migration and also addresses various personal/individual as well as societal consequences resulting after migration. Related to migration model is the term *migration interval*, which is the period of time over which a migratory move is taken by potential em-migrant agents from the source or sending society. This migration interval is also measured in discrete time steps.

The migration model, which we are going to present is an empirical migration model based on combination of gravity model [10] given by Greenwood and social- psychological model of immigration given by Andrew and Zara in [3], and we have given it a name **W5- SGMIM** for *W5 social-gravity migration model* for inter-societal or external migration between agent societies. The characters **W5** which are mentioned in the name of the SGMIM model, are basically **5 W's** (*Who, Why, Where, What and When*) related to the process of migration and they stand for the following information related to migration model for modeling the behavior of migration process amongst agent societies.

- 1) *W for Who?* - Who amongst the set of member agents residing in the society wants to migrate? This *W* is related to the selection of em-migrant agents in the source society, who are to move to destination society.
- 2) *W for Why?* - Why a particular agent or set of agents want to migrate? This *W* is related to various factors or determinants in source and destination societies, that are leading to agent migration from the source society to destination society.
- 3) *W for Where?* - Where do agent(s) want or plan to migrate? This *W* is related to selection of the destination society to which em-migrant agents in source society, want or plan to migrate and act as immigrant agents there.
- 4) *W for What?* - What will be the consequences of this migration? This *W* is related to various societal and personal consequences, which will be resulting out of this migration in both source and destination societies.
- 5) *W for When?* - When do agent(s) want to migrate? This *W* is related to the description of beginning of *migration interval* of em-migrant agents from the source society to move to destination society.

This model is called a social-gravity model because the migration function used in the migration process is based on gravity model [10] of human migration, which is based on modified version of *Newton's Law of Gravitation*, i.e., the attractive force between two bodies is directly related to their size and inversely related to the distance between them. And, the keyword *social* is added, because, it is based on input of a set of social-psychological factors (push-pull factors), which are the basic determinants of the migration process.

A. A Migration Function

Definition VII.1. (The Agents World)

The *Agents World* is a set of societies existing in the world of agents, and is defined as $\mathcal{S} = \{S_1, S_2, \dots, S_n\}$ with a finite number of n societies.

Definition VII.2. (Population)

A *Population* is a set of member agents of any society S_i , and is defined $\mathcal{P}_i = \{A_{i1}, A_{i2}, \dots, A_{im}\}$, with m being finite number of residing member agents in a society S_i .

Definition VII.3. (Roles)

Roles are place- holders assigned to various member agents of the society according to their capability and role-assignment/allocation protocols of the society. They are defined using a finite set $\mathcal{R} = \{r_1, r_2, \dots, r_k\}$, where k , is the number of roles in the role set \mathcal{R} .

Definition VII.4. (Agent)

An *Agent* $a \in \mathcal{P}_i$ is a tuple $a = \langle r_{ia}, u_a, B_a \rangle$, where r_{ia} is the role allocated to an agent a , u_a is utility function of an agent a , and B_a is behavior of an agent a .

The behavior B_a of an agent $a \in \mathcal{P}_i$, where \mathcal{P}_i is the population of society S_i , describes the behavior of an agent from external point of view. This behavior function is a combination of many external (push-pull) factors, which are existing in the source and destination societies. This behavior

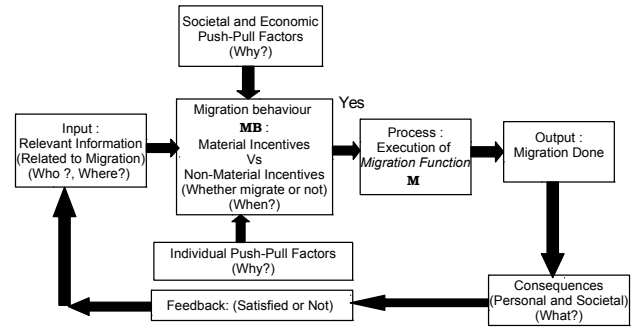


Fig. 1. The Social- Gravity Migration Model

function, acts as very important decision making factor in the migration process in the form of migration behavior function, in our migration model.

The *migration function* leading to the process of migration can be described as:

Definition VII.5. (A Migration Function)

A *Migration function* $\mathcal{M}_{i,j}$ for agent $a \in \mathcal{P}_i$ in source society S_i for migrating to destination society S_j at any time $t \in \mathcal{T}$, where \mathcal{P}_i and \mathcal{P}_j are populations of source and destination society respectively, and $\mathcal{D}_{i,j}$, is distance between them, leading to the process of agent migration amongst them can be defined as

$$\mathcal{M}_{i,j} : (a \times \mathcal{T}) \rightarrow S_j. \quad (1)$$

Here, \mathcal{T} is a time set comprised of discrete time steps, $\{t, t + 1, \dots, t + n\}$.

Also, The Migration Function $\mathcal{M}_{i,j}$ can be written as:

$$\mathcal{M}_{i,j} = \frac{G \mathcal{P}_i \mathcal{P}_j}{\mathcal{D}_{i,j}^2} \quad (2)$$

Where G is constant. and $\mathcal{D}_{i,j}$ is distance between the two societies S_i and S_j and it is measured in terms of number of hops agent has to take to move from one society S_i to S_j .

The above relationship states that *migration function* is directly related to the populations of source and destination societies' population sizes and inversely related to square of distance between them.

B. A Migration Model

The *social- gravity model*, which has been framed by us for the modeling the behavior of migration process occurring between societies, is a multi-dimensional model based on the concepts of system modules of "input, process and output" as described in Figure 1.

- 1) **Input** : comprises of relevant information related to the agent or set of agents who want to migrate from their society of origin to some other society of destination. This information also contains the name

and location of the destination society or societies to which agents wish to migrate. Therefore, all the information related to the “Who?” and “Where?” part of migration process is provided in this module of migration model. This input information launches the individual agent’s decision making process, which is known as *migration behavior*, which is going to help agent decide, whether to migrate or not, hence serving a stimulus to migration process.

- 2) **Migration Behavior** : comprises of the decision - making part and behavior of agent(s), who want to migrate from their society of origin into some other destination society, and this behavior is affected by societal and personal push- pull factors existing in the source or origin society. In this module, all the *material as well as not-material benefits* related to migration process, are compared with costs which will be incurred for migration, and it is decided by agent, that “When?”, it is going to initiate the process of migration. If everything goes well, and benefits overweigh the costs incurred for migration, then agents initiate the migration process, other wise no migration will be performed and the process of migration will stop altogether.
- 3) **Process** : is the module in which migration process is actually realized, and the agent from its society of origin is relocated to the destination society, it has wished for. The theory for the migration function has already been described in the previous subsection by using equations 1 and 2.
- 4) **Societal-Economic Factors** : comprise of all the societal and economic push-pull factors existing in source and destination societies, which become very genuine causes and reasons for agents to migrate between them and become very vital “Why?” part of migration process. They have already been explained in the section dedicated to them. They help agents to evaluate the *material benefits*, which can be realized from agent migration process.
- 5) **Individual Factors** : comprise of personal push-pull factors existing in source and destination societies, which lead to agent migration. These factors also comprise “Why?” part of agent migration process and help agents evaluate all the *non-material benefits*, which can be realized from agent migration process.
- 6) **Output** : is the outcome of the process of migration, in which agent from its society of origin gets relocated to the destination society, it has chosen as migration sink.
- 7) **Consequences** : are various after effects related to the process of migration, which can be categorized at both societal and personal levels of source and destination societies and the agent(s), who have migrated between them. They form “What?” part of the agent migration process. All the consequences related to agent migration process have been already illustrated in the previous section, which was dedicated to their description.
- 8) **Feedback** : consists of the individual agent’s level of satisfaction or dissonance, after it has migrated to the destination society and have become aware of the consequences resulted from the migration process.

This is fed to the member agents of source society, in order to formulate their decision to migrate from the same to any destination society.

The *migration behavior* **MB** can be stated as

$$\mathbf{MB} = f(\mathbf{RI} + \mathbf{SE} \text{ factors} + \mathbf{Individual} \text{ factors}) \quad (3)$$

where **MB** = migration behavior,

f = is a function of (i.e., result of certain variables and factors),

RI = Relevant Information or input variables,

SE = Societal and Economic Factors,

and **I** = Individual Factors respectively.

The migration model, which has been described by us, is based on migration behavior, which is derived from behavior of an agent, and the migration function, which is facilitating the migration process. There are three parties involved in migration process, i.e., an agent, the society of origin, and the destination society. All three of them help stimulate the process of migration and perpetuate it.

VIII. CONCLUSIONS

In this paper, we have presented, almost all the dynamics related to agent migration process (specifically organizational and external migration process), in artificial agent societies, which have not yet been covered under the dynamics of artificial agent societies. As, mentioned in the related work section, many authors have presented their work on agent migration, but none of them is providing deep insight into the dynamics of agent migration process. All the dynamic aspects which are discussed by us for agent migration are inspired by the dynamic aspects of human migration, as both of them have quite a number of similarities. We have elaborated on various types of agent migration, various causes which lead to agent migration between artificial agent societies and various after effects or consequences of agent migration also. Also, we have formulated in this paper, an empirical agent migration model, i.e., W5 Social-Gravity Model, to model the complex behavior of multi-dimensional, dynamic migration process, which is responsible for moving agents from their society of origin to any other destination society. This migration model uses a two functions, i.e., migration function and migration behavior function for modeling the spatial phenomenon of agent migration process. Also, all the five (5) W’s (Who?, Where?, Why?, What?, When?), related to the migration process have described in this model by using its various modules which are based on system’s concept of operation.

IX. FUTURE WORK

In this paper, we have covered various types, causes and consequences related to agent migration process and have formulated a 5W Social-Gravity model for agent migration process also, which is used to model the behavior of complex agent migration process for the migration of agents between societies. Although, we tried to cover many aspects of dynamics of agent migration process in our presented literature, but still many aspects such as discussion of migration metrics (which

will illustrate the number of agent migrating into and out of the source and sink (destination) agent societies and hence, measuring the net and gross migration of the society can be taken up as future research directions. And, migration protocols, which will be governing the migration process in agent societies can be framed. The discussion of various types of patterns of migration, the concept of re-migration process and emergence of migration norms, can also be considered as few of the future research challenges in agent migration process.

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