TOWARD A UNIFIED APPROACH TO MODELING AND COMPUTER SIMULATION OF SOCIAL SYSTEMS

Part I: Methodology of Model Construction

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ABSTRACT

Can we rely on a model to understand social phenomena? A reliable model is a necessary step to simulate social systems, and reliability should be discussed through all levels of modeling. There are three levels of modeling: conceptual, specification and computational. A conceptual level describes the model at a high level. Since reliability is an important aspect of modeling, it should be addressed first on a conceptual level. This paper proposes a theoretical foundation of a unified approach to conceptual modeling of social systems. From the description of the phenomenon, we construct a system that can be used to simulate behavior. The construction follows a systematic procedure to build a complex social system model from basic elements. The dynamics of the complete system is an outcome of the interacting dynamics of the system components. To complete the model the rules of interaction of the system components and the laws that govern the dynamics of each element as well as the entire system must be described. The structure and dynamics are described using the methodology of control and games theories. Reliability, then, is discussed from the suitability of structure and laws to code the social phenomena. This paper consists of three parts. Part I outlines the theoretical foundation of the unified approach of model construction, and research areas for coherent molding of the complete system. Part II shows how much of the published research can be viewed from this unified approach viewpoint. Reliability is associated with the ability of a model to simulate real social phenomena. The application of the approach to specific examples shows how it can be developed from a simple model to a complex one by including more real features that make the model more reliable. Part III outlines simulation issues of elements, subsystems and systems and how to integrate the simulations of elements into the simulation of the system. Part III also, presents research areas in the field of computer simulations.

1. INTRODUCTION

Many research efforts have been directed towards investigating social phenomena by using modeling and computer simulation [1]- [16]. This new field of social studies has produced many concepts and definitions like artificial societies, a multi-agents system model, social simulation, emergence theory, connectionist theory [11] and others. Examples of modeling include academic science structure [2], marriage system [14], segregation problems, socio-economic phenomena [4], and other studies [1, 3, 5-13, 15]. In an effort to view the different models and methods in a global view, this paper uses a systematic approach to model social systems. Models of social systems should be developed at three levels: conceptual, specification and computational. The development of a model at the conceptual level involves describing and understanding the model at a high level. The specification level of a model incorporates variables, equations, algorithms and logic to describe the model in more detail. The computational level of a model is characterized by the actual implementation of the model as a computer program [16]. This paper focuses on the first level.

2. FROM OPTIMAL CONTROL AND GAME THEORY TO SOCIAL SYSTEMS

A social phenomenon is treated as a system problem. A social system is synthesized by the construction approach, which is used to build the social system from basic interacting elements. Concepts and tools from control engineering, game theory and operation research are utilized to formulate the problems of social modeling.

2.1 Optimal Control Theory

The state of the control system can be determined at any time by state and control variables X and U. X is an n-dimensional state vector and U is an m-dimensional control vector. Laws, physical or chemical, when applied to the system, using control and state variables, produce mathematical equations of the system dynamics in the form:

$$DX/dt = f(X, U, t) \quad \ldots\ldots (2.1)$$

With initial condition X (to). These are n equations in n+m variables. To solve the problem we need additional m equations. The additional equations can be derived using the optimization method to extermize a specific performance index I:

$$I(U) = I_o + \int L(X, U, t)\, dt \quad \ldots\ldots (2.2)$$

The problem in control is to determine the evolution of control U and the state X so as to maximize or minimize I (U) and satisfy the constraints (dynamics) of the system. The feedback solution to this problem is given by

$$U = U(X, t) \quad \ldots\ldots (2.3)$$

In general, a measurement relation measures the state variables through another set of variables Y. This relation is given by:

$$Y = G(X, U) \quad \ldots\ldots (2.4)$$

This equation must be taken into consideration in computing the control and state vectors at any time. Block diagram and flow chart representation of dynamics is useful to implement solution methods and algorithms for simulation

2.2 Game Theory

Game theory is a mathematical theory that deals with the general features of competitive situations in a formal and abstract way. It places particular emphasis on the decision-making process of adversaries. There are different types of games: two-person zero-sum game with finite or infinite number of strategies. There are also games of n-persons with zero-sum either with finite or infinite strategies. Much of the research on game theory has been on two-person zero-sum game. These games involve only two players (who may be armies, teams, firms, and so on). They are called zero-sum because one player wins whatever the other one loses, so that the sum of their net winning is zero. The basic characteristic of a game model is given by:

1. The strategies of player I
2. The strategies of player II
3. The payoff table (or matrix) or utility function.

A strategy may involve only a simple action. In more complicated games it involves a series of moves. A strategy is a predetermined rule that specifies completely how one intends to respond to each possible circumstance at each stage of the game. Before the game begins, each player knows the strategies available to himself, the ones available to his opponent, and the payoff table. The actual play of the game consists of the players simultaneously choosing a strategy without knowing their opponent's choice. The payoff table usually is given only for player I because the table for player II is just the negative of this one, due to the zero-sum nature of the game. The entries in the payoff table, may be in any units desired such as dollars, provided that they accurately represent the utility to player I of the corresponding outcome. A primary objective of game theory is to develop rational criteria for selecting a strategy. This is done under the assumption that both players are rational, and that each will uncompromisingly attempt to do as well as possible, relative to his opponent. This is in contrast to decision theory, which essentially assumes that the decision-maker is playing a game with a passive opponent- nature- which chooses its "strategies" in some random fashion. Instead, game theory assumes that both players are actively trying to promote their own welfare in opposition to that of the opponent.

Game theory is not limited to this kind of game, there are several more complicated types of games. One such type is the n-person game, where more than two players may participate in the game. This is a particularly important generalization because, in many kinds of competitive situations, there are more than two competitors involved. This is often the case, for example, in competition among business firms, in international diplomacy, and so forth. Another generalization is the nonzero-sum game, where the sum of the payoffs to the players need not be zero. This reflects the fact that many competitive situations include noncompetitive aspects that contribute to the mutual disadvantage of the players. For example, the advertising strategies of competing companies can affect not only how they will split the market but also the total size of the market for their competing products. Since mutual gain is possible, nonzero-sum games are further classified in terms of the degree to which the players are permitted to cooperate. At one extreme is the non-cooperative game, where there in no preplay communication between the players. At the other extreme is the cooperative game, where preplay discussion and binding agreements are permitted. For example, competitive situations involving trade regulations between countries or collective bargaining between labor and management, might be formulated as cooperative games. When there are more than two players, cooperative games also allow some or all of the players to form coalitions. Another extension is the class of infinite games, where the players have an infinite number of pure strategies available to them. These games are designed for the kind of situation where the strategy to be selected can be represented by continuous decision variables. For example, this decision variable might be the time at which to take a certain action, or the proportion of one's resources to allocate to a certain activity, in a competitive situation ([17], [18], pp. 280-295). This last aspect leads us to decision theory.

2.3 Decision theory

Individuals and groups within a social environment receive information, interpret it, select the relevant information, decide and take action to implement their decisions. Decision analysis gives a framework for making decisions when experimentation is infeasible and experimentation is possible. Statistics is a science that deals with making decisions from observed data in the face of uncertainty. Some social elements select their strategies and takes action using decision analysis.

2.4 Reliability

Reliability is the probability that a device performs adequately over a specified interval of time. The device under consideration may be an entire system, a subsystem, or a component. Although this definition is simple, the systems to which it is applied are generally very complex. In principle, it is possible to break down the system into black boxes. Mathematical models of the system can then be abstracted from the social processes and the theory of combinatorial probability utilized to predict the reliability of the system. The black boxes may be independent or dependent upon, each other. The reliability of models must be taken into consideration when investigating social systems.

2.5 Graph Theory

This area of mathematics can be used to describe the social network. This tool is very useful to represent the structure and communication of a social network. A social network is an important factor that helps to understand the influences of information, connection and power on the workings of the social system. Block diagrams, feedback links and graphs are used to represent the social system models.

3. A SUGGESTED METHODOLOGY FOR A SOCIAL SYSTEM

A social phenomenon is studied as a social system. The social model is constructed by utilizing control and game theories. Modeling relies on the structure and the dynamics of the system. A social system structure is constructed through the specifications of a set of rules. Rules of structure show how elements are combined to form a group as a system and the formation of a social network of systems and units. Individuals are the basic building units of the social system structure. Social Dynamics follows another type of laws and rules. It is assumed that the behavior of a system and its units, as natural entities, follow certain laws. These are the laws that describe the social processes and social behavior for each element and aggregation of elements. These laws must be discovered from the society. In addition to the social laws there are rules that describe the interactions among various units, rules of interpretation of signals, rules to select strategies and rules to implement actions. To model social systems properly, to study reliability, and check the validity of models, all these rules must be considered. Basic ideas and concepts, from optimal control theory and game theory will be extended and combined to model a social system.

4. DEFINITIONS

To model the system on a solid theoretical foundation, the terms and concepts used must be well defined in correspondence to definitions in engineering, mathematics and physics. Examples are: social system units, subsystems, systems, social networks, structure of the social system, concept of law within social context, types of laws, dynamics and social processes, social change, social control, social force, social distance, social field, social power, model, state and control variables, equations, time delay, environment and situation, goals, interest and performance index. There are many definitions in the literature that need to be measurable (procedural) definitions.

5. HYPOTHESES

The dynamics of a social system, to produce a social phenomena, must take into consideration the laws, constraints, goals, interests and control of system units. Therefore modeling is based on the following hypotheses:

H1. Modeling: Different aspects of social phenomena can be studied from system perspectives.

H2. Correspondence of Concepts: Concepts borrowed from control theory, dynamical system, physical sciences and game theory can be extended and applied to social systems.

H3. Structure: The structure of a social system follows the composition hierarchy from the system's units to subsystems to systems. The basic elements of the system are individuals. The system is a collection of ideas and individuals linked together in a certain way. The systems interact within a certain environment.

H4. Social network: Social networks influence the behavior of elements, subsystems and systems. Communication, languages and interpretations affect the working of social networks in a feedback manner.

H5. Laws: The behavior of each element changes with time and follows certain laws. To include many real features of a society, the laws that describe the element behavior and interaction should be discovered from real societies. Change of the system from one state to another state is a process. Social processes follow specific laws. The dynamics of a social system follows two types of laws universal laws and local or special laws. Universal laws are similar to universal laws in physics (Newton, Einstein, etc.) which relate forces, energies and fields to changes in the physical states. Universal social laws relate rate of changes of social states to changes in social forces, social fields and social control. On the other hand, local or special laws relate social processes to specific types of forces and fields which depend on the environment, culture and values (examples are norms, commitments, obligations, rights, permissions, responsibilities, etc.) Special laws are considered as local rules of action. Laws, from a control point of view, are the constraints that must be satisfied to produce the social phenomena.

H6. Dynamics of a social system: The behavior of a system as a whole does not follow all the laws of its units. The laws of the global behavior emerge as a result of the interaction of many local laws. The dynamics of a system is the result of the interaction between structures, the elements' chemistry, the laws of the system's units and social networks. To simulate the dynamics we need to specify the situation, which is equivalent to initial condition in optimal control problems, and the environment, which is equivalent to boundary condition. In this respect, environment reflects the effects of the social field.

6. CLASSIFICATION OF SOCIAL SYSTEMS ACCORDING TO THE STRUCTURE

A social system is constructed from basic elements and the aggregation of elements. Instead of using micro and macro terms, we suggest using units, subsystems and systems as our terms. These units may be individuals or groups. Basic elements are individual (I). From basic elements we construct social units (G). A subsystem is a collection of linked units. The system (S) may be constructed from basic elements, units and subsystems. A block diagram of the system is used to represent the dynamical connections between different elements of the system. A social network is used to represent the communication of information. Ideas, theories, doctrines and postulates are considered as rules that motivate actions of the system units.

7. CLASSIFICATION OF SOCIAL SYSTEMS ACCORDING TO THE LAWS

Depending on the nature of laws of structure and dynamics, social systems are classified as artificial, organized or planned and natural systems.

Artificial
The laws/rules are rational or logical with pre-assigned meaning. The action and reaction are simultaneous without delay. There are no ambiguities in the interpretations of these rules. Researchers who study artificial society impose these rules. Examples are virtual societies for research as artificial societies using multi-agents.

Organized
Managers and planners of institutions, organizations, parties, or companies formulate the laws/rules according to a design or plan. They are man-made systems following bylaws and constitutions. Examples include parties, companies, banks, and sports team.

Natural
Laws/rules have rational, irrational and emotional features. Rules/laws evolve with time, education and experience. These social systems form naturally without intentional planning. They do not follow prior planned rules, bylaws or constitutions. Examples of normal societies are tribes, families and languages.

The system as a whole follows rules that control the behavior of the interaction of all elements. Units of the system may follow different rules. Flow charts are used to see the successive actions of different units.

8. MODELING SOCIAL SYSTEMS

It is assumed that a social system works conceptually as an engineering system. We can view a social system as a control system with active or null control (strategies). In this respect we can apply the concepts of optimal control, game and decision theories, as outlined above, and use their tools to model a social system. Social phenomena are very complicated and societies do not work like engineering systems.

Features of Social Systems

Social systems do not follow strictly logical and rational rules. Their behavior is constrained with restrictions. These restrictions appear in the laws and rules that determine the dynamics of the social system. These correspond to the constraints in optimal control theory. Within this framework they represent norms, values, commitments, obligations, rights, permissions, responsibility, etc as imposed on the social system. These exhibit the effects of culture on local laws and norm, which can not be neglected. Also, education, experience, interpretations of laws and rules must be taken into consideration. As a system, there are laws and constraints on the social element as well as rules and restrictions on the institution or organization. The goals of each are not always the same. Goals, rules and norms of a system as a whole and its units are not necessarily consistent. Controls are employed to achieve goals or interests of elements as well as the entire system. Conflicting goals of elements of the society and the society is a common feature. Not all elements of society are equal in their effects on the social dynamics. In general, few persons have strong influence. Examples can be cited from banks, armies, companies, parties and families. Each element has a partial knowledge about the goals and rules of actions of other elements. Interpreting the language, selection of specific meaning and taking action all these depend on understanding the meaning embedded in the language. Rules of communication and interaction of language between different elements of the system must be considered.

Life is full of conflict, competition and cooperation. Numerous examples involving adversaries in conflict include parlor games, military battles, political campaigns, advertising and marketing campaigns by competing business firms, and so forth ([18], p. 280). Noncompetitive examples can be cited from families, fraternities, clubs and tribes. A basic feature in many of these situations is that the final outcome depends primarily upon the combination of strategies selected by the adversaries. The aspects of game theory appear within this context. For modeling purposes we need to extend and combine the basic ideas from the optimal control and game theories to model social systems. In addition to these two main fields we need to add the fields of decision theory, graph theory and reliability. In this respect the terms and definitions used in these scientific fields must be used in an appropriate way to tackle social phenomena.

9. FORMULATION OF THE SOCIAL SYSTEM PROBLEM

The social phenomenon is described as a game with n connected systems or players. Each player has interests and strategies to achieve his goals. There are laws and constraints that limit the state and control of each system or unit. Each system selects strategies to maximize his interests (sometimes minimizing the interests of others). In so doing a system uses certain power. Social networks are a part of the power resources that assist in control and implementation of strategies.

Communication affect action through interpretation and ambiguities. Thus, to model the social system we need to describe the following:

1. Number of systems
2. Number of state variables of each system
3. Number of control variables or strategies of each system
4. Universal laws, if any
5. Local laws that describe system dynamics
6. Payoff matrix, utility functions or performance indices of each system
7. Type of the game (competitive, noncompetitive and degree of cooperation)
8. Knowledge of other systems interests and laws (no, partial or full knowledge)
9. Environment of the game
10. Situation necessary to activate the behavior
11. Resources to implement controls and the practical means of implementation
12. Effects of social networks, communication and interpretation on resources and actions
13. Effects of learning, education and experience on evolution of state variables

One-unit Social System

A one-unit system may be used to represent an individual (man or woman) or a group of individuals. If the system is a basic element (man or woman) then it represents the individual characteristics, intelligence, his/her social laws and goals. If the system is a company, team, bank or tribe, then we can use the one-unit system to study the internal workings of the organization or institution. Since humans are social beings it is necessary to add other individuals to study social behavior. Two-unit systems can be used to study the interaction of individuals or groups in a given type of a game. The one-unit system can be used to investigate an individual's psychology, his interaction with society, his cognition abilities, his influence on a society, and the individual's chemistry as an aspect that gives measures of his sensitivity to other members of a society. Also, creativity how he/she generate ideas and theories. To model the one-unit system we need to specify the structure (I or G), state and control vectors, the dynamics of the basic element through universal laws and local laws. Local laws or rules are the constraints (norms, values, obligations, etc.). Other aspects of modeling include interests of the system and its influence on behavior; effects of situation, environment, communication and interpretations on interaction with others to achieve goals; critical conditions and sensitivity to initial conditions or situation and the field or environment; learning experience and how it modifies laws and interpretation; the time delay between action and reaction.

Two-units Social System

This is the first practical social system. We have two units S1 & S2 as shown in the figure. Since this model is a special case of a multi-unit system, we go directly to the general case.

Multi-units Social System

Let us assume that we have N systems: S1, S2, …., SN. Each system is described by state and control vectors: X1, X2, X3…, Xn and U1, U2, U3,…, UN. Each system has constraint R1, R2, R3,..., RN. Also, The interests of the system are I1, I2,…, IN. The dynamics of the system is given by applying the laws on the variables. These will result in a set of differential equations, f1, f2, f3,…, fN. For certain environment and given situation the equations describe how the variables evolve with time for certain types of games. To solve the equations controls are needed to satisfy the dynamical equations and the constraints. Controls are determined to maximize or minimize specific performance indices. It is instructive to use block diagram representation of the multi-units system and a graph to represent the social network. This will be done in part III.

Mathematical formulation of multi-units social system problem
For a given type of the game find the evolution of the state and control vectors that satisfy the differential equations and constraint while maximizing the respective performance indices.

10. SIMPLE EXAMPLE

Let us model a man and woman relation. The problem is formulated as follows:

Number of systems: two
State variables: Xm and Xw
Control variables: Um and Uw
Objectives: Im and Iw
Type of the game: Love affair (cooperative game)
Universal laws: Rate of change in their relation is proportional to their states and controls.
Local laws or constraints: Rm and Rw
Environment: The social field effects at a specific place
Situation: initial condition when man met the woman

This is a two-unit system, each unit has goals, interests and constraints. Each one follows laws consciously or unconsciously. These laws depend on culture, experience and level of education. The state vectors that specify the man and woman's behavior toward each other at any time (t) are Xm and Xw with dimensions Nm and Nw respectively. The control vectors of man and woman strategies are given by state vectors Um and Uw with dimensions Mm and Mw respectively. The dynamics are given by

dXm/dt = fm(Xm, Xw, Um, t), given Xm (to) ……………………………………………….….(10.1)

dXw/dt = fw(Xm, Xw, Uw, t), given Xw(to)…………………………………………….…(10.2)

These are Nm + Nw equations in Nm + Nw + Mm + Mw variables. The man and woman select the control variables or strategies to achieve their objectives. Each one has limitations or constraints to his/her behavior; these can be represented by a set of rules Rw and Rm.

Rm = Gm(Xm, Xw, Um, Uw, t)……………………………………………………….....…(10.3)

Rw = Gw(Xm, Xw, Um, Uw, t)……………………………………………………………(10.4)

The objectives depend on the case under study. Let Im1, Iw1, Im2 and Iw2 represent the man and the woman's interests. The subscript 1& 2 refer to short term and long term interest such that

$Im = Im1 + Im2$ ………………………………………………………………………..………(10.5)

$Iw = Iw1 + Iw2$ …………………………………………………………………………(10.6)

The differential equations (10.1) &(10.2) give the states of man-woman at any time. Man and woman select their strategies Um and Um to maximize their interests Im and Iw (10.5) &(10.6) and to satisfy a set of rules Rw and Rm (10.3)&(10.4). The evolution of their behavior depends on the environment and the situation. The second step, after formulating the problem using game and control theories, is to study the effects of communication, social network on selecting and implementing strategies of each to achieve his/her goals. As an example the variables (Xm and Xw) in the case of a love affair are intimacy, passion and commitment ([21], pp. 95-113), in this case the number of variables are three for each. Objectives of the men and women regarding love are different; examples of their goals are discussed in [20]. A very simple case of linear systems with two variables and without control or performance indices are discussed and solved by Strogatz ([19] , pp. -].

11. STEPS TO MODEL SOCIAL SYSTEM

The first step is the selection of a social phenomenon and investigating the feasibility to transform it to a system. The modeler then identifies the system's basic elements and uses it to synthesize the system's structure. Next he describes the behavior by statistical or deterministic descriptions and assigns the state and control variables. Measurements of states and controls through measurability relation are investigated. The most difficult step is finding the universal and local laws to formulate the equations and the rules of action. To complete the model description the type of game, the performance indices, the environment and situation must be given. Solution methods are employed to find the control variables or strategies to achieve the required performance. The decision to take action depends on the limitations due to resources and influences of social networks. Simulation is the final step in which one must simulate each unit separately and study effects of changing local laws due to experience and learning. It is also necessary to investigate the effects of environment and situation and how this is reflected on control. Finally a procedure to integrate the working of subsystems in an algorithmic way to model and simulate societies or the entire structure is essential. A flow chart shows these steps.

12. THE UNIFIED APPROACH AND COMPUTATIONAL SOCIETIES

By using the methodology of this paper the terms used in the literature of computational societies (multi-agents, norms, institutions, emergence, connectionist model, etc.) can be related to system units, strategies, laws, constraints, interests, field, force, and other game and optimal control definitions. Also, many problems of individuals, groups or ideas can be viewed using the unified approach. The concept of statistical averages in physics and thermodynamics that relate micro to macro physical phenomena may be utilized to explain emergence theories.

13. THE UNIFIED APPROACH AND SOCIAL SCIENCES

Many aspects of social sciences (Sociology, psychology, political science, economics, history, language, culture, etc) can be viewed from system perspectives. Ideas, theories, ideologies, doctrines, etc. can be formulated using the system approach. The main point of view is that actions, reactions, theories, ideas, etc. all are the creation of individuals. Few individuals and organization have a major influence in changing the social environment.

14. PROBLEMS AND RESEARCH AREAS TO MODEL SOCIAL SYSTEMS

The ultimate goal of the unified approach is to use it to advance social science to a level equivalent to the level of physical and engineering fields, using mathematics and computer tools to quantify the social phenomena. To do that, a research program is needed to cover all aspects of the unified approach as outlined above. Research topics include: 1) checking the validity and limits of the Hypotheses H1-H6. 2) discovering the social universal laws. 3) finding the local laws (for marriage case see [14]) and main laws of human interactions. 4) classifying local laws, in specific categories, according to social phenomena and culture, planning to have knowledge banks of the local laws of different cultures (similar to encoding of DNA in Genetics). 5) Classifying interests and different social goals [20]. 6) Constructing social systems using basic elements. 7) Using construction approaches to list interests and goals from basic limited human needs. 8) Defining variables to be measurable ([21] pp. 95-113). 9) Finding the rules of formation of social networks and their influences. 10) studying effects of communication, languages and ambiguities on social actions. 11) Developing a theory of interpretation and connectionist models. 12) relating the emergence theory to the concept of universal and special laws. 13) studying effects of experience, learning and education on interpretation, restriction, norms and values. 14) how to include the partial knowledge of the social elements about the laws and interests of other elements in the model. 15) quantitative definitions of Social processes, social controls, variables, types and social mechanisms. 16) Rules of forming many elements' ties, and relations of different elements. 17) Chemistry of interaction and social relations. 18) Social network and information transfer among social element and its effect on the coherent structure of the society.19) Sensitivity social dynamics to initial conditions or situations and environment. 20) Effects of conflict of goals and interests on the dynamics of the social system. 21) developing techniques to solve the problem on the computer. 22) constructing modules to model and simulate different aspect of basic element or subsystems for different social aspects. 23) developing a scheme to integrate the modules to investigate evolution of behavior and study social change

15. CONCLUSIONS

Effort is directed to design a research program to study in a systematic way the modeling and computer simulation of societies. This research activity is a step in the transition from simulating artificial societies to simulating natural societies and to setting the stage for investigating the reliability of social modeling. Many research works (from the literature) can be viewed using the unified approach. In the next part we will select many pieces of researches (from literature) and show how it can be viewed from the unified approach. Research is needed to show how to solve the problem as formulated in this paper and to outline systematic steps to simulate social systems as an integration of various modules representing different aspects of the system. These will be dealt with in coming research.

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