Standardization for Agent-based Modeling in Economics

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Comments are welcome!

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Abstract

By combining the general characteristics of economic system and economic agents with methodologies of multi-agent system analysis and development in the scope of software engineering and computer science, this work proposes an integrative framework that provides standardization for agent-based modeling in economics. This framework serves as a standard for analyzing from 'bottom-up' the economic system that embeds with the properties of complexity in structure, heterogeneity in agents' beliefs, and interactions among agents' behaviors. It serves as a guidance on designing a standardized agent-based model for economic system. This standardized agent-based model works as the system model of economic system that can be used and reused among interdisciplinary research across economists and computer scientists.

Keywords: agent-based modeling, economic system, software engineering, complexity, standard.

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1 Introduction

Agent-Based Modeling (ABM) refers to studying the behavior of the whole system by computerized simulation of heterogenous interacting agents. Applying this methodology in economic research is particulary concerned with the strand of agent-based computational economics (ACE), see (Tesfatsion, 2006). It emphasizes on understanding economic system from 'bottom-up', considering the macro behavior of economic system rooted in the interaction of heterogenous economic agents.

When ABM went on stage of economic research, it was considered as a supplementation of the 'mainstream' economic research that heavily relies on formal models developed deductively by the toolkits of mathematical analysis. The ABM methodology has been applied in virous field of economic research, see (Tesfatsion & Judd, 2006) for a comprehensive survey and review of the development of ABM in economic research before the recent financial crisis at 2007, which includes the topics in network economics, social dynamics, financial markets, industrial organizations, and market design.

The impotence of the 'mainstream' economic models in forecasting the recent financial crisis starting at 2007 and its failure afterwards in deriving effective policy to drive the economy out of the Great Recession rouse policy makers and economic researchers to consider seriously the limitation that 'mainstream' economic models heavily rely on the assumption of representative agents, rational expectations, and market equilibrium such that these models are highly irrelevant to real world, not mentioning these models ignore or simply exclude the situation that market is far away from equilibrium or in crisis. See, for example, the comment in (Trichet, 2010) from policy maker and (Stiglitz, 2011) from academia.

Given its 'bottom-up' nature that potentially supports studying economic system with large market fluctuation driven by interactions of heterogenous economic agents, ABM economic research has attracted substantial attention and promotion in economic research agenda. A number of research projects have received support in applying ABM toolkits to study economic phenomena which 'mainstream' economic models are incapable of analyzing. As a consequence, increasing volumes of literature in ABM economic research emerge, e.g., see (Gallegati *et al.*, 2011), (Stiglitz & Gallegati, 2011), (Battiston *et al.*, 2012a,b), (Caccioli *et al.*, 2012), (Delli Gatti *et al.*, 2012), etc. It has reason to believe that ABM economics is expanding as an important branch in economic research.

The current ABM economic research follows a general procedure, illustrated in Figure 1. It starts with economists applying ABM methodology to develop an agent-based model that depicts the economic system and its dynamics through the interaction among economic agents. Then economists send the agent-based model as a blueprint to computer programmer to develop the computer software system for simulation. On request, computer programmers utilize computer programming language to implement the software system. With the software system to simulate the dynamics of the economic system, economists study the behavior of the economic system by analyzing the simulation data.

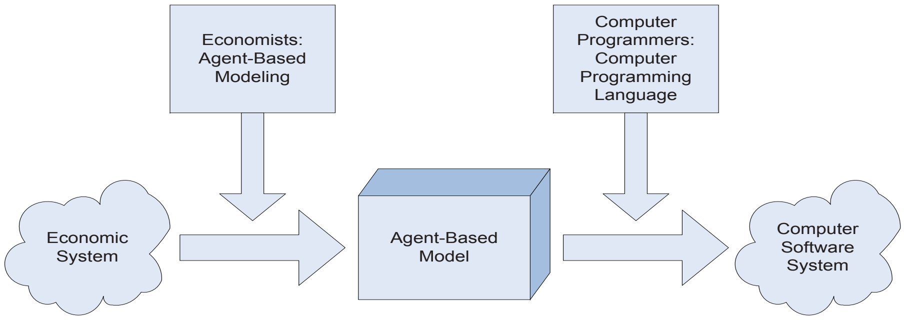

Figure 1: The general procedure of current ABM economic research.

ABM economic research is an interdisciplinary subject that is involved with economic modeling by economists on one hand, and the computer software implementation by computer programmers on the other hand. From the viewpoint of software development, economists are clients and end-users of the computer software. The agent-based model passed from economists to computer programmers is regarded as the requirement specification. The job of computer programmers is to implement and to deliver to end-users – economists – the computer software system that meets the clients' requirement, i.e., the computer software system simulates exactly the behavior and interaction of economic agents that is consistent with the agent-based model.

A skim on the general development process in software industry discovers that the role of software engineers which lies between clients and computer programmers is by and large missing in the current process of ABM economic research. The job of software engineers is to analyze the client's requirement and to design the corresponding system model as the blueprint for computer programmer to develop the software system. In current ABM economic research economists play the role of software engineers to develop the blueprint — the agent-based model. However, most economists conducting ABM economic research are lack of formal training as software engineers. They build up the agent-based model mostly based on the knowledge and the practice in economic modeling. Thus, it is not difficult to understand the difficulty for computer programmers to understand the agent-based model and the inefficiency on developing the corresponding computer software system. This inefficiency hampers the effectiveness of the communication and interaction between economists and computer programmers, which results in a bottleneck of ABM economic research. This bottleneck is particularly significant in the scenario of applying ABM economic research in policy analysis, since policy makers demand the delivery of policy analysis with time constraint.

This work addresses the aforementioned problem of inefficiency in current ABM economic research. By observing computer system development is indispensable in ABM economic research, this work looks into the experience in the development of software engineering and system engineering for some hints of overcoming the bottleneck in current ABM economic research. If one looks at the field of software engineering, one can easily find the strand of agent-based software engineering that is aimed at proposing a general framework for analyzing and modeling multi-agent systems which agents have the characteristics of autonomy, e.g., see (Wooldridge, 1997) and (Jennings, 2000). This strand of research has proposed several types of general platforms for modeling multi-agent systems. For example, distributed Multi-Agent Reasoning System (DMARS) presented in (Rao & Georgeff, 1995) and (d'Inverno *et al.*, 2004) considers primarily agents and the relationships between agents with the agent model and the interaction model. The Gaia methodology in (Wooldridge *et al.*, 2000) and its extension in (Zambonelli *et al.*, 2003) proposes as another general framework that considers agents and their interaction with agent model, services model, and acquaintance model. Although these frameworks differ from each other in some detail, they have the consensus or backbones on modeling the system from the perspective of agent types, of the services or functionalities that agent types contain, and of the organizational structure of the system which is the pattern of interactions among agent types. Since economic systems fall into the category of multi-agent system, the consensus in general frameworks for modeling multi-agent system lays the foundation of building an integrative framework for modeling economic system in particular. This integrative framework is to standardize the agent-based model for economic system, which is to develop standardized channel for communicating among economists and computer programmers to overcome the bottleneck in current ABM economic research.

In order to develop this integrative framework, the first step is to investigate the common characteristics shared among economic system and, more importantly, shared among economic agents and their behavioral rules. Then one adapts the backbones of modeling multi-agent systems to these common characteristics to develop the integrative framework for modeling economic system. Following this line, this work begins with investigating the common characteristics of economic system in Section 2. Then it proposes a classification of economic agents, and develops in Section 3 for each type of agents a general pattern to model its functionality. After that, it discusses how the dynamics of the system boils down to the behavior of economic agents and their interactions. Then by tailoring the general framework proposed in agent-based software engineering to match these common characteristics in economic system and agents, Section 4 formailizes the integrative framework.

2 Constructive Perspectives of Economic System

An economic system from 'bottom-up' is considered as a dynamical open system that interacts with the environment outside its boundary. Specifically, an *economic system* is viewed as a collection of economic agents (consumers, firms, commodities, markets, etc.) interacting with each other such that the interactions among economic agents perform macroscopic behavior of the system, given exogenous influence from the environment. This indicates four perspectives when considering an economic system, denoted as *constructive perspectives of economic system* as follows:

I. The scope of the economic system and its environment;

II. The interrelation between the economic system and its environment;

III. Elements of the economic system, i.e., economic agents considered in the economic system;

IV. The structure of the economic system, which is the interrelation among elements of the economic system.

As a scientific practice, economic research starts with specifying the research scope, which defines the scope of the economic system and its environment as well as the exogenous influences which the environment brings in. These exogenous influences regulate the interrelation between the economic system and its environment, which is represented as information flows.[1]

According to contemporary economic literature, economic entities are classified into different types with distinct characteristics. For example, (Pindyck & Rubinfeld, 2001) considers microeconomic entities of consumers, producers (firms), commodities, markets, etc. In principle, this classification of economic entities identifies components in the economic system.

The structure of the economic system represents the connections among economic agents. Agents communicate through their connections with others. The connections among agents are substantially studied in economic research with the tools of network theory, e.g., see (Jackson, 2008). In this strand of economic research, economic agents are represented by nodes while the connections among them are represented by links. This proposes one possibility to explicitly depict the structure of the economic system as network, which can be achieved by the *network diagram*. Specifically, the network diagram contains nodes representing economic agents and (directed) edges representing the channels of information flows among agents.[2]

An economic system can be treated as an economic agent that is a component of another economic system. This property of system-element duality guarantees

[1] The information considered in this work has the property of quantifiability. Knowledge, behavioral rules, and actions are regarded as information once they can be quantified.

[2] One may compare the network diagram with the class diagram in Unified Modeling Language (UML), as they serve the same purpose in describing the system structure: The class diagram describes the static structure of objects in a system and their relationships, see (Blaha & Rumbaugh, 2004). On the other hand, the network diagram emphasizes on the connections or channels of information flows among agents in economic system. As the economic system evolves, the structure of economic system may change, which implies that the network diagram of the economic system evolves as well. In this sense, the network diagram is not restricted to a representation of the static structure of the economic system, but rather can be applied in a dynamic manner to model the evolution of the structure of the economic system.

the hierarchy of economic systems, see (Potts, 2000). It implies that one can consider the economic system and its environment as nodes in the network diagram as well, with the interrelation between the economic system and its environment as edges between these two nodes. For example, consider the network diagram shown in Figure 2. It illustrates the structure of the stock market system with N traders and one market center. The bond market is considered as the environment of the stock market. Traders in the stock market connect with the market center for stock trading. The topology of the stock market belongs to the star network with the central node as the market center.

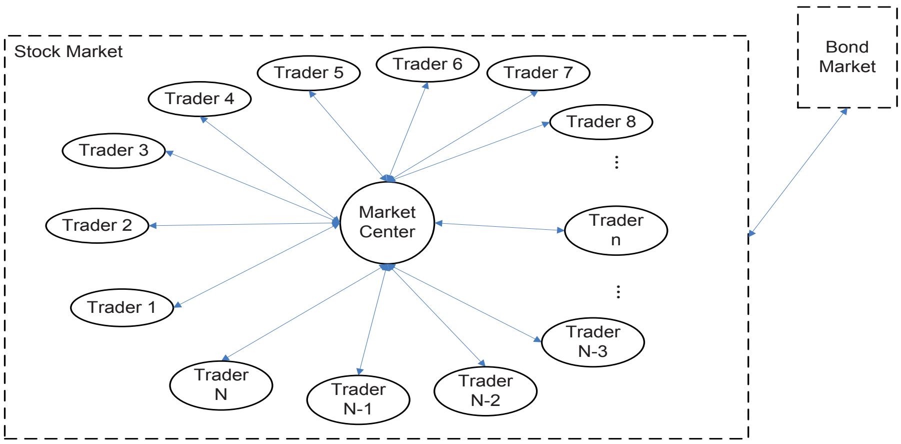

Figure 2: Network Diagram of Stock Market System.

Most economic agents investigated in economic research are concerned with the functionality and behavior of individual or a group of people in real world. Denote all these economic agents interpreting the functionality of human subject as **active economic agents** such that they behave actively or autonomously to fulfill their needs and objectives. Economic agents which are not directly involved with the functionality of human subject, e.g., commodities traded in the markets, are classified as **passive economic agents**. The following section investigates the general patterns embedded in the structure and the behavior of these two types of economic agents.

3 Economic Agent

Active economic agents represent the functionality of decision makers in economy. The concept of the decision maker has been investigated interdisciplinary with a large volume of literature in economics, psychology, sociology, computer science, etc. In economics, there is a field of behavioral economics that studies the behavioral rules of decision-making among economic agents. It has discovered, e.g., in (Kahneman & Tversky, 2000), that human's decision is not consistent with the assumption of 'rationality' in standard decision theory, it is rather by and large subjective with heterogeneous beliefs and goals. In view of this, economists have attempted to propose alternative decision models with the flavour of psychological realism, see (Camerer *et al.*, 2003). Decision-making process with cognitive pattern has also been employed in ABM economic research, e.g., (Landini *et al.*, 2013) considers a decision model for heterogenous interacting agents (HIA) with learning capability.

Inside these heterogenous decision models as well as the standard 'rational' decision model lies a general skeleton for economic agent's decision-making process. Similar pattern has also been proposed in other fields for studying decision-making process, c.f., the concept of intelligent agent in the field of artificial intelligence, see (Russell & Norvig, 2003). This general skeleton constitutes: the description of the information set that the agent obtains; the objectives or goals that the agent intends to fulfill; the forecasting on uncertain factors that the agent is concerned with; the action plans that the agent can possibly take, normally interpreted as the agent's feasible constraint; and the learning ability with which the agent may apply to update its behavioral rules. These intrinsic characteristics in economic agent's decision-making induce a general framework for modeling active economic agent, denoted as the *module of active economic agent (MAEA)*. This framework can be regarded as constructive perspectives of active economic agent. It is composed of the submodule of information acquirement, the submodule of storage, the submodule of learning, the submodule of objectives, the submodule of forecasting, and the submodule of action transmission. The structure of MAEA is illustrated in Figure 3. The functionality of each submodule is sketched as follows.

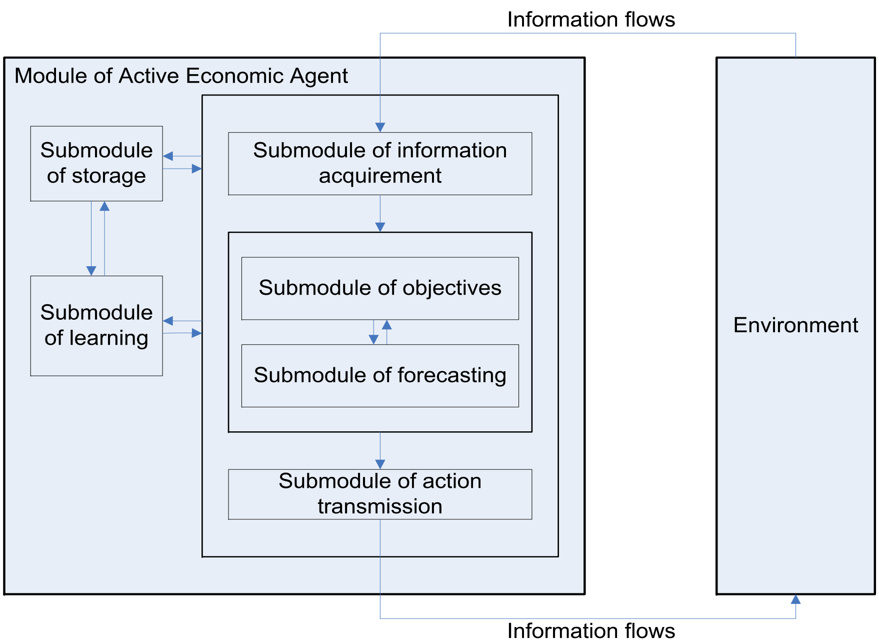

Figure 3: The structure of MAEA.

The environment in Figure 3 represents other agents in the economic system. The information flows between MAEA and the environment represent the interrelation of the agent with other elements in the economic system.

The submodule of information acquirement considers the agent creates the connections with other agents and collects information through the connections. The submodule of storage stores the information contained by the agent; it also provides the information to other submodules on request. The submodule of forecasting generates the forecast on uncertain factors that the agent needs for making decision. The submodule of objectives depicts the objectives that the agent intends to achieve, selects the action plan based on its designated objectives, and sends out the action plan to the submodule of action transmission. The submodule of action transmission receives action plans from the submodule of objectives and realizes the action through its interrelations with the environment. The submodule of learning specifies the learning rules that the agent uses to update its behavioral rules.

With MAEA, economists can seamlessly translate human subject's behavior into modeling the structure of the active economic agent, by filling in the context for each submodule and by specifying the connection among them.

The state of the active economic agent evolves when the agent acts to fulfill its objectives. The dynamics or the updating rule of the agent is thus the decision making process of the agent, which is realized by the interaction among submodules. The agent starts the decision-making process normally with initiating its state. The agent observes information via the submodule of information acquirement and keeps the information in its memory via the submodule of storage. If the submodule of learning exists with certain learning rules, the agent then applies them to update itself, e.g., to update the forecasting methods currently contained in the submodule of forecasting in order to provide more accurate forecast on uncertain factors that the agent considers. After that, the agent generates its subjective forecast via the submodule of forecasting, selects the action plan to fulfill its objectives via the submodule of objectives, and then transmits the action to other agents in the economic system via the submodule of action transmission. Finally, the agent receives from the environment the feedback of its action to update the agent's initial state for the next round of decision-making. This general decision-making process, illustrated in Figure 4, works as a benchmark for depicting the dynamics of the active economic agent.

Passive economic agents, e.g., the stock traded in financial market, do not behave actively or autonomously to fulfill their objectives. They mainly act as information providers that disseminate information to other agents on request. The main characteristics of this type of agent is information holder and provider. This leads to a relatively simple framework, denoted as the *module of passive economic agent (MPEA)*, to model the passive economic agent. MPEA consists of a set of information that represent the *economic properties* considered in the economic system. The dynamics of the passive economic agent focuses on the updating of the information of economic properties that the agent contains.

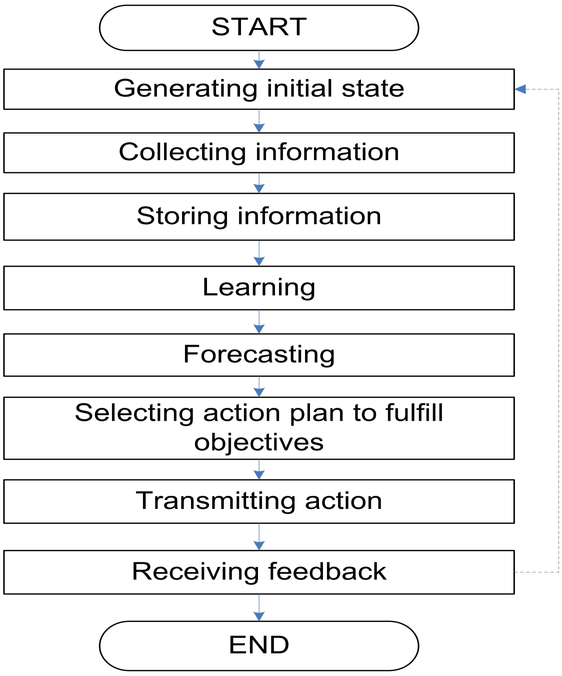

Figure 4: The general decision making process of active economic agent.

4 Integrative Framework

The integrative framework for agent-based modeling in economics is a general modeling process that applies the constructive perspectives of economic system and of economic agents to translate the economic system into the corresponding agent-based model. With the guide of the general framework for multi-agent system, this integrative framework targets on modeling the static state and the dynamics of the economic system. To model the static state of the economic system, the integrative framework starts with specifying constructive perspectives of the economic system. Then it applies MAEA and MPEA as templates to formulate the corresponding economic agents in the economic system.

The economic system evolves along the time horizon as long as economic agents autonomously conduct their behavior and interact with each other. It is the autonomous behavior and interactions of economic agents that drive the dynamics of the economic system. Thus, given exogenous information flows from its environment, the dynamics of the economic system boils down to the dynamics of economic agents in the system interacting with each other. The integrative framework models the dynamics of active economic agents with the agent's decision-making process and that of passive economic agents with the operation of information updating.

To explicitly present the dynamic process generated by the interaction among agents in the economic system, it is useful to consider in the level of economic agents a visualization, denoted as *diagram of agent interaction*, to describe the time sequence of agents' activities or behaviors.[3]

In summary, the integrative framework contains the modeling procedure as follows:

1. Specify constructive perspectives of the economic system;
2. Construct corresponding agents in the economic system by applying MAEA and MPEA respectively, model the decision-making process for active economic agents and the operation of information updating for passive economic agents;
3. Present the diagram of agent interaction to describe the sequence of activities and behaviors among agents.

5 Concluding Remark

The integrative framework for agent-based modeling serves as general guidance that is sufficient for analyzing economic system from 'bottom-up' and for seamlessly translating economic system into standardized agent-based model. The MAEA proposed in this framework is capable of modeling economic agents with complex decision-making processes that contain psychological patterns.

The standardization of analyzing and depicting agent-based model in economic research overcome the bottleneck that results from the inefficiency of communicating among economists and computer programmers in current ABM economic research, thus unleashes the potential of ABM economic research especially in economic policy analysis. Moreover, the standardization of agent-based model generated by this integrative framework enhances the reusability of the agent-based model in the sense that part of or the whole of existing agent-based models can be quickly adjusted and assembled together to develop a new agent-based model. synchronically, the corresponding computer software codes can be quickly modified and assembled to generate the software system for the simulation of the new agent-based model.

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[3]The diagram of agent interaction can be regarded as a special version on the level of economic agents of the activity diagram in UML, which is to represent the sequence of activities among components in the system in all levels, see (Blaha & Rumbaugh, 2004).

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