Standardization for Agent-based Modeling in Economics

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Abstract

This work combines generic complexity of economic system and economic agents with methodologies of multi-agent system analysis and development. This combination results in an integrative framework that serves as communication protocol for delivering and transmitting agent-based model for economic system. The integrative framework provides guidance for analyzing economic system in micro-level, which embeds with properties of complexity in structure, heterogeneity in agents' beliefs, and interactions among agents' behaviors. It provides routines on developing standardized agent-based model for economic system that can be used and reused among interdisciplinary research.

Keywords: Economic system, Agent-based modeling, Complexity, Standardization

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1 Introduction

Agent-Based Modeling (ABM) refers to studying the macro-level behavior of the whole system by computerized simulation of heterogenous interacting agents in micro-level. Applying this methodology in economic research is particulary concerned with the strand of agent-based computational economics (ACE), see Tesfatsion [18]. It emphasizes on understanding economic system from 'bottom-up', considering the macro-level behavior of economic system rooted in micro-level 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 fields of economic research, see Tesfatsion and Judd [19] 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.

In retrospect, the incapability of the 'mainstream' economic models in foreseeing 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 [20] from policy maker and Stiglitz [16] from academia.

Given its 'bottom-up' nature that potentially supports studying economic system with large market fluctuation driven by micro-level 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. For example, European Commission supports the project of "(CRISIS) Complexity Research Initiative for Systemic Instabilities" to develop "a new approach to modelling and understanding financial system and macroeconomic risk and instability" by employing the method of bottom-up agent-based simulation. Another supported project is "(FOC) forecasting financial crises" to "understand and possibly forecast systemic risk and global financial instabilities" by applying agent-based methodology. On the other hand, ABM considers explicitly the relation between micro-level agent interaction and macro-level complex system dynamics, which naturally fits in the interdisciplinary research scheme of dynamics of multi-level complex system currently supported by European Commission, e.g. see the research project "(MatheMACS) Mathematics of Multilevel Anticipatory Complex Systems".

As a consequence, increasing volumes of literature in ABM economic research emerge, e.g. see Gallegati, Palestrini and Rosser [7] on financial stress, Stiglitz and Gallegati [17] on monetary economics, Battiston et al. [1, 2] on default cascades in financial markets, Caccioli, Catanach and Farmer [3] on contagion in financial networks, Delli Gatti et al. [5] on the interrelation between production sector and credit markets, etc. It has reason to believe that ABM economics is expanding as an important role in economic research as well as in interdisciplinary research.

The current ABM economic research follows a general procedure, illustrated in Fig. 1. It starts with economists applying ABM methodology to develop an agent-based model that depicts the economic system and its dynamics. Economists deliver the agent-based model as the formal model of the economic system in consideration for simulation. On request, computer programmers consider the agent-based model as the requirement specification and system model, utilizing computer programming language to implement the computer software system for simulation. Then economists study the behavior of the economic system by analyzing the simulated outcome. In this regard, ABM economic research is an interdisciplinary subject involved with economic modeling on one hand, and computer software development on the other hand.

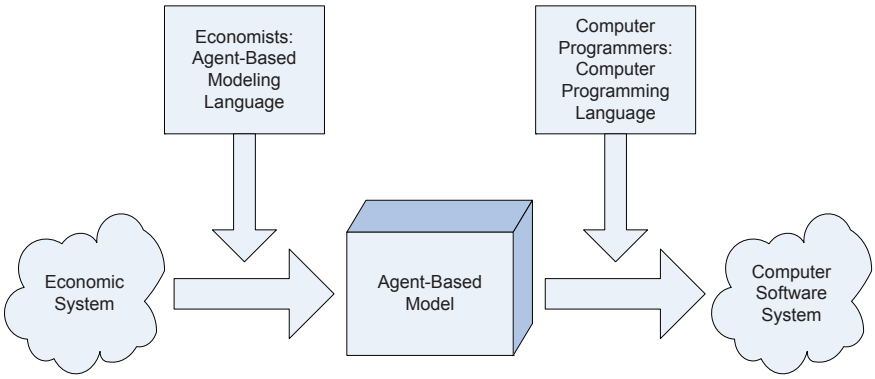

Figure 1: General procedure of current ABM economic research.

In current ABM economic research, economists build up the agent-based model by mostly following the common practice in economic modeling, which is lack of consistency with routines of system analysis and design in computer software development. Thus, it is not difficult to understand the difficulty for computer programmers to understand economists' requirement and specification contained in the agent-based model, which inevitably leads to inefficiency on developing the corresponding computer software system. This inefficiency hampers the effectiveness of the communication and interaction between economists and computer programmers, which generates a bottleneck in current ABM economic research. This bottleneck becomes crucial when ABM economic research

is required to deliver the analysis with time limit, for example, authorities in general practice demand the delivery of policy analysis under time constraint.

This paper addresses the aforementioned problem of inefficiency in current ABM economic research. The root of this work is to consider economic system from 'bottom-up' as agent-oriented complex system. On one hand, from the perspective of economic research, economic system as well as economic agents, although complex and heterogeneous, embeds with common characteristics in statics and in dynamics. On the other hand, from the perspective of system engineering and software development, one can easily notice the strand of agent-based software engineering that is aimed at proposing a general framework for analyzing and modeling multi-agent systems, e.g. see Wooldridge [21] and Jennings [9] as primary promoters. 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 and Georgeff [14] and d'Inverno et al. [6] considers primarily agents and the relationships between agents with the agent model and the interaction model. The Gaia methodology in Wooldridge, Jennings and Kinny [22] and its extension in Zambonelli, Jennings and Wooldridge[23] 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.

This suggests us to start from investigating and deriving generalities shared among economic system and economic agents. Then by applying these generalities with tools from agent-based software engineering, we could develop a tailor-made integrative framework that works as communication protocol between economists and computer scientists. Economists could follow this integrative framework to analyze and to develop agent-based economic model in a standardized way. As the other side of the same coin, computer programmers could follow this integrative framework to understand the specification and requirement contained in the standardized agent-based economic model and to translate the agent-based model into computer codes in an efficient manner.

Following this line, section 2 and section 3 begin with investigating, in static view, generalities of economic system and economic agents respectively. Then section 4 and section 5 investigate, in dynamic view, generalities of economic system and economic agents respectively. Section 6 derives the integrative framework and section 7 concludes.

2 Static View of Economic System

An economic system from 'bottom-up' is considered as a dynamical open system that a collection of economic agents (consumers, firms, commodities, markets, etc.) interacting with each other such that microscopic 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 in statics, 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 and Rubinfeld [12] 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 [8]. In this strand of economic research, economic agents are represented by nodes while the connections among them are represented by links. This proposes 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.

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 the hierarchy of economic systems, see Potts [13]. 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 Fig. 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

[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.

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.

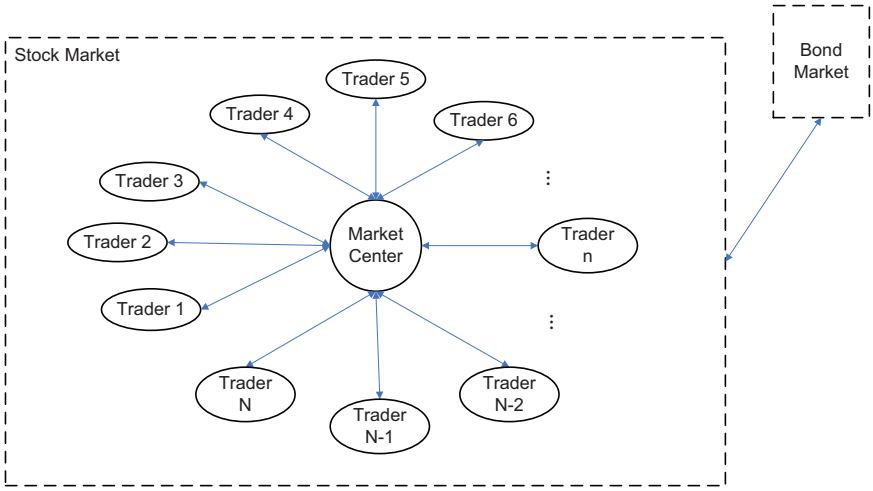

Figure 2: Network Diagram of Stock Market System.

3 Static View of Economic Agent

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**.

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. Researches in the field of behavioral economics that studies the behavioral rules of decision-making among economic agents, e.g. Kahneman and Tversky [10], have shown 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 proposed alternative decision models with the flavour of psychological realism, see Camerer, Loewenstein and Rabin [4]. Decision-making process with cognitive and learning pattern has also been employed in recent ABM economic research, e.g. Landini et al. [11] 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 and Norvig [15]. 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 capability 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 information 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 Fig. 3. The functionality of each submodule is sketched as follows.

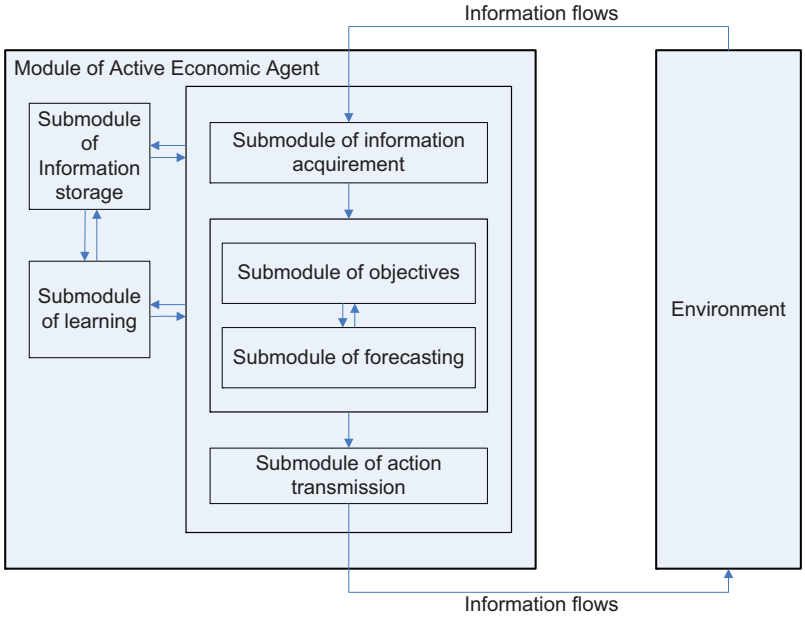

Figure 3: Module of active economic agent.

The environment in Fig. 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 connection with other agents and collects information through connection. The submodule of information 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.

Passive economic agents, e.g. the commodity traded in the 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 represents *economic properties* considered, e.g. see Fig. 4.

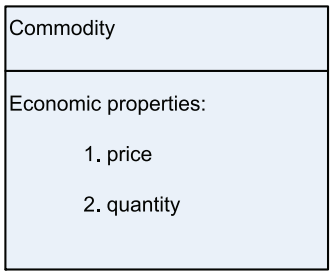

Figure 4: Passive economic agent: commodity

4 Dynamic View of 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.

To explicitly present the dynamic process generated by the interaction among agents in the system, it is helpful to depict in the level of economic agents a visualization of the sequence of agents' activities, represented by *diagram of agent interaction*. As an example, the diagram of agent interaction in Fig. 5 shows the sequence of agents' activities in stock market system with bond market as its environment.

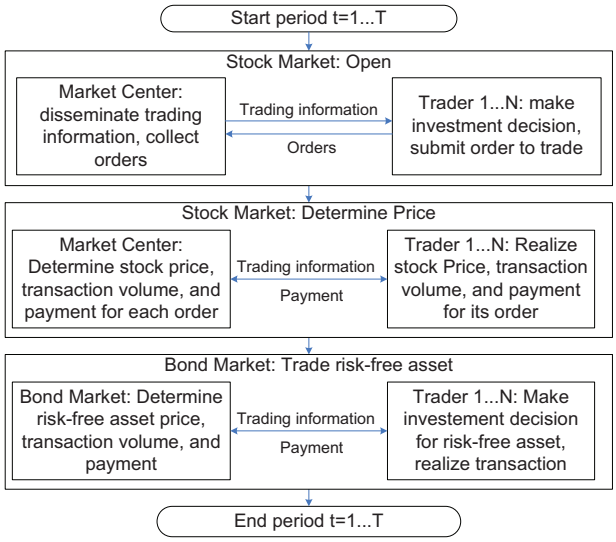

Figure 5: Diagram of agent interaction for stock market system with bond market as its environment.

5 Dynamic View of Economic Agent

The state of the active economic agent evolves when the agent acts to fulfill its objectives. The dynamics 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 information 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 Fig. 6, works as a routine for depicting the dynamics of active economic agent.

The dynamics of passive economic agent focuses on the updating of the information of economic properties that the agent contains, i.e. information updating rule.

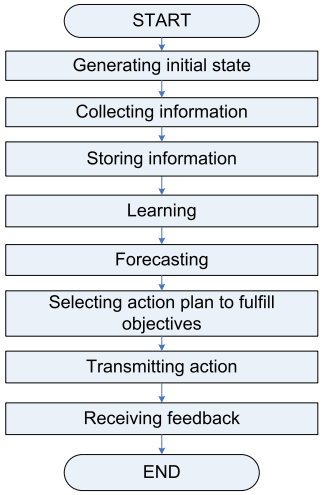

Figure 6: General decision making process of active economic agent.

6 Integrative Framework

The integrative framework proposes a general modeling procedure that applies the constructive perspectives of economic system and of economic agents to translate the economic system into the corresponding standardized agent-based model.

To model the statics 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 system.

As the dynamics of economic agents is sufficient for depicting the dynamics of economic system, the integrative framework focuses on 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.

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

1. Static initialization:
   (a) Initialize economic agents involved: specify each submodule in MAEA for active economic agents, and specify each economic property in MPEA for passive economic agents;
   (b) Use network diagram to specify the initial structure of economic system.
2. Dynamic specification:
   (a) Specify dynamics of active economic agents by using the routine of general decision-making process, and specify dynamics of passive economic agents by information updating rules;

(b) Use diagram of agent interaction to visualize the sequence of agents' activities, so as to explicitly present in agent-level the dynamics of economic system.

7 Concluding Remark

The integrative framework serves as general guidance for analyzing economic system from 'bottom-up' and for seamlessly translating economic system into standardized agent-based model. The integrative framework serves as communication protocol between economists and computer scientists, as well as between agent-based economic research and other strands. It overcomes the bottleneck that results from the inefficiency of communication and interaction in current ABM economic research. The standardization of agent-based model generated by this integrative framework enhances its reusability such that part of or the whole of existing agent-based model can be quickly modified and assembled together to develop new agent-based model. In this regard, applying the integrative framework unleashes the potential of ABM in economic research as well as in interdisciplinary research.

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