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GABRIELE: The General Agent Based Repast Implemented Extensible Laboratory for Economics

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HIGHLIGHTS

- The present work provides an open-source agent-based model addressed to the investigation of economic systems dynamics.
- The software is made available with a collaborative intent.
- A particular effort in providing a comprehensive documentation (UML, Javadoc, LaTeX, HTML) in order to make the cooperation possible.

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ABSTRACT

The present work provides an open-source agent-based model addressed to the investigation of economic systems dynamics. This includes a general framework where interested researchers can insert and develop additional elements to analyze more specific issues. The software is made available with a collaborative intent. Cooperation among scholars interested in different aspects of human behavior will make it possible to endow economic agents with traditional or more recent and sophisticated knowledge-based decision techniques. This process will also deliver a tool for supporting policy makers decisions. In order to make the cooperation possible and to provide scholars with a user-ready tool that can be promptly applied for simulations in research, a particular effort in providing a comprehensive documentation (UML, Javadoc, LaTeX, HTML) describing how to use, develop and improve the features of the current version of the model is provided together with the open-source code at https://github.com/gfgprojects/gabriele.

Software metadata

Current software version	1.0
Permanent link to executables of this version	https://github.com/gfgprojects/gabriele
Legal Software License	GPL
Computing platform/Operating System	platform independent
Installation requirements & dependencies	Repast Simphony
If available, link to user manual — if formally published include a reference to the publication in the reference list	https://github.com/gfgprojects/gabriele/blob/master/manual.pdf
Support email for questions	gianfranco.giulioni@unich.it

Code metadata

Current code version	1.0
Permanent link to code/repository used of this code version	https://github.com/ElsevierSoftwareX/SOFTX_2018_54
Legal Code License	GPL
Code versioning system used	git
Software code languages, tools, and services used	Java
Compilation requirements, operating environments & dependencies	JDK, eclipse
If available Link to developer documentation/manual	https://github.com/gfgprojects/gabriele/blob/master/manual.pdf
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1. Introduction

This paper presents an agent-based software built to investigate the dynamics of macroeconomic systems.

The understanding of macroeconomic dynamics is at the heart of economics and has been continuously tackled by economists. How to improve living conditions (especially in poor countries) or avoid their worsening and preventing severe crisis are macroeconomists' priorities. These goals have been pursued using the most advanced tools offered by the progress of human knowledge, but the outcomes of economic systems sometimes surprise economists, questioning the validity of their theories [1]. The diffusion of computers and the continuous improvements in their computational power represents one of the most relevant opportunities to progress various disciplines. Among the copious applications of computational techniques for economics, the agent-based approach, which is able to create artificial economic systems and observe their dynamics, is considered one of the most promising. The use of these techniques has been supported with an increasing intensity, especially in the aftermath of the "big recession" [2]. The "meltdown" of advanced economies during the recent recession showed a wanting in the prevailing economic methodology. Therefore, the agent-based approach gained interest because it provides a framework with which to analyze the dynamics of complex macroeconomic systems. The need to understand why large economic crises occur and how their diffusion can be dampened is, quite reasonably, a priority [3].

As we will highlight below in the text, there are several interesting agent-based models aimed at investigating macroeconomic issues currently under development. Each of them has its own peculiarities. There are, however, common features that macroeconomic agent-based models should have. The work presented in this paper is an effort to build a model having such common features. The code is open source and a particular effort has been made to provide detailed documentation. In other words, the aim of this project is to provide a base that a researcher having some programming skills can customize to investigate by means of simulations the scientific topics s/he is interested in.

2. Problems and background

The main problem with macroeconomic agent-based modeling is that the economy is a complex system. Indeed, we can think of the economy as a set of nested complex systems where the components of each subsystem are themselves complex. On the other hand, there are many outcomes of the economy, namely economic growth, fluctuations, income and wealth inequality, to cite a few, that are relevant to the society and, therefore, worth being investigated. In this context, it is natural that macroeconomic research using agent-based techniques sees researchers or research groups progressively including new features into their models that were initially developed starting from a specific research question. This process has produced a set of models with different focuses. Some of them, for example, spotlight the importance of the financial sector in shaping macroeconomic dynamics, hence providing a particular effort in modeling agents' balance sheets [4,5] and/or of the role of the banking system [6]. Others also include a modeling of the technological progress (models building on [7]). There are many other works that could be cited,[1] but the following sentence found in the abstract of a paper describing the EURACE model (which is considered one of the most complete agent-based macroeconomic models to date) highlights the point better than a (in any case non exhaustive) citation list: "In spite of this general agenda the model has been constructed with certain specific research questions in mind and therefore certain parts of the model, e.g. the mechanisms driving technological change, have been worked out in more detail than others" [9].

An alternative approach to the building of a macroeconomic agent-based model would give all interested researchers the possibility of revising and progressively enriching the framework. From this point of view, a computational macroeconomic model should have a number of desirable features. The most relevant of them, among many others, are:

- having detailed documentation,
- having an open source and easily obtainable code,
- being developed in a largely diffused programming language,
- having the possibility to be run on a personal computer as well as on a larger scale,
- providing common features that characterize a macroeconomic model (such as types of agents, relationship among them, static and dynamic consistency of variables) giving to researchers the possibility to concentrate on alternative and detailed modelization of agents' behavior.

A close look at the currently available macroeconomic simulators reveals that all of them have one or more of these desirable features, but none have all.

The macroeconomic simulator presented in this paper aims at having all the above listed features and at reverting the workflow discussed at the beginning of this section, according to which the representation of the macroeconomy (the model) is adapted to a specific research question. The intent here is instead to provide a generic representation of the macroeconomy which can then be used to tackle specific research questions. This intent gives a special importance to the provisioning of detailed documentation, which is a premise that will allow researchers to use, adapt and develop the simulator to answer their research questions. In particular, the software comes with a documentation set available at http://erre.unich.it/gabriele/docs. In addition to the standard documentation represented by the user manual and the Javadoc API, a rich set of UML activity diagrams describes the details of each simulation event.

3. Software framework

The software is developed in Java, which is the most used language in the field of agent-based modeling. Among the 85 agent-based toolkits reported in [10], 47 are developed in Java. At least two are the macroeconomic simulator with a Java source code:

- Java Agent-based MacroEconomic Laboratory (JAMEL), which is also reported in [10]. It was developed to investigate complex monetary economies [5] and its source code is available at https://github.com/pseppecher/jamel;
- Java Macro Agent Based (JMAB). It was developed for building macro stock-flow consistent agent-based simulation models [11] and its source code is available at https://github.com/S120/jmab.

The architecture of the software described in this paper differs from that of these macroeconomic simulators mainly because it is built on top of a general purpose agent-based simulation system: Repast Simphony (https://repast.github.io).

Repast provides, among others, the following important facilities:

[1] Because this paper is not intended to survey the literature, references provides only few examples. We invite the reader to look at [8] to have a wider "sight" of the literature.

- a powerful scheduling mechanism,
- an easy way to record data from the simulation,
- the possibility to run a model both in batch and graphical mode,
- an easy way to create graphical elements such as time series charts, histograms, Geographic Information Systems maps and so on, in order to monitor simulations running in graphical mode,
- facilities to run a simulation in parallel using different remote computational resources.

This creates significant advantages to the user that can direct her/his effort uniquely to the development of the model. On the other hand, this choice introduces the cost of learning how to use Repast functionalities. These costs are, however, strongly mitigated by the documentation provided, which gives a step by step guide to the installation and use of Repast facilities. Furthermore, Repast is well documented and has a very active mailing list for supporting users.

The model has the usual Java structure and is therefore organized in packages. Classes are grouped in the following packages: `agents`, `institutions`, `bargaining` and `utils`. Because a more detailed description is not possible due to limited space, the interested readers are pointed to the documentation included in the software, which provides all the details.

4. Implementation

A visual representation of the model is used in this paragraph to provide an effective concise description of its implementation. Fig. 1 reports agents, markets, goods and contract that make up the model, while Fig. 2 describes the dynamics of events. The latter reports a clock like representation of the dynamics; each event is identified by a number giving its execution order in each iteration. The information on which agents are performing the action and on which other agents (if any) are involved is given together with a brief description of the action. Abbreviations in Fig. 2 are as follows: *OFS*: office for statistics, *G*: Government, *CB*: Central Bank, *F*: firms, *C*: consumers, C_S: the subset of consumers that are students, C_E: the subset of consumers that are employed, C_U: the subset of consumers that are unemployed, *B*: banks, *LM*: labor market.

Looking at Fig. 2, the reader can see at a glance what is going on in an iteration. Just to give an example, one can see how employed consumers receive wage in step 1 of the loop. The following action (with label 2) consists of an interaction among the office for statistics, the government and the central bank to update the fiscal policy. Next, using the updated tax rate, consumers can compute their available income (step 3) and progress to decide their desired consumption going through the following steps. Due to limited space, we cannot go on with the description of all the actions listed in Fig. 2. Hence, we invite the reader to look at the software documentation. In particular, the exploration of the "UML activity diagrams for the sequence of events" section at http://erre.unich.it/gabriele/docs would provide a fast an deep understanding of what is going on in each simulation event. Notwithstanding the deferment to the documentation, the potential application examples given in next section provide occasions to hint at some main loop actions also making use of Figs. 1 and 2.

5. Illustrative examples

There are a large number of potential applications of the software presented above. The few briefly discussed in this section will serve to assess the potential application of the software in selected topics, which are presently active fields of research and that will eventually benefit from using an agent-based approach.

5.1. The role of education

Because the importance of education and knowledge for economic systems has been highlighted for several decades [see12, for a recent update] and is an active field of research [see13, for a recent example], in the current version of the model the education history of each individual is modeled and the final level of education affects several aspects of the economy. Each consumer is characterized by a parameter that gives its ability. This parameter affects the level of knowledge gathered during the education period. The level of knowledge, in turn, is the main factor for the employment state and wage collected by the individual. The population of consumers is therefore partitioned into three categories: students, employees and unemployed people as reported in Fig. 1. The consumer's state is managed and is relevant in several points of the dynamics (see the C_E, C_U and C_S abbreviations in Fig. 2). In particular, the different types of consumers follow different consumption behaviors and are subject to different financing conditions (students and unemployed have for example a subsidized interest rate). These aspects could be used to evaluate the effects of different education systems on macroeconomic performances.

5.2. Population dynamics

The current version of the model has a constant level of population. Each consumer exits the model at a given age and is replaced by a student facing her/his first year of education and having a new randomly drawn level of ability. This is the simplest way to allow for dynamic coherence of financial stock because the exiting person's financial position is moved to the new entrant's. Ongoing research however, investigates the importance of population dynamics for the macroeconomy [see14, for a recent example]. Researchers interested in the effects of population dynamics can therefore substitute the simplistic individual replacement implemented in step 28 of Fig. 2 with a more realistic offspring generation mechanism. In doing that, it is recommended to preserve the dynamic consistency of the financial stocks ensuring the personal wealth to be transferred to other people in the economy.

5.3. Product differentiation

A possible improvement provided by this simulator is the option it gives to account for product differentiation, which is another ongoing research topic [see15, for example]. In particular, the user can activate a product differentiation process that introduces new products into the economy. In this process, products "climb" a quality ladder i.e. new products are improved versions of existing ones. The researcher can link the probability of success in improving a product in a firm to the education level of the firm's employees. Consumers gradually move their demand from less advanced to more advanced products. This creates a time changing variety of product. Firms producing products having the same level in the quality ladder are grouped in industries as displayed in Fig. 1. The firm belonging to the most advanced industry that innovates first creates a new industry. This firm is a monopolist at the beginning. The degree of competition in an industry increases when new firms succeed in moving to this new industry. Profits are therefore realized in more advanced industries.[2] As a consequence, firms that fail to innovate over long periods of time are doomed to failure.

[2] When the innovation process is not activated, the model production sector consists of one highly competitive industry grouping all the firms of the economy. In this case the researcher works under the homogeneous consumption good assumption that is often made in the existing macroeconomic agent-based models.

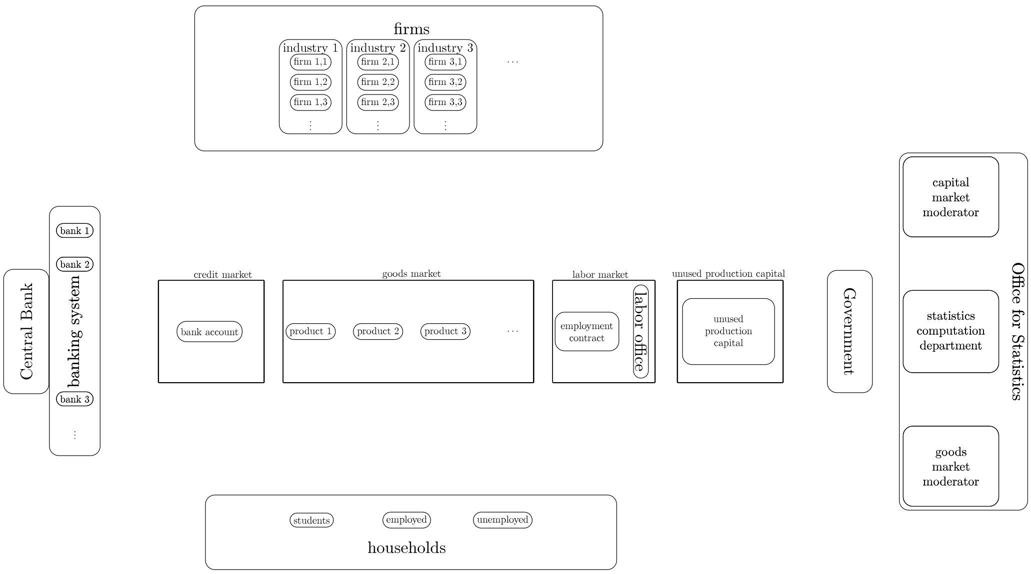

Fig. 1. Agents, markets, goods and contract of the model.

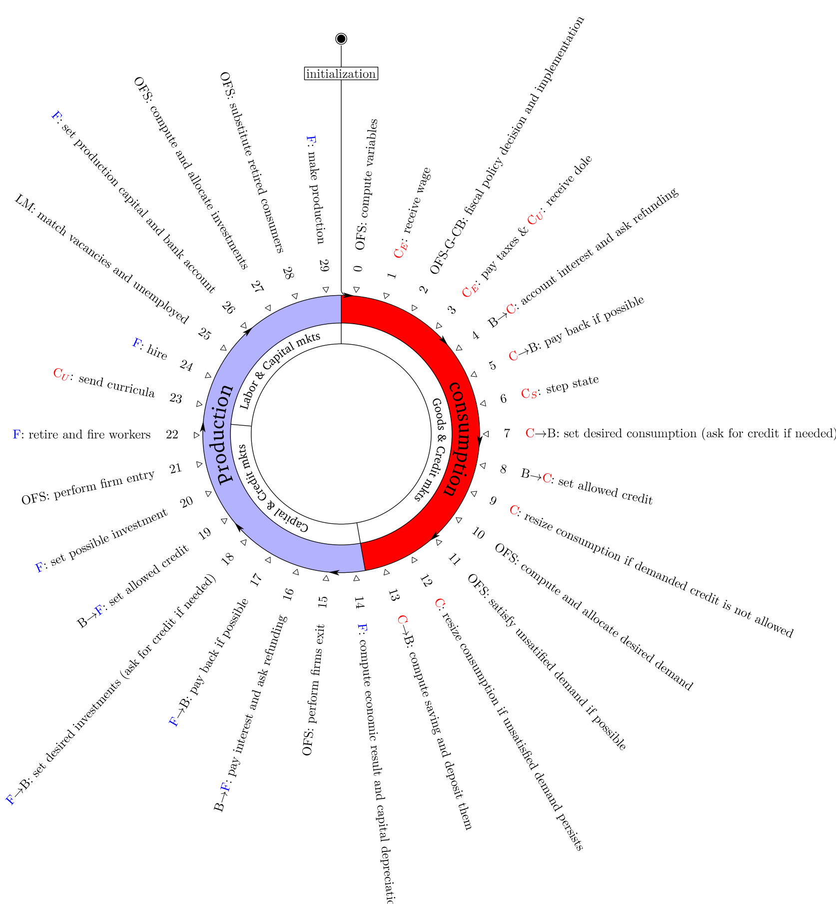

Fig. 2. The sequence of events.

5.4. Dynamic stock consistency

A firm's failure gives the opportunity to highlight the particular care the model puts in fulfilling the dynamic stock consistency. As highlighted in the recent literature [see 11, for example], models should be stock-flow consistent in the sense that when a flow goes from an agent to another, the stock of the first agent has to be reduced and that of the second has to be increased by the flow amount. The most obvious application involves the flow of funds implied by financial operations (see for example the recommendations given above in the population dynamics section about the exiting people's financial legacy). However, other aspects need the same care. The firm failure case can be used to discuss this point. A firm goes bankrupt if its debt is higher than the value of assets. In the model, the value of assets is given by the production capital. Removing a failed firm from the model would make the residual production capital of the firm disappear from the model. To avoid this unjustified removal, we put the firm in a wind-up state. Banks move the credit granted to these firms from the regular loans budget item to the non-performing loans item. Part of these amounts could be still recovered because we include a secondary market for production capital in the model (see Fig. 1).[3] If the firm succeeds in selling a part or the whole unemployed production capital on this market, the production capital is moved to the firm who bought it[4] and the amount raised is used to pay back banks. Unemployed production capital, is in any case, subject to depreciation. Depreciation gives the occasion to highlight another difficulty in managing dynamic stock consistency. The economy is not a closed system, i.e. values appear and disappear; the true difficulty is identifying as much as possible these flows and give them reasonable justification and modelization.

6. Conclusions

The software presented in this paper aims at providing a model that has the basic elements for performing analysis of macroeconomic systems. There are many topics to be investigated in macroeconomics. However, these analyses ask for a detailed modeling of some aspects of the macroeconomy or require that a choice is made among several modeling strategies concerning agents behaviors. The model presented in this paper does not enter into these more specific issues. It aims at providing a framework where these more specific issues could be inserted and developed.

The software is therefore provided with a collaborative intent. From this point of view, a particular effort to provide a comprehensive documentation has been made. This will allow for both a fix of the possible flaws in the current implementation of the model and the possibility that other researchers could benefit and contribute to the development of the model.

Conflict of interest

No conflict of interest is involved.

[3] The effects on the macroeconomy of the dynamics of secondary markets for physical capital have been recently considered in a Dynamic Stochastic General Equilibrium Model [16].

[4] In this model, the level of adaptability of the existing unemployed production capital to other production activity is tuned by an adaptation costs which is ascribed to the seller.

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