Research Proposal

Functional methods in agent-based modelling & simulation.

Jonathan Thaler

October 27, 2016

Institution: University of Nottingham
Department: School of Computer Science
Project: PhD Programme 2016-2019
Supervisor: Dr. Peer-Olaf Siebers
Co-Supersvisor: Dr. Thorsten Altenkirch

Abstract

Agent-Based Modelling and Simulation (ABM/S) is still a young discipline and the dominant approach to it is using object-oriented methods. This thesis goes into the opposite direction and asks how ABM/S can be mapped to and implemented using functional methods and what one gains from doing so. To the best knowledge of the author, so far no proper treatment of ABM/S in this field exists but a few papers which only scratch the surface. The author argues that approaching ABM/S using functional methods offers a wealth of new powerful tools and methods. The most obvious one is that when using pure functional computation reasoning about the correctness and about total and partial correctness of the simulation becomes possible. Also pure functional approaches allow the design of an embedded domain specific language (EDSL) in which then the models can be formulated by domain-experts. The strongest point in using EDSL is that ideally the distinction between specification and implementation disappears: the model specification is then already the code of the simulation-program. This allows to rule out a serious class of errors where specification and implementation does not match, which is especially a big problem in scientific computing thus making functional methods in ABM/S especially suitable for scientific computing. The application will be in the field of agent-based computational economics (ACE) where the primary goal will be to compare functional and non-functional methods for developing ACE simulations and to identify in which scenarios pure functional methods shine and where their limits are.

1 Introduction

WHY FUNCTIONAL? ”because its the ultimate approach to scientific computing”: fewer bugs due to mutable state (why? is thos shown obkectively by someone?), shorter (again as above, productivity), more expressive and closer to math, EDSL, EDSL=model=simulation, better parallelising due to referental transparency, reasoning
scientific results need to be reproduced, especially when they have high impact. a more formal approach of specifying the model and the simulation (model=simulation) could lead to easier sharing and easier reporduction without ambigouites
pure functional agent-model & theory, EDSL framework in Haskell for ACE

1. Which kind of problem do we have?
2. What aim is there? Solving the problem?
3. How the aim is achieved by enumerating VERY CLEAR objectives.
4. What the impact one expects (hypothesis) and what it is (after results).

Note: It is not in the interest of the researcher to develop new economic theories but to research the use of functional methods (programming and specification) in agent-based computational economics (ACE).

2 Methods

The following methods were selected because they are either functional ones or very well established methods in the field of ABM/S and ACE.

2.1 Method 1: Haskell

This is the main functional method this thesis wants to investigate as it is the purest functional programming language of all the methods.

2.2 Method 2: Scala & Actors (Akka)

This method was selected because Scala is an object-oriented functional programming language and has a powerful library included which implements the actor-model. Because actors and agents are closely related this is an obvious method to follow.

2.3 Method 3: AnyLogic / NetLogo / Repast

These tools are state-of-the-art in ABM/S and ACE and are included to show how one can perform scenarios (see below) with these tools.

2.4 Method 4: Java

Java is the state-of-the-art programming language in ABM/S and ACE and is thus included as well as a benchmark against such a state-of-the-art.

3 Scenarios

To apply and test functional methods in ACE, four scenarios of ACE are selected and then the methods applied and compared with each other to see how each of them perform in comparison. The 4 selected scenarios represent a selection of the challenges posed in ACE: from very abstract ones to very operational ones. Each solution is then compared against the following criterias:

1. suitability for scientific computation
2. robustness
3. error-sources
4. testability
5. stability
6. extendability
7. size of code
8. maintainability
9. time taken for development
10. verification & correctness
11. replications & parallelism
12. EDSL

3.1 Scenario 1: Equilibrium & out-of-equilibrium models

Continuous (decentralized) bartering / trading
Botta et al. (2011), models of H. Gintis Herbert (2006) and Gintis (2007) , Gode & Sunder Zero-Intelligence explicit time needed

3.2 Scenario 2: ?

Something in between 1 and 4 but closer to 1

3.3 Scenario 3: ?

Something in between 1 and 4 but closer to 4

3.4 Scenario 4: ?

Many parallel, concurrently interacting objects with non-continuous, complex behaviour. explicit time needed dynamic networks
Budish et al. (2015) Aldridge (2009)

4 Goals/TODOs 1st Year

4.1 Practical

- Implement SIRS in AnyLogic - DONE.
- Implement Wildfire in Akka.
- Implement discrete SIRS in Akka.
- Implement decentralized bartering in Akka.
- Implement SIRS using Monads.
- Implement discrete and continuous SIRS in Yampa.
- Implement the ACE model of interest (e.g. H.Gintis decentralized bartering) in Haskell and Akka at the end of the year with all the knowledge acquired so far.
- Explore data-parallelism in Haskell to speed-up.

4.2 Reading

- Understanding Capitalism. Bowles et al. (2005)
- Debt . TODO cite
- Multiagent Systems Wooldridge. TODO cite
- Multiagent Systems Weiss. TODO cite
- Actor model Agha. TODO cite
- A computable universe. TODO cite
- The nature of computation. TODO cite
- Economics and Computation by Parkes and Seuken `http://economicsandcomputation.org/`
- Functional Compiler Design and Internals.

4.3 Studying

- Get into basics of economics and equilibrium theory. Why: because i need to understand basics to understand the models better and to talk and sell my models better to economists.
- Get into category theory. Why: deeper understanding of Haskell type theory and computation.

- Get into theoretical basics of agent-based simulation and get to know more types of agent-based models. Why: To know the requirements my EDSL/framework has to cover.
- Understand theory of out-of-equilibrium / non-walrasian models: TODO (various Gintis & Mandel Papers)
- Understand Market Micro-structure: Lehalle and Laruelle (2013), Baker et al. (2013) Part II: Chapter 8-12.
- Do literature research on dynamics of equilibrium: eme (2008)

4.4 Research on Papers (see the papers pdf)

- The use of Actor-Model in ABM/S.
- A model for pure functional agents.

References

(2008). *Emergent Macroeconomics*. Springer Milan, Milano.

Aldridge, I. (2009). *High-Frequency Trading: A Practical Guide to Algorithmic Strategies and Trading Systems*. John Wiley and Sons. Google-Books-ID: fEXKZAAVu4oC.

Baker, H. K., Kiymaz, H., Alan, N. S., Bildik, R., and Schwartz, R. (2013). Market Microstructure in Emerging and Developed Markets. *Business Faculty Book Gallery*.

Botta, N., Mandel, A., Ionescu, C., Hofmann, M., Lincke, D., Schupp, S., and Jaeger, C. (2011). A functional framework for agent-based models of exchange. *Applied Mathematics and Computation*, 218(8):4025 – 4040.

Bowles, S., Edwards, R., and Roosevelt, F. (2005). *Understanding Capitalism: Competition, Command, and Change*. Oxford University Press, New York, 3 edition edition.

Budish, E., Cramton, P., and Shim, J. (2015). Editor's choice the high-frequency trading arms race: Frequent batch auctions as a market design response. *The Quarterly Journal of Economics*, 130(4):1547–1621.

Gintis, H. (2007). The Dynamics of General Equilibrium. SSRN Scholarly Paper ID 1017117, Social Science Research Network, Rochester, NY.

Herbert, G. (2006). The Emergence of a Price System from Decentralized Bilateral Exchange. *The B.E. Journal of Theoretical Economics*, 6(1):1–15.

Lehalle, C.-A. and Laruelle, S., editors (2013). *Market Microstructure in Practice*. World Scientific Publishing Co. Pte. Ltd.