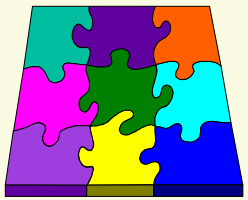
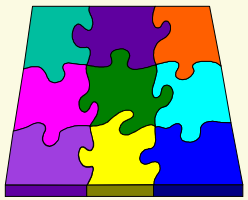
Development and testing of an artificial stock market

Michele Marchesi
DIEE, University of Cagliari
Silvano Cincotti, Marco Raberto
DIBE, Università di Genova
Sergio Focardi
The Intertek Group



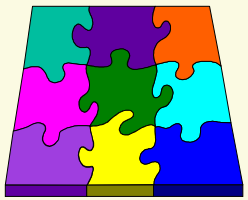
Summary of the Talk

- Introduction
- The Genoa Artificial Stock Market (GASM)
- GASM microstructure
- The market maker
- Clustering of traders
- System development techniques
- Some results
- Concluding remarks



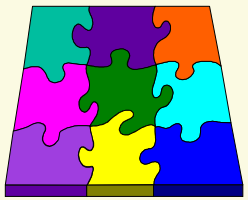
Introduction

- Modern digital computers are so powerful that they allow not only to study reality, but also to simulate it
- The availability of a realistic financial market simulator could be very useful for research and practical purposes:
  - What-if analysis
  - Financial training and gaming
  - Volatility studies
  - ...



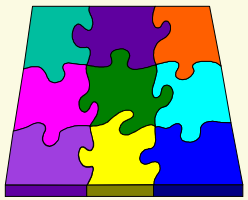
Introduction

- Presently, there are some computer simulated financial markets
- The most famous is perhaps Santa Fe artificial stock market
- Among others, there are:
  - Vienna University of Economics
  - MIT
  - Iowa State University
  - Max-Planck-Institut, Dresden
  - ...



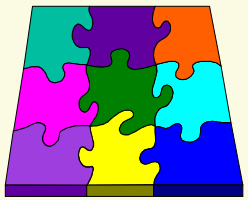
Yet Another Artificial Stock Market?

- We decided to launch a project to build an artificial stock market
- We took advantage of the following experiences:
  - Experience in stock market simulations
  - Experience in Neural Networks and GA
  - Experience in software development processes
  - Experience in Smalltalk language



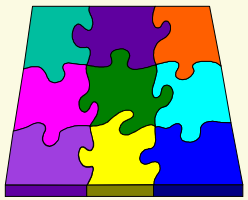
The Genoa Artificial Stock Market

- We called the project “Genoa Artificial Stock Market” (GASM) since:
  - The project is performed mainly at Genoa University, Centre for Economic and Financial Engineering
  - Genoa was a major financial center in the Middle Ages, where they invented:
    - The I Owe You
    - The first derivative contracts
    - The compound interest



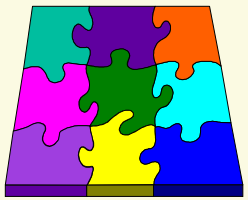
Main features of GASM

- Developed using state-of-the-art programming techniques
- Easily upgradable and modifiable
- It keeps track of portfolio and cash of every simulated trader
- It keeps track of every order and transaction
- It is endowed with a realistic price formation mechanism.



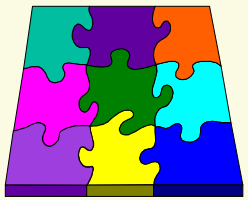
The Genoa market microstructure

- Each trader is an autonomous agent
- Traders are endowed with cash and stocks
- Traders can issue buy and sell orders
- Every trader is tracked by the system
- Traders place orders at random
- The system has three state variables:
  - the total amount of cash,
  - the total number of stocks
  - the price of the stock



Genoa market simulation

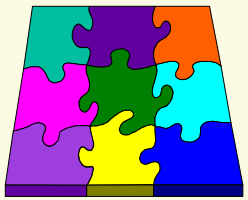
- The price computation proceeds in unit time steps of one day
- Only one stock is traded in the market
- At the beginning of the simulation, the price p(0) is set in an exogenous way
- The price is cleared by a market maker
- Once the price is cleared, the compatible orders are executed
- Other orders are discarded



Order generation

- At each simulation step, each trader randomly “decides” if and how to trade
- First, an extraction is made to decide how many trading operations he/she will perform
- Then, for each operation it is decided if it is a buy ($p = p_b$) or a sell ($p = 1 - p_b$)
- Another random number, r, is then generated to decide the percentage of cash/stocks to use:

$$percentage = 0.9\ r\ qty$$



Order generation

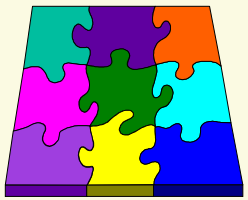
- Each buy order has a maximum price, generated at random:

$$p_{max} = p(k)\ N(1.1, 0.01)$$

- Each sell order has a minimum price:

$$p_{min} = p(k) / N(1.1, 0.01)$$

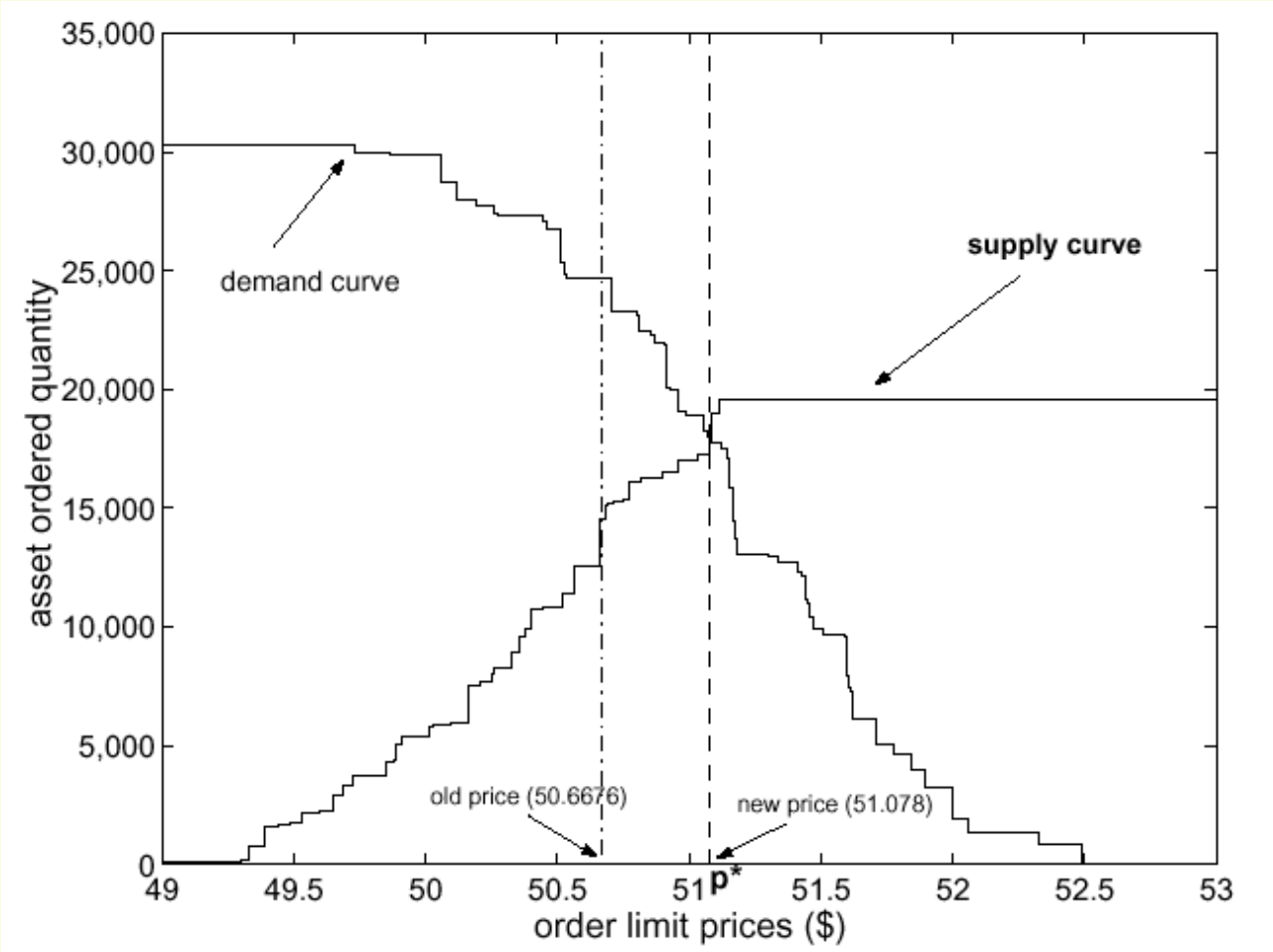
- Each order is random, but there is an intrinsic mechanisms of reversion to the mean

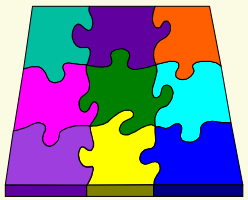


The market maker

- Once orders for time step $k + 1$ are placed, the market maker determines the optimum price $p(k + 1)$
- Then it clears the market, satisfying all the orders that match this price
- The demand and supply curves are computed
- Their intersection is the optimum price

Demand and supply curves

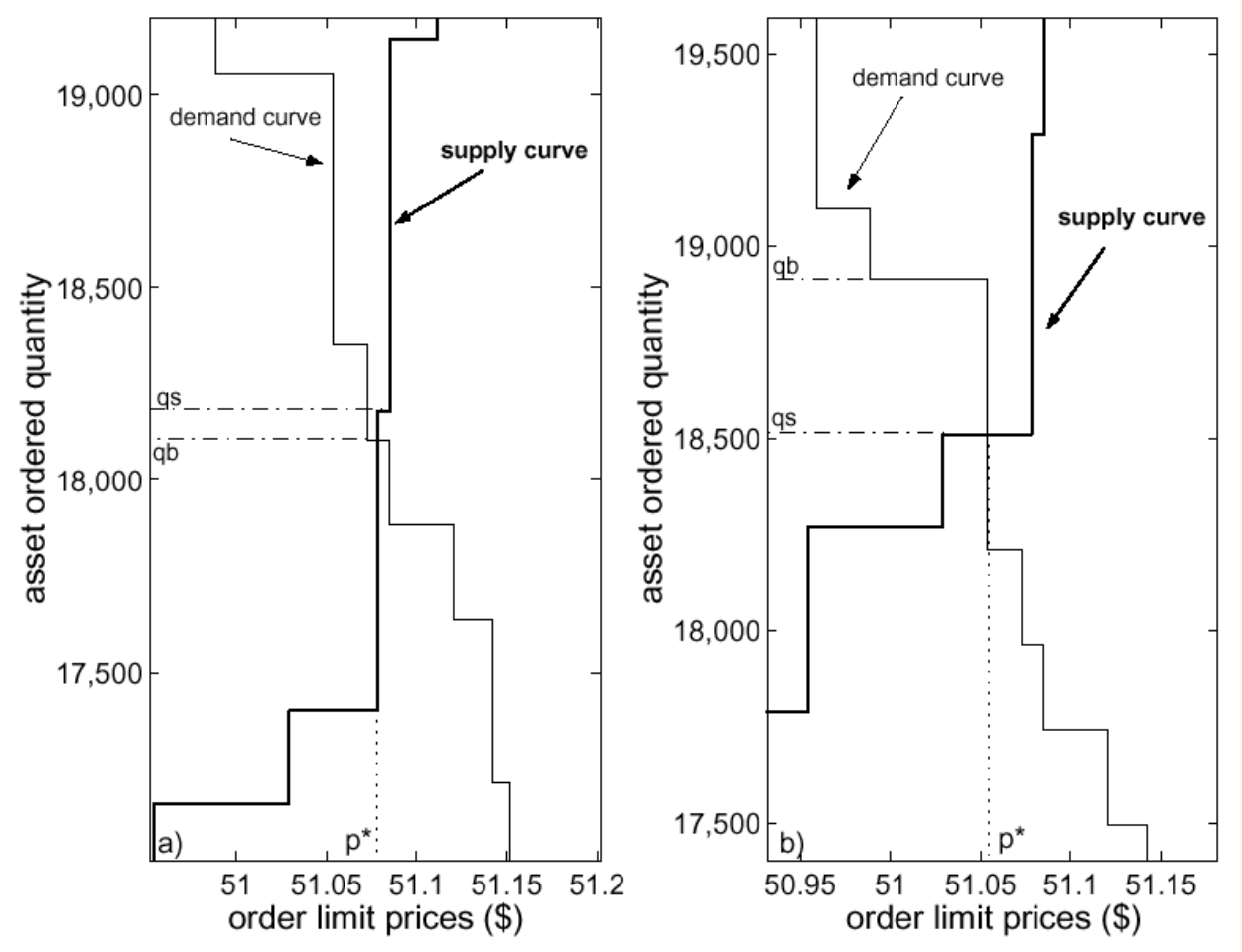


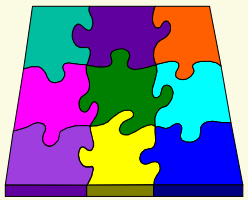


The market maker

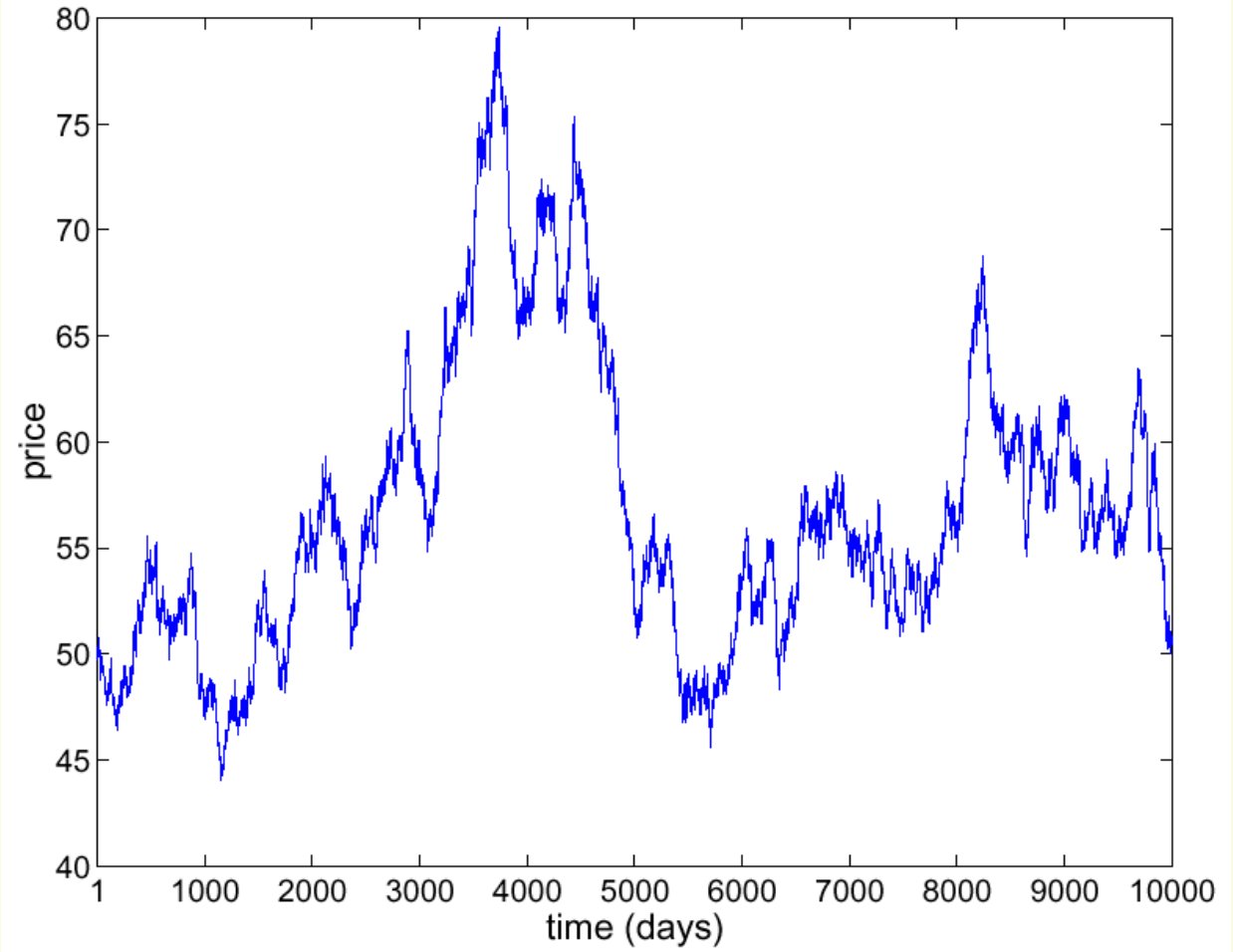
- If the size of compatible sell orders is larger than the size of compatible buy orders, the market maker adds cash to the system and subtract assets from it, and vice-versa
- So, we assume an ideal market maker with an unlimited availability of cash and stocks, satisfying all compatible orders
- The orders that do not match the clearing price are discarded

Demand and supply curves (enlarged view)

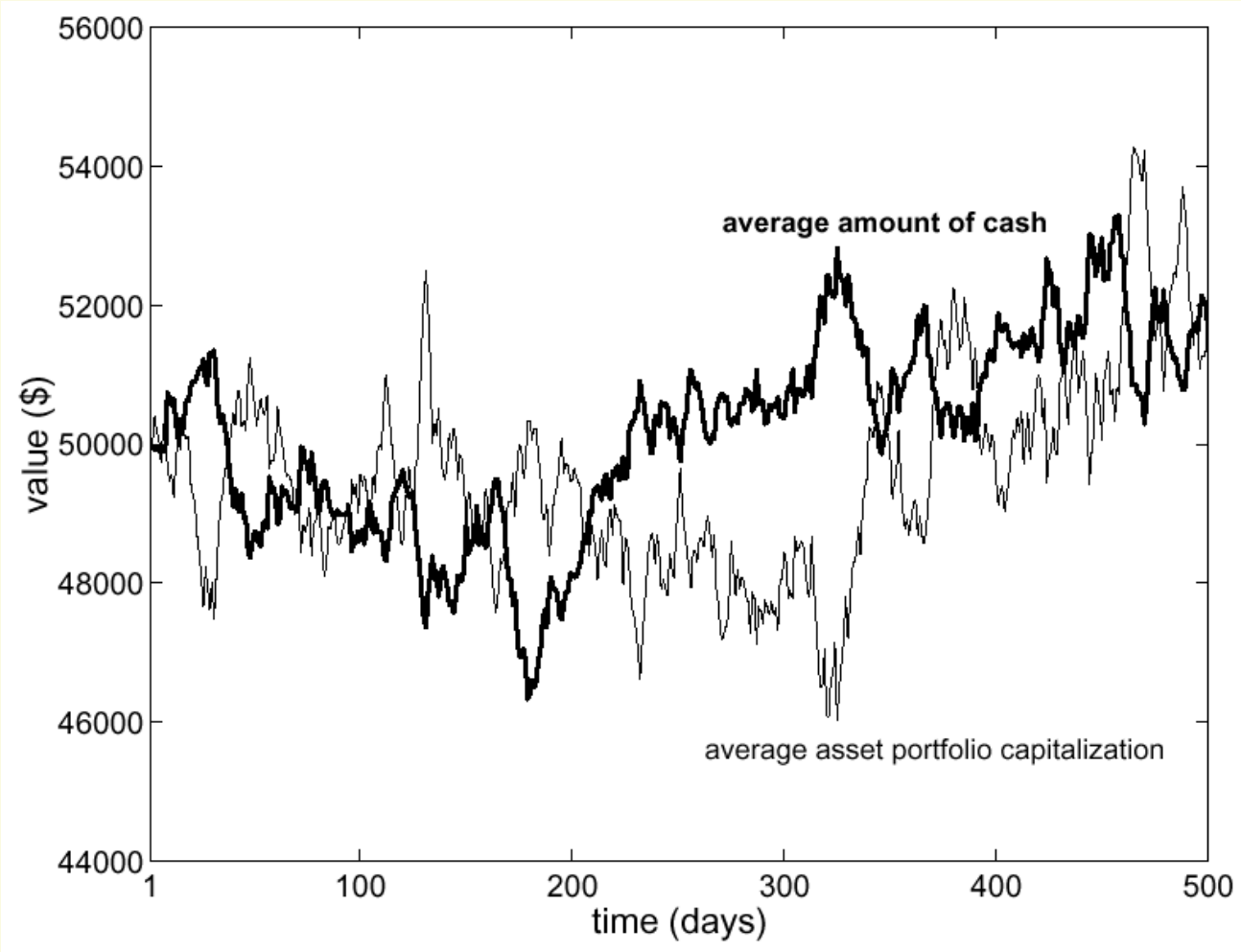




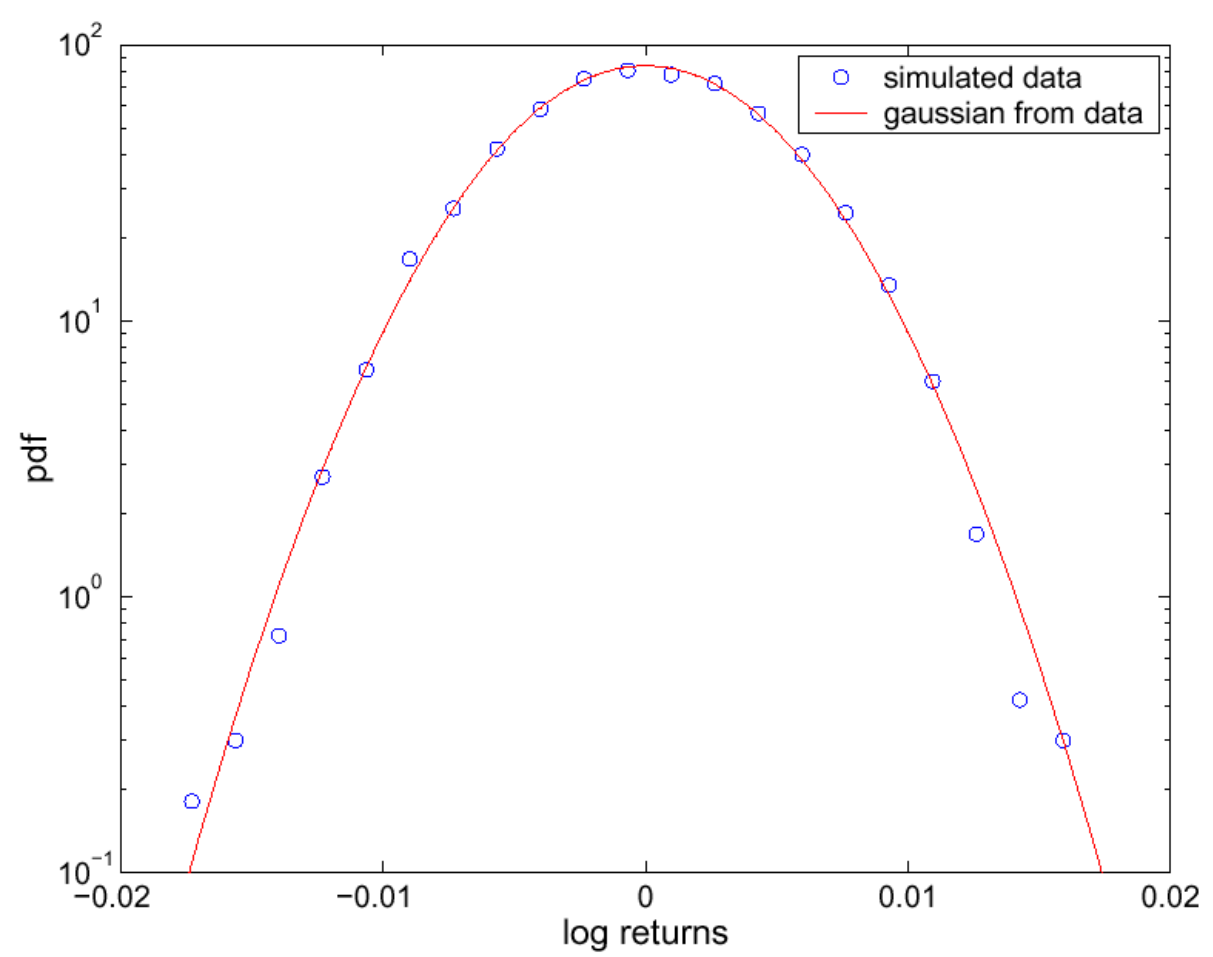
A price path (N = 200)

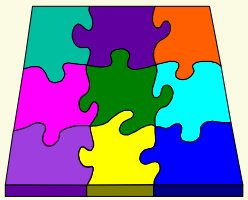


Cash v/s portfolio capitalization



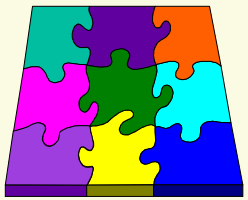
Distribution of returns





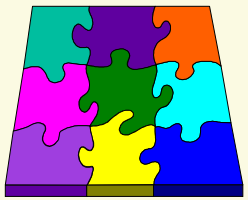
An aggregation mechanism

- The described traders have a balanced behavior and are totally independent
- So, it should not be a surprise discovering that daily returns follow a normal distribution
- To model the aggregate behavior of traders in real markets we added an aggregation mechanism based on random graphs



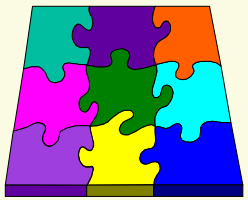
An aggregation mechanism

- Each trader is marked with a *tendency* to be optimist or pessimist (50%-50% at the beginning)
- The tendency does not immediately affect the trader behavior
- At each time step random links are added with probability p_a among traders with the same tendency
- In this way, clusters of traders sharing the same opinion gradually take shape

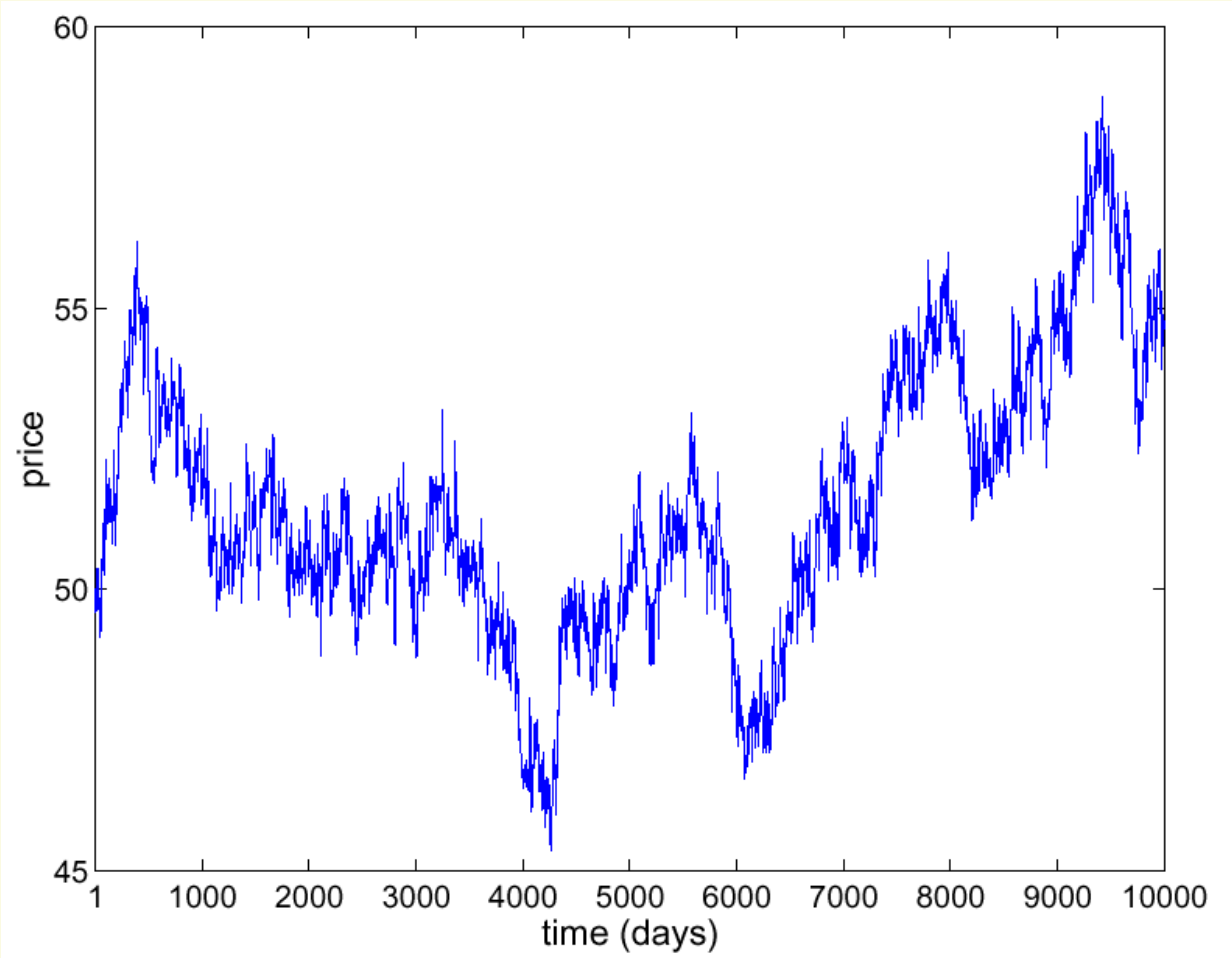


An aggregation mechanism

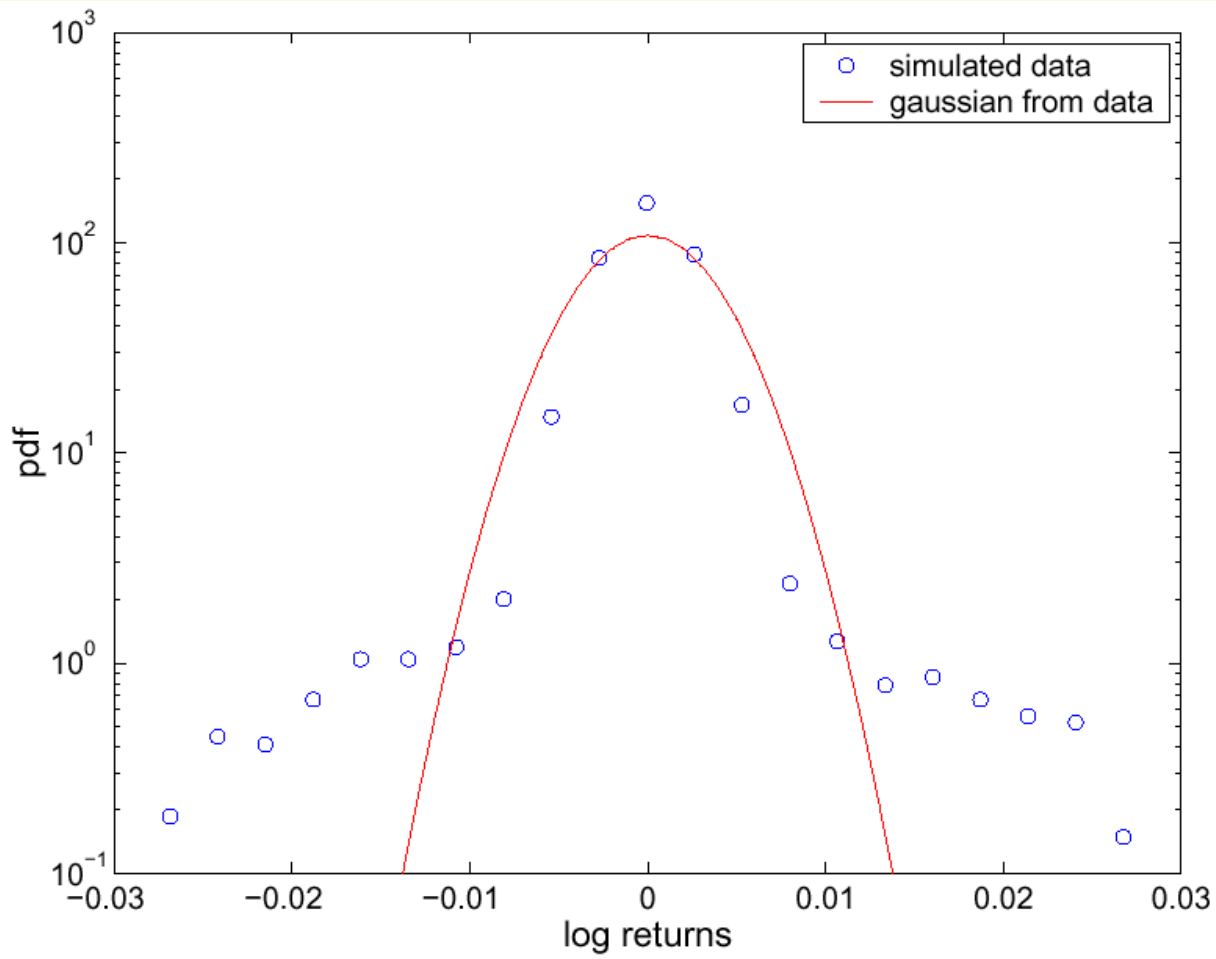
- At each simulation step, clusters of both optimist and pessimist traders are randomly chosen with probability p_c
- All traders belonging to a chosen cluster receive a message to buy (if optimist) or to sell (if pessimist) as far as they can
- Then, chosen clusters are broken and their traders switch tendency
- This simplified mechanism mimics opinion formation in real markets

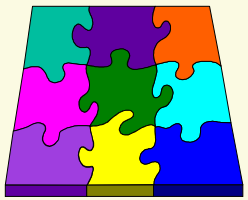


A price path (N = 500)



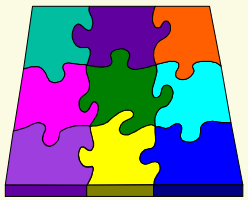
Distribution of returns





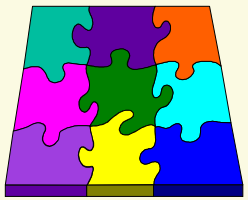
Developing market simulation software

- The simulator was implemented in Smalltalk
- We used pure object-oriented technology
- We used eXtreme Programming (XP) as development process
- XP is characterized by very short development cycles (1-3 weeks) and thorough automatic testing
- Refactoring and simplicity are key concepts in XP

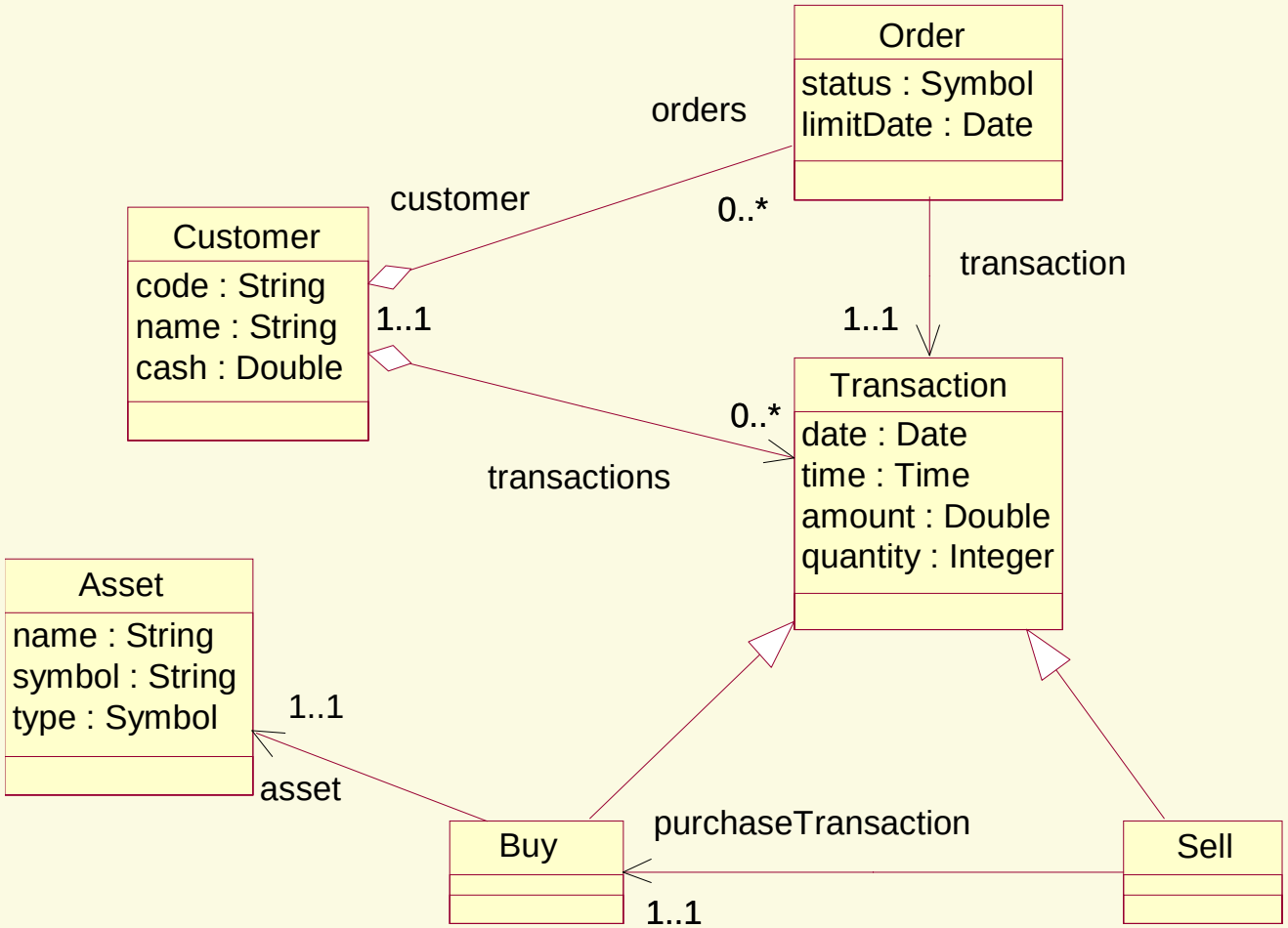


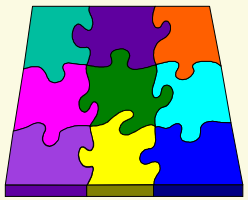
OO Modelof GASM

- 5 subsystems:
  - Assets
  - Trading
  - Clusters
  - Simulation
  - Testing
- System documentation in UML
- System conceived to grow and to be easily modified



An UML class diagram

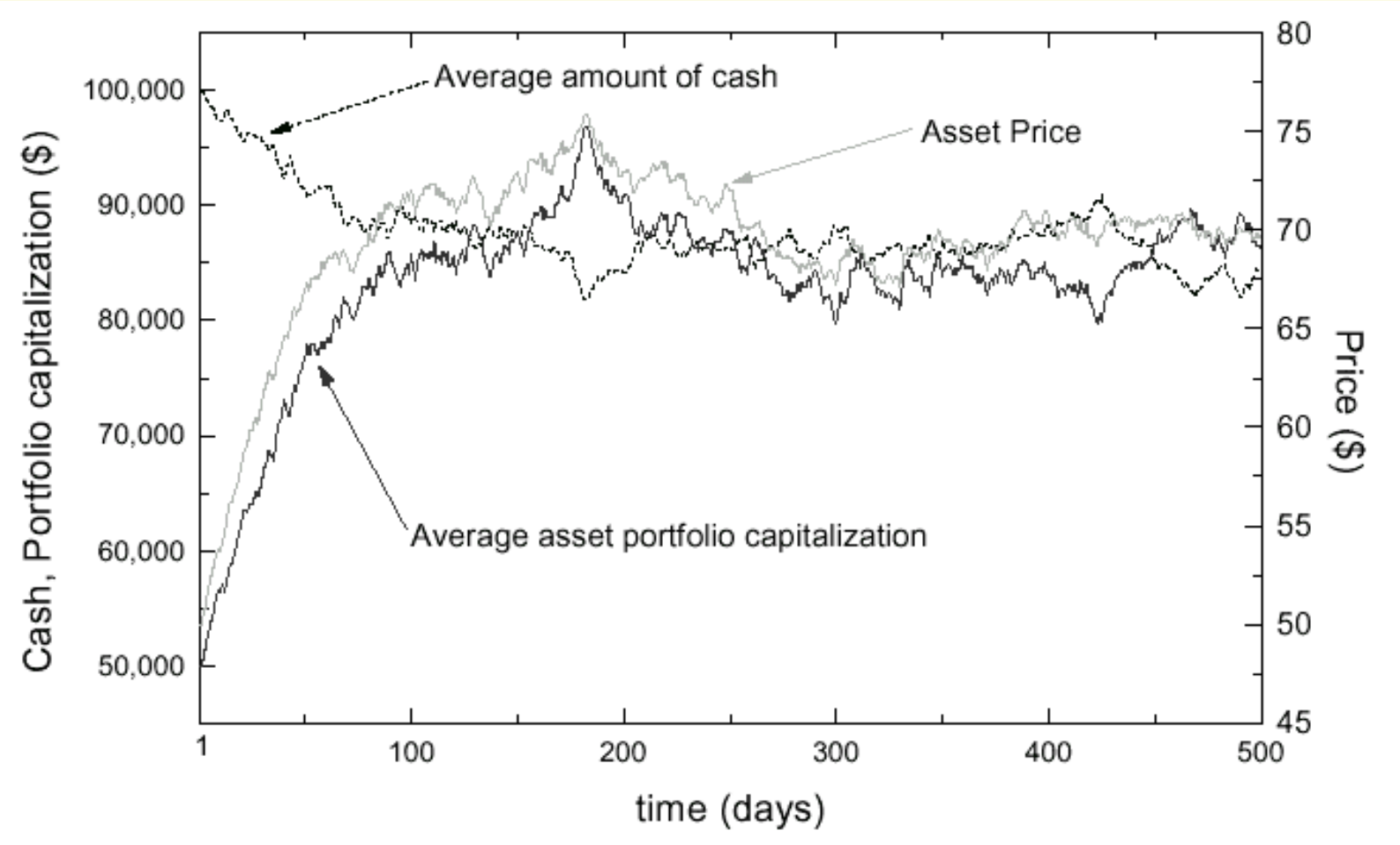




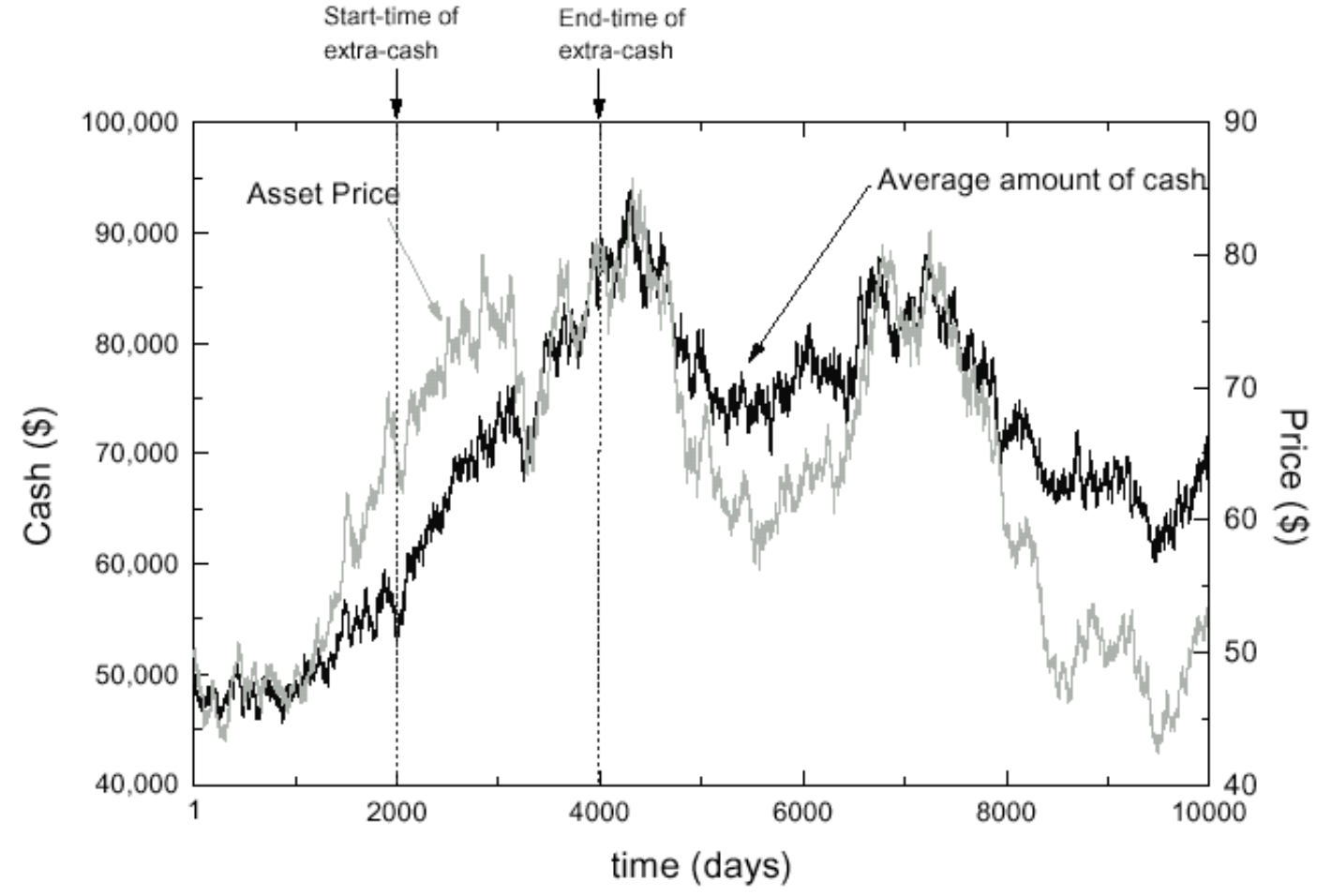
Some actual figures

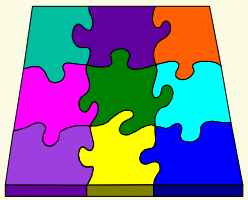
- Present system: 18 classes and 220 methods
- Test suite of 11 classes and 112 methods
- 100 traders for 1000 time steps can be simulated in about 4’ on a Pentium III 600MHz computer
- A first release of GASM was operational in 3 months

A simulation example



Another example





Concluding Remarks

- The system is operational and used for research experiments
- GASM has been conceived to continuously evolve
- Present projects:
  - Add intelligence to traders (with NN and GA)
  - Link the artificial stock with a simulated “economy”
  - Build a trading game on GASM, in which players’ operations may influence the market