Multi-agent system to model the FishBanks play process

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The article presents decentralized multi-agent system for FishBanks play simulation. The participants of the game are fishing companies aiming to generate maximum profits on fishing while sticking to their assigned limits of fish catching thus avoiding excessive overexploitation of the fish banks. The system allow for the participation of both computer-simulated players as well as real players. The system enables to research the problems of reaching agreement in negotiations, maintaining the common renewable resources on the appropriate level (the problem of "the tragedy of commons") and provides for satisfactory functioning of the system regardless of any change in its conditions of operation (the problem of maintaining functional integrity which we are working on).

1 Introduction

FishBanks system is based on the FishBanks game designed for teaching effective co-operation in using natural resources [Meadows 93a], [Meadows 93b]. It allows for the analysis of the phenomena which are typical for the whole class of similar problems such as soil erosion, fossil fuel depletion, deforestation, ground water pollution, over-fishing and urban decay, etc. Several teams of players - fishing companies are the participants of the game. Each company aims at collecting maximum assets expressed by the number of ships and the amount of money deposited at a bank account. The money is generated on fish catching at fish banks - the bigger the catch is, the higher initial profits are; however, excessive fish catching may result in overexploitation of the fish banks resources. The aim of the play is to teach and research the negotiation techniques applied by the company (players' teams) in order to avoid overexploitation of the resources.

The following basic objectives were kept in mind while we were creating the computer implementation of the game:

- simulation of the FishBanks game with the artificial players (negotiations as the method of effective application of the renewable resources in the system);
- game with human participation (researching human behavior and teaching effective strategies in negotiating exploitation of the renewable common resources);
- analysis of the maintenance of the functional integrity of the system (impact that the state of the resources has on maintaining the functional integrity of the system).

The nature of the multi-agent systems (they are composed of the autonomous, intelligent elements) is very suitable for carrying out such experiments. There is a number of multi-agent systems which deal with the problems of the exploitation of the common renewable resources and they undertake both the analysis of the general problems ([Bousquet96], [Antona 98], [Rouchier98]) as well as specific situations when we deal with the problem of the common renewable resources e.g. the analysis of the community of hunters and farmers [Proton97].

2 Description of the "tragedy of commons"

"Tragedy of commons" appears when several users have the free access to the resources. There is always the danger that exploitation of the common resources may result in their overexploitation called "the tragedy of commons". Let's assume that the warehouse of resources is able to offer resources and reproduce them at a certain speed of their consumption by the users. Excessive speed of consumption may result in overexploitation of the resources. The problem was described by Hardin ([Hardin68]). He brought back to light works of the mathematician William Forster Loyd of 1833 in which Loyd had analyzed utilization of the common pastures by the sheep farmers in England. The pastures constitute common property - they are available for many sheep farmers at a time. Each farmer is interested in having the biggest herd possible. Only a limited number of sheep can graze on the meadows. Problems emerge when the number of sheep reaches the maximum limit permissible for the pasture. On one hand the sheep farmers should not increase their herds any more as it leads to devastation of the pasture and unables to maintain their herds in the future. On the other hand, all the farmers share the inconvenience of increasing the herd in number while the one who increased his herd anyway, profits. Thus rationally reasoning farmers will be increasing their herds.

A similar problem emerges in many situations when the operational effectiveness of user depends on the level of their utilization of the renewable common resources. It concerns fish and whales catching, environmental pollution, preservation of the tropical forests, urban transportation problems, etc. The problem "the tragedy of commons" always emerges when the user (not necessary a human being) acts in a rational way - therefore it also relates to the multi-agent system. The problem may emerge in the computer systems which resources are common for many processes - utilization of time resources of the processor, memory, capacity of the message channels, etc. It may additionally include real resources management if they are managed by computer and not by man. The problem "the tragedy of commons" was presented from the point of view of the multi-agent systems in the work of R.M.Turner [Turner91]. Certain methods were proposed in order to avoid "the tragedy of commons" both for the societies made of rational individuals (mainly human communities) as well as specifically for the multi-agent computer systems [Turner91] :

- multiagent planning approaches. One of the agents is elected the planner and he makes decisions concerning availability of the resources ([Cammarata83], [Georgeff84]). The disadvantage of the approach is that the planning agent needs to posses extensive knowledge on the other agents. Otherwise he will not be able to make assign optimum limits.

- partial-global planning [Durfeel87]. The agents exchange information on their objectives and plans and a common plan is created. It may be a difficult task to develop such plan for individual cases. Moreover, it is only possible for a certain class of systems e.g. FA/C systems with co-operating agents. If the agents' objectives contradict drastically, it may be impossible to work out such plan.

- voluntary measures and conventions. Voluntary measures are not sure means of problem solving ("free rider problem" - e.g. a person/participant is not willing to face inconveniences in order to maintain the state of the resources as it/he may assume that the others will do it for him/it). Only when the designer has full control over the resources the convention may work.

- monopolies. Rights to the resources are given to one agent only. The approach works similarly as the multi-agent planning, however there is no chance here to change the managing agent as he forces his position on the other agents. The resources can be also ruined by the competition for the monopolists position, moreover, it may result in a decrease in the effectiveness of the system providing the decisions made by the monopolists contradict with the objectives of the other agents.

- privatisation. It is a simple rule to avoid many cases of "the tragedy of commons", however not all types of resources can be privatised (the system may not have the information on its actual amount, also it may not be able to enforce the rights of ownership on the other agent, indivisibility of the resource).

- mutual coercion mutually agreed on. The agents negotiate the right of access to the resources among themselves and jointly undertake certain coercion which prevent collapse of the system (e.g. introduction of progressive taxation on the amount of the exploited resources). The solution is proposed in [Hardin68] and it is also used in our negotiations in the FishBanks system.

3 Rules of the Fish Banks game

The Fish Banks game is played in succeeding rounds which represent years of the game.

Few teams participate in the Fish Banks game. Each team represents one of the fishing companies. Each company aims at collecting maximum assets expressed in the amount of money and ships. The companies are allowed to catch fish in two fishing waters (inshore or deep-sea fishing) or they may keep their ships at the port. Initially it is assumed that the number of fish in deep-sea fishing waters is higher than the number of fish in inshore fishing waters therefore deep-sea fishing is more profitable. Costs of fishing (ships preparation) are higher for the deep-sea fishing and lower for the inshore fishing. The company may also leave their ships at the port and pay even lower rate for their maintenance, however this way it cannot fish. The companies may order new ships to be built as well as they may cross-sell their ships. The ships may be also sold at the auction organized by the game manager. The players can enter negotiations. The subjects of the negotiations are not limited, in practice they typically concern limitations in terms of the fish catching limit in the fishing waters which are endangered with overexploitation. The costs of building a ship, costs of its maintenance and use as well as the cost of sold fish is fixed for the whole game. At the end of the game the value of the ships owned by the companies is estimated. In the course of the game a standard case of "the tragedy of commons" is faced as the fish constitute the common renewable resource.

4 Description of the model

4.1 Introduction.

In the following sub-chapters we describe the model of the FishBanks system : we give the main assumptions, describe the types of resources in the system, the types of the agents in the system, the types of actions performing by the agents, the mechanisms of the reasoning of the agents and the kinds of interactions in the system.

4.2 General assumptions

There are several types of the agents in the system (such as company, game manager, ship-builder, fish-seller, fish-bank, weather, visualizer, clock). Each type of agent has the skills to perform its typical actions, also their objectives may be similar. The actions performed by the agents may be classified into two groups:

- actions connected with transfer or production of resources;
- actions connected with negotiations to prevent or enforce some actions which belong to the first group.

4.3 Resources

The agents operate using three types of resources: fish, money and ships. Each resource has its specific features.

Fish. Fish are renewable resource. Their number grows in a specific time period Δ t (one year of the game) and depends on their actual number and the maximum permissible number:

$$\Delta R = R(t) \times R_v \times (1 - R(t) \div R_{Max}) \tag{1}$$

Δ R –the number of fish born within the period (t, t $+\Delta$)

R(t) - the number of current resources

R_{Max} – the maximum number of resources

R_v – reproduction co-efficient

Although fish are actually owned by specific agents (fish bank, company or fish–seller), the fish bank agent must make them available to each agent who is capable of performing appropriate actions, therefore it may be considered common resource.

Money. The system views money as renewable resource. Every period (a year of the game) its amount is updated as a result of the interest rate on the account (depending on the negative or positive balance on the account the interest rate may be also negative or positive). The money is also owned by specific agents and there are no limitations as to their use (they always constitute private resources of the individual agents).

Fishing ships. Ships are private resources owned by the agents (company, ship–builder and game manager) and some of them have the capacity to build new ships (ship–builder and game manager). The ships may be also seized i.e. as they are used by the agent for certain actions (e.g. sending to the fish bank) they cannot be used for any other one. Moreover, there is a specific charge for ships storing which is borne by the agents (company) which own the ships (for every year of the game).

4.4 Dynamics of the game

Owing to the nature of the FishBanks game, the system must make synchronized transfer between several stages. Types of the actions to be currently performed by the individual types of agents depend on the stage of the game. There are 4 regular stages of the game which take place subsequently in each year of the game:

- ships and money collection;
- ordering new ships to be built;
- fish catching;
- resource regeneration.

There are also two special stages of the game to be moved to by the system as requested by the agent:

- the auction;
- negotiations;

The agent observes synchronization of the stages and years.

4.5 Agents

There are several different types of the agents in the system. Each type has its specified actions to be performed as well as the objectives and strategies of their implementation. The system includes the following types of agents:

- **company** – the agent of such type represents the company participating in the FishBanks game. He may send ships to the fishing waters to catch fish (*SendShips*), order building of new ships (*OrderShips*), buy or sell ships (*SellShips*, *BuyShips*), sell fish (*SellFish*), calculate the state of its account (*CalAccState*), pay charges for the ship storage (*ShipsStorage*). He may also participate in auctions and negotiations.
- **ship-builder** – builds ships and delivers them to the companies which order them (*DeliverShips*).
- **fish-seller** – buys fish (*BuyFish*).
- **game manager** – initiates auctions of ships, he may also execute the agreed rights which come as the result of negotiations.
- **fish-bank** - represents the fishing waters and calculates the current number of fish at the fish bank. The number is subject to fluctuation as a result of catching and regeneration (*FishReg)*.
- **weather** – tells the weather on the fishing waters and has impact on the state/level of catching.

- **visualiser** - responsible for presenting the results of the operation of the system and recording the history of the simulation.
- **clock** – responsible for synchronization of years and stages.

4.6 Actions

The table describes the actions which the agents are capable of performing. The actions are related to the operations on the resources. As a result of an action the resources may be:

- exploited - the agents produce the resources, obtain the resources from another agent;
- used - the resources are irrevocably spent by the agent;
- locked - the resources are not available as long as the action takes place, when it is completed they are available again
- transferred - the resources are transferred to another agent

Each action and operation may involve even all kinds of the resources - triples are used in their description in the table (money, fish, ships).

actions	res. exploited	res. used	res. locked	res. transfered
SendShips(n,m)	(0,n $\times$ cL(m),0)	(n $\times$ cC(m) ,0,0)	(0,0,n)	(0,0,0)
Catching(n)	(0,0,0)	(0,0,0)	(0,0,0)	(0,n $\times$ cL(n),0)
OrderShips(n)	(n,0,0)	(0,0,0)	(0,0,0)	(n $\times$ pNS,0,0)
DeliverShips(n)	(n $\times$ pNS,0,0)	(0,0,0)	(0,0,0)	(0,0,n)
BuyShips(n)	(0,0,n)	(0,0,0)	(0,0,0)	(n $\times$ pS,0,0)
SellShips(n)	(n $\times$ pS,0,0)	(0,0,0)	(0,0,0)	(0,0,n)
BuyFish(n)	(0,n,0)	(0,0,0)	(0,0,0)	(n $\times$ pF,0,0)
SellFish(n)	(n $\times$ pF,0,0)	(0,0,0)	(0,0,0)	(0,n,0)
ShipsStorage(n)	(0,0, 0)	(n $\times$ cost,0,0)	(0,0,0)	(0,0,0)
CalAccState(n)	(n $\times$ add_1 ,0,0)	(n $\times$ add_2,0,0)	(0,0,0)	(0,0,0)
FishReg(n,m)	(0,ΔR(n,m),0)	(0,0,0)	(0,0,0)	(0,0,0)

The meaning of the actions:

- SendShips (n,m) – sending n ships to the fishing waters m;
- Catching (n) – realization of fish catching in the fishing waters with n number of ships;
- OrderShips(n) – an order to build new ships, the transaction takes place only at the beginning of the next year of the game;
- DeliverShip(n) – ship order and delivery;
- BuyShips(n) – sale of n ships;
- SellShips(n) – purchase of n ships;
- BuyFish (n) – purchase of n units of fish;

- SellFish(n) – sale of n units of fish;
- ShipsStorage(n) – charge for owing n number of ships;
- CalAccState(n) – calculation of the new state of the account;
- FishReg(n,m) – regeneration of fish at the fish bank with n number of fish and with the maximum number of fish in the fishing waters equal m. Values (other than the amount/number of resources) which have impact on the actions are:
- cC(m) – the costs of fishing on m fish bank per one ship;
- cL(m) – the current level of fish catch on m fish bank per one ship;
- pNS – the price of building a new ship;
- pS – the price of one ship sold/purchased;
- pF – sales price of a fish unit;
- cS – the price of the maintenance of the one ship;
- add1 – interest rate on bank deposit (if the level of the account greather then 0);
- add2 – interest rate on debit (if the level of the account smaller then 0);
- R(n,m) the number of newborn fish (described by the formula 1).

4.7 Reasoning

The majority of types of the agents in the system are at the moment reactive agents who react to what is happening but don't conduct their own reasoning process. There are two types of agents with more developed decision-making mechanism: game manager and company. **Game manager** must make a decision when to start of the auction of ships, their number and the initial price. The current number and the price are specified at random from the numbers included in specific brackets, however the decision about the very beginning of the auction is made when the catch is low and it does not provide the required level (as the level is given and it is expressed by the brackets including the number of fish bought by fish sellers). More complex decisions have to be made by the company. The company's decisions come from its nature which is defined by the following initializing parameters:

- w – parameter describing the strength of the market strategy impact (profit-oriented);
- e – parameter describing the ecological strategy impact (oriented towards maintaining the balance);

- k – parameter describing the achieving information strategy impact (oriented towards collecting information about the system). Those three parameters abovemust sum up to score hundred.

- risk adverse – indicates the agent's inclination toward making risky decisions. This parameter is represented by a logic value.

The agent uses three strategies: gaining fortune, taking care of the balance in the system and achieving the information of the system. The initial parameters describe, how much is each of these strategies important to the agent. The goal function of the agent company is described by:

- W – estimation of the current state of agent from the market strategy position;

- E – estimation of the current state of agent from the ecological position;

- K – estimation of the current state of agent from the archiving information position.

The main goal function (G) of the agent company is described by:

$$G = w \times W + e \times E + k \times K \tag{2}$$

The agent try to chose the solution which improve its main goal functions. The decisions concern:

- sending ships to fish banks;
- order ship building;
- ships sale/ purchase;
- proposal to start negotiations;
- proposed solutions in negotiations;
- proposal to start auction;
- proposed auction price.

4.8 Interactions

Interaction take place in the system by using messages exchanged by the agents. The messages are created according to the Interaction Language presented in [Demazeau95]. Such messages consist of three segments where each segment transfers a different type of information:

- message language - contains information about the sender and the receiver of the message as well as the identifier of the message;

- application language - contains information typical for the application

- multi-agent language. The language is to present the intention of the sender and his expectations. It contains information about the message protocol used in a given message thread and information about the position of the message in this protocol.

The system has three types of the interaction protocol:

- "simple" - inform/ perform - used for the action to be performed by agents;
- auction - "escalating bids" - used for the auction of ships;
- negotiations – Sian ([Sian92]) - used for negotiations;

The figure presents the complex interaction protocols (of auction and Sian protocol) in use.
The auction is conducted according to the standard protocol "who gives more". Starting the auction the auctioneer sends the information messages to the participants, The participants initiate the communications threads to remember the state of the auction. Auctioneer (company or game-manager) may be in two main states:

- WaitingForPropose – while waiting for the price proposals;
- Warning – while sending the information about the current state of auction (current winner and his proposition);

The participant (company) may find himself in the following states:

- WaitingForWarning – waiting of the auctioneer answer with the information about the current state of auction;
- Winning – the participant has proposed the best offer;
- Losing – the other participant has proposed the better offer;
- Win – the participant wins the auction;
- Lost – the participant loses the auction.

The negotiations are based on the Sian protocol [Sian92]. Each proposition is evaluated by the agent, who may accept, reject or ignore it (4th opportunity – the proposition of the modification is not implemented). Each agent evaluates the course of negotiations and takes the final decision: whether the proposition is accepted or rejected. We assume, so that the proposition would become law it must be accepted by all the agents. The negotiated propositions may concern:

- forbidding catching on the particular fish bank;
- accepting catching on the particular fish bank only some quantity of ships for each company;
- accepting catching on the particular fish bank only some percent of ships for each company;
- setting the tax for catching on the fish-bank (game-manager executes it).

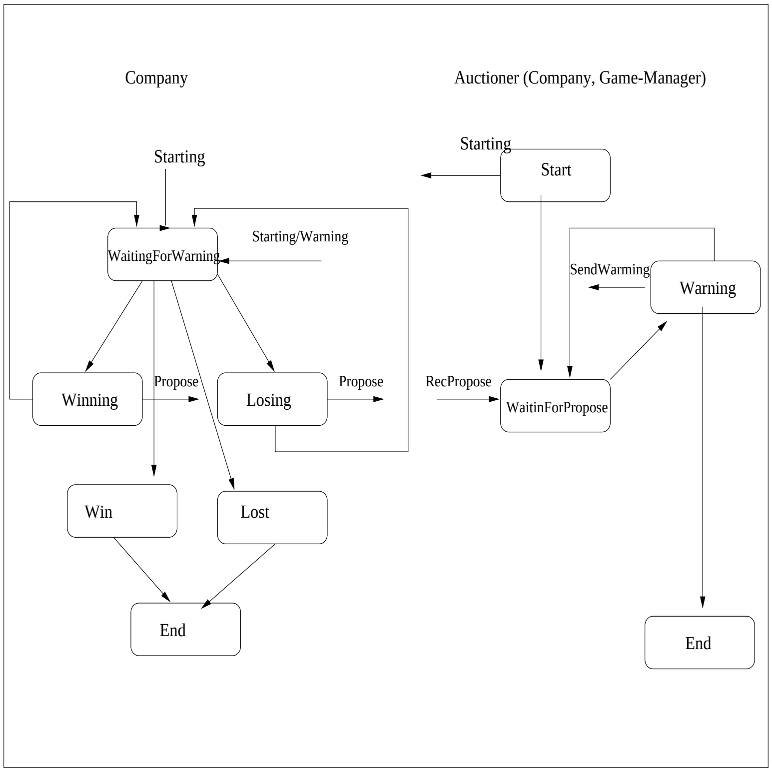

Figure 1: Auction protocol.

4.9 Remarks

Our research concern the problem of the maintenance of the functional integrity by the multi-agent system – to guarantee that the system will perform its functions independent from the changes in it (linked with the number of the agents in the system, the types of agents or the resources in the system). The FishBanks system makes possible to analyze the influence of the change of the resources to the proper functions of the system. We assume, that system FishBanks works correctly (its functional integrity is maintained) if the level of the catching (the quantity of fish bought by FishSeller) is in the given period.

5 Realization

5.1 Introduction

In this chapter we present the structure of the FishBank system, the structure of the agent and tools used to implementation of the system.

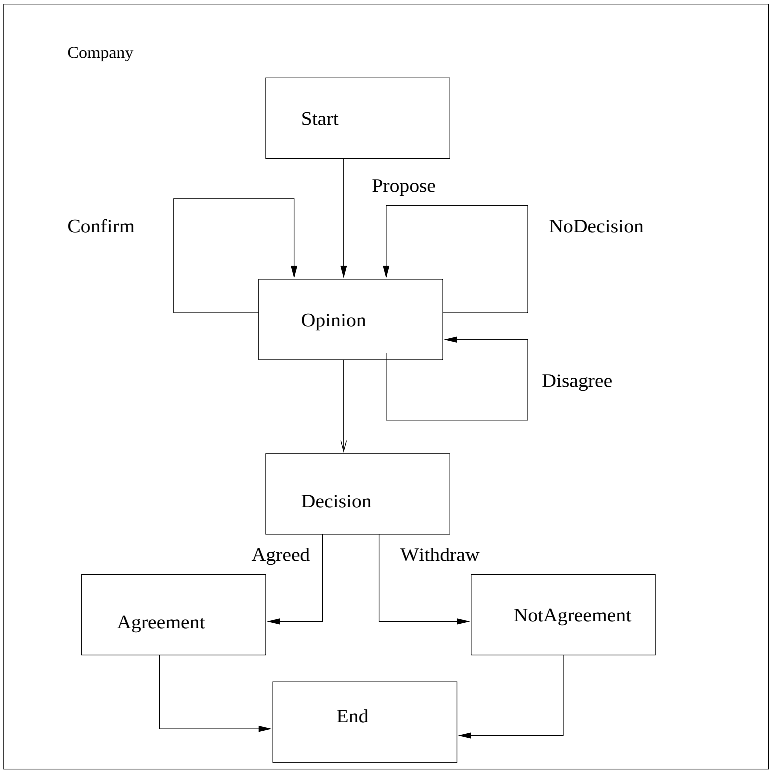

Figure 2: Sian protocol.

5.2 Structure of the system

There are two classes of processes in the system:

- the process of server - responsible for simulation of game with participation of artificial companies;
- the process of customer - owing to this process a man can participate in the game as one of the fishing companies.

Message between customer and server is realized by using "remote method invocation" (RMI). The figures present how the processes of server is build (Fig. 3). The server contains following modules:

- Multi Agent System – contains all the agents;
- Parameters – contains the initialization parameters of the agents;
- User Interface – realizes the communication with the user : setting the parameters and presenting the results;
- Human Interface Listener – realizes the connection to the human players;
- Coming Agents Listener – realizes the migration of the agents;

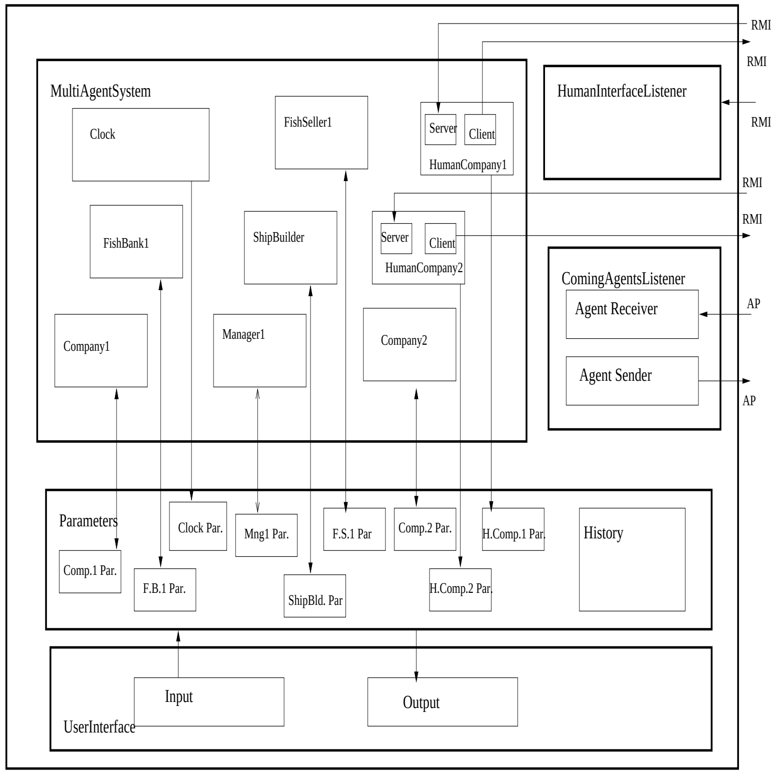

Figure 3: FishBanks server.

5.3 Structure of the agent.

The server's process is a multi-thread one where each agent acts as a separate thread. The agent company is the most t complex one as it consists the following elements (4):

- **message receiver** – receives and puts in order messages incoming from other agents;
- **register of current message state** – stores the state of current realised message threads (auction and negotiation);
- **knowledge** – stores data on the state of other agents, history of the game, etc.
- **state** – stores information about the owned resources;
- **decision module** – on the basis of the own state of resources and knowledge and taking into account the negotiated rights it selects the actions which are the best for realization of the agent's objectives;
- **message sender** – prepares and send messages to other agents.

Other types of agents are simpler - they do not have a module responsible for remembering the state of communication and their decision-making modules are simplified.

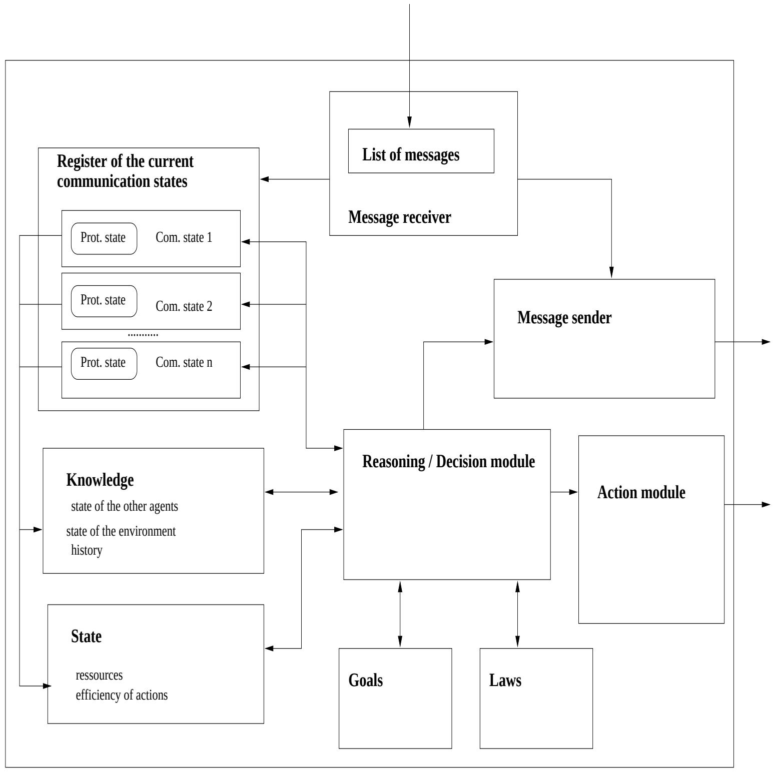

Figure 4: Model of agent.

5.4 Remarks

The system Fish Banks is written in Java language (JDK 1.1.6 and library Swing 1.0.3 to make user's interface are used). The sources has about 16000 lines and contains about 140 classes.

6 Results.

The results of the simulation are presented on Fig. 5

Moreover, we analyzed the change of the state of the system during the simulation and compared the game with negotiations and without it. We did the experiments on the balanced population of the four agents (some of them have stronger market preferences, some of them – ecological) and two fish-banks. The agents have following characteristics:

- company0 – w = 100, e = 0, k = 0;

- company1 – w = 0, e = 100, k= 0;
- company2 – w = 0, e = 0, k = 100;
- company3 – w = 40, e = 40, k= 20;

We compare the changes in the quantity of the ships and companies' money and the quantity of fish in fish-banks. The games without the negotiations were finished with the exploitation of both fish-banks. And with the negotiations process the agents made an agreements and limited the level of catching, giving the time for fish to breed.

7 Conclusions

FishBanks system The FishBanks system's goal is to modelize the course of the game so that the behavior of artificial players is similar to the human players' one. But the system indeed may have wider utility. It is possible to change the parameters of the simulation (the prices of ships, fish, interest rate on loans and savings, quantity of the fishbanks and their parameters etc.), which are the constants in the Fish Banks game. We work on the version where the agents migrate between the games (using the Aglets library for migration of code in the computer network).

FishBanks system and tragedy of commons In the FishBanks system we analyze one of the preventing mechanisms of "the tragedy of commons" – negotiations to agreed mutual commitments. However the system is based on the FishBank game, still – thanks to "the tragedy of commons" which takes place in very different situations – we may to adopt to the researches on the similar problems.

FishBanks system and MAS theory. In the FishBanks system the negotiations guarantee the maintenance of the functional integrity of the system, assuring the sufficient level of the resources. The functional integrity of the system may also be damaged by the lack of the agents with proper capacities. The solution to this problem is to give the agents the possibility to enter to or to leave the system (the agents may be useful in the system or not, and the conditions in the system may satisfy or not satisfy the agents). It is the reason, why we work on the version including the migration of the players between the games.

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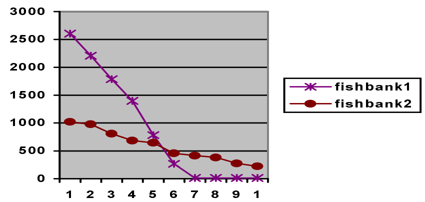
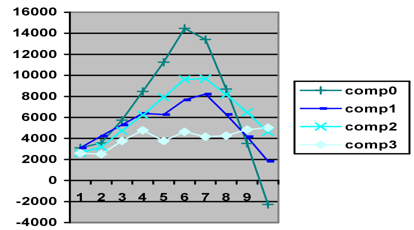
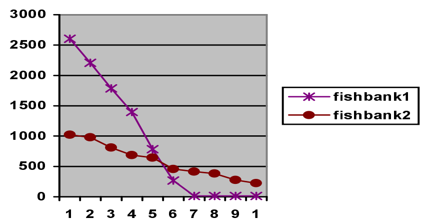
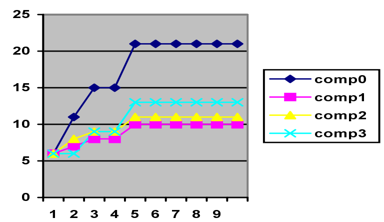


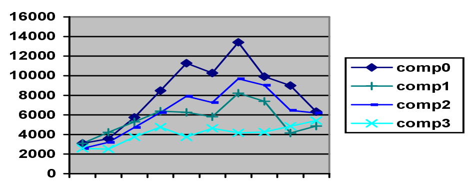


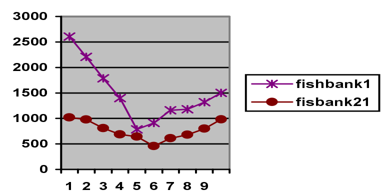
a (number of ships of companies) b (money of the companies)





c (number of fish on fish bank) d (number of ships of companies)





e (money of companies) f (fish on fish bank)

a,b,c – for the game without the negotiations
d,e,f – for the game with the negotiations

Figure 5: Results.