

Recent progress on formal and computational model for A. Smiths Invisible Hand paradigm.

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Abstract—The recent economic crisis has boosted a very strong demand for quite new tools to analyze and predict the behavior of quasi-free¹ markets. The paper presents our effort to build a formal theory of A. Smith's Invisible Hand [5] paradigm (ASIH) and simulation model for a selected case. It proves that ASIH is not only an economic idea, which conflict on ways to govern [16], but something that really exists, for which formal a theory can be built. Moreover, ASIH can be measured [17], and in the future probably utilized for quasi-free market analysis and prediction. In advance, we want to state, that ASIH according to our theory, can generate both correct and incorrect decisions. For this, we use the theory of computational Collective Intelligence [18] and a molecular model of computations [1], [2]. Our theory assumes that ASIH is an unconscious meta-inference process spread on the platform of brains of agents. This meta-process is: distributed, parallel, and non-deterministic, and is run on a computational platform of market agents' brains. The ASIH inference process emerges spontaneously in certain circumstances and can vanish when market situation changes. Since the ASIH platform is made up of brains of agents, conclusions of this inference process affect the behavior of agents and therefore the behavior of the entire market. Our research unveils that ASIH is in fact a family of similar meta-processes; thus ASIHs for different economic eras are different because corresponding models of brains of market agents are different. The paper will present and explain, on the basis of a simulation model, a case of powerful ASIH response at the end of the 15th century due to a blockade (taxes and the Dardanelles sea-route cutoff) of spice trade by Turks and Arabs. ASIH also responded to the discovery of America, the emergence of a sailing route around Africa, the establishment of plantations (sugarcane, spices) and modern galleons² technology. This case demonstrates how powerful and with far-reaching consequences, ASIH can be.

I. INTRODUCTION

Secondary schools textbooks define Economics as a study of human behavior.

Our research effort to build a formal computational theory of ASIH under the assumption that it is a form of Collective Intelligence of a quasi-free market, perfectly fits this point of view. In our research, we abstract from widely used terms such as money, production, consumption, inflation, etc. Instead, we concentrate on large scale inference

¹Quasi-free means that markets are subject to restrictions of political, ethnic and environmental nature e.g. during the 15th century in fact, only the Arabs were able to trade in the Levant.

²In only a few decades, European ship displacement had increased from approx. 100 tons (Columbus' ships), to almost 2000 tons (Manilla galleons).

processes collectively run in the brains of market agents. The molecular model of computations applied here, starts to be efficient when computations are: parallel, distributed, multi-threaded (many interleaving calculations are run at the same time), non-deterministic; with at least tens of thousands of information molecules representing participating agents. This approach perfectly fits the observed behavior of a quasi-free market.

We model the information molecules³ representing market agents, with the help of an abstract Virtual Machine (automate) denoted by VMa. This approach is to some extent similar to a Java Virtual Machine concept. VMa architecture will be given further on. Depending on the era in economics, this virtual machine is equipped with a corresponding model of economic behavior, a corresponding inference and calculation engine and a corresponding ability to displace (to carry out a business trip) in computational space, thus modeling the whole market. Such an approach is necessary, because agents in a pre-monetary era will carry out business inferences in a different fashion than for example a 15th century Venetian merchant would, to a modern derivatives trader. It is also difficult to observe occurrences of ASIH in different markets in different eras. When we analyze real, live agents from a mental and inference/computational point of view, we see how far this agent is mentally redundant. This redundancy allows unconscious, parallel, distributed and multi-threaded inferences to emerge, run and to conclude in their brains. Results can have a kind of landslide/shake effect on a given quasi-free market - what we perceive as ASIH.

Now, some statements regarding considered meta-inference process should be given to make our theory more intuitive.

I. Observability: Many physical processes can serve as local computers (e.g. analog computers) and we observing it can be unaware about real nature and function of this computer for the environment.

It is quite natural that computational processes which are the basis of ASIH remain unnoticed until now. A perfect example of this is an analog computer (Fig. 1) constructed of

³For an extensive discussion on the information molecule concept see [1], [2], [8].

strings and bags of sand, by architect Antonio Gaudi, used to calculate the structure of the Sagrada Familia cathedral (Fig. 2) in Barcelona, Spain. Even computer science students will not realize - without special explanation - when looking on it, that this is a problem oriented computer.

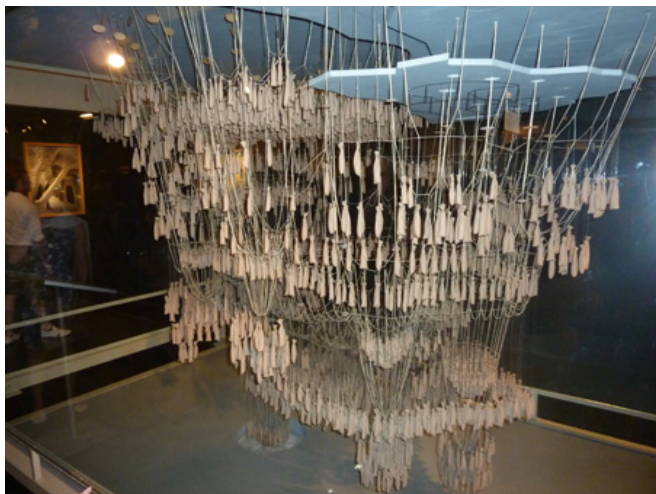


Fig. 1. **Gaudi analog computer.** Source: <http://www.sacredarchitecture.org>



Fig. 2. **The Sagrada Familia cathedral, Barcelona, Spain.** Source: Google pictures.

II. Unconscious: A market agent can be unconscious about the fact that "doing his business as usual" the agent participates in a distributed meta-inference process. Conclusions of such inference can affect a different agent, or profits from inference conclusions can be appropriated by other agent(s).

A perfect example of this is academic and/or, scientific world. University staff receive salaries for teaching students, whereas usually two good publications per year are a must for contract renewal and promotion. It is usually unimportant for the chairman what the publications are about. Instead, it is the quotation index that is important, which is a guarantee

that a researcher participates in the global, common research effort. A given scientist can be quite unaware, that in the end someone, not even related to his study will put together even partial results of the study, and will build an inference chain profiting from the conclusion⁴.

III. Implied computations: Building a certain tool to reach a given goal, we are almost always unable to define what the real domain of possible applications is. It is true for hardware tools, for programs, as well as for algorithms.

A good example is the A* algorithm which has a double nature: can serve to find an optimal path between two points and find a path from a start to finish, in-between obstacles. Thus the A* algorithm - built into a VMA of agents trading spices to optimize (from an economic point of view) their sea routes during a stable trade period; will unveil it "second nature" as a path finding algorithm, when path optimization is impossible due to new obstacle (Arab's taxes for example).

All three above mentioned statements perfectly interact together in our formalization of the ASIMH case analyzed in this paper.

Perhaps the best way to provide an intuitive insight into our theory and the nature of ASIH, is to tell a short tale.

...suppose that somewhere, at some time, a small, anonymous city is rapidly growing. Because of the ignorance of the inhabitants and greed of developers, houses are built close together, using timber, and covered with straw making them cheaper. Garbage lay commonly between the houses. Some foreseeing inhabitants protested because of spreading epidemics and a constant threat of fire, but they are being ignored. Fate seemed to observe this and finally an overturned candle caused the city to burn down (London 1666 ?). Residents blamed destiny for this disaster, however, they drew the right conclusions. While rebuilding the city; wider streets with greenery were introduced to separate blocks, fireproof separating walls between buildings were made obligatory and several other regulations were introduced...

Now, if we replace the fire jumping from building to building, to the outbreak of distributed inference transferring between brains of residents, the result will be similar...

II. STATE OF ART

For years now, the notion of the *Invisible Hand* of the market has been stirring controversy. In everyday life, it is customary to put all economic processes for which no other reason can be found down to the operation of the invisible hand.

So where has this notion, that has been used in both science and daily life for years, come from?

The source of this notion can be traced back to the 18th century, when Thomas Hobbes, having fled the civil war-

⁴It is demonstration that our theory extends beyond problem of ASIH. Most probably the phenomenon of universities can be explained. Teaching layer corresponds to business layer, whereas university research corresponds to ASIH. It will be the subject of upcoming publications.

torn England to hide from his political opponents in France, formulated his concept of the Leviathan [7], [8]. Hobbes, assuming that the human nature is egoistic, argued that it was necessary to establish absolute power. He believed this to be the only way of taming the egoistic human nature, or else humanity ran the risk of irreversibly drowning in chaos. To better illustrate this concept, he used the metaphor of a sea hybrid⁵, the aforementioned Leviathan⁶. Over a century later, the thesis of the egoism of the human nature was elaborated further by Adam Smith, who explained its reasons as follows [5]:

„As every individual, therefore, endeavours as much as he can both to employ his capital in the support of domestic industry, and so to direct that industry that its produce may be of the greatest value; every individual necessarily labours to render the annual revenue of the society as great as he can. He generally, indeed, neither intends to promote the public interest, nor knows how much he is promoting it. By preferring the support of domestic to that of foreign industry, he intends only his own security; and by directing that industry in such a manner as its produce may be of the greatest value, he intends only his own gain, and he is in this, as in many other cases, led by an **invisible hand** to promote an end which was no part of his intention.”

This quote represents the essence of the thoughts of this Scottish thinker and economist. It was an attack of a kind on the mercantilist trade philosophy (dominating Europe then), according to which unregulated aspiration to private profit inescapably had to lead to anarchy. A. Smith used the *Invisible Hand* theory to try and describe a mechanism characteristic for capitalistic economies, whereby activities of particular individuals, driven by their egoistic intention to satisfy their own needs, actually contribute to meeting society's needs as well. By ASIH, A. Smith proved that the market mechanism is able to self-regulate the process of satisfying social needs, and thus rejected the need for state interventionism and protectionism as the condition for achieving public interest.

The central theme of the work by A. Smith is the operation of the *Invisible Hand*, the essence of which is that it is not from the benevolence of the baker, that we expect our bread, but from his regard to his own self-interest. A. Smith saw the perspective of a promising analysis, discovering that in certain social conditions, which are nowadays often called the functional competition, private interests are in fact harmonized with the social interest. Without collective regulation or a common plan, market economy still operates in accordance with orderly rules of behaviour. Every individual, being one of many, can only exert insignificant impact on the overall

⁵In the sense of something composed of different, often mismatched parts.

⁶The title of Hobbes book, which is the source of the above metaphor, is taken from the Old Testament, in which Leviathan (which in the contemporary Hebrew means a whale) is mentioned, inter alia in the Book of Job, as one of sea monsters, and in the Book of Psalms, where it has a more negative connotation.

situation on the market. As a result he/she accepts prices as given and only has the freedom to choose the quantities bought and sold at these prices, driven by the motive of maximising his/her personal benefits. However, the sum total of these isolated actions determines the prices. Every person, considered separately, follows the prices in his/her choices, however the prices themselves are governed by the sum total of the individual reactions. The *Invisible Hand* of the market thus produces a social effect independent of the will and intentions of individuals.

In 17th and 18th century Europe, wages, prices, interest rates, employment, foreign trade as well as the quantity of goods and services were subject of strict controls by the governments. The purpose of these controls was to ensure the achievement of the vision of social justice as understood by the governing class by way of managing what was produced as well as the method of producing and distributing it. An idea was widespread that every action motivated by aspirations to private profit must be antisocial by this very fact. Even today, Keynesian economics says that free market economy cannot satisfy public interest because it is governed by the profit motive rather than by consciously planned social objectives.

Yet for A. Smith, self-interest was an obviously constructive and coordinating force. In striving to meet their own needs, people taking care of their interest had to refer to the interests of others. Self-interest is a stimulus, a reason for cooperating and coordinating one's own activities with those of others [10].

Critics of the market system perceived profit as an unjust charge on employees wages, but A. Smith saw it as a stimulus, a gratification which persuades a producer to strive to meet the needs of others. He felt that competition between producers would keep profits and prices low so that consumers would not be overcharged. In his reasoning, he also presented a simple proof of the benefits accruing from free trade. It is not profitable for anyone to produce something they can buy cheaper from someone else. He proved that „*what is prudent*” in the private life of every family (in the micro scale) cannot really be crazy in the life of a great kingdom (in the macro scale). A. Smith knew history, politics and economics very well. When he pronounced his famous words about the *Invisible Hand*, he was using his extensive knowledge, and not just a deductive reasoning [5]:

„It is not from the benevolence of the butcher, the brewer or the baker, that we expect our dinner, but from their regard to their own self-interest. We address ourselves, not to their humanity but to their self-love, and never talk to them of our own necessities but of their advantages.”

If this passage from A. Smith's book is taken out of context, as it very often is, it may suggest a very narrow, cynical view of human behavior.

However, if we read it in the whole context, A. Smith's thesis is simply logical. In a complex, internally complicated society, prosperity simply cannot rely on the benevolence of others to satisfy all our desires and needs. People are given

to charity at least the majority of them but they also feel restrictions. As A. Smith said, an individual person [5]:

„...stands at all times in need of the cooperation and assistance of great multitudes (of people), while his whole life is scarce sufficient to gain the friendship of a few persons. (...) He will be more likely to prevail if he can interest their self-love in his favour, and show them that it is for their own advantage to do for him what he requires of them.”

The essence of the *Invisible Hand* is the conviction that individuals' striving to further their own interest within the free market lead to an allocation of resources efficient from the perspective of the entire society. This turned into a legend that the entire *Wealth of Nations* is based on such naive reasoning, on the so-called doctrine of the spontaneous harmony of interests [3]. It sometimes seems that this only means the ability to arithmetically adding instances of individual satisfaction with meeting ones needs: if everyone is maximising their satisfaction when they are only allowed to, a *laissez-faire* system [21] will maximise the satisfaction of the entire society's needs. In fact, in his proof of the maximum satisfaction doctrine, A. Smith went much further.

In Book I, Chapter 7 [5] he demonstrated that free competition contributes to bringing prices down towards production costs, thus leading to the optimum allocation of resources inside an industry. In Book I Chapter 10 [5] he showed that free competition in the means of production market aims at equalising the net benefit stemming from using those means in all industries, and thus to achieving the optimum allocation of means between industries. He did not prove that various means are combined in the production process in the best proportions or that the product sold is distributed in the best way between individual consumers. Neither did he prove that economies of scale and external effects in production and consumption often hinder achieving the competitive optimum, although his analysis of public facilities does contain a kernel of such reasoning.

However, he did make the first step towards a theory of the optimum allocation of specific resources in the conditions of perfect competition [10]. The *Invisible Hand* is nothing more than an automatic equilibrium mechanism of a competitive market - A. Smith claimed. If competition is perfect and the market is not deficient, it will squeeze as many useful goods and services out of the available resources as possible. However, if monopolies, environmental pollution or similar market deficiencies spread, the efficacy of the *Invisible Hand* may be destroyed [4], [10], [20].

The paradox of the *Invisible Hand* is that even if every person separately behaves in a non-cooperative fashion, the economic result is socially efficient. What it more, competitive equilibrium says that no individual can improve their situation by changing their strategy if all others resolutely stick to their strategies [10].

The law of supply and demand [4], [20] indicates that the quantities of a given product that are purchased and offered for sale change in different directions as a result of a price

change: as the price increases, the quantity purchased falls, but the quantity offered for sale increases. If these two regularities are put together, we find that at a given time and in a given market, there is only one price of a given good at which the quantity purchased is equal to the quantity offered for sale. This is the so called equilibrium price [4], [20].

Market prices get set under the influence of mutual competition, as a result of the interplay of supply and demand in particular markets [11]. In free competition markets, supply curves are determined by the marginal cost [4], [20]. A. Smith perceived the market as a method of forging cooperation between strangers. Give me what I want and I will give you what you want is the offer which forms the cornerstone of every market deal [3], [10], [20]. However, it is true that A. Smith's personal belief in the benefits stemming from the *Invisible Hand* was only to a limited extent due to a static analysis of the allocation efficiency in the conditions of perfect competition. He deemed the decentralised pricing system desirable due to its dynamic impact of broadening the market and increasing the benefit of labour division, or in simple words, because it was a powerful machine stimulating the accumulation of capital and a growth of income.

Although he never said this in so many words, A. Smith was deeply aware of the imperfection of the market system. He also conceded that the market often adjusts to changes slowly and may not maintain the appropriate quantities of certain goods without government intervention. The *Wealth of Nations* did not try to prove that the free-market system is perfect. It was rather a classical impression of the relative advantages of a free market system compared to alternative economic systems [3].

Smith was definitely on the side of the ordinary people. He believed that replacing monopolistic enterprises with state regulation of the economy would probably spoil the economy and not improve it. A. Smith's views opened the way for the industrial revolution and the golden age of capitalism. His book, published in 1776 [5] still remains a classic economic work today [3].

Making economics mystical with the *Invisible Hand* of the market had far-reaching consequences. Even the terms market and economy themselves are so imprecise and ambiguous that they cause a lot of misunderstandings. All the more so the term *Invisible Hand* of the market. In the simplest sense this expression should be synonymous to the word people. In this situation, requesting that the *Invisible Hand* of the market be allowed to work should be equivalent to allowing people to act.

The *Invisible Hand* of the market was also understood as **the hand of God**. It can be understood even more generally, as a self-organising general harmony, an abstract property of the reality. In that situation it can mean anything, or in other words nothing. The emptier a concept, the more useful it can turn out to its user, when they use it to justify solutions favourable to themselves. One could even be tempted to draft a law on using this metaphor. It would say [3]:

„demand that all industries with the exception of

your own be subjected to the power of the Invisible Hand of the Market”

In the conclusion, it is worth noting that A. Smith is also the point of reference for one of the main contemporary currents in business ethics utilitarianism. A. Smith's theory aimed at demonstrating that the market and market economy are most natural, consistent with human nature and the Creators intention. The same is true for the concept of *homo economicus*⁷ and the *Invisible Hand* of the market as well as the laws governing the socio-economic life. In A. Smith's opinion, in the conditions of a free market, if a person aspiring to maximize his utility function follows the law and moral principles, he/she automatically contributes to achieving social objectives, as it were. In a sense, the market system itself is a kind of educator in virtue and an effective way of bringing up a person of integrity.

The concept behind the metaphor of the *Invisible Hand* is often used as an argument for economic liberalism and has been criticized numerous times by supporters of state interventionism. They have been proving that there are many circumstances which prohibit the public interest from being achieved as part of the market mechanism, which they believe to justify the regulatory action by the state.

A doctrine that has undermined the assumptions of the classical economics was Keynesianism [12]. According to this doctrine, state interventionism is necessary to correct the operation of market forces. Unlike the classical economics, Keynesians claim that there is no complete flexibility in the adjustment of the prices and there is significant price sticking (particularly downwards). The private economy does not achieve equilibrium as a result of the market forces in the conditions of a given state policy, whereas market deficiencies lead to forced unemployment and excessive GDP fluctuations. According to Keynes' followers, the *Invisible Hand* of the market cannot convert egoistic, private interests into the social optimum. Although they believe that competitive markets can fully utilise means of production, they cannot determine the optimum values of employment and production this must be done by the government.

Stiglitz is among the more important contemporary critics of the concept of the Invisible Hand of the market. The main argument against the *Invisible Hand* is the existence of *public goods* [14]. Their characteristic feature is that they can satisfy the needs of many people at the same time, but the cost of their generation is greater than the individual benefits that a single individual can reap. For this reason, the *Invisible Hand* of the market will not lead to such a good being created, even though its existence is beneficial at the level of the whole society. Thus supplying it will require the action of a public institution. Examples of such goods are public national defense, an efficient court system, scientific research on a new

type of drug, roads, schools etc.

Another argument against the autonomy of the market mechanism in meeting social needs is the existence of external effects or the information asymmetry in the market [20]. The tobacco industry is frequently given as an example here: although it produces goods desired by a part of the society, the actual social effects of its operation are very detrimental. In this case, the *Invisible Hand* of the market leads to a situation in which there is an overproduction of specific goods above the socially desirable level (called the production of anti-goods, which include cigarettes, illegal drugs, alcohol and gambling).

An important argument of interventionists is the imperfect competition in the economy, particularly the existence of monopolies. The *Invisible Hand* of the market ensures the socially desirable level of production of a given good only if strict assumptions of perfect competition are met, which almost never happens in real life [10].

Another issue is many peoples fear of the *Invisible Hand* of the Market due to their ignorance of the essence of this phenomenon. If something is allegedly so powerful as to be responsible for all matters of the economy, then it is likely to cause fear, which can be easily used as a pretext by all sorts of *saviours*. The defence they propose against this threat is to limit personal freedoms. Thus the *Invisible Hand* of the market becomes useful not just to entrepreneurs or corporate officers, but also to government officials. By effectively manipulating people and their fear of the menacing *Invisible Hand* of the market, they can boost their power. They will then claim that the wage cuts or price hikes are not caused by human action reflected in the law of supply and demand [4], [20], but by some *Invisible Hand* of the market. So when the state fails to meet its obligations, this apparently has nothing to do with the errors made by politicians, but is the consequence of the operation of the evil *Invisible Hand* of the market, which in this case becomes its own caricature.

Mark Blaug also mentions in the Economic Theory [3] that the *Invisible Hand* of the market is not an uncritical rule. He claims that the theory of „solutions worse than the best” leads to one of the objections against the rule of the *Invisible Hand*: the inability to create a partial economics of prosperity solving its problems „piecemeal”. He reaches the conclusion that the „public” nature of certain goods significantly reduces the accuracy of the *Invisible Hand* theorem in a way that A. Smith had never dreamt of.

In a milestone article published in 1956, Lipsey and Lancaster [9] proved that if the optimum conditions are not met on at least two markets, the Pareto prosperity theory [20] cannot justify a policy aimed at eliminating the imperfection on one of these two. The movement towards the optimum in the Pareto understanding is not enough: either we reach the best solution the first of the best or there are no grounds to choose between the following worse than the best solutions: of the second, third etc. grade. Lipseys and Lancasters proof, greatly simplified, is as follows: lets assume that we have a certain overall equilibrium system with constraints expressed by two equations and that we solve this system for the second

⁷In the free translation this means the *economic human* – this is a concept of the individual assuming that a human, as a rationally acting being, always strives to maximise the profits he/she earns and make choices due to the economic value of the results of those choices. In the colloquial sense, a „homo oeconomicus” is a person acting in accordance with this principle.

grade optimum using a normal technique of maximisation with the given constraints. Let us assume that one of these two constraints concerns a certain political parameter, e.g. a customs duty, and the problem consists in detecting whether reducing that duty would improve social prosperity. Proving that this must happen is impossible and this is what the general theory of the second grade optimum as the authors call it is all about [9].

Today, the *Invisible Hand* term is understood much more broadly. In the contemporary perspective, the *Invisible Hand* of the market is a meta-process whose results are achieved in a decentralized way without overt agreements between its participants [Joyce01]. In addition, this process is unintended and the goals pursued by individual market players are neither synchronized nor identical with the results of this process: the result is achieved by the way as it were. However, this process has a strong impact on the market in the regulation sense. Its participating agents may be unaware of it: this is why this process is called invisible. This process is visible if the market is analyzed from a higher level. It is assumed that this process occurs in a free market.

III. CONTROLLING COMPUTATIONS WITH THE HELP OF AN ABSTRACT VALUE.

In a digital processor, computations are driven by a hardware control layer, which fetches (from instruction cache) and decodes lines of program. In the ASIH model of computations, calculations/inferences are controlled and thus driven by an abstract parameter: "value", which labels all business objects being processed by an agent. It is assumed that the agent is able to label any given object with this subjective value on the basis of fixed business rules or on the basis of his private considerations. Thus, value⁸ in our theory is not a price: value is abstraction of logical nature⁹ used to label objects; whereas the price (measured with the help of money) is of an economic nature. Locally however, value of a given object can be projected onto specific exchange instruments, e.g. money. In our theory, value must be transitive. It means that agents performing business e.g. based on barter - must be able to directly compare two goods in terms of value, with the ability to analyze change and to evaluate/estimate this value for the last element in the exchange chain. In the example of ASIH given in this paper, value is expressed with the help of money on the basis of a simple decision table. Individual costs (of agents) are based on the length of a trip of an agent and local taxes (if any). When defining resale price, small individual overhead for mediation is added. Another approach¹⁰ to problem of calculations, costs and value can be found in [6].

⁸The difference between value and price is also explained and dissected in the book: K. Marx: Das Kapital.

⁹Predicate calculus style inference rules are applicable.

¹⁰Eberbach: ...In fact, it can be considered as a new cost programming paradigm, where each statement of the language has its associated cost, and instructions with the smallest cost are those selected for execution (i.e., the execution is cost-driven in contrast to control-driven, data-driven, demand-driven and pattern-driven control)...

Observation of our simulation model (which is under development to obtain more cases of ASIH) demonstrates, that it is an astonishingly powerful and universal computational mechanism, which we can not fully comprehend at this very moment... Most computational algorithms (if not all, no proof as yet¹¹) can be redefined by applying value abstraction, and can be found to still function properly. Labeling with value must be done in such a way that advancing computations provides benefit for the involved elements (agents, processors, etc.) with maximum benefit for those who finish computations. It must be done dynamically by agents.

The above discussed situation, including that in part VI, is relatively simple, because there are no relations between objects; beyond the fundamental, business question if \exists somebody, somewhere, wanting to sell and if \exists another agent somewhere wanting to buy.

Now suppose that agents are "more intelligent" i.e. they can not only use integer calculus to calculate money, profit, trip costs, etc. but also they can analyze relations between business objects they trade. Let this ability will be on the propositional calculus level¹². Example is given below.

Example

Suppose that the case of fire discovery is formally defined by set of facts and rules, using propositional calculus as given below. Let us also assume (for the moment) that fire is temporarily not necessary (e.g. for agents trading spices), and therefore all items in the set below are labeled by agents with value=low.

$$\left\{ \begin{array}{l} \langle \text{tinder.} \rangle^{\text{value=low}}, \quad \langle \text{fire_striker.} \rangle^{\text{value=low}}, \\ \langle \text{flint.} \rangle^{\text{value=low}}, \quad \langle \text{fuel.} \rangle^{\text{value=low}}, \\ \langle \text{tinder} \wedge \text{fire_striker} \wedge \text{flint} \xrightarrow{\text{making-small-fire}} \\ \text{temporary_fire.} \rangle^{\text{value=low}}, \\ \langle \text{temporary_fire} \wedge \text{fuel} \xrightarrow{\text{making-permanent-fire}} \\ \text{permanent_fire.} \rangle^{\text{value=low}}, \\ \langle \text{permanent_fire} \xrightarrow{\text{heating}} \text{heat.} \rangle^{\text{value=low}} \end{array} \right\}$$

Now suppose, that all of the above facts and rules are randomly spread (as business items: goods, skills or knowledge) among agents and treated in the same way as other business items are. Some items will exist in parallel in different locations, e.g. $\langle \text{fuel.} \rangle^{\text{value=low}}$. Agents will not trade above items (e.g. they will continue trading spices), because there is nobody expressing the will to buy even one item from the list.

Now, let a strong demand for heat emerge, expressed as below:

$$\langle ?\text{heat.} \rangle^{\text{value=veryhigh}}$$

Assuming that agents are able to process value according to inference rules (a, b, c are business items):

$$\frac{a, a \Rightarrow b^{\text{value=high}} \quad \vdash}{a^{\text{value=high}}}$$

¹¹Under research.

¹²We should not assume, that businessman are philosophers.

$$\frac{a \Rightarrow b, b \Rightarrow c^{value=high} \quad \vdash}{a^{value=high} \Rightarrow c^{value=high}}$$

the system of agents will discover fire in the background of doing usual business.

This is probably (currently under investigation) the gateway to proper analysis on how in certain situations, ASIH can act as a universal inventor in terms of new technologies, which can also overturn the present state of quasi-free market as a consequence.

We can therefore risk the following statement; that perhaps sometimes, the real inventor of scientific and technological progress is not always one, devoted researcher or scientist, but "the anonymous world of business".

IV. STRUCTURE OF VIRTUAL PROCESSOR REPRESENTING AGENT

The assumed business structure of a single agent and corresponding Virtual Machine (VMA) is given in Fig 3. and Fig. 4. As mentioned before, in the ASIH model of computations, a single VMA does not take a fixed position (in terms of inter-connections) in abstract computer architecture, but moves in an abstract *computational space* reflecting a given quasi-free market. This implies a permanent and unpredictable change of ties. Movements are random or are driven by a business plan which is the result of business conclusion.

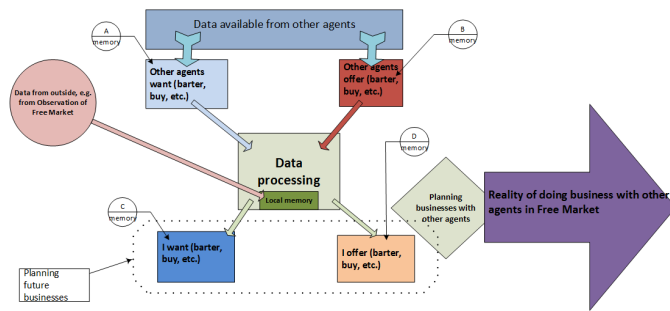


Fig. 3. Model of business agent.

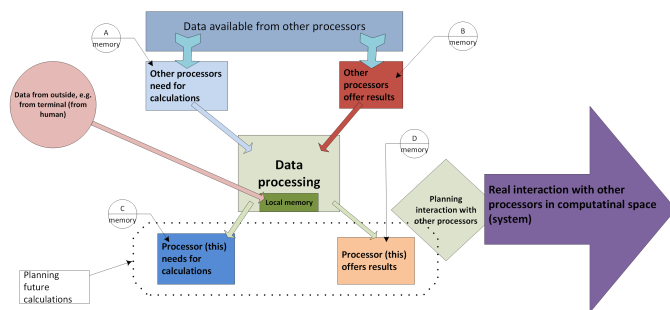


Fig. 4. Virtual machine representing single business agent.

V. MENTAL AND COMPUTATIONAL ABILITIES IMPLEMENTED ON THE VMA OF AN AGENT.

Our research strategy is based on the modification of business, mental and computational abilities of agents (implemented on VMA); until "great discoveries" happen in the

modeled environment. All agents are the same in terms of abilities. The only difference is that a class of agents called "townsmen" do not travel (they represent settled agents in, for example, cities). Similarly, for Europeans, Arabs, Indians there exist specific areas where each do not or cannot travel. Agents incomplete knowledge of the surrounding geographic world is therefore assumed. As an example, we can give Europeans (poor) awareness that Spice Islands (Moluccas) where located somewhere in the East.

It was necessary to equip agents with only elementary abilities such as the ability to trade, infer about present business situation, build business plans and finally to implement them. This includes the ability to travel in an optimal fashion. Thus, agents behave according to the following specifications:

- 1) When two agents A and B rendezvous, they mutually exchange information: what they want to sell, buy, what others according to agents' knowledge want to buy, sell (where, amount, price);
- 2) When agent A finds, that agent B wants to sell a certain item, which he wants to buy, allowing agent A to infer a reasonable profit; a transaction will be carried out;
- 3) When agent A finds that there is an item on his *OthersWantsToBuy* list, which agent B wants to sell, and that the profit minus travel costs (to deliver item to the future client) is sufficient, a transaction will be carried out. Next, a business plan is generated to deliver the item and to make a profit;
- 4) When agent A does not have a business plan, the agent moves/travels randomly along sea-routes of the known world. For all agents (except Columbus and Vasco da Gama) a traveling range of the agent's ship is imposed, which will limit the search tree. Columbus and Vasco da Gama (at the beginning) do not participate in trade because their costs (a flotilla of 3-4 ships) which exceed the expected profit threshold. Restrictions are also imposed. For example: the Europeans (and Indians) cannot travel through the Levant Barrier (Middle East) and Arabs fear sailing the Mediterranean Sea. However the Arabs sail and trade on their dhows as far as the Moluccas.

Thus, to perform the above mentioned activity, mental abilities of agents must include integer calculus for evaluating costs, profits and an inference engine to generate a business plan. The implementation of ability 3 requires in addition, another algorithm to find the shortest path between two geographical points¹³.

We decided to base the traveling behavior of agents on the A* algorithm, for several important reasons. Firstly, this algorithm uses "a set of nodes already evaluated", "a set of tentative nodes to be evaluated" and "a map of navigated nodes" in such way, that they can be used in parallel like a blackboard by many agents. An interpretation can be assigned to all these sets e.g. "a map of navigated nodes" can be

¹³T. Szuba has yacht sailing experience in the Mediterranean, thus we are aware, what were real conditions to travel that time.

interpreted as portolan charts¹⁴. A definition of the algorithm is based on the minimization of function $f(x) = g(x, y) + h(y)$ where g function is a past path-cost function and h function is a future path-cost function, which is an admissible "heuristic estimate" of the distance from x to the goal. This easily allows us to include Arab taxes as well as hypotheses about an alternative path to India bypassing the Levant. It can be done in such a way, that the A* node generator can produce starting nodes (Lisbon and Palos), and abstract neighbor nodes (West-Indies and Indies) with extreme high cost associated $h(y)$; equivalent to cost of 3 or 4 ships equipped for 3 months of non-stop oceanic sailing. Such nodes will be not taken into account by the algorithm as long as the costs of importing spices through the Levant remain reasonable. This was a key-point in building favorable conditions for ASIH, because the A* algorithm also unveiled its pathfinding abilities. Animations¹⁵ demonstrating how the A* performs its pathfinding, can be found at http://en.wikipedia.org/wiki/A*_algorithm

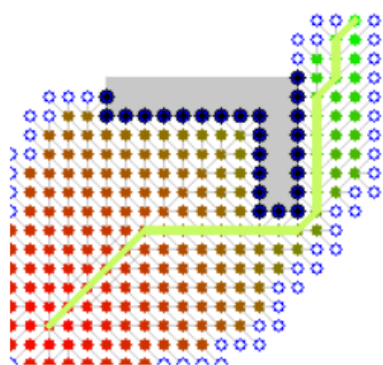


Fig. 5. A* algorithm in action. Cost of edges are same as their Euclidean lengths. The gray shape represents an obstacle. The filled circles in red and green represent expanded nodes (nodes in closed set). The color indicate the g-score (red: lower g-score, green: higher g-score). The empty nodes with blue boundary are the ones in open set. The nodes of the graph are generated on the fly, and nodes falling inside the obstacle are discarded as inaccessible.

VI. THE STRUCTURE OF THE SIMULATION MODEL

During our research process, it has been found that a simulation model is key to both understanding what ASIH really is, and building its theory. On one hand, a very precise historical description of 15th century the spice trade crisis prevented us from making some non-realistic assumptions, but on the other hand, it allowed the removal of all unnecessary elements from the process. This way we managed to build an abstract model of a single agent and a model of business cooperation so simple, that the agent has become almost automatic in operation, while ASIH was still functioning. This resembles the research approach which has led to the

¹⁴http://en.wikipedia.org/wiki/Portolan_chart

¹⁵A* Progress Animation by Subhrajit Bhattacharya, used under CC BY 3.0 license.

construction of the ant colony algorithms (ACO)¹⁶, which explain Collective Intelligence of a colony of ants, using an automate model of a single live ant and a pheromone-based model of communication.

At the lowest level of our model, the QGIS system is used to allow editing of all necessary geographical data, basic for the 15th century spice trade. Important cities (trade centers, with their geometric properties and relation), important sea-routes and a map of the then-known (15th century) world have been defined, with the help of QGIS. QGIS¹⁷ is powerful, user friendly Open Source Geographic Information System (GIS).

A basic structure and behavior of agents has been programmed in the Mason system. Mason¹⁸ is a fast discrete-event multiagent simulation library core in Java, designed for large custom-purpose Java simulations. It is a joint effort by George Mason University's Evolutionary Computation Laboratory and the GMU Center for Social Complexity.

Since agents interact and move in a geographical environment, it was necessary to use GeoMason¹⁹ also. This is a geospatial support for MASON, also designed at George Mason University.

As mentioned in the introduction, business items are labeled with logic expressions (predicate calculus) and abstract *value*. This SWI-Prolog²⁰ (University of Amsterdam) was used to equip agents with an inference engine. For this, JPL²¹ (Java-Prolog interface) was necessary.

The size of the model is more than 4500 lines of code as counted in the Eclipse environment.

Constructing a set of procedures for a single agent in our model, while keeping consistency in-between databases: *WantsToSell*, *WantsToBuy*, *OtherWantsToSell*, *OtherWantsToBuy* appeared astonishingly difficult and complex in our model. Every single rendezvous and contact between two agents, resulting with information exchange and a real transaction, forced reshuffling of all these databases. Moreover, the flow of time forced keeping only up-to-date records in *OtherWantsToSell*, *OtherWantsToBuy* databases.

VII. ASIH AS A COMPUTER: NATURE AND FLOW OF COMPUTATIONS

On the basis of our simulations, natural properties and behavior of computational process, which are at the basis of ASIH, will be explained. A common digital computer and computational processes will be used as reference.

- In order to calculate something, a digital computer must a priori be programmed (initialized) by a human programmer. After such an initialization, computations must be started by execution of the first line of the program. In contrast, ASIH is self-programming computer, i.e. quasi-free market activity provides continuous influx of data

¹⁶http://en.wikipedia.org/wiki/Ant_colony_optimization_algorithms

¹⁷<http://www.qgis.org/pl/site/>

¹⁸<http://cs.gmu.edu/~eclab/projects/mason/>

¹⁹<http://cs.gmu.edu/~eclab/projects/mason/extensions/geomason/>

²⁰<http://www.swi-prolog.org/>

²¹http://www.swi-prolog.org/packages/jpl/prolog_api/overview.html

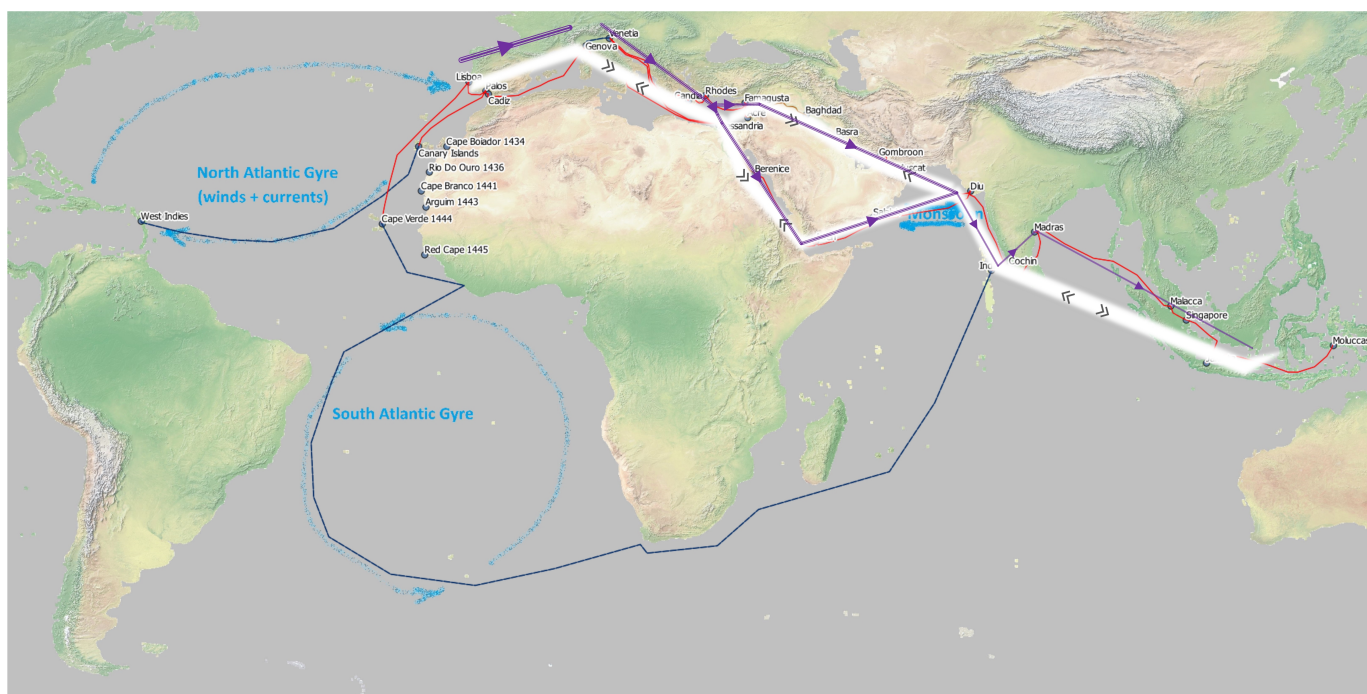


Fig. 6. Basic elements of computational behavior of ASIH.

for computations. In our formal model of ASIH, data items are represented with the help of predicate calculus expressions. It is not even necessary to use the term "start of computations" because ASIH processes available data continuously, and computations will conclude when all components are available.

- In a digital computer, a given real-life problem can be solved, if a program is written to solve this problem in and automatic fashion. The situation with the ASIH Computer is somewhat similar; a given real-life problem can be solved if it can be translated into a business problem. As mentioned before, the ASIH Computer is self-programming, thus as soon as problems are translated into a business form, they will emerge naturally for the ASIH computer to be solved.
- The ASIH Computer is vast (spanning over a quasi-free market) and requires some time to conclude computations - in some cases, even several years.
- In a digital computer, data processing modules e.g. RAM memory or FPU, take fixed positions in computer architecture. Only data is transferred between them for processing. In case of the ASIH Computer, data is still transferred for processing, but agents as data processing modules move around a quasi-free market scene. Moreover, they move in an intelligent way to such locations where they can do business, which affects data processing. For example, they will cycle between two business points, providing significant speed-up of computations. Cities such as Venetia, Genoa, Alexandria will start to be important nodes of data processing.
- When used to watch and/or control and industrial process, a digital computer must be equipped with some hardware interface e.g. sensors, servos, etc. In contrast, the ASIH Computer does not require such hardware, because brains of agents are actual components of the computer. Agents respond directly to conclusions which emerge in their brains. Moreover, conclusions can emerge in many brains of many agents almost simultaneously, at different locations. This can resemble the behavior of super cooled water rapidly changing its state. For example; agents can quickly conclude, that an expedition to the Spice Islands to bring back precious spices, will result in higher profits when selling them later on in say, Lisbon.
- In case of the ASIH Computer, several basic flows, which constitute computations can be identified (see Fig. 6). First (white) is a bidirectional flow of information: what/where/price/amount, and who has/wants. It is a flow of pure information. The second flow (purple) is a flow of goods (in our example: spices). In general, if agents start to trade e.g. know-how (like in example on discovering fire) it will also be a flow of information. The third flow (not shown because is exactly like flow of goods (in this case), but in the opposite direction) is the flow of money. However, if trade will have a form of barter or cash-free turnover; it will not exist, or will also take the form of a flow of information. These flows are interrelated through the inference process: the flow of business information (from agent to agent) regarding high prices of spices in Lisbon, and a flow of business information about low prices of spices in the Far East, will cause a flow of

spices westwards, because the Arab traders will buy all spices from Indian producers for resale to the Europeans. After some time, the first supply of expensive spices will arrive in Lisbon via Genoese and Venetian traders. All information accumulating in the brains of Portuguese and Spanish, will ultimately result in a conclusion that it will be a good idea for business to sail around (bypass) Arab world, to get directly to Spice Islands (Moluccas) to buy cheaper spices directly from producers.

- All digital computers have the same architecture based on von Neuman architecture, the same semiconductor physics and the same 0/1 calculus used for computations as a constant common denominator. Similarly, for different manifestations of the ASIH Computer, the human, trade and profit is also a constant common denominator. The rest is different: communication abilities in terms of mutual data transfer, physical travel and goods transfer abilities, personal calculation abilities of agents, etc. Thus, as we can see, the presented model of ASIH is tuned for the 15th century spice trade.

VIII. RECONSTRUCTION OF THE INVISIBLE HAND'S RESPONSE TO THE CRISIS IN SPICE TRADE AT THE END OF THE 15th CENTURY

Before we are able to offer a reasonable new tool to analyze and predict the complex behavior of today's free markets based on our theory; we must concentrate on the reconstruction of historical events, which can be considered as the landslide/shake, from a market point of view, and can be considered as a symptom of the activity of Adam Smith's Invisible Hand (ASIH).

This way, we can also develop and validate our theory in a practical way; building convincing examples one by one.

Such historic events are perfect from research point of view, because they are sufficiently documented, their analysis is finished and completed, therefore the possibility of questioning or different interpreting of conclusions is restricted.

When simulations are started, at the beginning, the situation is as follows:

- 1) Townsman in Lisbon offers a high price for: pepper, cinnamon, nutmeg, cloves. Indians from Madras offer pepper, cinnamon for sale very cheaply. Molluscan in Moluccas also offer nutmeg, cloves for sale very cheaply. Portuguese, Venetians, Genoese, Arabs, Indians are sailors and traders. At the beginning of simulations, they move about randomly (doing e.g. local business) inside areas they are allowed to (or can) sail. However, they also come into contact with agents residing in the cities (trade intermediary), as well as other sailors arriving to the given city's harbor. This way, knowledge is spread of business items offered elsewhere for sale and business items somebody (somewhere) wants to buy. Thus, the knowledge about demand and supply is spreading slowly between the East and West.
- 2) In Lisbon, Vasco da Gama with his fleet of 4 ships and an idea (+ navigation plan) that it is possible to

sail around Africa the Indies, is waiting for the right moment/circumstance. The same is with Palos where Christopher Columbus with his fleet of 3 ships is waiting; with an idea (+ navigation plan) on how to sail to Japan, sailing Westwards. The costs of executing both expeditions are so high, that the A* algorithm will take into account routes to the West Indies and Indies, as the absolute last resort, *iff* all other possibilities in searching graph are exhausted.

Vasco da Gama and Christopher Columbus are considered in our model of ASIH as positive examples of breakthrough "government intervention" on a quasi-free market. A regular business willing to maximize profits and minimize risk, will hesitate to endow a small fleet of 4-5 ships and to send it on a high-risk, nonprofit voyage. However, in both cases, the monarchy should be considered as a selfish super-agent looking for own profit, and not as a government investing money for public good. The task to find maritime route to India was offered to Vasco da Gama by King Manuel I of Portugal in 1497. He was aware that the uncharted coast of Africa stretched away to the northeast after Bartolomeo Dias returned in 1488 from rounding the Cape of Good Hope, having explored as far as the Fish River (Rio do Infante) in modern-day South Africa. Columbus speculative proposal, to reach the East Indies by sailing westward, has received the support of the Spanish crown, which saw in it a chance to gain the upper hand over rival powers in the contest for the lucrative spice trade with Asia.

- 3) As a consequence, after a certain amount of simulation time, the Arabs (able to sail to the Far East) start to buy pepper, cinnamon, nutmeg, cloves from Indians and Molluscan for resale to Europeans in Alexandria and Acre. The real availability of spices start to shift Westwards, until first supplies of spices reach Lisbon.
- 4) After a certain amount of simulation time, the global flow of spices will stabilize, i.e. the A* algorithm in connection with simple business plan generator, will replace random displacements of agents, into regular, geographically optimal business trips of agents, buying spices and returning to resale them e.g. in case of Europeans: Lisbon → Alexandria and back.
- 5) Now, very high taxes are imposed on spices in all cities where Arabs supply spices, i.e. in Alexandria and Acre. This will increase the costs of spices for Europeans to the level of negative profits (loss), thus the spice trade will (almost) cease.
- 6) In response, after a certain amount of simulation time, townsmen in Lisbon will start to raise their price offer for spices. However, from previous periods they will know, that Indians and Molluscan offer cheap spices, but the location of India and Moluccas Islands (Spice Islands) is not known to them (Arabs took care of this ...). Only the general direction (go East) is known.
- 7) Europeans will start again to behave in a chaotic way. At

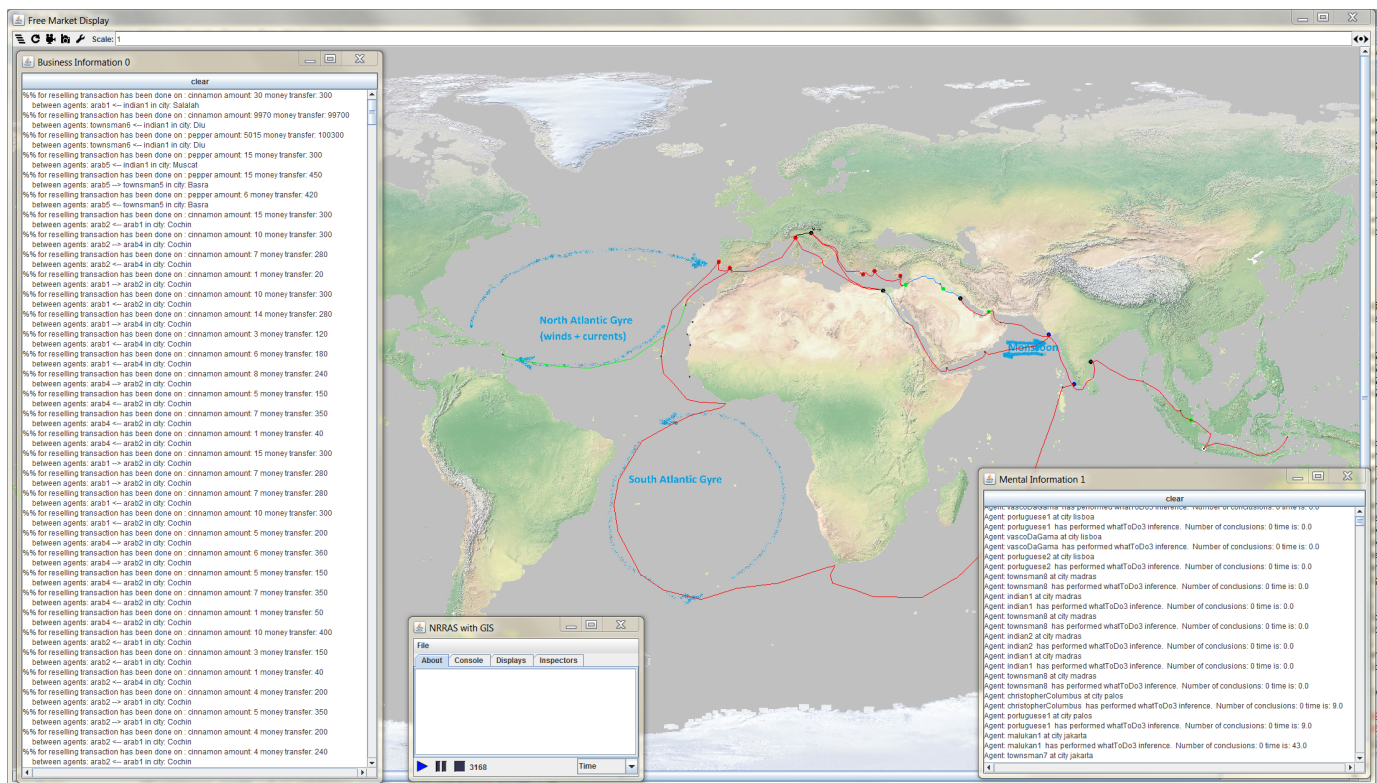


Fig. 7. Environment for simulations of ASIH response to Turkish and Arab blockade of spice trade at the end of the 15th century.

a certain moment, prices offered by townsmen in Lisbon will be so high, that they will cross the threshold cost of expedition to find a sea-route to India. At this moment, the A* algorithm will also take into consideration "expensive nodes". This will result with Columbus and Vasco da Gamas expeditions. **It will also be the success of our simulations.**

Thus, equipping 15th century agents with:

- 1) Basic ability to buy/sell/resell;
- 2) Ability to calculate costs and profits;
- 3) Ability to optimize costs of trips from A to B on basis of A* algorithm;

was sufficient to create the basis for ASIH, as a response to excessive taxation of spice trade by Arabs ⇒ resulting with discovery of America and sea-route around Africa. Further consequences for spice trade, like creation of spice plantation in India, Ceylon, Indonesia, and islands in the Caribbean, can be noted.

IX. CONCLUSION

Our theory presents ASIH as a parallel, distributed, non-deterministic inference process over agents participating in a quasi-free market. Since the inference process takes place in brains of agents, conclusions stay there and affect the behavior of the market, usually in a soft, optimization kind of way; however in many cases in a landslide/shake way.

In the considered case of ASIH, these aspects can be depicted as an interruption of the flow of goods from Europe

to the Far East through the Levant, and a rapid emergence of a large flow of goods around Africa (by the Portuguese) and to America (by the Spanish) as well as the Philippines.

Such inference process can emerge (will be started) if the market situation is favorable, i.e. necessary logic expressions (describing market situation) are present in distributed way, in the brains of agents, and (brains of) agents are able to perform required computations. A state of gradual emergence of sets of building blocks in the brains of agents, for their further global inference, is analogous to the programming of a digital computer, before computations begin. The output in case of ASIH is also different - it is the state of market; not printout or print-screen, etc.

As introduced in the abstract of this paper, we are showing that ASIH is not only an economic idea, but something that exists, for which a formal theory can be built. Computational processes creating ASIH can be measured and probably utilized for quasi-free market analysis and prediction in the future. Measuring can be done in such a way, that a simulation model will be created for a given quasi-free market. Our simulation model's complexity is comparable to weather forecast models, due to the number of agents. It may require variations on personal behavior. Such a model will be investigated with regard to how some global, social and economic parameters influence the behavior and economic output of quasi-free markets. There is a wrongly belief that that ASIH always take optimal and correct decisions over quasi-

free market. Since ASIH is inference process of Collective Intelligence style, it can be always provided set of data which will lead ASIH to wrong decisions. We plan to play with simulation model, to find what was necessary to stabilize spices trade without discovering America and sea routes to India around the Africa. Interesting is also question on how far single agent (genius investor or ruler) provided with partial information about free-market is able to compete with ASIH solutions.

Powerful response of ASIH to the Turkish and Arab blockade of spice trade, had the nature of "discovery" (America, sea-route to India around Africa, big galleons, etc.). Thus, our research plan for the coming future, is to work on the emergence of money in the Phoenician era. As demonstrated before, the concept of *value* labeling business items is one of the basic components of the ASIH theory. However, an abstract *value* assigned arbitrarily by agents to items (convenient form individual inference point of view) is not convenient in more complex business contacts.

Our hypothesis is, that at the end of a barter era, ASIH has discovered money and integer calculus as a tool to deal with the problem of *value*. We will simulate barter trade and analyze what must be present (in terms of the structure and abilities) in VMa representing agents, to arrive at the situation where money and integer calculus emerge.

The second research direction, is to analyze what will be the nature of ASIH in a business environment, where agents can also perform logic analysis of relations between business objects they trade (see part II). It will be important to identify a historical event which can be assigned to ASIH (in terms of cause) allowing us to perform an in-depth analysis.

The third research direction for our research team, is to use our methodology for a formal description of a "university" phenomenon. Nothing better was found in terms of joined education and research institutions since the medieval times when universities as we know them now had emerged. Perhaps we will be able to propose some formal tool to analyze the efficiency of a university from scientific progress point of view.

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