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***Research paper***

# On Distributed Reflexive Complex Mechanisms of Decision-making in a Transportation System of a Smart city

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**Abstract**

We describe distributed reflexive complex mechanisms of decision-making in a SMART city. These complex mechanisms are a cognitive self-organizing decision support system for development governance. These mechanisms utilize local information from all nearby sensors of city sensors on buildings, sensors on other cars, sensors on pedestrians and some additional information. We describe the way to a new level of safety of citizens by additional vision and automated reasoning. It provide transparency in Augmented Reality Devices by virtually eliminating obstacles e.g. buildings. The problem is that development of a city is a process so people still have to make suggestions and now these suggestions are about awareness of other agents. Distributed reflexive complex mechanisms can assist and support their decisions in solving these problems.

***Keywords***: *sensors, information fusion; smart city; safety*

## 1. Introduction

### 1.1. Motivation and scope of investigations

Decisions are important part of a governance. Authorities make decisions that depend on decisions of other active participants of an ecosystem of SMART city [1]. We refer such active participants of the technical and social systems that are able to make decisions as agents. Decisions for complex cyber-human systems (for example transportation system of a SMART city) includes strategies for safety of people and depends on behavior of many technical and social systems [2, 3]. Behavior of agents depends on information that depends on an environment that depends on a behavior of agents.

Decisions of agents depend on their models of a real world [4]. The difference between models and a real world could be a problem. We discuss it in the first part of the paper. This part makes this governance of a whole system a cognitive decision support subsystem.

Models that people use differs too. There are a good thing and a bad thing about it at the same time. Benefit of the difference between models is that the difference helps to distribute calculations and gives access to distributed sensors [5]. One can work with Big Data in this way. This part makes this governance of a whole system a cognitive, self-organizing decision support subsystem. We use here models of consensus.

The bad thing is that reasoning [6] becomes more complicated when at least some models incorporate models that in their turns incorporate models and so on… It is usually occurs in reasoning like “I think that he thinks that I think that he thinks and so on”. This part makes this governance of a whole system is a cognitive, self-organizing decision support subsystem. We use strategic reflection and epistemic doxatic logic.

At last part of the paper, we suggest a way of governance of this complex system that use all these mechanisms for prediction of agent’s activity. This governance will be complex since include and combine several simple mechanisms. This part makes this governance of a whole system is a complex cognitive, self-organizing decision support system for development governance. We use here mechanisms for stable development of governance. It means that it allows mixed types of agents – with and without most advanced systems of Augmented Reality.

These models depend on incoming data from sensors, on incoming messages from other agents and authorities. IT-systems of a SMART city receive information from many sensors and agents [7], and provide information for many agents and can change configuration of elements of a city. These complex cyber-human systems have to incorporate data from sensors [1, 8, 9] and handle uncertainties. There are several principal problems: information fusion [5, 10], uncertainties [11], filtering [12], knowledge representations [11, 13, 14], sensor placement [15], human behaviour [16], especially reasoning, machine learning [17].

We can create a model of agent behavior, see Fig.1 [3]. Agents can incorporate received information into virtual visual environment that helps him make a decision. So main parts of this system are sensors, panels and drivers. Sensors dynamically gather information about and entire environment in real-time mode, panels get information from all sensors of a system and prepare is for center of making decision and drivers that make decisions.

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## 2. Model of Transportation System

We refer to vehicles, pedestrians and other actors in transportation system as agents. Consider network of roads as combination of representations – physical part, informational part and reflexive part.

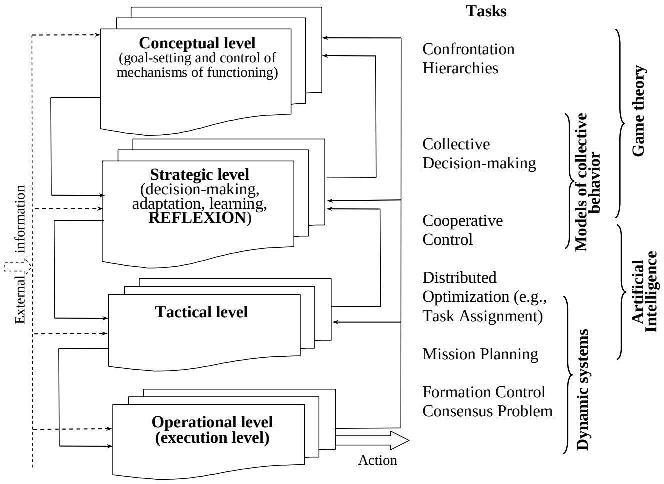


**Fig. 1:** MAS: The hierarchical architecture of an agent [7]

Let describe a physical part of the networks of roads by a graph with directed vertexes. Vertexes are places on a territory of a city. The graph shows direct connections between places on a territory of a city [2].

Let describe an informational part by a graph with directed vertexes. Vertexes are places on a territory of a city. The graph shows direct observability some places from other places using special kind of sensors.

Let describe a reflexive part by a bipartite graph with directed vertexes. Vertexes are places and facts of direct observability on a territory of a city. The graph shows awareness of agents at some places about awareness of agents at some other places about agents at some other places. We can create a series of such graphs.

Move of an agent depends on moves of other agents if any and these graphs.

## 3. Basic Control Mechanisms

In this paper, we propose to consider A as an uncertain parameter for agents and they have to make some suggestion about it. Their suggestion could be different.

### 3.1. Control mechanism that is based on Game Theory models of interaction

There is a set of agents, strategies and utility functions. There is a well-known way to find Nash equilibrium for the game of collective actions. It is to compose and solve a system of equations where strategy of each player is equals her best response. The technique of incentive compatibility analysis for Nash parametric equilibrium is proposed on the basis of analysis of metagames generated by the corresponding direct mechanisms. It was shown on this basis that for all the resource allocation mechanisms under consideration, the truthful choice of parameters for determining the Nash equilibrium is not rational for agents. This result shows that the integration of Nash implementation control mechanisms may lead to a loss of incentive compatibility of these mechanisms. It also leads to extension of domain where it is sufficient to looking for efficient solutions of control problems in class of strategy-proof direct mechanisms.

The key components of the models of strategic reflection used in game theory are determined. Based on these results possibility for integration models of strategic and informational reflection is proved and several variants of such integration, including so-called automatic integration.

### 3.2. Control mechanism that is based on De Groot model of social behaviour/consensus

A cooperation is important but there is a problem to choose information to share among vehicles to decrease data traffic without losing efficiency of cooperation. [7]. There are two ways to operate it: use data only from own car without sharing at all. This way is very fast and well-tested solution, but there is no enough info about neighbours that could be important. Transmitting data to a centre then process it there and receive data gives a good opportunity for optimization, but there is a need of a very powerful data centre and a need of very powerful antenna. There are problems of delays.

There could be a communication between agents but then trust each one only partially and they can communicate according de Groot model [16]. There is not difference if an existence of such communication is a common knowledge among all agents or it is not.

### 3.3. Controls mechanisms that is based on tree of Reflexion

There is a problem with iterated reasoning while making decisions. We call this type of reasoning Reflexion [3] or one can use term epistemic reasoning or epistemic logic.

Let consider an example with to vehicles A and Z that are moving to junction. We consider two variants – obstacle that is between them are transparent and it is not. We suppose that we can make basic transparency by system from the first section. See scheme on Fig. 2 and examples of CCTV data for this case on Fig.6

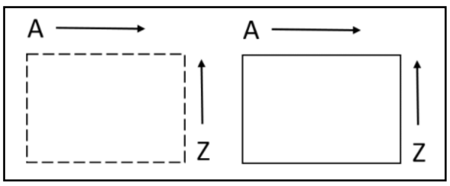


**Fig. 2:** Two variants of uncertainty

One can arrange this complex reasoning into a table as we show on Fig.3 using following definitions.

- $A_M$ equals True iff A is moving,
- $Z_M$ equals True iff Z is moving,
- $B_XY_M$ equals True iff X believes that Y is moving.
- $B_XY_M$ equals True iff X believes that Y is moving.

So we have, $B_AB_ZB_AB_Z \ldots B_AZ_M$ and $B_XX_M$ equals True and $B_XX_M$ equals True for any $X$.

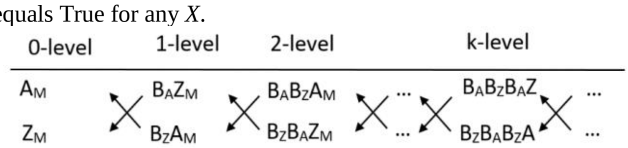


**Fig. 3:** Levels of reasoning in epistemic terms

One can bind these reasoning with actions or go through logical description of the reasoning and describe actions directly as on Fig. 4

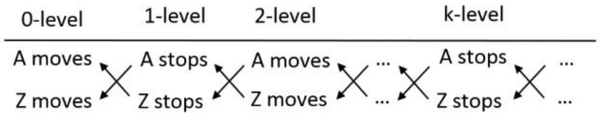

**Fig. 4:** Actions of each levels of reasoning

There is problem on Fig. 4. that one can easily see – both vehicles are stopped or both are moving while optimal solution for system is move of exactly one vehicle – A or Z. We can make ordering who will move when but then we have a problem with deadlock like it is on Fig 5. There is ordering but there is no solution.
We can try to avoid this situation by de Groot model of consensus. If there is a communication with no trust at all then all agents become stubborn and other opinion doesn't change their opinions though they have to be taking into account. There is not difference if an existence of such communication is a common knowledge among all agents or it is not. The important information is that Ai is a common knowledge and that all agents are stubborn in our sense

### 3.4. Controls mechanisms that is based on graph of a Reflexion

Another topic for future research is to consider that agents does not make themselves choose opinion about $A_i$ as one not negative real number. Agents could think about it at in two different manners as least. Agents can choose not a one number and a range or a number of numbers like "Ai is 3 or in a range from 1 to 2". There is a way to handle this and the most interesting results occur when we allow agents play this game several times. It will help us to use methods from [4].
Alternatively, agents can choose a probability distribution of Ai. It will lead us to Bayesian games [5] and modifications of de Groot model [8].

## 4. Results

### 4.1. Architecture that provides transparency.

Solution that provides transparency in Augmented Reality Devices by virtually eliminating obstacles e.g. buildings. Its main idea is replacing obstacles by 3D models that constructed by local information about vehicles and database of typical cars models. This gives transparency of obstacles for a driver to pedestrian who uses Augmented Reality devices.
The most important issue that it gives to users no cognitive problems concerning transforming just 1-D points or 2-D marks on a map into comfortable knowledge representation. Users operates objects in their minds, as they are real without additional efforts. The benefit of this technical decision support system is greater for those users who have disabilities.

### 4.2. Architecture of a complex mechanism

For computational simulation experiments models for several integrated mechanism are developed Fig 8.
Computational simulation experiments for comparison of the counter-expensive mechanism and incentive scheme for counter plans were conducted revealing that with the appropriate choice of parameters reduction in the gain of one agent can lead to a decrease in the gains of others, which in turn reduces the effectiveness of solving the planning control problem with help of these mechanisms.

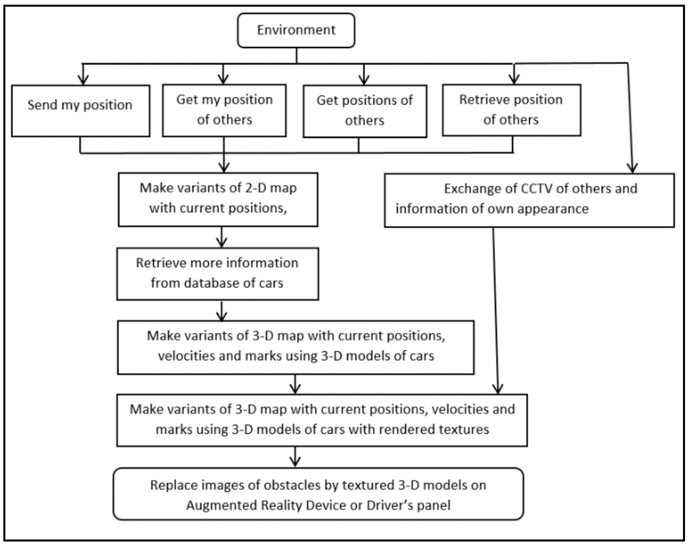

**Fig. 7:** The main algorithm for transparency.

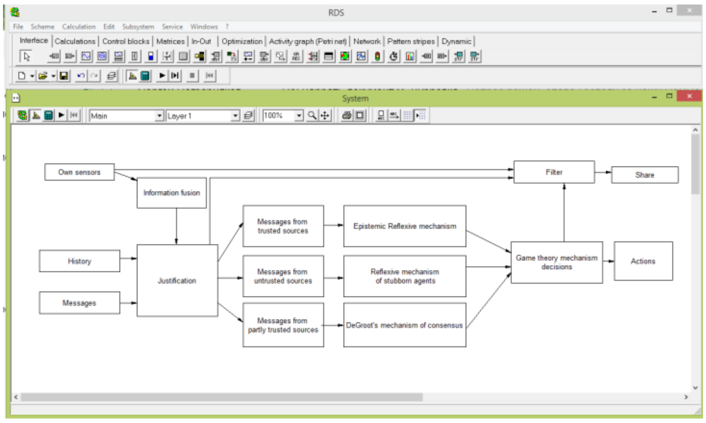

**Fig. 8:** The main algorithm for transparency.

### 4.3. Simulation

Software simulation and software for numerical solutions were created. This idea was supported by engineers in presentation in ZF company and discussion with Microcab.


**Fig. 9:** Screenshots of simulation software

We describe the system and prove that it is cognitive self-organizing decision support system for development governance. There are many parts of this system on the market (for example we took a pic.1 from a site of one of large vendors) but this is no such system as a whole solution. The theoretical results and software simulations of the paper were presented in ZF Company [17], Microcab and Brussel [2].

## 5. Conclusion

In this section you should present the conclusion of the paper. Conclusions must focus on the novelty and exceptional results you acquired. Allow a sufficient space in the article for conclusions. Do not repeat the contents of Introduction or the Abstract. Focus on the essential things of your article.

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