Virtual Environments 4 MAS

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Abstract. The environment is a key point when talking about MAS applications, being a key concept when developing a platform or application in the past ten years: what is important in it and how to access it. At the same time, technology has evolved so that Virtual Environment-kinds of applications have grown out of science fiction novels till research papers and even real applications. Current technology makes possible to MAS to interact also in this environments.
In this paper, we have looked for the common ground that have all the different domains relating Virtual Environments as E4MAS, and we have characterized those domains according to three dimensions: connection to the physical world of the environment, agents nature, and sociability. Moreover, we comment one of these domains, Mirror Worlds, as it is one of the most complex domains commented, that we believe that is one of the topics to take into account in the near future both as a researh and developing domain.

1 Introduction

Ten years ago, when talking about environments for MAS, the focus was on a very restricted type of environments, papers were focused on MAS environment. They were concerning what layers. what infrastructures, do we need to tackle for MAS environments, where these environments were seen as the real world or a set of non-agent applications. During these ten years, different approaches, frameworks and platforms have appeared that allow to access to what is called the environment for a MAS, that is, being interfaces to access the real world continuous and time restricted data (to perceive and to act) or other kind of programs, as databases, ... The environment has gained an increasing place in the different branches of the multi-agent technology, seeing it as the right place for developing agreement technologies [1].

At the same time, these years have seen a huge development in virtual environments (VE), looking for more and more sophisticated and credible simulations

of some reality that allows the user to get immersed into. To create interesting interaction partners for the human, agent techniques are used [9].

"Virtual environments" (VE) cannot just be found in virtual reality applications of agent technology, but there is a variety of other sophisticated possibilities mixing real world, virtual worlds, simulated worlds, etc. With the tremendous development of related technology, intelligent agents may interact with other agents or with humans in environments far beyond the MAS-environments discussed in the E4MAS community.

In this paper, we identify, analyze, and characterize the domains related to these VEs-kind-of applications (cf. Section 2). Taking into account three different dimensions allowing to define this kind of domains as environments for MAS: connection to the physical world of the environment, agents nature (artificial or human) and sociability.

The rest of the paper is structured as follows: next section presents a short comment about science fiction background which is not so far away as it seems right now; after that, Section 3 focuses on the introduction of the three dimensions we use to classify the different domains. Next, we focus on commenting one of such domains that is one of the present and future trend, Mirror Worlds. Last, some comments about trends are given.

2 From Science Fiction to Science Research

Nowadays, we are as close as possible to be able to reach what Gelernter defined as "Mirror Worlds" [5]. These are software models of some chunk of reality that can mimic every change in real-time and host a massive number of users each with a different view of the mirror world. Also other Science Fiction authors introduced virtual worlds for interaction between humans (and artificial agents): "Cyberspace" by William Gibson in 1984 [6] or "Metaverse" by Neal Stephenson in 1992 [16].

Mirror World, Metaverse, Cyberspace are not independent. Their analysis shows three main common dimensions related to (i) the way they are syncing between the physical and virtual worlds, (ii) to the agents (artificial or human) populating the worlds and cooperating/competing with each other to fulfill their goal, and (iii) to the social relations taking place among the agents. "Mirror Worlds" are particularly interesting as the idea contains synchronization between real and virtual environment. We will come back to this idea in section 4.

3 Virtual Environment Domains for MAS

Driving these considerations beyond visionary literature, worlds coupling, partners of interactions and sociability, one can identify three dimensions: types of environment, types of interaction partners and sociability with more possible values than the ones presented in these not-so-far-away futuristic scenarios. Hereby the dimension of interaction, its intensity, mode and richness, is actually the decisive factor: Who may interact with whom in which role and how this

interaction can be mediated by the environment. In the following, we will first characterize the different values and then locate interesting combinations (see Figure 1).

The first dimension is the type of environment. This dimension distinguishes between systems that access directly to real environments and virtual environments. Here,"Virtual Environment" refers to "A high-end user-computer interface that involves real-time simulation and interaction through multiple sensorial channels" [2]. Yet, there is no clear definition, in literature one can found alternatives, for instance, [8] characterizes it as a synthetic environment for which there is no real counterpart.

So, we will refer to Virtual Environments as subsuming such Synthetic Environments but also the Simulated Environments. The important feature distinguishing both of them is that the Simulated Environment has a reference environment. It makes only sense as a mapping from a real environment that it sufficiently precisely represents. Simulated agents interact with a simulated environment in a way that represents how real agents interact with the reference environment [7]. A synthetic environment exists without a reference; its usefulness is not determined by how well it matches another reference environment, but by how much fun it is to interact with it or how well it supports interaction between humans, agents and other entities. Thus, virtual environments not necessarily represent a real-world example, but focus on user interaction, immersion and imagination (the so called *Virtual Reality Triangle* or i^3).

Agents may take different forms, not necessarily corresponding to an existing example in the real-world. Humans are immersed into a virtual space. The difference between Cyberspace (as introduced above) and Virtual Reality is also discussed in [15]: Cyberspace provides virtual meeting opportunities for a group of humans without really referring to a explicitly spatial environment, in contrast to Virtual Reality that is usually created for a single human immersed in it and thus has spatial extension.

The range of values for the environment dimension could be: Real, Synthetic or Simulated – taking into account that "Virtual" subsumes both Synthetic and Simulated.

The second dimension to characterize application domains is the nature of the agents interacting in the system. Traditionally, one may find descriptive values along "passive - active", "reactive, deliberative, cognitive", etc. The dimension that we want to use for characterizing domains here – fitting to the range of the environmental dimension – is whether the entity is real or artificial. Hereby, we only characterize agents - no static objects. Possible values for an individual along this second dimension are: Human, Physical, or Virtual. Physical agents are basically robots, they and humans possess a (physical) body that allows physical interaction. "Virtual" again subsumes simulated and synthetic, and means that the entity is created by a technical device, but is not physically existing in the environment. Simulated or synthetic either have an example or reference in the real world or not. Simulated entities can be Virtual Characters which are often humanoid and believability of their behavior is an important measure for their

quality. Synthetic agents are created for a particular objective - for example a fully artificial playing partner for children such as a Tamagotchi. Clearly, the overall system may contain different forms of agents at the same time.

The social dimension which is structuring and regulating a world W (the real or virtual one) raises questions in the way this world W is playing the environment role in the other world W' : - do the agents of W' enact some roles in the social dimension of W - does the social dimension of W regulate (directly or indirectly) the interactions taking place among agents of W' - how does the social dimension of W interact with the social dimension of W'?

The third dimension is the social dimension, characterized not so much with respect to its organization, but based on the intensity of interaction between agents and between agents and the environment. Characterizing "interaction" is also not done for the first time, see a quite comprehensive example in [4]. Organizational model capture possible relations, protocols, etc. Knowing that background, we are aware of the simplification when we just consider how intensive and on what level of abstraction agents interact with each other and with their shared environment. We identify domains on a continuous range between extreme values of "individual" worlds, in which each agent just interacts with its individual environment being completely agnostic of the social dimension that could exist in the other world. So, only stigmercic interactions may happen between agents. The other extreme are called "social": one agent knows and intensively interacts with a large share of other agents, if not all others, being aware (and maybe participating) to the social dimension sustaining the other world. Agents issued of the two coupled worlds coordinate their activities or exchange information.

In Figure 1 we show how different domains for multiagent systems can be located along these three dimensions. In the following we shortly characterize the domains:

- The pure *Reality* contains humans who intensively interact with each other and the real environment.
- *Robotic Domains* are characterized by the concept that artificial physical agents populate the real environment. Additional humans may impose challenges for the interaction between humans and robots, as the autonomous robot needs to be aware what the humans are doing. Interacting with one human works quite well, multiple humans are still difficult. Swarm robotics or multi-robot systems form the corresponding domain based on intensive interaction. An impressing example is the Swarmoid project [10], in which swarm robot achievements are based on intensive, carefully designed stigmercic interaction.
- Clearly, *Multi-Agent Based Simulations* form here an extreme, yet well established, case. Environment is simulated, agents are simulated, interactions are defined following a given reference system. A special case are participatory simulations. We decided not to list them as the involvement/immersion of stakeholders is mostly used as a tool during model development or for communicating simulation results.

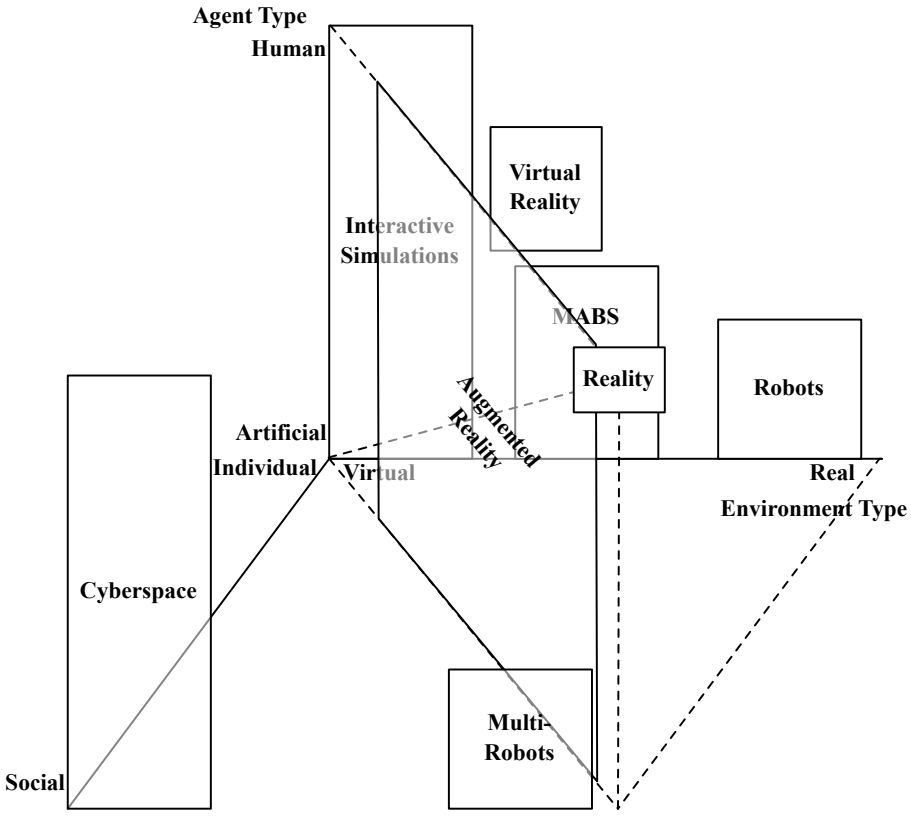

Fig. 1. Domains locations in the area spanned by Environment, Agent and Interaction dimension.

- For us more interesting cases are *Interactive Simulations* which may characterize a number of sub-domains: the environment is virtual and one or more of the agents are human, others may be virtual. The environment may have an example in the real world or may be completely synthetic. Examples for applications flight simulators. Usually some physical process is simulated, which reacts to user actions.
- We located *Virtual Reality* nearby interactive simulations and multi-agent based simulations: the environment is virtual, it may include humans and virtual agents - more humans than in multiagent-based simulations. The environment may be more realistic than in interactive simulations. Again, entertainment simulations such as games or social networks, such as "Second Life" where immersive virtual environment is used in which humans interact with other humans and artificial agents, are included here. This domain would include not only the Metaverse of Neal Stephenson, but also the Cyberspace of William Gibson.
- *Augmented Reality* is characterized by an environment which is physical, but populated with human agents and virtual ones. [11] introduced the term "Mixed Reality" describing a continuum of environments from fully real via augmented reality and augmented virtuality to fully real environments. In Augmented Reality the main part of the environment is real. This mix of virtual and physical environment enables a new forms of interaction in the overall system mixing for example haptic experiences or smells with virtual information displays. This is interesting not only for entertainment (see for example the INVIZIMALS[4] game), but also information services depending on the physical location. Mirror Worlds as characterized below will be located within this domain.
- In *Ambient Intelligence*, the environment is real, and the agents are human and both physical and virtual. In this domain, the task of the artificial agents is to support the human adapting the environment and providing access to different functionalities in the environment. Examples are agents in charge of adjusting temperature and light intensity for individual humans. Depending on the task and the number of agents, there might be intensive interaction between the agents, but the main focus is on supporting the human.

4 Mirror Worlds based on Agents & Environment First-class Abstractions

The idea of agents and environments as first-class abstractions [] makes it possible to devise a conceptual extension of Gelernter's original idea of mirror worlds, towards a conceptual framework useful for integrating the various dimensions discussed above [].

In Gelernter's view, Mirror Worlds are software models of some chunk of reality, "some pieces of the real world going on outside your windows", endlessly

[4] *http://invizimals.eu.playstation.com/*

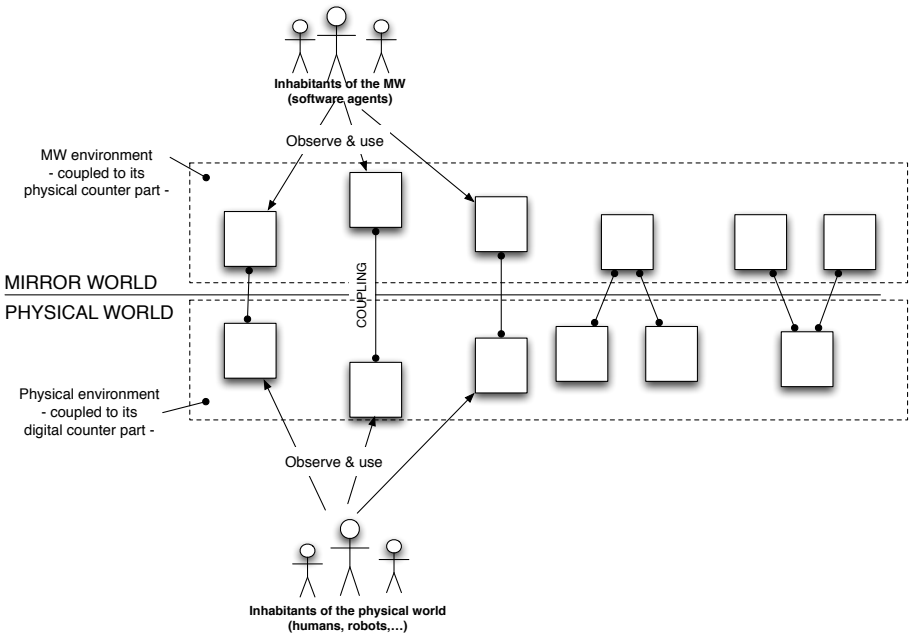

Fig. 2. A Vision of Mirror Worlds and Situated Agent Societies.

poured by oceans of information through hardware and software pipes [**?**]. Using Gelernter's words, they represent a true-to-life mirror image trapped inside a computer, which can be then viewed, zoomed, analyzed by citizens living in the real-world with the help of proper *software assistant agents*. They are meant to be like scientific viewing tools – like microscopes, telescopes – focused not on hugely large or small items, but on the human-scale social world of organizations, institutions and machines. The final objective is to strongly impact on the life of the citizens of the real-world, who can exploit such tools to tackle the increasing perilous complexity of their government, business, transportation, health, school, university and legal systems.

In Gelernter's vision *tuple spaces* are the coordination media where information from the physical world are stored and then queried by software agents by means of Linda's coordination primitives. From an agent point of view, tuples spaces represent their environment. In the context of multi-agent systems, tuples spaces and coordination media have been the starting point to define the more general concept of *coordination artifact* [13] and *artifact* [12, 14]. Such an abstraction aims at being used for modelling any environmental object – possibly encapsulating some kind of functionality and behaviour – which can be shared, observed and used by agents to do their job. So if agents are useful to model autonomous pro-active and reactive task/goal-oriented entities, artifacts are useful to model basic non-autonomous environmental bricks, to be composed to design complex and possibly distributed environments. At a metaphor level, if agents

are like people in an organization, artifacts represent the things and tools, that is the environment that people use.

This concept makes it possible to go back to the mirror world idea and conceive an extension in which the environment based on information spaces is re-shaped in terms of by an open set of artifacts, part of them directly *mirroring* artifacts in the real world (see Fig. 2). Mirroring in this case means a form of *coupling*, such that an action on artifacts of the real word cause some kind of changes in artifacts in the mirror, perceivable then by software agents. Viceversa an action by agents on artifacts in the MW can have an effect on artifacts in the real world, perceivable by people. In that view a MW is conceived as situated agent society [3], built upon agents and artifacts as basic computational first-class bricks.

In that view the MW becomes an open computational layer, strongly coupled with the physical one, structured and organized as an open digital city whose inhabitants are software agents. The bridge between the two layers – the physical and the digital ones – is given by a multitude of heterogeneous networked (invisible or not) devices, sensors and actuators, making it possible to keep a continuous and consistent coupling between the two layers. Objects of the physical world may have – explicitly or implicitly – a digital / computational extension in the mirror world representing the object itself, in terms of a software agent or as part of the agents' environment. Such an extension can include a kind of *augmentation* as in the case of (mobile) augmented reality: so it may be possibly perceived also by inhabitants of the physical world through devices like glasses or smartphones, superimposing some kind of information on the pure physical view. Differently from augmented reality, here the augmentation would not be only about visual information: artifacts in the mirror world could augment artifacts of the physical world in terms of capabilities, services and functionalities.

5 Conclusions or what is waiting ahead of us

In the last year, there has been a growing interest on Virtual Environments both in the society and in the research topics. This has been possible due to the maturity of the technologies that possibilitate those kind of environments. As a reflection of this, there have been also growing applications of MAS to this kind of environments. In this paper, we have presented a clasification of these kind of domains according to three dimensions (connection to the physical world of the environment, agents nature and sociability).

Future work in this research area will focus on developing not only frameworks for implementing these kind of applications, but also meta-models, methodologies, and developing toolkits to facilitate the designer to create these applications and to easy modify them. We have also commented Mirror Worlds as being one of the most complex domains presented, where the needs above commented are easily detected, and where the application of MAS concepts, frameworks, and methodologies is needed.

Acknowledgments

We would like to thank Olivier Boissier for its comments and participation in the ideas here presented.

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