Mirror Worlds as Agent Societies Situated in Mixed Reality Environments

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Abstract. In this position paper we introduce *mirror worlds* as physically situated agent societies, useful in particular as a conceptual framework for investigating inter-disciplinary aspects – from cognition to interaction, cooperation, governance – concerning future smart environments and cities shaped as large-scale mixed-reality systems.

1 Introduction

In recent years, the impressive development of HW technologies related to mobile and embedded computing, Internet and the web is going to make the futuristic scenarios envisioned by Ambient Intelligence (AmI) and Smart Environments [15] an every-day reality, integrating research contributions from Ubiquitous Computing, Sensor Network Technology and Artificial Intelligence (AI).

Following the ubiquitous computing vision [17], AmI environments are characterized by the pervasive use of information processing devices thoroughly fused into "the fabric of everyday life until they are undistinguishable from it" [18], and integrated with other key enabling technologies such as sensors and wireless networks. On this fabric, the software layer exploits AI techniques to create environments that are sensitive and responsive to inhabitants' needs and capable of anticipating their needs and behaviors as well. Moreover, Augmented Reality (AR), Mobile AR and mixed reality [5, 10] are going to strongly impact on how we interact with these systems, by exploiting wearable devices such as AR glasses.

In spite of this convergence of technologies and the availability of formidable but *ad hoc* solutions, we lack a conceptual foundation, effective enough to model open, possibly-large scale smart environments and their interaction with aspects related to human cognition, psychology, sociality.

To this purpose, we introduce the notion of agent-based *mirror worlds* (section 2), extending the original idea exposed by Gelernter [7] with concepts and visions based on the research on multi-agent systems and agent societies. Mirror worlds (MW) are like digital worlds shaped in terms of organisations of agents situated into virtual environments [19] that are *strongly coupled* with

some physical environments. MW aim at being an interesting framework where to investigate the integration of various technologies – for instance, multi-agent systems and mobile augmented reality – but, above all, the definition of open computer-supported cooperative environments where human and software agents interact and cooperate – typically implicitly. Furthermore, MW aim at being *laboratories* where to explore together inter-disciplinary aspects, ranging from how human/agent action, perception, cognition is enhanced and supported by MW, to how to think about the co-design of physical objects and environments and related digital counterpart, down to the definition of proper models for interaction, coordination, organization, and governance of these agent-based mixed-reality systems.

The idea is related to existing works exploring the application of agent technologies to develop mixed-reality systems [8], agent-based intelligent virtual environments [9, 1], as well as embodied organisations [13] and situated electronic institutions [2].

2 Mirror Worlds – Overview

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 poured by oceans of information through hardware and software pipes [7]. 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* [6] 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* [12] and *artifact* [11, 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.

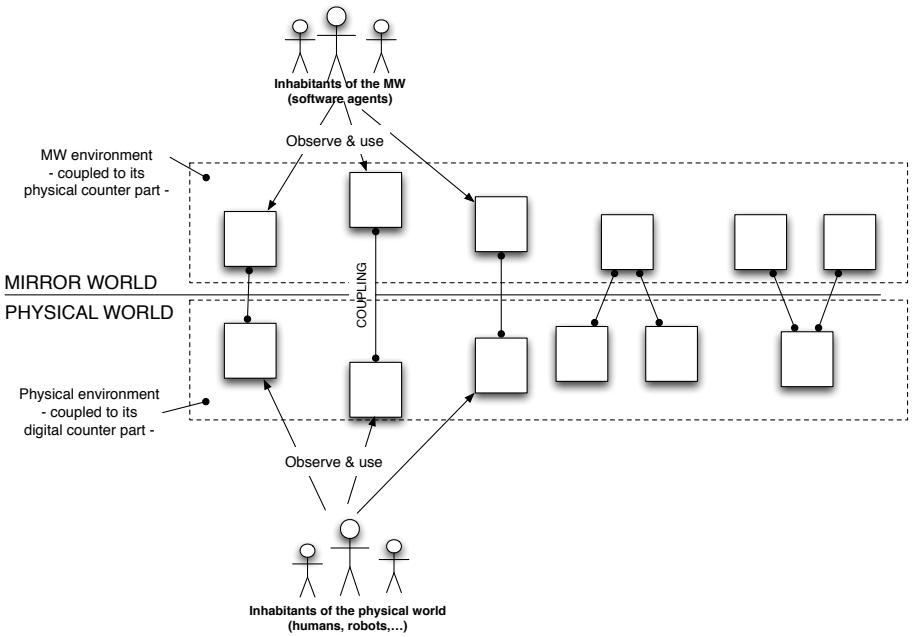

Fig. 1. A Vision of Mirror Worlds as Situated Agent Societies.

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 an open set of artifacts, part of them directly *mirroring* artifacts in the real world (see Fig. 1). Mirroring in this case means a form of *coupling*, such that an action on artifacts in the physical world causes 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 physical world, perceivable by people. 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. It can be understood then as a kind of *situated agent society*, built upon agents and artifacts as basic computational first-class bricks and where *stigmergy* plays an important role to bridge the human and the agent layer [4]. From an hardware perspective, the bridge between the physical and the digital layers 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. So, Internet-of-Things is an enabling technology for mirror worlds.

Another enabling technology is given by (mobile) augmented reality. In fact, 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 also an *augmentation* as in the case of (mobile) augmented reality,

that is some *manifestation* – either static or dynamic – that can be perceived by inhabitants of the physical world through devices like glasses or smartphones, superimposed on the physical image. Besides, also purely virtual entities of MW can have a manifestation in the real world, either in some specific location or anchored to some physical object. Differently from augmented reality, here the augmentation would not be only about visual information: artifacts (and agents) in the mirror world could augment artifacts of the physical world in terms of capabilities, services and functionalities.

2.1 Mutual interaction between physical and mirror worlds

Like existing ambient intelligence frameworks, MW can be conceived as an intelligent environment designed to support activities of human/robot actors living inside. However, we believe that the MW view allows for investigating several dimensions that are currently not fully developed in such frameworks.

In MW, the environment is not *just* supporting the (human/robot) actor in her autonomous intentions: the proactive and intelligent environment will not just "read" the actor's behavior and her mind in order to anticipate needs and behaviors and to help or over-help, but will read behavior and ascribe beliefs and goals in order to *change the mind* of the actor, to *influence/manipulate* her, by means of explicit advices and explanations or by practically modifying the world in order to block or promote the actor's intentions. A fully "social" interaction and psychology. But also on the side of the actor, the role is not passive: the actor is not just "assisted", supervised and supported by the environment: The relationship between the sensitive, responsive environment and the human or robot is not merely unilateral but bilateral and active also from the actor's side. There will be a real social interaction in which the actor will not only try to understand and exploit the intelligent environment but will *try to change its "mind", to influence it*, and frequently to deceive it. The inhabitants of MW will act feeling the "presence" (visible or invisible) of this floating intelligence, of this observing "eyes", of this protective "spirit". Moreover, the actor will *practically act and "physically" interact* also in a virtual and in a mixed (real and virtual) environment with the other artificial agents: via explicit communication and message but also by means of behavioral communication and stigmergy [3]. In fact since the actor will realize that the world is intelligently reading her behavior and interpreting her mind, she will act also on purpose in order to make the environment understand what she has in mind. Since sociality does not consists (just) in communication, the inter-action will be more socially significant: the environment and the actors will practically inter-act, by cooperation, conflict, or independent activities in just one and the same mixed world. They will interact with each other by moving objects, building or eliminating things; "physically" changing the common (physical? virtual?) world.

Finally, the "augmented" reality will be augmented also in terms of affordances ("What is that for?" and "How to approach/use that?"), of understanding, explanations, and of an "intentional stance": we will perceive things by reading their "mind"; we will be able to "see" what is hidden in general in the

object: not only the internal body and mechanisms, but its history, working, mind, rules. At the same time, reality wil not be "augmented" in a static way but in a context-dependent and intelligent way making us "see" different things in different moments according to the relevant purposes and contexts. Cognition already "select" the information and we see what is *relevant* for our goals or for our survival or learning; but this "selection" and "attention focus" will be enormous and projected on the world. Our augmented, mirror, "niche" will be continuously adjusted to what is relevant for us.

A Toy Example: Ghost Game in the City as a MW — Here we consider a classic mobile AR game [16] modelled as a MW, to clarify some aspects. The MW is composed by a collection of treasures and ghosts distributed in some part of a city. There are two teams of human players. Their objective is to collect as much treasures as possible – walking around – without being caught by the ghosts. Players have AR glasses and a smart-phone, used as a magic wand. Ghosts are agents autonomously moving in the MW – and in the city. Players perceive ghosts by means of their AR glasses – as soon as they are in the same location. Ghosts as well can perceive the players, as soon as they are within some distance. Ghosts' objective is to catch human players: so they follow them as soon as they can perceive them. A ghost catches a human player by grabbing her body in the MW—this can be physically perceived by humans by means of the magic wand (trembling). Different kinds of ghosts may prefer different kinds of zones, according to some physical parameter of the zone—e.g., humidity, light, temperature. So ghosts can perceive the physical world too, by means of proper artifacts in the MW. This fact can be exploited also by players: a player chased by a ghost which is known to be intolerant to light can run under a street lamp (in the case of a night setting of the game...). However a ghost can have the power to switch off the physical lights (by acting on its counterpart in the MW), supposing to include also physical places that can be controlled by the MW. A player with enough power can create temporary holes in the ground by means of the magic wand, which can absorb ghosts. Ghosts can set up team strategies to catch players exploiting their knowledge about the physical world, e.g. for doing encirclements. And so on.

In spite of being a game, this example shows a number of features that may be found in a MW concerning the action/perception of human actor players and agents in the augmented/mixed environment.

3 Augmenting human cognition and sociality in MW

Given the tight coupling between the physical world and its mirror, the vision of MW will have a profound impact also on our human cognitive systems and on the way human societies function. Below we discuss three of these consequences.

3.1 An extended and hybrid brain

Once MW will be in place, we will behave in this augmented reality with the assistance and in interaction with (more or less hidden) artificial intelligences.

However, more importantly, what will actually emerge and be technically and culturally built is a *new extended mind*, with intelligent functions out of our brain, not only actively "consulted" by us (like our agenda, calculators, books, search engines...) but just spontaneously provided, emerging, like when we have a memory retrieval or an intuition. A mixed artificial and "natural" brain, which will be at the same time individual and social: a collective cooperative intelligence, that I will experience in several cases as "my" intelligence/mind; necessary for dealing with the new augmented and mixed (mirror) world, where other eyes, senses, actions, data, reasoning, are needed. When will I feel these functions as "my" extended mental (and practical/behavioral) activities? And when/why I will perceive them as cooperative "team" activity? And when as a "animistic" presence in the world and a "spirits" protection? And when as a conflict against other intelligences (ghosts) and actions; or against prescriptions and a surveillant power? Will we have and externalized "mirror" Super-ego? All these psychologies will be there in our mirror world.

3.2 Individual and joint action ownership

At the same time, the feeling of agency, that is, the feeling to be the author of one's own action or to participate to a joint endeavor is crucial for ensuring that humans achieve a sense being in control and responsible for what has been caused. Recent research in the cognitive sciences have revealed that such feeling of agency depends on the perceived congruence between predicted and actual outcomes both in individual and in joint action contexts. In order not to disrupt this core cognitive process, the extended range of agency of individuals and groups that will be available in mirror worlds should match this requirement by design. In particular it should be possible to support the simulation of individual and combined effects in the mirror world in a way that is shared and observable both by human and artificial agents, that is updated in runtime and that can be matched to perceived results in the physical world.

3.3 Augmenting the perception of distal and combined effects of collective action

Human collective behaviors are stable even when the combined effects of autonomous decisions is inefficient, negative or even harmful for the population. Changing such dysfunctional collective patterns is often hampered by specific cognitive limitations. For instance, the perceived negligence of individual contributions to such collective outcomes might downsize one's own personal responsibility, the complexity of anticipating the negative future consequences of present-directed decisions might obscure individual and collective interests, well-known cognitive biases discount the value of larger future rewards in favor of smaller but temporally closer ones and thus ease myopic and poor choices. All these cognitive limitations might be tampered in mirror worlds whose role in making these combined and temporally extended effects visible and perceivable could influence individual decision making in ways that today are not possible.

4 The Road Ahead – Investigations and Open Issues

In this position paper we sketched some of the key concepts concerning the idea of mirror words as situated agent societies, providing some views about their power in functioning as amplifiers of both individual and collective action, perception, cognition, imagination. There are many inter-disciplinary issues that we believe are worth to be explored in the future besides further developing the ones sketched in this paper. Among the others:

Organisational models and normative systems for MW — The definition of proper organizational models appears an important aspect of MW, in order to deal with aspects such as the openness, the autonomy of the agents living in the MW, the size in terms of number of entities composing the MW, and so on. So natural questions are: are current organization (meta-)models proposed by open Multi-Agent System effective for modelling MW organization? Is it useful to support some explicit coupling between organization models adopted in the physical/social layer and the ones to be adopted in the digital one, in the MW? Can we exploit the coupling between the two levels for effectively defining a notion of institutional actions and institutional facts inside MW?

Principles and technologies for building and running MW – From an engineering point of view, we are not interested (only) to build specific MW for some ad hoc application domain. Instead, we are interested in devising an open general-purpose methodology and platform to support the design and development of MW for heterogeneous purposes and application domains, integrating enabling technologies related to (mobile) augmented reality, Internet-of-Things, etc. as well as multi-agent systems.

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