$\mathcal{V}$*i*TAL*i*SE: Virtual to Augmented Loop in Smart Environments

Extended Abstract

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ABSTRACT

Future workplaces will be smart environments providing human users with features and functionalities augmenting their capabilities while lowering their cognitive/physical efforts. $\mathcal{V}$*i*TAL*i*SE is a vision of future smart environments integrating Human-Agent Collectives (HAC) with Digital Twins (DTs) fostering the synergistic interplay between the physical and digital reality.

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1 THE VISION OF $\mathcal{V}$*I*TAL*I*SE

$\mathcal{V}$*i*TAL*i*SE is a vision of future *smart environments* supporting humans activities being a *digital-physical mashup*, inextricably interwoven to form a Mixed Reality (MR) continuum, where digital and physical objects are *dynamically coupled* during operation, and *embodiment* of the digital into the physical is explicitly managed.

We define as smart environments those workplaces where human activities are *enhanced* through computational technology by either augmenting their physical or cognitive capabilities, or by relieving the associated workload—as in the case of personal assistant agents [14] and decision support systems [18].

The mashup between the physical and digital worlds is defined in the spirit of *Mirror Worlds* (MW) [7, 17], where physical objects have a digital counterpart continuously mirroring their structure, properties, and dynamics, and considering the full spectrum of Milgram and Kishino's Reality-Virtuality continuum [15], where objects in the virtual environment may have or not an image in the physical one, with varying degrees of coupling.

We let objects in the digital and physical worlds have their *degree of coupling* dynamically established, depending on the goals of their users (or the application at hand). For instance, a user may decide to "switch off" virtual-to-physical coupling of objects structure and dynamics when performing "what-if" analyses in a simulated environment—while still perceiving changes in their properties.

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We let digital objects be *dynamically embodied* into physical ones upon need, during operation, depending on the goals of their users (or the application at hand), along two directions: *(i)* digital-to-virtual, when digital objects are embodied into a visible representation in the virtual world (e.g. the case of a personal assistant agent associated to an avatar); *(ii)* digital-to-real, when digital objects are embodied into a visible representation in the real world (e.g. a software robot controller deployed on a physical robot).

It is worth noting here that the degree of *coupling* and *embodiment* fit the MiRA conceptual framework [10] for MR agents: respectively, as *interactive capacity* and *corporeal presence* are concerned.

$\mathcal{V}$*i*TAL*i*SE supports the following concept of *co-evolution* within augmented / mirror worlds: *(i)* digital and physical agents (humans) *together* build the virtual portion of the world, possibly (partially) coupled with the physical one, and act and interact with and within it to bring about their activities; *(ii)* in turn, the augmented world *reacts* to such activities in a number of ways, all meant to realise its function of better supporting agent behaviour; *(iii)* this causes a continuous *tension* between the virtual and augmented worlds, in which the agents and the digital objects continuously strive to improve their performance by learning from past experience, while the overall digital representation of the world improves by learning from the continuous *feedback* of the agents living therein.

2 THE $\mathcal{V}$*I*TA LOOP

As the enabler of the co-evolution peculiarity of $\mathcal{V}$*i*TAL*i*SE, the $\mathcal{V}$*i*TA loop revolves around three main phases—Figure 1.

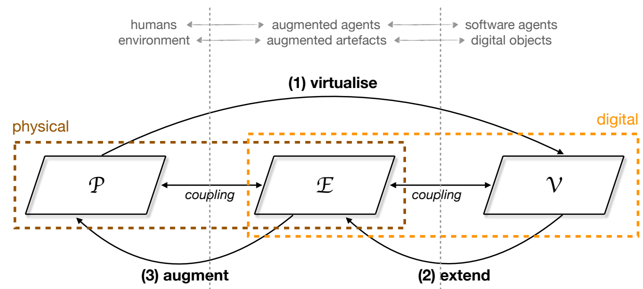

Figure 1: The $\mathcal{V}$*i*TA loop.

(1) Virtualisation. The physical environment $\mathcal{P}$ is virtualised by proper sensor, computer vision, and data analysis technologies. This stage outputs a virtual model $\mathcal{V}$ coupled to the physical environment $\mathcal{P}$ in the sense described in Section 1. The complexity of the $\mathcal{V}$ model can vary dynamically along different dimensions, such as the *temporal coupling*: from a static model completely built at one point in time, and later used solely to retrieve and affect the properties therein tracked, to a dynamic model, built incrementally and cooperatively in real-time, accounting for the run-time actions and interactions of the agents (either humans or not).

(2) Extension. The virtual environment $\mathcal{V}$ is extended by means of a VR-based system that allows humans to explore and work inside $\mathcal{V}$ through smart tools enabling them to annotate, adapt, act upon, and extend the virtual environment according to their needs. This could be done either by an individual user (as in DTs [8]) or by a team of human users working and cooperating simultaneously inside the virtual world (as in HAC [11]), potentially supported by smart applications and tools such as personal assistant agents and decision support systems. The core idea is to provide humans with the possibility of building and affecting an *Extended Virtual Environment* $\mathcal{E}$, to be considered an enrichment of $\mathcal{V}$—i.e. in the sense of augmented virtuality or mixed reality.

(3) Augmentation. $\mathcal{P}$ is augmented with $\mathcal{E}$, by means of an AR/MR-based system realising the $\mathcal{V}$*i*TAL*i*SE vision: a form of *bi-directional augmentation*, so that virtual objects (e.g. holograms) are used to enrich / augment the physical world, and physical things are meant to enrich / interact with the virtual world in turn. By designing MR-based systems as Augmented Worlds [3, 4] based on the extended virtual model $\mathcal{E}$, humans can play inside the smart environment where the physical reality and world are augmented with the digital objects and functionalities defined in $\mathcal{E}$, to be potentially further extended, manipulated, and adapted.

Let us discuss an exemplary scenario to clarify what described above. The Island of Stromboli, in Italy, experienced in 2002 severe damages along the entire coast as hit by tsunami waves. The evacuation plan conceived after the 2002 event has never been tested, neither virtually nor in reality. Here, *(i)* computer vision and data analysis are used to build $\mathcal{V}$ from $\mathcal{P}$, *(ii)* field operators train themselves in $\mathcal{V}$, effectively building $\mathcal{E}$ through their monitoring and feedback collections, and *(iii)* $\mathcal{E}$ is then deployed as the augmentation layer of later "in-vivo" training sessions and simulations, where field operators act in the resulting Mixed Reality scenario.

3 ENABLERS & CHALLENGES

The $\mathcal{V}$*i*TAL*i*SE vision relies on a handful of technologies as key enablers for its realisation, many of which bring along challenges and issues to be still addressed—Figure 2:

Computer Vision, VR, AR. Technologies for registering virtual content in 3D with the underlying physical environment and track changes are already here, such as magnetic, inertial, GPS, or vision-based tracking approaches [1]. Besides tracking, *semantic instance segmentation* approaches are emerging to recognise distinct instances of the same object [5], [13].

Agents, MAS, and Decision Support. One promising source of abstractions, methodologies, and technologies for designing the kind of empowerment envisioned in $\mathcal{V}$*i*TAL*i*SE comes from the research area on Multi-Agent Systems (MAS) [6] Here, a pressing issue to be still fully dealt with concerns the concept of *adjustable autonomy*, that is, the capacity of software agents to dynamically vary their degree of autonomy, possibly (and temporarily) delegating *decision making* control to others.

Smart interfaces and tools. In a $\mathcal{V}$*i*TAL*i*SE smart environment voice commands or gestures are naturally preferred over traditional UI [12]. The current situation concerning, for instance, VR devices such as Oculus Rift, Go, and the foreseen Quest, considers the presence of ah-hoc controllers, connected wirelessly with the processing unit. These devices enable the usage of gestures, as an alternative or complement to vocal command.

Data analytics. Machine learning is clearly involved in the pipeline that elaborates data coming from the physical world, while building its virtual representation, and from the augmented world, while analysing users' behaviours and outcomes of their actions [16]. Also during actuation, where actions from the augmented world are to be enacted in the physical one, machine learning may prove invaluable, as in the case of the reinforcement learning approaches extensively used in swarm robotics contexts [2].

Humans-in-the-loop. Current applications are mostly focused on the activities of an *individual* user, thus do not consider the potential scenario of different users simultaneously connected to the same VR/AR or MR system. A significant challenge is to target this class of *social* applications, where the nature, structure, role, and interactions means of software agents have to be re-discussed according to the "humans-in-the-loop" perspective [9]. One significant challenge in $\mathcal{V}$*i*TAL*i*SE is thus that of considering humans as seamlessly integrated with the software substrate of the system, possibly aided by personal assistant agents meant to support decision-making.

4 CONCLUSIONS

The multi- and trans-disciplinarity of the envisioned $\mathcal{V}$*i*TAL*i*SE approach calls for many different technologies to overcome their existing challenges and be seamlessly integrated together. Nevertheless, a unifying framework for the design of the system can and should be based on the agent abstraction, as it has been widely proven to be the most effective conceptual tooling to model both human behaviour and autonomous software agents, as well as to implement the latter.

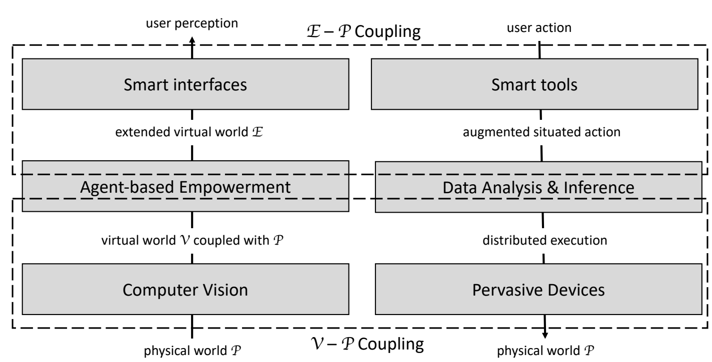

Figure 2: Key technologies.

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