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Swarm Intelligence via the Internet of Things and the Phenomenological Turn

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Abstract: Considering the current advancements in biometric sensors and other related technologies, as well as the use of bio-inspired models for AI improvements, we can infer that the swarm intelligence paradigm can be implemented in human daily spheres through the connectivity between user gadgets connected to the Internet of Things. This is a first step towards a real Ambient Intelligence, but also of a Global Intelligence. This unconscious (by the user) connectivity may alter the way by which we feel the world. Besides, with the arrival of new augmented ways of capturing and providing information or radical new ways of expanding our bodies (through synthetic biology or artificial prosthesis like brain–computer connections), we can be very close to a change which may radically affect our experience of ourselves and of the feeling of collectivity. We call it the techno-phenomenological turn. We show social implications, present challenges, and and open questions for the new kind of swarm intelligence-enhanced society, and provide the taxonomy of the field of study. We will also explore the possible roadmaps of this next possible situation.

Keywords: Techno-phenomenological turn, consciousness; neuro-interface; radio-transmission; wireless communication; internet of everything; social development

1. Swarm Intelligence and Systems Intersections

Swarm intelligence (SI) is a concept which describes how complex social behaviours can come from simple non-coordinated individual actions. Ants/bees/termites/wasps colonies, for example, follow this kind of self-organizing and collective intelligence [1]. While no single member of the colony has the power or skills to make decisions about general coordinated actions, the colony behaviour is finally organized efficiently following basic rules. This natural and simple algorithmic behaviour has proven to be so successful that it has inspired AI experts for decades in the attempt to implement similar mechanisms into robot interactions or AI systems, creating a research field called computational swarm intelligence (CSI) [2]. However, we can also find SI activity among humans [3,4], and with the evolution towards a society of information, we can also talk about an SI implemented into the Internet of Things (IoT) [5–7]. Therefore, we can see that bioinspiration is a successful trend in AI research and that SI provides a reliable framework for the generation and modulation of social behaviours, even at computational and electronically-connected levels. Taking into account the increment of available smart materials and the technological possibilities of the augmenting/upgrading/enhancing of human bodies, we suggest a future scenario in which SI is part of human behaviour, managing not only unconscious but also conscious actions.

2. From Forests to Ants and Smart Gadgets

We see the current biological cognitive world as the result of multiple processes across a long evolutionary temporal progress, with no final state or definitive achievement. Biological evolution has developed for several billion years on planet Earth, following an unsupervised process (unless you consider ambient forces as a determinant of those changes, although without any aim or teleological guiding)...but is there any other way of achieving evolutionary changes? The success in the development of PNA (peptide nucleic acid) indicates the answer—"yes" [8].

Perhaps the main problem of cognitive sciences and their corollaries once embedded into hard or top-down AI has been the identification of intelligent behaviour with the functional properties of brains or central nervous systems [9] and (cultural) symbolism [10]. Some other forms of managing intelligent decisions, such as those related to embodied properties [11], collective behaviour [1], or minimal cognition [12], were not considered as good or sufficiently powerful models for AI. However, the truth is that intelligent behaviour can even be found at very simple stages of life, such as slime mould [13] or bacteria [14]. The next possible question is what other function not implemented in biological cells as isolated entities following a cooperative and social (bodily) pattern do we want to implement? Thanks to technological advances, we can consider how a bioinspired model of information communication could be implemented into smart human environments: through wearable devices, augmented bodies, ambient intelligence, smart cities, virtual or augmented realities, and other new ways of combining computational advances with electronic possibilities.

However, what if we add a new channel of communication? Currently, only humans have wireless communication with all the "benefits" of the Internet or radio/TV broadcast. What if we could add a new global medium of communication in which all complex organisms on the planet could share multimodal informational mechanisms? Will it trigger new step of evolution or could be total disaster? According to Tononi [15], the integrated information processed via organism Φ identifies the consciousness of the organism, extending this to seamlessly connect organisms which we could identify that their level of consciousness should be increased via the integration of wireless connection devices, as they could be capable of processing more integrated information than in a non-connected state. Even now, at a certain point we are all cyborgs [16], partially-augmented humans using old techniques and mechanisms to deal with last generation devices.

3. From Natural to Augmented Bodies: Devices, Augmentations, and Implants

The human body is not finished, but a transient structure that has been evolving over millions of years. In a coupling relation between body and environment [17], human beings have been capable of modifying their behaviours [18] thanks to several technological advancements: physical tools, symbolic models, language, or social strategies, among several others. Today, thanks to genetic engineering, synthetic biology, wearable computing, and a long list of technological advances, human beings can radically modify their bodies and their minds. The embodied and extended paradigms [19,20] explain the intrinsic coupling between the cognitive system and embedded mechanisms that contribute to the informational process at its several steps. From this perspective, the cognitive process is grounded on a multidimensional net of places, facts, and events [21].

Using technological enhancements, we can find the first official cyborg—Neil Harbisson, a man with achromatopsia who uses sounds to capture colour information [22]. Recently, the company CyborgNest has released the "North Sense" [23], an external device that provides their users with a feeling about the position of North coordinate. According to CyborgNest, the North Sense is an exo-sense intelligently designed for evolution, which means it sits outside the body but is permanently attached. It allows a person to sense the electromagnetic field of the planet. The North Sense is typically attached to the upper chest and gently vibrates when facing magnetic north. This experience (to have a mechanism to experience the North direction) until know has only been related to some bird and insect species [24], and is now under the phenomenological affordance of human beings. We can easily imagine new kinds of devices that enhance the human experience,

augmenting bodies or senses, increasing actual senses range, or even creating interesting synesthesic environments. This will completely transform our experience and the possibilities of interaction with other beings. Artificial empathy, for example, will be possible to modify using an enhancing use of human neuromodulators. As a consequence, we can affirm that how we feel in the world and how we interact between humans, new humans, or machines is totally open to new rules and behavioural scenarios.

One of the key enhancements of a mammalian body is a body–computer interface. The advantages of non-invasive or even invasive body-to-computer interface were introduced several times and even in popular literature and films like "Ghost in the shell" and "Matrix". A high-level view of the problem could be like the one expressed in the following scenario: we have to provide the interface for 86×10^9 neurons and 10^{13} synapses, considering that the size of a mammalian neuron is in the micrometer range and the size of a synapse is in the nanometer range [25]. Another way around this could be to create radio frequency transmitting cells; neuroglia cells could possibly be good candidates to transmit the neuronal activity in radio frequency, converting bio-chemical signals to wireless protocol. We could propose two possible solutions for a cellular radio transmitter: in-cell or in-organ. The in-cell solution is represented in Figure 1, where the DNA is used as an antenna and the set of synchronized ion receptors could act as modulator and amplifier of the neuronal activity in the electrical activity of the antenna. We can see several problems, especially considering the nanometers size of DNA in eukaryotic cells that could make the radio frequency radiation of this kind of transmitter highly ineffective, and thus the output signal could be extremely weak, interfering with the existing radio frequency noise of a mammalian brain. The in-organ solution has the advantages of avoiding the nanometer-ranges of the sizes, but it is still an open question how we could create an effective antenna based on the materials of a mammalian cell, especially in a way that is safe for an animal. Some previous experts have called this possibility "The Internet of Bio-Nano Things" [26] or "Nano-Networks" [27]. These new cyborgs can be connected through neuromuscular interfaces [28] or be spread and embedded into several biological systems[29], which can be enhanced in several ways [30]. The deep challenges that these changes could produce to our sensing, experience, and feeling of the world can face us in front of a radical evolutionary scenario—as a species and at an individual level. This is the crucial point: to see that at this level, the individual and collective paths flow in different and not always complementary ways. From a biological taxonomical perspective, this can justify at certain moment the dilution of the species as a whole and equal macro-entity. At the same time, this disruption could be considered the logical new step into the evolution of our species: when the techno-symbolic forces take control over random biochemical and social evolution. For example, we can fuse our bodies with other biological bodies which do not belong to our direct evolutionary family (e.g., cockroaches) [31].

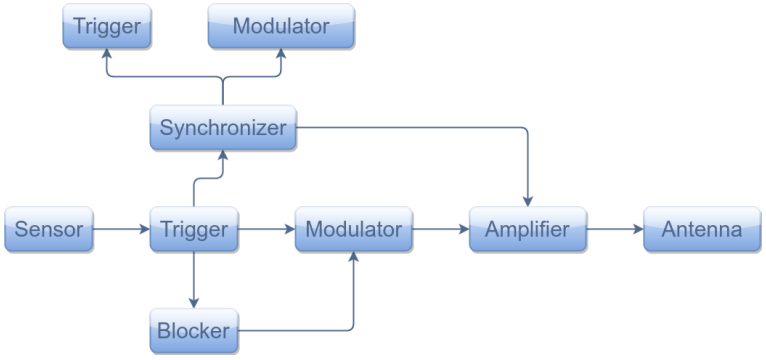

Figure 1. The principal schema of cellular radio-transmitter. The main components are: *sensor*—this could be a receptor that is triggered by light or neurotransmitter (serotonin); *trigger*—this could be a second messenger such as a ligand that could unblock the modulator and synchronizer, and the trigger should act on a *blocker*; *modulator*—this is the array of receptors, for example ion pumps that could be synchronized via a *synchronizer* mechanism; *amplifier*—we understand it as currently coupled with a modulator or it could even be same array of receptors or ion pumps; *antenna*—could be DNA electrical currents.

4. The Swarm Behaviour of the Augmented and Quantified Human—The Next of the Internet of Everything?

After some decades of hard work on symbolic processing, AI experts tend to consider other reliable and effective ways of dealing with information and decision-making processes. Social insects—especially ant colonies—emerged as a superb model of what is called "swarm intelligence" [32]. This decentralized way of achieving collective decisions (even for human scenarios, see [33]) and collaborative workflows has demonstrated its value for robotic applications in some special domains [1]. We consider that this bioinspired method, combined with the Internet of Things that is emerging at this moment, can provide new ways of dealing with the collective experience of being an individual as well as being a member of a broad collective. Our augmented devices can, for example, collaborate between them with or without our conscious decision; for example, allowing certain permissions of collaboration under special circumstances. A network of informational devices can provide new ways of managing social interaction, beyond classic structures of power or control. For example, recall the Hong Kong protests against Chinese censorship and how thousands of citizens avoided governmental censorship of networks using a phone-to-phone connection app (Firechat) to avoid the loss of connectivity [34]. At the same time there is another crucial aspect: how these new technological mechanisms can enhance, upgrade, or radically modify feeling and sensing of the world: creating augmented worlds, expanding the scope and thresholds of our natural senses, or creating new synesthesic ways of experiencing the world. Imagine, for example, a military vet which could provide sensory pressure experience of a radar evaluation of close targets into a 360º perimeter: combining the position of pressure and its intensity, a soldier could experience the proximity of non-visual targets and increase their response accuracy. Thus, not only one of the generally accepted twenty-one human senses can be utilized in order to expand human perception abilities, but radically new senses can be introduced in humans by directly activating certain areas of human brain. This enhancement can affect not only individual minds, but thanks to dozens of gadgets and sensors, can connect us to others' experiences and feel other kinds of informational values in a more complex way. Our smart clothing could combine its regulation properties according to the proximity of other persons, creating a smarter and efficient management of collective temperatures (inside a plane, a tank, the metro facilities, or a bus, for example).

Humans evolved as social animals, and have always been communicating with other individuals through language, writing, publishing, telegraph, and finally the Internet. We have certainly and dramatically expanded the cohort that every single individual belongs to since the invention of

language. However, we still use the same "language" of communication as we used before the Internet age. We type, we talk, and we see. However, what new patterns of human swarm behavior become possible on the larger scale when we introduce another "language" of communication—a language that might not contain words? How large can the "collective intelligence" of the human swarm of that kind be? We already know examples of how a large number of human individuals can be synchronized, share common objectives, and be in a sense smarter together than as individuals (e.g., [35]). States, corporations, and federations of various sorts also represent how the communication of multiple individuals bring about a new cybernetic entity. However, all of these examples—especially the crowd—are very limited in their cognitive ability. How far we can get in making crowds smarter with the introduction of a new technology of communication? How differently would the crowd or the cohort behave when AI entities will be part of it, as well as non-intelligent communication devices and distributed sensors and actuators [36]? We now have computational power that we have never possessed before. Even with the present communication technology, social and political revolutions have sped up tremendously [37]. The new internet of everything with the power of intelligent assistants, connected devices, robots, and abundant computational power available through clouds and on the edge [38] will change the way individuals perceive, interact, think, and feel—not only as individuals within smart infrastructure and the new society, but as *societies* itself. This will have certain implications for public service, law enforcement, and many other facets of the civil sphere. It will change how the economy works, and even the state itself. The new *people-to-people economy* [39] fits perfectly well with these new kinds of *super-connected societies* that we could call *social connectomes*.

5. Security of the Next Generation Internet of Everything

Even with the existing level of IoT proliferation, the security of the IoT is garnering a great deal of attention [40,41]. Indeed, compromising the security of an intelligent transportation system or a smart energy grid could bring down a whole nation and lead to severe causalities comparable to those of nuclear war. Just imagine the magnitude of consequences of compromising the security of a *super-connected society*! Works on ubiquitous IoT security have been underway for some time now (e.g., [42]), but issues of the dependance of the *super-connected society* on the complex technology, security aspects of the augmented bodies, and direct brain-to-brain connections, has not yet been thoroughly studied.

Privacy issues against the public security challenges of the *social connectome* deserve special attention from the ethological point of view, technological, and even legislative aspects. While it is not yet clear what level of privacy would be available for such societies, the challenge would also be to secure and regulate it. Compare the change in approach over the course of a bit less than a century in [43] and in [44].

Certainly, security issues for swarm intelligence are multifold, through the projections of the system to the physical world. We already considered transportation systems and energy grids, but there are also robots and avatars, mobile platforms of various kinds that interact with each other and with humans. Therefore, physical security for the swarm intelligence must be considered separately.

The very nature of the *social connectome* is vulnerable to social engineering. It is enough to "hack" a member of the *social connectome* in order to influence the whole cohort. Therefore, for this *super-connected society*, the issues of individual physical security must be also considered in the context of the public security of the *super-connected societies*.

6. Challenges for the Collective and Individual Experience of Self and Others

Human societies have been possible thanks to cooperative strategies [45]. Today, we can even implement engineering upgrades which make possible new cooperative processes [46] between humans as well as between humans and machines [47]. The possibility of having a new kind augmented human (through extensions of modifications of their bodies) makes it possible to extend the notions of swarm intelligence to the spheres of human life. At the same time, this new interconnectivity

can increase and severely modify our experience of the world, not only as individuals, but also as a collective of living entities. Therefore, we can think about ways of enhancing empathic responses or engineer the feeling about a vast range of data, ignored until this new revolution [48,49].

From this point of view, our body and our cognitive processing are upgraded—two facts that will completely change the phenomenological experience of not only ourselves, but also of the social world. This is what we call the *techno-phenomenological turn*, the revolution of minds and bodies, now connected in new ways among them and also with machines. The difference between previous enhancements and this one is that the direct sensory connectivity between humans can experience a revolutionary change. This process faces us with several challenges and opportunities, which can be discussed under ethical but also cultural and engineering perspectives. With this techno-phenomenological turn, we can intensify the experience of being "me" and of being social.

Another challenge for the member of the *super-connected society* is that we are all very different. Some people may have a bad mood, be depressed, or even be dying at a particular moment. This experience should not be shared by everyone in the *social connectome*. Additionally, mentally ill members of society should not impact the rest of the individuals with their distorted perception of reality, otherwise our augmented worlds would turn into a perpetual nightmare for their inhabitants. On the other hand, an individual joining the *social connectome* will gain a sort of immortality—in a sense, how parents live in their children, because everyone in the *social connectome* will share parts of the personalities of other members.

The challenge is in not only collective vs. individual perception, but also in the social implications of the emergence of the new humankind and what social upheaval this transition could bring about.

7. End Remarks

The increasing presence of AI into humans' lives cannot be reduced, although it is omnipresent, to Big Data mining, deep learning, or complex ways of dealing with informational values. We can consider them as vertical approaches, where huge systems capture and process from the users' raw data. On the other hand, there are (and surely will be more and more in the future) also horizontal ways of communicating information between closed systems, without a necessary main control (again vertical). The reasons for this strategy can be several: as a way of reducing computational power required in daily activities, as a way to undergo some kind of control, or as a political decision about how we want to feel the world (ignoring other aspects of reality through our intelligent sensors), among other possibilities. Swarm intelligence—united to the world of the Internet of Things and the possibility of physically or virtually augmenting our worlds—provides us with a new scenario, which we have called the "techno-phenomenological turn". Considering the importance of the emotional aspects of our life [50] and the increasing implementation of emotions into artificial systems [51], we can foresee the emergence of a new sphere of collective feelings, even of augmented feelings that may radically alter the ways by which we consider the world. New mechanisms of intracellular, inter-neuron, nano-technological or biochemical enhancements can provide an exponential growth and change of the informational flows we process, as well as substantially modify both their raw and processed nature.

Another aspect of the swarm intelligence-enhanced societies is the society itself, with implications for state, law, public services, and security. In fact, security is a separate important issue of the *super-connected societies*. Swarm intelligence not only makes us act, think, and feel differently in our "collective soul", but also creates another sort of society—an organizational form that has never before been achievable.

We introduced several notions for the subject of our study: *swarm intelligence*, *super-connected society*, and the *social connectome*. They reflect various levels of abstraction of the approach. We talk about *swarm intelligence* as the most general term of the next generation Internet of Everything augmented with AI, robots, and computing power. However, when we consider the new kind of society, where individuals are connected through the *swarm intelligence*, we talk about *super-connected society*. Finally, when we mean that the *super-connected society* is connected through direct brain-to-brain

interface, we get the *social connectome*. The main differences between the super-connected society and the social connectome is that in the first case we are considering society as a whole (including people, machines, tools, objects,etc.), while in the second case we are specifically referring to the enhanced biological aspects that allows new kinds of human–human interaction.

We would like to stress that the swarm intelligence presented here is nothing revolutionary, but rather evolutionary in human development. It fits well with the new *Uberized economy*, computing power, and infrastructure development. It is the next step of the development of the Internet of Everything. However, it also brings qualitative change, because new social models become possible, and new challenges await the researchers to be met in the near future.

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