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On Artificial Agents within Human Social Networks: Examples, Open Questions, and Potentialities

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Abstract—**Social networks, which until recently were populated exclusively by human actors, are starting to become increasingly populated by artificial agents, which play various roles within them. Thus, they can be viewed as an interesting digital ecosystem, with two qualitatively different kinds of agents: biological as well as artificial. An example of such an artificial agent will be presented, which is in this case physically embodied: Sarah the FaceBot, a conversational mobile robot equipped with a social database and interaction memories. Sarah not only participates within the actual human social network by forming relationships with its physical interaction partners, but is also a member of the FaceBook social networking website, which she automatically queries for information which she uses in her dialogues, and on which she also actively deposits social information. Starting from this example, an extensive discussion of open questions, purposes, and potentialities regarding the introduction of artificial agents within human social networks will take place, exposing multiple avenues towards beneficial application of such agents within the newly arising digital ecosystem of hybrid human-machine social networks.**

Keywords-digital ecosystems; artificial agents; social networks;

I. INTRODUCTION

The notion of a digital ecosystem is a powerful one, bridging the conceptual framework of biological ecology with the rapidly expanding digital world. As any young concept, a variety of attempts towards a definition exist; notably [1][2][3]. In this paper, the digital ecosystem under consideration, consists of two qualitatively different kinds of agents: artificial agents (also in actor roles), and human agents. Furthermore, the digital ecosystem is mainly viewed as a social network, under two different lenses: both as an actual social network, and as social network sites (SNS), which are close to a partial digital representation of the actual network. SNS, which have recently become tremendously popular[1], have so far been exclusively populated by human actors. On the other hand, at least part of the functionality of such networks, relies on software agents – for example, in order to implement recommendation systems for friends. However, such agents were not playing actor roles within the network. Recently, the monopoly of human actors within SNSs has been broken; disembodied or even physically embodied intelligent software agents are just starting to populate SNSs. A huge range of potentialities exists regarding useful roles for such artificial agents, which might furthermore have varying degrees of autonomy.

1. Before the introduction and wider spread of SNS, the primary means of online self-presentation were home pages, which while changeable, were not dynamic [4]

This paper starts by introducing a *concrete example* of such an agent: Sarah [5][6], a robotically-embodied artificial agent, which carries out natural language interactions with people, physically present or remote, and which utilizes and publishes social information on FaceBook - even having her own automatically-updated page. Then, five areas of *open questions* that have arisen will be presented, and we will close with an exposition of the *potentialities* and *purposes* for artificial agents in SNSs, which as we shall see are promising to unleash new possibilities and beneficially transform social networks.

II. SARAH THE FACEBOT

Sarah is a physical mobile robot with *face recognition*, *spoken dialogue*, as well as *navigation* capabilities (figure 1).

Figure 1. Sarah the FaceBot Robot, while interacting with a human

Furthermore, it is a robot which is also equipped with an *interaction database* (keeping information about previous interaction episodes) as well as a *social database* (keeping personal info as well as friendship relations for the people the robot knows). Most importantly, the robot also has a *live connection* to the "*FaceBook*" social network site – and utilizes online information towards crafting dialogues with humans, as well as publishes information on its own facebook page. Sarah has *three kinds of friends*: those that she has met physically, but which are not her friends on FaceBook (P), those that she has met physically, and which are also friends with her on FaceBook (PF), and those that she has not (yet) met physically, but which are friends with her on FaceBook (F). Interaction

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with human friends can happen over a *number of channels*: real-time spoken dialogue with physically present friends, real-time dialogue over chat for friends which are online on FaceBook, as well as offline FaceBook messaging.

A transcript of a typical interaction with Sarah follows:

//Greetings / Recognition:

R:Hello! My name is Sarah. Welcome to the IRML lab

R:Hi! Are you Panos Toulis? (from Face recognition)

H:Yes (Robot changes its online status to "interacting with Panos Toulis")

//Query of overall state:

R: Hey, Panos Toulis, are you doing well today?

H: Yes, pretty well

//General news-based discussion:

R: Let me tell you some interesting news that I've heard

R: Space shuttle endeavour prepares for second go (from BBC news online)

R: Have you heard about this?

H: Yes

R: That's great!

//Robot discusses Facebook status of human

R: I see you are chasing robots in the desert

//Robot gives news about a mutual friend

R: Did you know that our friend Shervin Emami has posted a new photo on Facebook? (info taken from Facebook minifeed)

H: No

//Robot sends reminder to human

R: I am sending you a message about this to check it out

//Robot remembers past encounter with mutual friend

R: I saw Shervin yesterday evening and he was doing well. (information acquired from interaction database)

//Robot gives news about a mutual friend

R: Did you know that our friend Chandan is "waiting for Sarah to have that little sweet conversation with me"? (information acquired through chandan's Facebook status)

H: Yes, of course.

//Robot connects an online friend with the human

R: One of our friends, Nikolaos Mavridis, is online – would you like me to send him a message?

H: Yes ('Nikolaos, Panos says hello" is sent)

//End of interaction

R: Hey, Panos, it was nice talking to you! I have to go now. See you later! (Robot continues wandering)

Thus, currently Sarah is capable of producing *dialogue turns* for (for videos of the robot: youtube channel irmluaeu)

D1) Recognition / Greeting

D2) Querying the state of the human

D3) Relaying customized general news

D4) Relaying facebook minifeed-based news about human or common friends

D5) Relaying previous interaction-based memories about human or common friends

D6) Performing a real-time connection with a third common friend which is online

D7) Saying Goodbye

It is worth noting that all of these dialogue turns contribute towards *real-time information diffusion* within the social net; and apart from these, Sarah's updated facebook page contents as well as messages also diffuse information, but in a *non-real-time* manner[2].

Sarah was originally created in order to test an interesting *hypothesis* in the field of HRI (Human-Computer Interaction), which was formulated in [5]: "Can reference to *shared memories and shared friends* in human-robot dialogue create more meaningful and sustainable relationships?"

Motivation for positing this question was provided by disappointing early results on long-term human-robot interaction experiments, as exemplified by [7] – although robots seem to be exciting and interesting to humans at first, upon multiple encounters quite quickly humans lose interest. Thus, the following *chain of argument* led to the postulated hypothesis: "Let us examine random human encounters, without explicit purpose of interaction – say, short chat with a colleague or friend. What is their content? First, there seems to be continuity in these dialogic episodes, connecting the current with the previous encounters; a common, shared past is being created, and reference to it is often made in the dialogue. Second, this common past is not exclusive to the two partners conversing at the moment; it actually extends to their circle of mutual acquaintances – and thus news and memories regarding shared friends are often being mentioned. Thus, let us try to create a conversational robot that can refer to *shared memories and shared friends* in its dialogues; and examine whether this will lead to better long-term human-robot relationships".

Upon closer examination, and in AI terminology, in a sense Sarah is a form of a chatterbot; and there exists a long line of such systems in the literature, starting with the classic ELIZA [8]. But there are a number of *important differences* between FaceBots and classic chatterbots; not only Sarah is physically embodied, but most importantly her dialogues are driven by a rich context of previous interactions as as well as social information, acquired physically or online, and which is dynamic and conversational-partner specific.

Two further comments worth making: first, regarding *"shared" entities*, and second, regarding *implicit teleology*. The primary hypothesis that FaceBots were created for, is concerned with two postulated "shared" entities and their effect

2. Currently, and primarily due to speech recognition constraints, Sarah is mainly diffusing information acquired through online news, facebook minifeed and status, and interactions; but there is not much direct acquisition of information from the human, except from a basic state query and "did you know x" queries. This is an active direction for extensions.

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in human-robot relationships: shared past and shared friends. Both of these belong to a wider set of *shared entities* that might prove to be important: shared interests, shared goals – actually often quite correlated with shared past and shared friends, at least in certain contexts / for certain subsets. All of these shared entities can be hypothetically unified under the "intersection" I(A(t),B(t)) of the two actors (human and robot in our case), at a given time instant t – a time-varying concept. It might well be that the creation, maintenance, and synergistic co-evolution[3] of such an intersection, turns out to be a crucial factor towards long-term human-robot relationships.

Before proceeding to five areas of open questions that have arisen from this project, a short note on *teleology*: The casual conversations that Sarah is attempting to replicate, seem not have an explicit purpose from the conversational partner's point of view. However, their teleology is probably better localized not at the personal or the dialogic-partners level – but at the social network level. The establishment of an adequate intersection enabling understanding and co-reference, the flow of local-context relevant information, and the resulting bonding might well be three main components – ultimately tied to collective social capital[4].

III. Five Areas Of Open Questions

Apart from the original motivation behind the creation of Sarah the FaceBot, this line of research opened up a number of interesting avenues as well as questions related to artificial agents and social networks:

Q1) Interaction patterns of agent: What will be the interaction patterns of such agents with physically present or remote humans? For example, what will be the frequency, duration and content of such interactions?

In practice, for artificial agents within social networks, this would amount to logging and analyzing the different types of interaction events that will occur – synchronous or asynchronous, mutually visible or unidirectionally visible: viewing a profile or photo, sending a message, chatting, adding a friend etc. For agents that also have a physical embodiment, such as Sarah the FaceBook, proxemics, gaze and other such external measurements might also be utilized.

Q2) Friendship graph of agent: What will be the form and temporal dynamics of the friendship graph of such agents? (figure 2). What will the connectivity patterns, tie strengths, as well as the individual social capital [10] be?[5]

One might expect significant differences with human actors in this respect[6]; for example, the sustainable social circle size of technologically unassisted humans is constrained by cognitive limitations – which seem to be somewhat relaxed in the case of artificial agents. On the other hand, one should also note that there also exist important limitations of the current state of agents as compared to humans (for example, in unconstrained natural language dialogic capabilities).

Q3) Effect of introduction of agents in social network: How will the interaction and structural patterns of the existing social network will be affected by the introduction of such agents? Will connectivity patterns be disrupted? Will the evolutionary dynamics or node distributions change?[7] How will collective social capital [12], or diffusion patterns, be affected?

Here, we move from the ego-centric viewpoint of the agent towards the collective viewpoint of the network, which is where human actors belong to – and which is ultimately the locus of importance.

Q4) Relation of agents with multimedia content of SNS: How will the image or video content of SNS be altered through such agents? For example, what is their potential in posting photos and videos, and/or recognizing faces, objects, places and events in posted photos and videos, on the basis of their own observations or other pre-tagged photos?

Given that human actors do not live in a symbolic/language-only world, and they populate SNSs with multimedia content, it is important for artificial agents to be able to handle and/or contribute such content. On the other hand, again given the different domains and activities on which the current state of agents is more capable as compared to humans, and vice-versa, this also creates an opportunity for overall benefit.

Q5) Social engineering potential of such agents for SNS: How will such agents be designed / positioned in order to affect connectivity patterns, diffusion patterns, social capital, and other such important parameters at will? How will one exploit the different capabilities of artifical agents for such a purpose?[8]

From a practical point of view, this might be the most important question – and we will return to some aspects of this in the last section of this paper.

Currently, some very early answers to aspects of Q1 and Q2 for the case of Sarah have been reported in [6], together with an extensive discussion of the synergies between SNS, interactive robotics and face recognition. Furthermore, the use of live photos in conjunction with online photos towards better face recognition, as well as algorithms utilizing social context towards better and / or faster recogntion through such agents is discussed and algorithms are given in [15]. Also, simple algorithms for empirically estimating the social graph given only photos containing co-occurring faces are presented.

Figure 2. The "touchgraph" depiction of the first level friends of the robot in March 2009, before public opening: 79 first level friends, 13989 second level

3. This co-evolution often indirectly relies on input from personal evolution and interaction with other entities inside or outside the shared circle of friends; such interactions might lead to growth of the personal non-shared component of each actor, which in turn leads to novel input for co-shaping the intersection

4. For a somewhat complementary evolutionary view, including a theory postulating the transformation of primate grooming into gossip, look at [9]

5. For a concise introduction to the basic social network analysis terms used here, one could look at the opening chapters of [11]

6. Ultimately, after a number of layers, reducing to some of the differences between atoms and bits, in sense of [13], or at least to the differences between biological atoms and the current state of agents comprised by bits

7. For example, the well-established power law distributions arising from the model of [14], depend on preferential attachment processes – which, for the sake of experimentation at least, artificial agents might not chose to follow – and linear growth of the net.

8. For example, the much larger interaction memory as well as social info storage of such agents, or the possibility of having distributed embodiments spanning large geographical distances are two basic such differences.

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Of course, this is just a very early stage regarding the questions and avenues enlisted above – and much more work remains to be done, in order to reach a more mature stage. Also, one can pose the above questions (Q1-Q5) not only in their *predictive form* ("what will be"), but also in their *potential form* ("what could be"), their *normative form* ("what should / would one want to be"), and their *engineering form* ("how should we act in order to reach …"). Thus, we can for example ask, not only: how will social capital change with the introduction of artificial agents? But also: how could it change? As well as: how would one want it to change? And also: what action plan should be followed so that the introduction of artificial agents within social networks changes social capital towards the desired direction?

IV. The Physical vs. Online and Symbolic vs. Sensory Realms

Expanding upon Q4, another interesting observation regarding embodied artificial agents in *actor roles* arises: such artificial actors, as human actors do, belong to an actual social network, a subset of which is re-represented within facebook. Also, as mentioned before, they have three categories of friends: physical only (P), physical which are on facebook (PF), and facebook only (F). Their perceived identity thus depends on different primary sources for each of the three categories of friends (physical presentation vs. online); and the effect of differences and misalignments across these can thus be studied.

Yet one more observation is concerned with the *relationship of the linguistic/symbolic with the sensory* realms for such agents. Both realms are accessible physically as well as online; although different projections / selections of the two realms exist in the two. For example, consider photos; these belong to the sensory realm – and the robot has access to snapshots from its own camera (physically), as well as to facebook-posted photos (online). For example, consider the friendship relationship among two individuals; say George and Jack. This linguistic/symbolic information might be available through the online friendship graph on facebook, or might be acquired by direct/indirect questioning physically, through the robot's dialogue system. On the other hand, this linguistic/symbolic piece of information is not uncorellated to the sensory realm; as a simple statistical analysis can show (see [15]), we expect that "The face of X appears in photos together with the face of Y" (a sensory-realm relation) is a strong predictor for "X is a friend of Y" (a linguistic/symbolic-realm relation). In essence, this is yet one more instance of symbol grounding [16] – which is normally performed by human actors, and which in this case could potentially be transferred over to the artificial actors [17]. Thus, a *quartet of vertices* arises: sensory/physical (capturing a photo through the robot's camera), linguistic-symbolic/physical (hearing that X is a friend of Y), linguistic-symbolic/online (reading that X is a friend of Y from FaceBook), sensory/online (seeing a photo on FaceBook), and the *bidirectional connections* among these vertices are to be resolved by the actors involved.

Now, having seen a brief introduction to FaceBots as an example of a robotically embodied artificial agent in an actor role within the FaceBook SNS, and having let us move a step above, and tackle a question from *a wider perspective*: apart from early examples such as recommendation systems and the FaceBots robots, I will present a basic taxonomy and an exposition of the potentialities for other artificial agents in SNSs; either in actor or in other roles, and will discuss their possible effects towards beneficially transforming human social networks.

V. The Space of Potentialities for Artificial Agents Within Social Nets

The space of potentialities for artificial agents within social networks is quite vast, and a number of basic degrees of freedom / dimensions (D) will be introduced here.

D1) One first obvious choice is concerned with the *Appearance* of the Agent to the human actors of the network; one possibility for the agent is to have an active Actor role within the SNS, with a profile, a friendship network, and interactions – such as the case of Sarah, and either for it to be declared as an artificial entity or to posit itself as a human actor. Another is for it not to appear as a human actor, but as a distinct entity (for example, an installable facebook application) or as part of the architecture of the SNS itself (as is the case of the friend recommendation system of facebook). Yet another, quite interesting possibility, is for its existence to be unknown to the human actors; where the agent can be acting by effectively modulating what might appear as random events; for example, the order of presentation of items within a list, pushing forward and thus emphasizing some items in order to increase their availability in the human's mind.

D2) One other degree of freedom is concerned with the *Physicality* of the agent. One can have for example a physically embodied agent; a virtual character with a cartoon-like body; or a totally disembodied entity. Of course, this degree does not only cover form, but also movement and body dynamics of the agent.

D3) Yet one other interesting dimension is *Autonomy*; the artificial agent might be completely autonomous, or exhibiting adjustable autonomy through human assistance at specific times or in certain levels of abstraction. Such a configuration sometimes combines the best of both worlds (artificial and human); and enables successful application of agents to areas where their current state of the art would not allow them to be applied alone. Some recent examples of adjustable and sliding autonomy in the agents and robotics literature are [18] and [19] – and analogous guiding principles can be followed in creating effective man-machine hybrid agents participating in SNS.

D4) In the case of an agent in an actor role, another important dimension is that of the apparent perceived *Identity* of the agent; the profile information, linguistic style, dialogue system, posted pictures, friendship circles as well as interaction behaviors of the agent all contribute to this. As noted upon before, the agent's is performing his identity in two stages: the physical, as well as the online stage. Simple software tools for crafting artificial actor identities have not yet appeared; although one would envision that with appropriate machine learning techniques, information mined from the profiles, dialogues, and the other traces of the actor's performed identity would enable the creation of congruent identities for artificial

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actors, parametrized by a set of simple user choices. For example, one could envision the possibility of learning simplistic mappings from regional-socio-economic background (part of profile information) to linguistic style (mined from dialogues), for a limited dialogic range, and vice-versa, and thus using these mappings in order to minimize authoring time when crafting the identities of new artificial actors.

D5) Finally, and quite importantly, there is the question of the overall *Purpose* of the agent, a discussion on which follows.

VI. Possible Purposes for Artificial Agents Within Social nets

Let us start with an observation: moving on from *actor-role* to *non-actor-role* agents, one of the crucial differences is concerned with their *scope of visibility*; usually, an actor-role agent, can only have direct access to the resources opened to him via the adjusted security settings of the other agents that have chosen to connect to him on the network. In contrast, an overt non-actor agent, for example a facebook application, often gets wider access to all data of the actors that have installed it; and even more so, an *overt- or covert-* non-actor agent that is part of the SNS itself, for example the friend recommendation system of FaceBook, can have omniscient access to all actors within the SNS as well as their interactions. After this comment regarding the difference in scope of visibility between actor- and non-actor role agents, let us move back to some possible choices for the purpose of artificial agents within social networks:

The purpose of the example agent presented above, Sarah the facebot robot, is to *create sustainable relationships* with humans – which could be translated into a metric containing components related to frequency and duration of interaction over a longer period, human satisfaction, as well as number of friends, for example. Another possible purpose for actor-role agents is *teaching / education*; *specialist assistance*, as well as multiple forms of *persuasion* [20].

Also, artificial agents in actor roles, can be quite beneficial for setting up experiments in order to *test scientific hypothesis* related to social networks – for example, questions regarding diffusion – as they are, in a sense, limited but perfectly reliable puppets. As long as their divergence from human behavior is not detrimental for the purpose of the experiment, they can be used to create predictable responses and gather measurements within the social network: for example, when studying diffusion, agents can act as pre-programmed filters or targeted redistribution nodes; or when acquiring friendship request acceptance prediction models, agents can be set up with the desired apparent identities and initial messaging response patterns, and gather results regarding the acceptance of their requests by various actors. The interchange between human actor and artificial actor for social network research, is quite parallel to human/robot interchange when bi-directionally informing Human-Robot Interaction (HRI) by Human-Human Interaction studies and vice-versa, for example [21]; and as long as the nature of the experiment can benefit from the "limited but perfectly reliable puppet" constraint.

Another possible purpose for actor-role agents is to *intervene within the information flow* of the network – towards a number of potential goals: *respreading news*, monitoring for possible mutations, even counter-spreading information, or creating parallel flows and adjusting existing two-step flow of communication nets and *influencers* [22]. Another possible goal is the *active acquisition of information*: actor-role agents could potentially activate their own connections on demand, in order to seek, ask for, and relay back missing information.

One further possible purpose is *restructuring the connectivity* of the network, through suitable overt or covert recommendations; this might take place towards a variety of goals, for example related to useful matchmaking of actors towards personal or professional goals, which could be beneficial to the network or a sub-network as a whole – for example, in terms of social capital. For example, an agent might try to actively detection and manipulate structural holes. Due to the benefits of a possible wider scope of visibility and non-interactivity in this case, non-actor agents are more suitable for this purpose.

Another primary role for non-actor agents is *supervising* the network in order to detect possible criminal or otherwise harmful / illegal activity. Currently, there exist for example automated- or human-assisted picture censorship services within SNSs; but there exist many more areas which could potentially benefit from the appropriate form of supervision, given of course appropriate privacy and freedom concerns.

Finally, let us close this brief exposition of some possible purposes for agents within social networks, with a relevant comment: when arbitrating visibility / action scope across a number of agents, often hierarchical structures are quite beneficial, sometimes augmented with hierarchy-breaking patches. A recent example of a hierarchical multi-agent cognitive architecture is for example EM-1 [23], where the idea of higher-order agents having access to the internals of lower-order agents and acting as "mental critics" is central[9]. One could thus envision similar *hierarchies of visibility and action scope* within *hybrid multi-human/artificial agent systems* operating on social networking sites.

VII. Conclusion

In this paper, we have discussed the *entry of Artificial Agents*, in embodied or disembodied forms, within *human Social Networks*, which thus comprise emerging digital ecosystems. We started by introducing a *concrete example* of such an agent: Sarah the FaceBot, a robotically-embodied intelligent artificial agent, which carries out natural language interactions with people, physically present or remote, and which utilizes and publishes social information on FaceBook – and which publishes on her own automatically-updated page. Then, there was a brief presentation of five areas of *open questions* that have arisen, a short discussion on relevant aspects of the quartet created by the physical/online and symbolic/sensory realms, and an exposition of the *potentialities* and *purposes* for such agents; either in actor or in other roles. In conclusion, artificial agents, which are currently increasingly populating social networks, are promising to significantly change these networked publics in a beneficial manner, and unleash numerous new and exciting possibilities.

9. Such models are arguably quite reminiscent to implementations of the structures of a platonic republic, at least in some respects

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