Agents and Multi-agent Systems as Actor-networks

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Abstract: Agents and multi-agent systems are looked at through the lens of actor-network theory which plays a prominent role in the avant-garde of postmodern studies on socio-technological systems. The authors use the elements of applied semiotics and logics of action to formalize the basic actor-network concepts; they discuss prospective intercourses between the actor-network paradigm and the agent based approaches, potential synthesis of the two methods and the new semantics of certain MAS concepts suggested by actor-network theory.

1 INTRODUCTION

The core principle of the actor-network theory (ANT) is based on the idea that the actions of any human or nonhuman agent (or "actor" in terms of ANT) are mediated by the actions of a set of other heterogeneous actors. This set is informally defined as "actor-network". The origins of any actor-network are considered a "rhizome" in Deleuze-Guattarian understanding of this term, i.e. a self-organizing multiplicity with totally decentralized structure and no hierarchical relations between its heterogeneous elements having only an initial affinity with each other. It can hardly be identified as a system since it lacks order and never inherits any order from its predecessors or constituents, however the initial affinity between its heterogeneous members helps establish functional links between them (Deleuze et al., 1993). Heterogeneity of actors traditionally understood in the actor-network theory as their belonging to one of the two opposite worlds (human/social or nonhuman/natural/technological) and ability to form steady networks of human-nonhuman (socio-technological) hybrids (or quasi-objects) needs to be redefined with the recent advent and coming out of the blue of the artificial intelligence. The pendulum of the actor-network theory which was earlier oscillating in the two-dimensional field between the two opposite poles (human and nonhuman) leaving after every sway the two-dimensional hybrids, now acquires the third pole and the third dimension: nonhuman intelligent objects-subjects in their interactions with humans and non-intelligent nonhuman actors. Hence the emerging demand for integration of the actor-network paradigm with the intelligent systems research, multi-agent systems studies, knowledge engineering, ergonomics and other related fields of research and applications. We foresee the trajectory of evolution of the actor-network approach from the descriptive theory created (and further revised) by Latour, Callon, Law and other ANT protagonists, through its formalization and integration with other relevant methods of AI and agent-based research, toward its eventual conversion into a full-fledged applied tool for modelling and simulation of socio-technological systems. Starting paving this way we have demonstrated that the actor-network theory provides new semantics for some core concepts of the multi-agent systems theory (Iskanderov et al., 2020), and suggested to use the elements of applied semiotics and logics of action (TI, SAL) to formalize some basic concepts of the actor-network theory.

Semiotics is considered the ideological nucleus of ANT, the whole theory being viewed as the newest phase of evolution of semiotics toward its object-orientedness. Therefore, in our move to assemble basic formal definitions here we follow the semiotic route of conceptualization: sign – actor – actor-network.

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Sign *s* can be formally defined as a set of the four components (Kiselev et al., 2018): <*n, p, m, a*>, where *n* is the name of sign *s*; *p* is the portrait (image) of sign *s* corresponding to node $w_p(s)$ of the causal network on the portraits (W_p); *m* is the meaning or "sign significance" (Kiselev et al., 2017) of sign *s* corresponding to node $w_m(s)$ of the causal network of meanings (W_m); *a* is the ascription synonymous with attribution, individual sense or "personal meaning" (Kiselev et al., 2017) of sign *s* corresponding to node $w_a(s)$ of the causal network on the ascriptions (W_a). R_n defines the relations on the set of signs; Θ defines the operations on the set of signs based on the fragments of the causal networks where belong relevant sign components. Tuple of the five elements $<W_p, W_m, W_a, R_n, \Theta>$ represents the semiotic model of actor A_1 (Kiselev et al., 2018). We assume that actor A_1 has a predetermined goal $G_1(A_1)$ not achievable by his own efforts due to the existing obstacle(s). In this situation actor A_1 can either abandon the goal or try to achieve it by taking an alternative route (*detour*) through mediation of other actor(s): A_2,A_3… (human or nonhuman, intelligent or non-intelligent) (Shirokov, 2019). Together they can either strive to achieve the initial goal (G_1) or choose alternative goals (G_2,G_3…). Return to the initial goal G_1 is only one virtual scenario in the set of alternative scenarios (Figure 1) (Latour, 1994; Shirokov, 2019).

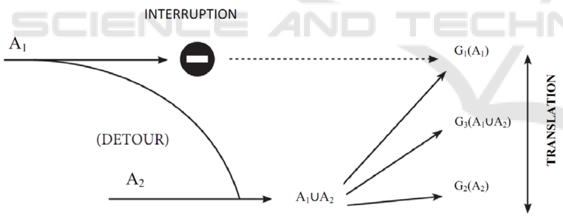

Figure 1: Translation (Latour, 1994).

Thus actor A_1 together with the mediating actors A_2,A_3… accepted by A_1 after negotiation and transformation form a network which, in turn, is transformed by A_1 (Callon, 1991). Such network of heterogeneous actors is called actor-network (AN). Formally speaking, all actions in an actor-network are distributed on a set uniting actors with human intelligence (humans), nonhuman actors with artificial intelligence (AI actors), and nonhuman actors without intelligence (other artificial/technological and/or natural objects), i.e. $AN_H \cup AN_{AI} \cup AN_{NH}$, where AN_H is the set of human actors, AN_{AI} is the set of AI actors, AN_{NH} is the set of other natural and artificial (technological) actors (Iskanderov et al., 2020). Any actor A can be involved (and in the majority of cases is involved) in multiple actor-networks $\{AN_j\}$, or: $A \in \bigcap_j AN_j$. The following core concepts were formulated in ANT:

Generalized Ontological Symmetry: Heterogeneous actors share the same capacity for agency (Balzacq, 2016). Equivalence of heterogeneous actors in their interplay within actor-network AN should mean that the same criteria and terms are equally applied to the technological and natural actors on the one hand, and the socio-cultural actors on the other hand (Bencherki, 2017). This vision represents a revolutionary paradigm shift from differentiation between the agency of intelligent (human and AI) actors and that of non-intelligent actors. The latter were totally deprived of agency in older paradigms.

Actor-Network Dualism: ANT rejects the dualism that tends to separate the social (human) from the material (nonhuman). Every individual actor of an actor-network is considered a network acting together with this actor. ANT is the theory of actors *as* networks. As Latour's famous maxim goes: "faire c'est faire faire" – when one acts, others proceed to action (Bencherki, 2017). Network is a work done by actors, i.e. by entities who act or undergo an action (Latour, 1996).

Nebular oppositions revised: ANT reconsiders some fundamental relations and metrics on the networks, e.g. (Latour, 1996):

- Far/Close. Physically close elements (when disconnected) may appear extremely distant from each other if we analyze their connections, and vice versa (cf. Latourian metaphor: "an Alaskan reindeer might be ten meters away from another one and they might be nevertheless cut off by a pipeline of 800 miles that make their mating forever impossible") (Latour, 1996).
- Large/Small. A network is never "larger" than any other one. It can only have a more complex topology.
- Inside/Outside. A network is its own border. A network in ANT has virtually nothing external.

2 TRANSLATION IN ACTOR-NETWORKS AND ITS CORRESPONDENCE WITH PROCESSES IN MAS

Operation of translation in actor-networks is defined as a delegation of powers of representation from a set of actors (actor-networks) to any particular (black-boxed) actor or actor-network in a particular programme of actions: $A=T(A_1,\ldots,A_n)$, where T is the translation of actors $A_1,\ldots,A_n$ to A. In other words, actions of actors $A_1,\ldots,A_n$ (translants) are brought into being or expressed through representative A acting on behalf of the entire actor-network. "A translates B" means A defines B. It does not matter whether B is human or nonhuman, a collectivity or an individual (Callon, 1991). Operation of translation equalizes actor-network actions in various space-time areas and various meta-levels of presentation (e.g. when behavior of an actor-network is translated through textual intermediaries: graphs, diagrams, algorithms, formulae etc.).

It appears convenient to use the formalism of TI-logic of action (Blinov et al., 1991; Von Wright, 1967) to describe the status shift of an actor-network in the process of translation in the following standard format:

$$[A]T([B]I[C]), \quad (1)$$

where [A] is the initial status of actor(s), [B] is the next status when translation of the actor(s) is successful, [C] is the next status when translation fails. If we suppose that all network situations are limited to two fundamental actor statuses [A] and [B], then the formula:

$$[\sim A]\&[B]T([A]\&[B]I[\sim A]\&[B]), \quad (2)$$

(like any other of the 64 formulae of this type) reflects one of the possible "complete" translations. The following two formulae are derivable from (2):

$$[\sim A]T([A]I[\sim A]) \quad (3)$$

$$[B]T([B]I[B]), \quad (4)$$

meaning that the translation: (a) has resulted in situation [A] and (b) has not "destroyed" situation [B] (i.e. network situation [B] was allowed to persist). Modal operator M was introduced in (Von Wright, 1967) as follows:

$$M([A]\&[B]T([A]\&[\sim B]I[\sim A]\&[B])) \quad (5)$$

This formula in terms of actor-networks states that the translation from the initial situation can prevent "destruction" of [A] and "destroy" [B], but if the translation fails the shift from the initial situation of [A] and [B] may end up in "destruction" of [A] and conservation of [B]. A successful translation generates a shared space, equivalence and commensurability. It aligns. A failed translation means that the players are no longer able to communicate (Callon, 1991). An actor-network starts to form as soon as at least three actors A,B,C are joined together by intermediaries. There are two possible elementary translation configurations (Figure 2) (Callon, 1991):

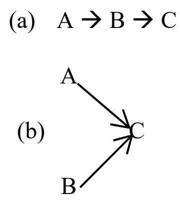

Figure 2: Elementary translation configurations in actor-networks: (a) complementarity and (b) substitutability (Callon, 1991).

The first is the transitive configuration of complementarity: if B=T(A) and C=T(B) then C=T(A). The second is the binary configuration of substitutability: C=T(A,B). These two elementary configurations join together to form longer chains of translations. All complex networks are built out of these two basic building blocks (Callon, 1991).

Potential of successful translation or "translatability" of an actor is determined by its prescription. Prescription index $P(A)\in[0,1]$ of actor A is a fuzzy estimate of possible actions of actor A from the viewpoint of other actors in actor-network AN. More formally, the more complete and determined knowledge actors AN\A of actor-network AN have in regard to actor A the higher the value of index $P_{AN\backslash A}(A)$. The less prescribed actors are more easily translatable in the interest of others, than more rigidly prescribed ones (Cordella et al., 2003). For any actors A_1 and A_2: $P(A_1)<P(A_2) \Rightarrow \tau(A_1)>\tau(A_2)$, where $\tau(A_i)\in[0,1]$ is the "translatability" of actor A_i: a quantitative metric to measure ability of A_i to be translated.

Any translation is in principle reversible. Irreversibility of translation means its ability to resist reversed translation (retranslation) and competing translations. The more numerous and heterogeneous the interrelationships in an actor-network the greater the degree of network coordination and the greater the probability of successful resistance to alternative translations (Callon, 1991).

The process of translation in actor-networks can be presented as a tuple of consequent operations: T=<*P,I,E,M*>, where *P* is problematisation, *I* is interessement, *E* is enrolement and *M* is mobilization (translation, in turn, is considered the first phase of the mediation metaprocess M=<*T,C,RBB,D*> by some authors (Latour, 1999), where *T* is translation, *C* is composition, *RBB* is reversible black-boxing and *D* is delegation).

Problematisation: Problematisation is the first step of translation, because according to Latour every action wants to solve a problem (Fischer, 2017). Problematisation can be defined as something that is indispensable and where one or more key actors try to define the exact nature of the problem as well as the roles of other actors that could fit with the proposed solution (Silic, 2015).

Problematisation embeds what MAS studies define as “commitments” of an actor postulated as the necessity of a chain of actions performed by this actor towards a predetermined goal in the interests of the community of actors (Gorodetskii et al., 2010). The commitments are viewed as pledges to undertake a specified course of action providing a degree of predictability so that actors can take the (future) activities of others into consideration when dealing with interdependencies of actors, global constraints or resource utilization conflicts (Jennings, 1993).

Interessement: Synonymous with interposition this stage of translation process represents a group of actions where an actor tends to impose and stabilize identities of other actors determined at the problematisation stage. To make a group of actors “interested” means to create a “virtual device” (Callon, 1986), which can be placed between this group and all other entities who strive to re-identify this group. In other words, A_1 makes A_2 “interested” when it breaks or weakens all links between A_2 and group $A_3, A_4, A_5, \ldots, A_n$ of n-2 actors who may tend to liaise with A_2. Figure 3 schematically demonstrates the process of interessement of actor B by actor A in actor-network AN={A,B,C,D,E} (Callon, 1986).

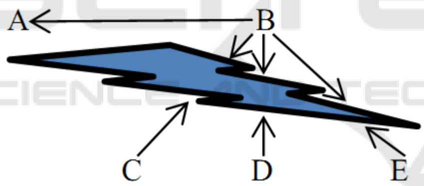

Figure 3: Interessement of actor B by actor A in actor-network AN={A,B,C,D,E} (Callon, 1986).

Successful outcome of the interessement confirms (more or less completely) the efficiency of the problematisation and supposed actor alliances (such heterogeneous alliances are often viewed as human-nonhuman quasi-objects or hybrids in ANT texts). Besides, this stage tries to break all competitive liaisons and build a system of alliances within actor-network. At this stage the socio-technological communities are formed and fixed.

This stage of the translation process embeds “conventions” discussed in MAS studies. According to the MAS principles conventions fix the conditions of fulfilment/rejection of obligations by an actor (Gorodetskii et al., 2010). “All coordination mechanisms in MAS can ultimately be reduced to (joint) commitments and their associated (social) conventions” (Jennings, 1993). The interessement goes further: in terms of MAS it is driven by the actor’s intention to weaken/break other actors’ commitments/conventions and thus create new conventions with them to achieve a particular goal.

Enrolement: The core function of the enrolement is the determination and coordination of roles of actors aiming at creation of a steady network of alliances (Silic, 2015).

This stage of translation is also interconnected with the MAS concepts where one of the forms of actor obligations is the role accepted by or assigned to an actor (Gorodetskii et al., 2010). The notion is that actors have general roles to play in the collective effort, and by using knowledge of these roles the actors can make better interaction decisions.

This notion can be explicitly manifested in an organizational structure, which defines roles, responsibilities and preferences for the actors within a cooperative society, and thus in turn defines control and communication patterns between them (Durfee, 1999).

Mobilization: Through step-by-step appointment of representatives and establishment of a series of equivalences heterogeneous actors are moved and then “reassembled” at a new place/time. This stage completes translation and certain actors start acting as representatives (delegates) of other actors (Callon, 1986). The “evolution indicators” were introduced in (Latour et al., 1992) to measure the progress of mobilization:

$$S_n = A_{n-1} + A_n, \tag{6}$$

where S_n is the number of associated elements at step n of the translation; A_{n-1} is the number of allies retained from the previous step; A_n is the number of the newly “recruited” actors.

$$IN_n = \frac{A_n}{S_n}, \tag{7}$$

where IN_n is the negotiation index. High value of IN_n indicates that the project represented by actor-network must be extensively renegotiated (Latour et al., 1992).

The mobilization concept of ANT can significantly invest into understanding of the team behavior of actors in MAS (where it is considered as something more than just a set of coordinated individual actions of the actors) (Gorodetskii et al., 2010). The mobilization concept suggests new semantics for translation-like effects discussed in the framework of MAS studies where a collection of actors needed to accomplish a task frequently includes humans who have delegated tasks to the [nonhuman] actors and/or humans who will be performing some of the work, and (hence) it is essential that the functions being offered by the actor communication language be common across the language of intelligent [nonhuman] actors and the language that people will use to communicate with them (Cohen et al., 1995). The new vision towards agency as a mere effect of interaction of heterogeneous actors regardless of their nature and inherent intelligence (or absence thereof) introduced in ANT (generalized symmetry principle) may thus help reconsider and enrich coordination scenarios discussed in the agent-oriented methods.

3 CONCLUSIONS

This paper introduces the actor-network paradigm and discourse to the world of agent based modelling. Some core concepts of ANT (e.g. generalized symmetry principle) represent a brand new vision towards agency and interactions in heterogeneous multi-agent communities. Correlation between certain ANT and MAS concepts makes their potential assemblage (enriched with approaches and formalisms provided, inter alia, by applied semiotics and action logics) a prospective tool for use in agent based models of socio-technological systems, including but not limited to: intelligent logistics; global business networks; complex research, engineering, industrial and construction projects; urban and regional governmentality; information security management systems; human-nonhuman communities encapsulated in space stations, human-nonhuman interactions in multimedia arts and many others. As an object-oriented semiotic tool actor-network theory provides an approach to the analysis of connections between the information in the form of texts and meta-texts (documents, contracts, messages, scripts, protocols etc.) circulating in a socio-technological system, and situations caused by the texts and meta-texts. This approach in our opinion has a good potential in data and information security studies (Iskanderov et al., 2019): investigation of dependencies between the level/quality of protection of the texts moved across the network and the network situations caused by protected/unchanged texts on the one hand, and deliberately or arbitrarily changed texts on the other hand. Unfortunately the space limits of this paper do not allow for more detailed discussion which will necessarily be continued in future texts. Our paper aims at bringing attention of the AI researchers, MAS theorists, human-machine systems engineers, ergonomists, knowledge engineers, logistics specialists and broader research community to the actor-network paradigm and its applied potential in socio-technological systems research.

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