# Towards Collaborative Creativity in Persuasive Multi-Agent Systems

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**Abstract.** Persuasive systems play a crucial role in supporting and counseling people to achieve individual behavior change goals. Intelligent systems have been used for inducing a positive adjustment of attitudes and routines in scenarios such as physiotherapy exercises, medication adherence, smoking cessation, nutrition & diet changes, physical activity, etc. Beyond the specialization and effectiveness provided by these systems on individual scenarios, we provide a vision for collaborative creativity based on the multi-agent systems paradigm. Considering novelty and usefulness as fundamental dimensions of a creative persuasive strategy, we identify the challenges and opportunities of modeling and orchestrating intelligent agents to collaboratively engage in exploratory and transformational creativity interactions. Moreover, we identify the foundations, outline a road-map for this novel research line, and elaborate on the potential impact and real-life applications.

**Keywords:** Collective intelligence · collaborative agents · social agents.

## 1 Introduction

Innovation and development of novel solutions to address complex problems derives from both incremental contributions and chiefly from creative processes. Although creativity has been traditionally been associated solely to individual inspiration, nowadays we cannot disregard its social components. Indeed, collaborative ideation is one of the driving forces of cutting edge developments in diverse areas such as medicine, computer science, space engineering, physics, or bio-engineering [32, 1, 20]. In particular, in the field of computational persuasion, the challenge of providing dynamic, personalized and engaging strategies for positive behavior change, calls for novel unconventional and creative approaches.

Although the importance and impact of human collaborative creativity have been analyzed in psychology and cognitive studies [25, 24], it has gathered relatively little attention in the context of artificial intelligence (AI) for persuasion purposes. In the last decade, computational methods for reasoning, reinforcement learning, and machine learning have remarkably advanced, focusing on specialized and optimized problem-solving methods [8, 29, 19]. While these results have had a tremendous impact in several application domains, there is a limited understanding of how individual knowledge-based systems and data-driven methods can find ways to cooperate, even beyond the boundaries of their own assumptions, and engage in collaborative creative interactions.

Nevertheless, ideation often requires considering behaviors and criteria, which are not typical of common AI approaches. Beyond the strive for precision/accuracy of given tasks, focusing on creative processes would emphasize the novelty of ideas, even if they might seemingly contradict previous assumptions or knowledge. Moreover, such processes are intended to explore and test new hypotheses, knowing that they may mostly lead to dead-ends or contradictory results. Similar to human creativity, collaboration is pivotal, and it can significantly improve the entire process, leading to more innovative and impactful results.

In this paper, we provide a vision of collaborative creative intelligent entities, embodied as autonomous agents. We argue for the use of multi-agent models as the building blocks to design decentralized computational entities capable of proposing and exploring novel ways of addressing a particular problem, based not only on their own knowledge but also on the shared experience with other entities. As depicted in Figure 1, our collaborative creativity model considers knowledge extracted from one or multiple domains, which is used by individual agents to explore and propose novel approaches and ideas, which are in turn submitted to a particular field (or multiple fields) where other agents may verify, examine or test them. From this social process creative outcomes are produced and reinserted into the domains of application. This envisioned collective creative process entails the necessity of considering different aspects such as specialization, knowledge sharing, hypotheses modeling, simulation, and novelty metrics. In the following, we identify the challenges (Section 2) emerging from this vision, as well as the opportunities of using multi-agent technologies and other building blocks (Section 3). Then we indicate the potential impact in different application domains (Section 4), before providing a research road-map in Section 5.

## 2 Challenges

Stemming from the agents' internal knowledge and vision, the key challenges revolve around the mechanisms generating new or rearranging existing knowledge. Following and expanding on theories in creative human communication [33] we illustrate in Figure 2 how a creative process may include several stages, from the common agreement of the problem to solve, to the different preparation, incubation, idea generation and verification of collectively created solutions. The cyclic nature of this model entails the possibility of jumping from different stages and iterating depending on the quality, originality and usefulness of the outcomes. In the following we expand on the identified challenges.

***CH1: Shared language.*** A creative process can only happen in a collaborative environment if the diverse entities involved can rely on a shared understanding of the subject in question [7]. This common ground may span from domain-specific representations of a specific problem, to complex interaction languages describing creative conceptual discussions about a particular topic [37]. The language

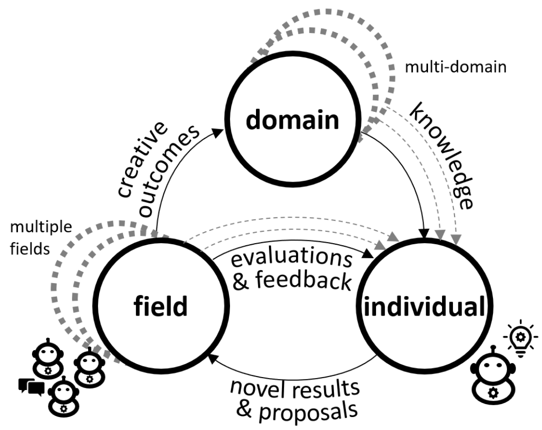


**Fig. 1.** Our agent collaborative creativity model, based-on, and extending the model in [10, 30]

must imply more than vocabularies or abstract models. Including interaction protocols and patterns may help to govern the different activities among the participants. Thus, a key challenge is to identify the appropriate expressiveness of such languages, so that an appropriate computational complexity balance is found. Moreover, given that different agents with entirely different backgrounds may interact with each other, the reconciling language must also allow representing high-level orthogonal concepts as well as more specific ones. The former can be used to exchange ideas and hypotheses, while the latter may allow deeper exploration and evaluation interactions to pursue a specific objective.

***CH2: Shared knowledge.*** Once a common language is established, representing the problems/topics under discussion with machine-understandable models is the upcoming challenge. In particular, such mechanisms should be able to specify different types of knowledge, such as background and results stemming from previous studies or interactions, representations of simulations, probabilistic scenarios, validation criteria, novel ideas represented as thought processes, mental models, etc [2]. Unlike traditional knowledge management approaches that mainly operate on facts, the new sharing scheme needs to handle possibilities, even risking to pursue possible invalid/unfeasible paths. Furthermore, shared knowledge may also need to deal with inconsistencies and conflicts coming from different participants.

***CH3: Interdisciplinarity.*** Creativity, in the form of novel ideas, often arise from cross-fertilization and exchanges of ideas coming from entirely different backgrounds. Reconcile expertise heterogeneity is a fundamental challenge to be addressed, exacerbated by the degree of specialization of current AI systems. Nevertheless, the richness of this collective diversity also entails the difficulty of

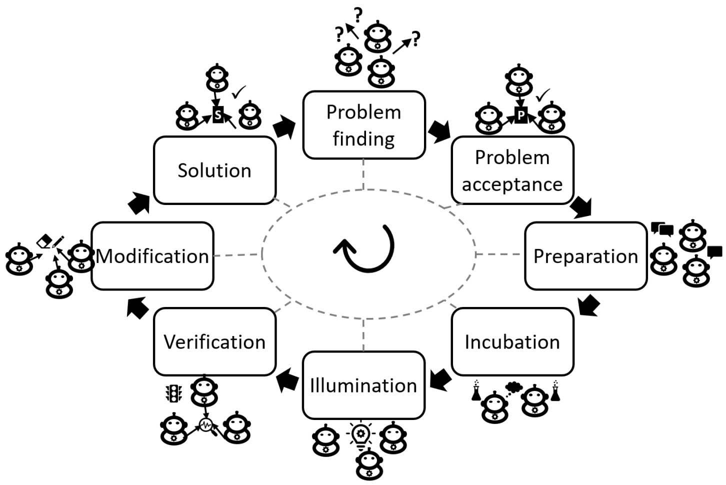


**Fig. 2.** Collaborative Agent Creativity cycle.

overcoming barriers across disciplines and completely different perspectives over the same subject [2]. For example, in the case of physical rehabilitation support, while a deep-learning-based system may accurately predict different outcomes regarding progression in physical exercises, a stress knowledge-based system may detect mental health risks due to anxiety or pain-coping mechanisms.

***CH4: Collaboration & exploration.*** Contributions from heterogeneous AI systems need to be circumscribed in a collaboration scheme that allows sufficient freedom to innovate, while maintaining longer term objectives. Beyond the individual goals and intentions of agents possibly wrapping ad-hoc AI systems (i.e., specific ML predictors), these may agree on different targets upon which they may explore different approaches and variations, taking into account other participants' proposals. Moreover, this collaboration should encourage considering risky options or challenging current assumptions. For instance, two coaching systems may have contradicting results concerning a patient's adherence to knee rehabilitation therapy. Through a contrasting exchange of assumptions and outcomes, a third system (i.e., agent) might propose an alternative treatment based on experimental hypotheses coming from physiotherapy research in areas such as hip strength reinforcement.

***CH5: Competition.*** Although pursuing similar interests, collaborative entities might share the same goals only partially. Therefore, the established cooperation strategies might entail competing for solving specific problems or even claim their share after a common solution was found. Drawing a line is necessary to protect individual interests while sharing ideas and potential elements that will constitute a collaborative effort. This may entail sharing data resources (or aggregated understanding upon them), which are vital for many AI systems. For example, let us consider the case of a smoking cessation persuasion system. It may temporarily withhold part of the technical details of its approach due to patenting constraints, while exposing the general strategy in order to encourage other systems to either provide feedback or competing solutions.

***CH6: Ethics.*** Several concerns arise regarding the implementation of new approaches, especially in application domains in which persuasion techniques are applied. First, to enforce the user's trust, it is essential to explain how these collaborative approaches emerged (e.g., providing a full trace and provenance descriptions and explicable results). Second, the participating systems must establish transparent conditions under which any data has been used, and if proper consent has been given for these tasks. Third, transparency characterizing collaborative endeavors (i.e., how the result is achieved) must be extended to the contributions brought by the several participants (i.e., how they collectively contributed to it). Finally, the influence that one party may play over the other participating entities may need to be regulated or at least assessed to avoid undesired effects [6].

The challenges proposed above are remarkably interconnected with each other. In particular, *sharing knowledge* (CH2) requires a *shared language* (CH1) among the collaborating entities/agents. *Collaborating & exploring* unexpected or irrational paths (CH4) can entail *competition mechanisms* (CH5) and *bridging interdisciplinary viewpoints, rules, and representations* (CH3). Finally, it is worth mentioning that each of these challenges already raises ethical concerns on its own. Nevertheless, their intersection can entangle the ethical boundaries to a point in which harmonization mechanisms might need to deal with cross-domain-related inconsistencies.

## 3 Opportunities & Building Blocks

Following the challenges above, this section discusses on the opportunities defining the building blocks, singularly and altogether.

***Persuasive multi-agent systems:*** The agent paradigm represents a convenient approach to embody persuasive systems. Several ideas relied on multi-agent systems (MAS) to tackle behavioral change exploiting contextual knowledge and persuasion goals [3, 34, 28]. Nevertheless, the agents' strategies employed in most of these approaches tend to adopt rigid persuasion strategies. In particular, being highly specialized, such strategies are difficult to be generalized, henceforth, unable to cope with new user-scenarios. Within the collective creativity paradigm, persuasive agents may need first to identify shortcomings in their own strategies and then brainstorm on potential ideas that may contribute to each other's persuasion assumptions and knowledge. For example, a cancer survivor support agent may find that some of their unsuccessful persuasion interactions may be linked to technology-related biases, which were not initially considered in its model. Nevertheless, it could be detected by another agent specialized in diet recommendations. Then, agents will be challenged to question their own facts to revise or enforce them within the collective creativity dynamics, for instance through argumentation [16]

***Collective Computational Creativity:*** Creativity is a human-centered concept. Yet, scientific studies passed from defining machines only able to perform to designed for [21] to defining with several models of computational creativity [11–13]. Creative machines have been envisioned collaborating with, mimic, and inspire humans. The need for a framework to model and reach collective, collaborative, and improvisational computational creativity as intended to be for the human society is well-known [11]. The enaction theory relies on the assumption that cognition is based on improvised (possibly real-time) environmental stimuli [36]. Moreover, further studies tried to understand how to introduce intentional creativity in virtual agencies and foster their emergence [14]. According to Froese & Ziemke, the purpose of an intentional agent determining its intrinsic goals is the maintenance of its existence [13]. Thus, pursuing creativity, computational and interaction models could be merged to actualize conversational creativity models for interdisciplinary debating agents.

***Agent simulation:*** As mentioned above, we envision agents undertaking or verifying both reasonable and possibly untenable plans and theories. Conversations are at the base of the agents' interaction. Nevertheless, the only way to verify a *point* might verify it (reasonably via simulations). Agent-based simulations have been extensively employed to implement inter-agent behaviors and decision-making processes in a controlled (and most of the times shared among all the agents) environment to verify the feasibility, cost, and sustainability of given solutions [38, 26]. By doing so, discussing agents willing to prove their point might generate pools of simulations to validate or confute each other standing. Besides the inherent advantages of employing simulations, persuasive agents might further benefit from them extracting unexpected outcomes, which can strengthen the motivations of their recommendation.

***Domain models & knowledge graphs:*** Knowledge graphs are broadly used to structure data and linking them according to models that accurately reflect a particular domain [23]. Furthermore, knowledge graphs enable logical reasoning to infer implicit information and answer queries through structured sub-graph matching [31]. Although ontologies and semantic vocabularies have already been proposed to represent persuasive agent knowledge, expectations, and goals [15, 5], they could further be used as the foundations for a cross-domain transformational creativity language. By doing so, agents with entirely different backgrounds would be able to exchange different hypotheses and engage in brainstorming sessions, extending each domain model beyond its current limits and assumptions. For example, an agent specialized in post-cancer support adherence may expand its domain model by importing knowledge graph concepts from other agents specialized in physical exercise. These agents may propose strength and balance exercises suitable for cancer survivors, which were not included in the original support strategy. Nevertheless, this process is not straightforward, as the *merging* knowledge graphs are not necessarily compatible, nor may have the same level of expressiveness. Moreover, a well-defined protocol should be defined to pass from the stages of incubation, illumination, and verification of the proposed integration of heterogeneous models.

## 4 Application Scenarios

Collaborative creativity in persuasive intelligent agents can have a substantial impact in different scenarios. In particular, in applications related to support users in managing health behavior, lifestyle changes, education, adherence to treatments, and concept exploration. Although potentially different, the use-cases mentioned above share the complexities of handling strategies that may span over extended periods and may need to adapt dynamically to changes in context and scope.

A first type of application regards the combination of previous knowledge from different multi-agent systems, using existing evidence across multiple domains. Examples include interplays between closely related topics (i.e., smoking cessation and dietary eHealth applications [9, 4]), as well as distant areas (i.e., music recommendation and mental health [17]). More specifically, in these applications users could build their behavior change plan with the assistance of a multi-agent system. Beyond traditional coaching agents, this would enable establishing co-creation schemes, where persuasion strategy goals are not imposed but mutually agreed upon. Collective interactions with other agents would allow these strategies to be revised and potentially enriched with others' experiences. For example, a coaching agent for stress and mental health may discover musical therapy and its positive effect from another agent specialized in leisure distracting activities. Based on the novelty, potential impact, and analysis of other validating criteria, the agent may need to revise evidence of this approach's adequateness or launch a pilot test to observe potential consequences.

A second type of scenario is the exploration of entirely new ideas among collaborative agents. In this case, the creative process undergoes a more elaborated path, in which agents require questioning certain limits of current strategies. Examples of such applications may include persuasive agents in physiotherapy. Targeting rehabilitation [27] (e.g., post-acute phase in knee intervention), an agent may initially plan a progressive introduction of exercises focusing solely on strength to enable a smooth transition towards recovery. Nevertheless, other agents may contribute with new evidence indicating that patients with similar characteristics may benefit from new approaches based on simultaneous and more intensive balance-strength routines, which could circumvent future complications. In this exchange, a specialized literature-review agent may initiate providing evidence for exploring a specific idea, while a decision-support agent may counsel the physiotherapist, and monitoring agents may verify compliance with the suggested treatment. In this way, collaborative exploration is not limited to foster creativity among agents, but it can include human intervention (if necessary).

A third kind of application refers to paradigm shifts in the way a problem is addressed. In this case, the agents interactions may lead to questioning assumptions and fundamental decisions, paving the way for a different type of solution that can be further explored and validated. For example, consider a treatment and medication adherence agent-based system based on ML for patient data analysis [35]. An agent in the system may infer that persuasion strategies based on ML predicted outcomes might not be enough to achieve the desired adherence goals. Another agent may then propose using adherence persuasive messages typical of logic reasoning applied to existing knowledge graphs that describe contextual medication advice [18]. Other agents involved in the incubation process of these ideas may then propose a third approach that integrates both the ML predictions and knowledge graph entailments in order to provide explainable persuasion elements to the adherence strategy [28]. This new approach actually disregards the original paradigm, even if it borrows certain aspects of the original ones it has diverged from.

## 5 Road-Map

This paper has introduced the main challenges stemming from the problem of adaptability and evolution of persuasion strategies implemented through multi-agent systems that incorporate different collective creativity types. Such challenges have been translated into opportunities and backed by solid foundations. From such a ground, we derive our vision of decentralized agents that are able to formulate common problems, debate on different ideas, and propose novel solutions that are both unique and useful. As discussed above, this novel type of agent system has great potential in persuasion-related scenarios, where strategies: need to cope with dynamic impulses, require to adapt to fast-changing assumptions and multi-disciplinary knowledge, and benefit from interdisciplinary influences producing unforeseen solutions. To foster the development of this research line, we foresee the following directions:

***Collective creativity language:*** In all the different types of creative interactions discussed in the paper, we anticipate the need for establishing a common language that enables agents to exchange ideas and hypotheses at both high (aggregated concepts) and in-depth (granular and specialized details) levels. This flexibility can only be achieved using semantically rich models that allow interconnecting knowledge expressed at different levels of complexity and across multiple disciplines. Moreover, this language should also explore the different protocols that will allow these different types of exchange. Agent combination of existing ideas, exploration protocols, brainstorming sessions, exchange of hypotheses, and verification procedures are examples of this type of collaboration schemes that should be formalized in such a language.

***Combination:*** Collaborative combinations of existing specialized approaches will require further studies of how agents may share and evaluate each other's strategies. Agreement technologies can be used at the different stages of the creative process, with a special emphasis on the comparison and homogenization of all proposals exposed by the participating agents. In particular, we see the need for alignment of knowledge and goals from highly heterogeneous agents so that the problem finding and incubation phases can lead to meaningful co-created ideas that can be later implemented and verified by the agents. This verification will also require the establishment of meaningful criteria that focus not only on the effectiveness aspects, but also on the novelty. Different types of creativity assessment methods exist, although there should be a focus on the collaborative nature of the outcomes.

***Exploration:*** Regarding the exploratory analysis of novel proposals emerging from collaborative creation, we expect further research regarding data-driven simulation and dynamic evaluation of divergent alternative paths of action. Collaborative exploration implies that simulations may need to include predictions from multiple agents with entirely different contributed datasets and algorithms. The simulation process may also need to consider when to stop scrutinizing and probing in a given direction before switching to a different path. During the incubation phase, agents may experiment several options independently. In turn, the singularly identified outcomes are shared and processed iteratively. The study of techniques exploiting this type of mechanism will also need to consider the limitations of relying only on simulations and may examine human-agent exploration scenarios, in which experts may use the agents' collective outcome as a guiding starting point for future persuasion strategies.

***Transformation:*** Persuasion strategies need to change over time as the individuals' conditions and their context change as well. Moreover, the knowledge in the application domain is in constant evolution (e.g., due to increased availability of relevant data, new discoveries in adherence/effectiveness, the introduction of novel technologies, or the testing of new theories). We argue that collaborative agents should be part of these innovations, incurring in transformational creativity tasks that emerge from contrasting and contributing ideas that defy the current assumptions. To make this possible, a collective knowledge model should be studied — thus, building a social representation per topic or application area. This knowledge should include the specification of risks and a computational representation of hypotheses and assumptions, possibly challenged by the participating agents. This type of information is currently manually curated by scientists in systematic reviews, discussed in conferences and papers, but we expect agents to take leading roles in these activities, contributing to a transformational generation of novel persuasion paradigms and concepts.

***Ethical creativity:*** To consider the risks of inducing or exerting a certain influence in a given person's decisions is essential in computational persuasion. If misused, inappropriate manipulations or undesired effects might occur. This could generate even worse consequences affecting users possibly unaware of the usage of his/her data. In this context, transparency and accountability mechanisms need to be studied and proposed [6, 22]. Thus, the entire collective creative process and its outcomes can be presented and exposed to all the concerned parties. To this end, multi-agent explainability is a fundamental aspect to be investigated [28]. The generation of explicable representations of the entire creative process would surely boost the trust in the system and facilitate to spot potential errors or agents' misbehavior. Furthermore, these explanations must deal with the degree of complexity, which may need to be translated from a domain to another, or even to comprehensible outcomes for end-users. Finally, the ethical aspects of data (re)use during the experimentation phases of the creative process need to consider privacy aspects and the justification of its inclusion.

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