Growing and Destroying the Worth of Ideas

Ricardo Sosa
Industrial Design Department
Tecnologico de Monterrey
Queretaro, Mexico
rdsosam@itesm.mx

John S. Gero
Krasnow Institute for Advanced Study and Volgenau School of Information Technology and Engineering
George Mason University
jgero@gmu.edu

Kyle Jennings
Institute of Personality and Social Research
University of California, Berkeley
jennings@berkeley.edu

ABSTRACT
This paper presents a novel computational approach to the study of creativity. In particular, it discusses a modeling framework that addresses the worth of ideas ascribed by agents embedded in a social world. The triple objective of this system is to improve our understanding of how ideas may emerge from a few individuals, how social interaction may result in the ascription of value to new ideas, and how culture may evolve through time, transforming or replacing dominant or consensual ideas. The proposed system encompasses commonalities in existing theories of creativity, and suggests future theoretical directions that can be explored via simulation.

Author Keywords
Creative destruction, change agents, social simulation, creative autonomy, multiagent simulation.

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Experimentation, Theory

COMPUTATIONAL STUDIES OF CREATIVITY
A variety of computational approaches to the study of creativity has been developed in the last few decades. We can distinguish at least three modeling types: *individualistic*, *interactionist* and social simulations.

The *individualistic* modeling approach results from aiming to build generative systems that in some way replicate or are inspired directly by cognitive research. Early examples aimed to model the discovery processes of scientific laws [19]. Others demonstrated the ability to generate interesting solutions that resemble divergent thinking puzzles [15]. Systems of this type continue to draw attention today in number theory [8], painting [7], and literary composition [20,24]. This approach has been a prolific source of models, capturing the attention of scholars, and igniting long debates about their achievements, shortcomings and implications [3]. An underlying assumption of this type of models is that creativity is a type or a combination of generative processes carried out by an isolated creator (the computer), and that the resulting solutions carry the creativeness to be recognized by an external judge (the programmer or the audience). A common goal of these systems is to model the learning processes by which the creator explores and possibly transforms the search space, producing final solutions that experts either consider surprising or indistinguishable from human solutions.

The *interactionist* modeling approach explicitly integrates the human into the system, guiding the generative processes by the evaluations of the human participant. This interaction aims to capture the needs, preferences or evaluation principles of experts. Human intervention often becomes a taxing demand, and constitutes a bottleneck in the process, although it does prevent the sprawl of unlimited random alternatives. Creative evolutionary systems are an example of this type of modeling [2], where human selection becomes part of the genetic operators in the system. A variant of this type includes systems that interact with their physical environment in order to constrain their search [4]. A key assumption of this type of models is that creativity -or more generally, learning- is a product of the interaction between computers and their context.

A third type of modeling approach, social simulation, is gaining acceptance in recent years. Instead of simulating only a single generator of new ideas, this approach includes multiple idea generators, and multiple idea evaluators, all linked within a social system. Early work in this field has addressed curiosity-driven agents [26], surprise and attention seeking [22], and conditions that facilitate the trigger of social change by a minority of agents [29]. These studies have drawn attention to the social dimension of creativity, and assume that creative value can only be explained as an emergent result in the interaction between generators and evaluators within a shared system. A main goal here is to model the psycho-social processes by which

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creators compete to explore and possibly transform the search space, producing solutions that satisfy other agents' evolving demands. The emphasis here is in 'growing' emergent complex patterns that resemble phenomena addressed in the creativity and innovation literature.

Agent-based Simulation of Creativity

The social simulation of creativity tends to adopt existing paradigms, including implementation frameworks, from the fields of computational sociology [14], artificial life, and agent-based economics [11]. Repast, Swarm, NetLogo and Mason [32] are popular simulation frameworks based on a variety of modeling units and processes, ranging from economic transactions, geo-based features and decisions, consumption patterns, particle interactions, epidemics, etc.

Computational simulations target social agency through the design, implementation, and execution of computer models that 'grow' complex global effects from rather simple local rules. In these models, the researcher defines hypotheses and seeks to implement and experiment with them to explore their consequences and to assess their veridicality - both at the local and the global levels- against empirical data [5].

Early creativity studies in these 'artificial societies' extended cellular automata (CA) models, which were previously introduced as a metaphor of the dissemination of culture [1], in order to account for cultural drift triggered by minorities [30]. Multi-agent systems (MAS) extend the CA approach via more complex agent decision rules and more flexible inter-agent connections. For instance, agent behavior in a design domain may consist of perception, evaluation and transformation of color palettes [26] or geometric shapes [29]. In such cases, assessment by observer agents ('adopters' in the innovation literature) is based on evaluation functions that can be shared or individual, ranging from objective measures to subjective preferences [31]. Limited to delayed and indirect feedback from adopters' overt decisions, and bounded by local conditions and resources, creator agents infer the evaluation rules at play, and engage in generative or transformative processes seeking to satisfy the evolving assessments of their social groups [29].

Though software and simulations can certainly 'create', this behavior usually falls short of what would be called 'creative'. A key reason is that evaluation criteria are either pre-programmed (especially in *individualistic* models), externalized (especially in *interactionist* models), or passive reflections of emergent, socially-derived standards (especially in social simulation models). One necessary condition for an agent to truly approximate 'being creative' is that it have 'creative autonomy', or the ability to apply and change its idea evaluation criteria without resorting to (a) directly parroting one or more outside authorities, or (b) making purely random changes to its standards. Contrary to the ideal of the lone creator, creative autonomy has been argued to require more, not less, interaction with the social world, as well as cognitive processes (e.g., cognitive dissonance, inferential errors and biases) and social interactions (e.g., selectively seeking acceptance from certain agents, or wishing to be different from other agents) that are orthogonal to the creation process [16].

The goal of autonomous creativity in a social world may require a major revision of the fundamental elements in this type of modeling. If social simulation is limited to individuals seeking to satisfy evolving social demands, no matter how complex, each agent's emergent results will be nothing more than 'a fun-house mirror reflection' of its social groups [16]. And, even if social preferences evolve according to realistic internal or external phenomena, this approach portrays creators as 'satisficing' consensual evaluation functions imposed by structural demands.

In current multi-agent systems aimed at the study of creativity, the unit of exchange between agents has inherited the passive character of precedent simulation paradigms: commodities, money, or information signals such as pheromones. In the analysis of social, economic or biological organizations, this approach may be appropriate. However, in the study of creativity, where ideas are generated, evaluated and interpreted by agents, further consideration is required in regards to such a static view of ideas, their meanings and values.

This paper challenges the passive view of ideas in current social simulation, and proposes a modeling framework where ideas have a dynamic role. Rather than considering culture as an idea repository -like the balance of a savings account or a food source- ideas are seen as interacting with each other; they mutually affect their meanings and effects; they can be manipulated and at the same time they induce the behavior of their adopters; they often tend to outlive their creators or adopters. To paraphrase Nobel laureate Octavio Paz: "Ideas behave as autonomous beings".

In the following section we introduce a range of fundamental principles that are seldom considered in combination. These concepts are foundational in the design of our modeling framework and enable a change of emphasis from agents into ideas. Next, scenarios are described for the application of our framework to concrete simulations of creativity. This paper concludes with a discussion of the major implications of this modeling approach.

EXISTING THEORIES

Kuhnian scientific revolutions provide a number of key insights related to origin and death of ideas [18]. According to the influential notion of paradigm shifts, radical changes are enabled by the recurrent development of crises - cumulative anomalies- of a dominant idea. There are at least two connotations of a 'paradigm': first, as the sociological constellation of beliefs, values, norms, and criteria shared by a community of practitioners; second, as an exemplary solution that serves as example for everyone within the community. One important aspect of this theory is that new ideas compete during a time of crisis for selection by a community, whose members agree in ascribing worth, rendering the winning idea as their exemplary solution, and collaboratively building a culture around this dominant worldview. Thus, according to Kuhn, paradigms define communities by their allegiance to shared ideas. Kuhn did acknowledge that non-scientific communities may be multi-paradigmatic; for instance artistic communities need not have one incommensurable paradigm. Art may accept the existence of complementary paradigms, although they do clearly compete for value or merit [18].

Schumpeterian evolutionary economics sees creative destruction as the engine of capitalism. Economic cycles are explained by periods of increased competition and commoditization that give way to disturbances by entrepreneurs, who introduce innovations that induce an economic upswing based on increased differentiation and associated profits [27]. After such disruption, equilibrium is gradually re-established as competition increases and differentiation gives way to convergence and lower profit margins. Under this view, innovation is not optional, but a necessary strategy at certain periods, to sustain the creation of wealth. This theory suggests that entrepreneurs play a key role in the introduction of new ideas, as they are not engaged in the preceding competition process, and they are uncommitted to existing infrastructure, technology and experience [6].

Morinian systemic thinking reinterprets the 'noosphere' as the ecosystem of ideas, i.e., a co-evolutionary space of emergent and unpredictable meanings. Morin [23] suggests that every new idea contains the 'seed of destruction' of dominant doctrines. He proposes a triadic system composed by psychosphere, sociosphere and noosphere. At the personal level, mind emerges from neuronal interactions; culture emerges from interactions at the social level; and meaning emerges from the interaction of ideas. This theory emphasizes the influence that culture has on individuals, while it recognizes 'strong spirits', as those individuals who escape 'domestication' by their culture and trigger cycles of change. The complex game of dependencies between the three spheres is responsible for both preventing and enabling the liberation of creative individuals from dogmas. Morin [23] warns that any analysis of the worth of ideas must consider that dominant ideas (ideologies, doctrines) rarely respond to actual advantages over other alternative ideas, inasmuch as their value is embedded in a social world and usually responds to a diversity of criteria other than inner qualities (virtue).

Domain, Field and Individual

Taking into account the cultural symbol system (domain) in which creativity takes place, and the social processes (field) that regulate creative activity, Csikszentmihalyi provides the Domain-Individual-Field Interaction or DIFI framework [10]. The role of each subsystem follows evolutionary operators (transmission, mutation and selection): "the domain transmits information to the person, the person produces a variation, which may or may not be selected by the field, and the field in turn will pass the selected variation to the domain" [10]. This model accommodates many causal perspectives, including cultural determinacy, change agency, and social validation. However, it still leaves fundamental details such as the means by which a field's experts would allow new ideas be incorporated into their domain, or the distinction between social selection and domain transformation. The DIFI framework shifts the unit of analysis from individuals to complex systems, where none of the components alone can explain it, but lacks the inner processes for the three levels [21].

Chance, Logic, Genius and Zeitgeist

The data to test systemic views of creativity are easier to gather in scientific domains [28]. Chance is a pervasive causal factor, with random events taking place at all levels: from accidental discoveries, to equal-odds idea selection by experts. Empirical data analyzed by Simonton [28] suggests that the most critical predictor of field recognition is the total number of individual contributions, inasmuch as authors of high-impact publications also create publications with the least impact. Simonton [28] provides a formal explanation for the recognition or impact of a scientist:

$$Hi = pTi + ui , \quad (1)$$

where Hi is the total output of high-impact works by scientist i, p is the average hit rate for that domain, Ti is the total productivity regardless of actual impact by scientist i, and ui is a random variable with a mean of 0. This model captures key factors from different levels of analysis, but leaves unaccounted for other relevant factors such as the clustering of scientific achievements in specific times, places and social groups; differences in motivation and skills between individuals; and the distinction between creativity and recognition by peers.

IDEA-AGENT-SOCIAL BASED FRAMEWORK (IAS)

This section presents a framework for studying creativity phenomena that moves beyond theoretical discussions into a method for empirical experimentation with these ideas. The aim in the design of this framework is to enable the computational modeling and simulation of systems that generate behavior related to creativity. As in any modeling process, decisions must be made in regards to the focus, the granularity, and the units of analysis. This is particularly hard when one sees creativity as fundamentally embedded in a complex system. Given the explanatory potential, we choose to focus on the modeling of interactions between ideas, agents and society. Table 1 introduces the three dimensions incorporated in the IAS framework: ideas (I), creator agents (A) and the social world (S).

Table 1. The three-tiered IAS framework: ideas, creator agents and society

Author	Level I	Level A	Level S
T.S. Kuhn	Exemplar	Proponent	Community
J.A. Schumpeter	Innovation	Entrepreneur	Market
E. Morin	Noosphere	Strong spirit	Culture
M. Csikszentmihalyi	Domain	Individual	Field
D.K. Simonton	Logic	Genius	Zeitgeist

Such three-tiered arrangement seems to map the theories discussed above, but some differences are clear, particularly the emphasis given to each element and the unit of analysis. For instance, Kuhn's 'paradigm' has two connotations, one at the idea (I) level and the other at the social (S) level, whilst he only briefly links scientific merit to the rise of new ideas at the agent level (A). Simonton's fourth element, chance, is considered as longitudinal instances of randomness at all three levels. Schumpeterian accounts of innovation tend to centre on macro trends, leaving the analysis of the entrepreneurial traits aside.

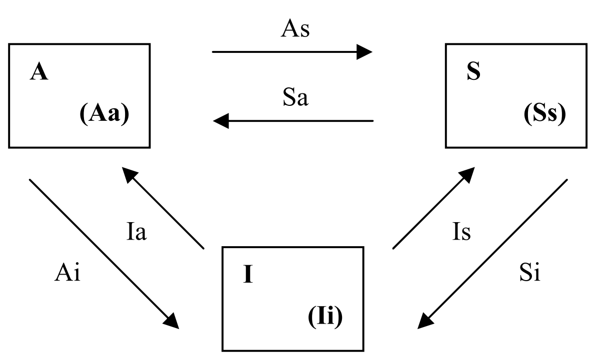

Figure 1. The IAS elements and interaction processes

Six interaction processes across IAS levels can be identified: *Ai*, *Ia*, *As*, *Sa*, *Is* and *Si*. Three intrinsic processes correspond to *Ss*, *Aa* and *Ii*. Each of these nine processes can be mapped onto the theoretical landscape of choice; for instance Schumpeter distinguishes between *adaptive* and *creative responses* as two different kinds of changes in innovation [27]. We may thus characterize adaptive responses as *Sa* reactions, e.g., a firm's response (A) to phenomena such as a sharp population increase (S). In contrast, creative responses can be represented as counter-intuitive *Ai* interventions, when a firm opts to do "something that is outside the range of existing practice" [27]. According to Schumpeter, *Ai* creative responses cannot be predicted by applying the ordinary rules of inference from the pre-existing facts (I); their defining characteristic is doing new things, or doing things that are already being done in a new way. Since the aim of this paper is to lay the groundwork for a computational modeling platform to explore theories of creativity and innovation, the more theoretical effort of analyzing the assumptions and epistemological similarities and differences of such theories is beyond the present scope.

These nine processes of the IAS framework are illustrative rather than prescriptive, and no comprehensive theoretical consensus can be cited to draw clear lines between any given agent-to-group relationship (As) and its social dimension (Ss). Instead, the researcher is required to define the modeling elements and processes in the IAS structure and to explicitly distinguish between the transition of an exchange of ideas by a pair of agents (*As*), into the organization of a clear group trait (*Ss*), for instance.

All implementations of the IAS framework must include rules of behavior and units of analysis at these nine channels: *Ai* functions are executed by creator agents (A) aimed at the set of ideas (I); *Ia* functions link ideas (I) to agents (A); *As* are overt actions originating from agents (A) that become visible in their social groups (S); *Sa* may represent social messages (S) that exert influence over agents (A); *Is* link ideas (I) to societies (S); *Si* methods define collective actions arising from social groups (S) acting on the idea level (I).

Aa, Ss and *Ii* functions are actions that are aimed at, and are available by, targets within the same level in the framework: *Aa* actions correspond to inner processes of a creator agent (A) standing for statements such as "I am", "I do", etc; *Ss* functions enable communication between and within social groups (S) and represent statements such as "we/you are", "we/you do", etc; *Ii* are interactions between instances at the idea level (I) and represent statements such as "it is", "it means". Naturally, neither societies nor ideas speak by themselves, but any IAS application may choose to explicitly implement behaviours at these levels if growing them from inter-agent interactions is not central to the aims of the investigation.

These interactions are directional; for example, "social to agent" (*Sa*) interactions are not the same as "agent to social" (*As*) interactions. Again, while no prescriptive rules apply in the IAS framework, the researcher's system should be capable of distinguishing bottom-up (*As*) and top-down (*Sa*) interactions. The long term goal is for model implementations to be modular and reconfigurable, but this awaits more explicit definitions of these nine IAS processes that only experience can provide.

The nine IAS processes need not be explicitly pre-programmed in the system. Researchers must decide which rules are defined algorithmically, what units of analysis are equivalent across different levels, and which results are expected to emerge during a simulation. Even explicit pre-programmed rules need not be deterministic: they may require reinterpretation or some type of inference by the receiver, or they may be random or seem random across levels, etc. Table 2 shows a sample collection of processes derived from the theories discussed above and classified at their corresponding type of IAS process.

Table 2. Sample processes in the IAS framework arranged in relation to ideas, creator agents and society

Ai	Mutation, combination, displacement, reinterpretation
Ia	Transmission, language, patents, 'normal science'
As	Dissent, promotion, simulation, product launch, affinity, selective acceptance seeking,
Sa	Norms, beliefs, evaluation, change resistance, recognition, social influence, conformity
Is	Allegiance, dogmas, crisis (anomalies)
Si	Selection, adoption, recognition, consensus
Aa	Creation functions and strategies, subjectivity, abduction, dissonance, pride, motivation
Ss	Communication, group commitments, fads, field's 'hit rate', agendas
Ii	Novelty decay, convergence, precedents, scale effects, laws and norms, emergent meanings, new evidence

Non-linear effects between the nine IAS processes need to be accounted for. The framework is intended to be one where small changes at one level can have huge consequences at another level. Feedback cycles and causal chains should also be included wherein changes at one level may trigger changes at other levels that may, in the long term, affect future conditions at the original level of change. Threshold models of interaction may prove useful when designing these functions [12]. Again, the researcher needs to clearly define what aspects are defined algorithmically in the model, and which ones are expected to be 'grown' and be detectable.

An IAS system is said to 'grow' creativity when change events at the agent, idea or social levels require explanation by events and effects at different levels, rather than be caused by a specific initial condition or external influences.

Because *Aa* functions follow cognitive models, a host of reasoning processes may be simulated, including inductive, deductive and abductive reasoning. 'Creative leaps' are associated in the literature to the generation of informed guesses through the logic of abduction [9]. The aim of the IAS models is not to focus solely on the *Aa* machinery behind such leaps, but to account for them in the interplay between the cognitive, social and symbolic dimensions where creativity develops.

Bootstrapping may be equally necessary for *Ss* and *Ii* processes. *Ss* functions are likely to implement sociological models of communication and evolution. *Ii* functions may enact semantic/semiotic rules, and impose constraints such as physical laws. Implementations of the IAS framework must clearly define their priorities and, at the same time, explicitly acknowledge their limitations. IAS systems are required to build test scenarios to track and record interaction between variables at the three levels in order to perform causal ascription of resulting patterns.

Sa processes may exhibit contradictory roles, as they are often found to simultaneously preclude and enable change. *Sa* functions that preclude change may do so by prescribing the criteria, norms and beliefs considered to be valid by the social group. However, such *Sa* functions enable change by always leaving alternatives available for some agents to explore. As a result of delimiting what constitutes a valid field, *Sa* also defines unknown or impossible features that may help redefine the field in the future. Under any given set of *Sa,Si* dynamics, new *As,Ai* proposals may trigger change trends at the S and/or I levels.

In IAS systems aimed at the study of multiparadigmatic fields, *Si,Sa* functions need not reflect absolute agreement; rather, clustering patterns may be temporary and communities may be shaped by members who share some but not all of the commitments. *Ss* disagreements in these systems are not only possible, but necessary as a potential source of change at the I and/or A levels.

Every creator agent in a system may have its own *Aa* identity, but *Ia* and *Sa* factors may overlap in this identity. These factors may stand for identity levels such as national and regional allegiances, family membership, interpersonal affinities and friendships, etc. Negotiating such a complex *Aa,Ia,Sa* agent identity may lead to conflict at certain times, but this should be a potent trigger for change.

Ai and *As* are the main sources of change agency in IAS systems, but these actions need to be accounted for in relation to *Sa,Si,Ia,Is* conditions. For instance, a suboptimal *Ai* work may be *Si* selected due to events such as *Sa* marketing campaigns or *Ss* word-of-mouth diffusion. Likewise, *Ii* domain interactions may help explain the fate of *Ai* works, independently from their socially-ascribed merits. A recent idea may help to gradually build distant analogies across previously unrelated fields.

At different time periods during an IAS simulation, *Ai* and *As* changes will face varying degrees of *Sa* change resistance. Likewise, the strength of *Si* consensus about the worth of ideas should vary over time, thus varying the scrutiny of *Sa* evaluations of the creator. In change episodes, an initial *As* stage of incipient acceptance (early adopters), needs to evolve into sustained *Ss* processes to enable collective change (tipping point).

Ii dynamics may involve a type of coevolutionary *Is,Ia* process, enabling the change of ideas both in relation to creator agents and social systems. Ideas may evolve by specialization, generalization, degradation, upgrading, transfer, distortion, association, or similar effects that could be desired/ undesired, direct/ indirect and anticipated/ unanticipated by creator agents and by social groups.

The dynamics depicted in Table 2 and described so far in this section are illustrative of the range and depth of processes that the IAS framework accommodates. The cognitive, social and symbolic interactions that could be implemented are as limitless as the associated research literature.

It is important to remember that all the theoretical frameworks described in the previous section (and arranged in Table 1) pay special attention to the non-creative periods of equilibrium in social systems. This implies that IAS systems are not meant to capture only creativity phenomena. Instead, in keeping with their underlying theories, these models should treat creativity as an epiphenomenon, a side-effect, or an occasional occurrence in an otherwise stable environment. Instances of change ('revolutions', 'paradigm shifts', 'creative destruction', 'renewal cycle', 'mutation' or 'high impact') are our subject of study, but they need to be seen as an exceptional feature of complex systems that tend to converge toward stability and order.

Ultimately, the IAS framework is aimed at exploring hypotheses, assumptions, and contradictions regarding creativity in an empirical, in-silico laboratory. Having just suggested how to model, the following section illustrates what types of phenomena the IAS framework could model.

MODELLING SCENARIOS

This section specifies sample scenarios that are suitable for the implementation of models with the IAS framework. As in every modeling exercise, attention must be placed on the desired accuracy: rather than aimed at a 'general model of creativity', each scenario focuses on specific issues and may be as valuable as their potential to shed new understanding of these complex issues. Each scenario presents a different theme, scale and scope in order to illustrate the flexibility of the IAS framework.

Scenario 1: Consensual Ideas

Classroom activities in studio-based learning (SBL) have consistently shown our teaching staff that as the acceptance of new ideas increases in a group of design students, the complexity of the dominant ideas tends to increase, whilst their originality tends to decrease. This small-scale effect is worth exploring in an IAS format. In a typical group of 20 to 25 Industrial Design students, a two-hour activity illustrates this pattern. Students are first briefly introduced to an open design problem or challenge such as how to encourage the recycling of PET bottles in our community. With this type of task, students have some previous experience -both as users and from previous courses on manufacturing, packaging, marketing, sustainability, etc.

The first activity consists of a 30-minute stage where students are required to work individually in the proposal of a new strategy to address the challenge. Students are provided with pen and paper and all communication between them is prevented. In IAS terms, students are represented as agents (A), their design proposals are ideas (I) and the group constitutes the social unit (S). Agents perform *Aa* exploration processes, whilst all *Ss* communication is disabled. The space of existing solutions (I) provides a reference to evaluate *Ii* criteria such as originality and feasibility in relation to the current technologies and behaviors in the community. Students tend to spend this first stage thinking, sketching and writing. Most arrive at an idea they regard as original and plausible. However, these ideas frequently show high resemblance amongst each other, and their plausibility varies considerably. This suggests that models should avoid high levels of variability in initial conditions.

In the second stage of this activity students walk around the room and select one classmate to exchange their ideas in short, 3-minute conversations. The instructor indicates that this rapid exchange process must produce one of the following outcomes: either each student decides to keep their initial idea, or the pair agrees to select the best idea to form a team. Should students decide to part ways, they must keep choosing a random classmate to exchange and negotiate their proposals. As teams form, subjects engage in conversations with random classmates or random teams, with the same aim of either adopting a new idea or keep theirs. This process is iterated until every student/team has had contact with every other student/team. Team formation tends to occur rapidly, so this stage usually runs for less than thirty minutes. Subjects gradually tend to cluster into teams, but sometimes students switch teams during the exercise. A typical end result is that in a group of 20 to 25 students, two or three teams of varying sizes will emerge, and few (if any) students remain alone -adamantly loyal to their initial idea.

In IAS terms, the following behaviors can be characterized: iterative decentralized *Ss* communication processes to explain, evaluate and negotiate first in pairs and later in teams; *Ai* understanding of the ideas put forward by competing subjects; *Ia* transmission and emergence of new meanings; *As* decisions to join or leave a team; *Sa* influence to conform; *Si* processes of value ascription to ideas by teams; and *Ii* transformation and combination of ideas. Several behaviors shown during this activity may be considered, including students' varying abilities to convincingly present their ideas, the imposed time constrains, the degree of similarity between initial ideas (perhaps due to a shared background: age, discipline, social status, habits), group pressure to comply, etc.

All these behaviors yield an interesting emergent result regarding the origin and fate of new ideas: as team membership continues to increase, students tend to break the rules to integrate competing or complementing ideas. In the end, the winning ideas shared by teams, tend to exhibit a higher level of complexity than the initial ideas generated by individuals. Students are then asked to reflect on the quality of the winning ideas, and their own satisfaction about their choices. In general, students acknowledge that a) winning ideas are not as original as some of the initial proposals (this has been confirmed by instructors), and b) a range of personal, social and cultural issues are involved in the process other than the actual merit or potential of the ideas. These include: friendship, the haste of the task, misunderstandings, argumentation, learning, and motivation levels.

This scenario illustrates the complexity of modeling creative situations even with a limited number of agents, a small set of rules, and a limited timeframe. An IAS simulation of this activity enables the testing and refinement of hypotheses limited today to speculative discourse. A plausible strategy is to implement a number of processes across the IAS levels such as those described above, running the simulation switching on and off each process in order to 'grow' target results regarding the originality of ideas, their level of complexity, and the degree of consensus. Amidst the range of results, the researcher could identify the variables and values that closely resemble the classroom activity. However, this only provides look-alike end results, informing us little about the workings of the actual system being modeled. The next step is to formulate new hypotheses informed by the behavior of the computational system and to test them in future classroom and laboratory settings.

The process is thus to describe and analyze a given situation by modeling the type of situations to which it belongs, not merely in order to align the target and the computational systems, but to extend our understanding and to design interventions in order to manage the outcomes. For instance, in this classroom activity the worth of the model would depend on its power to account for the effects of the level of originality in the initial ideas, or the type of rules that would minimize complexity whilst supporting high consensus.

Scenario 2: Tracking the Impact of Risky Decisions

Researchers and non-researchers alike have been interested in determining the makeup of the creative personality. Often, this is done by contrasting famous creators with their less successful peers. However, success and fame are largely due to external factors, not least of which is luck. With many creators exploring many pathways, chance alone predicts that occasionally a creator will suggest a bold new idea just when the field is ready to receive it. Others creators may have behaved no less creatively, but are lost to history due to poor timing, or gambles that didn't pay off. Because these unsuccessful cases are largely invisible in retrospect, observers may overemphasize the role of risk-taking and independence in the creative personality.

Longitudinal research can yield a more balanced view of the creative personality by tracking when risky decisions go bad, thereby forcing the creator out of the field (e.g., being passed up for tenure, bankruptcy). Before undertaking such costly and time-consuming research, it is beneficial to use computer simulation to better understand the phenomenon. One such simulation has been created [17]. Though completed before the IAS framework's inception, it is a good candidate for reimplementation using IAS as the substrate.

Since the primary goal of this simulation is to understand the fate of individual agents, the I level and elements of the S level were programmed, not grown. The space of ideas is a one-dimensional ring, and each idea is a Gaussian kernel on that ring. Ideas are initially tall and narrow, but shorten and broaden as they are discovered and exploited (*Ai*) until they are depleted and replaced with a new random kernel (*Ii*). In each time step, agents decide what point on the ring to occupy. Agents earn resources in proportion to the height of the ring at their position (*Ia*), as well as a "royalty" payment from other agents positioned on the same kernel (*Sa*). To provide cumulative advantage, the size of the payment is proportional to how much an agent has already earned from that kernel. What's more, each kernel's payoff rate decreases over time (decreasing marginal returns; *Ia*), and the payoff is split among all nearby agents (getting lost in a crowded field; *Sa*).

Agents lose a fixed amount of resources per turn, and exit the simulation when they exhaust their resources or reach a certain age. Their success depends on their exploration strategy, as well as on luck. Agents pick their position by randomly sampling a fixed set of alternatives, and choosing the best one. Depending on the agent's personality, it will either sample nearby or distant points, and prefer either densely populated regions (which are more likely to be paying off, even if the payoff must be split) or sparsely populated regions (which are unlikely to be paying off, but could be hiding an undiscovered jackpot).

To test the simulation's primary question, each personality type's chances of success are determined, first looking only at survivors, and second looking at both survivors and non-survivors. As expected, the first approach grossly overestimates the success rate of the "go it alone" strategies, and grossly underestimates the success rate of the conservative strategies. This is more pronounced for higher rates of cumulative advantage, and when cost per turn is high (but not so high as to make exploration prohibitively risky).

The long-term goal of the IAS framework is to provide modular implementations of simulation elements. The ring and kernel idea landscape described here could be modularized and used in other simulations. Successful applications of the ring and kernel component to new problems would increase the credibility of each simulation to use it. Likewise, the same phenomenon could be tested using other modules, particularly ones where things like cumulative advantage and diminishing returns were "grown" out of agent-to-agent interactions. This could provide a more realistic estimate of how strongly social selection of ideas favors the lucky over the deserving, and what this does to our perception of what it takes to be creative.

Scenario 3: Creative Situations

Historically, certain individuals have been able to find unique interpretations of contemporary ideas, of their surrounding social conditions, of future expectations and scenarios, and of their own personal ambitions and interests. This has allowed them to find opportunities to change the world by triggering cycles of change beyond their control, sometimes even after their lifetime.

In principle, there exists an unique situation for every individual, even when they share most conditions: social environment, local circumstances, random events, group ascriptions, etc. This results in every person potentially construing an unique situation within which they plan and execute all actions [13]. As context at time t is interpreted as a situation, opportunities may arise at time $t+1$ to trigger episodes of change in otherwise stable systems (status quo). Creative situations are those situations within which the process of destroying the worth of dominant ideas can be initiated.

Situations may not be entirely under an agent's control: external features could co-determine the nature and potential of every situation. Individuals may have differential access to creative situations due to economic pressures, war, lack of support, intellectual property constraints, etc. At the same time, certain conditions may facilitate the construction of creative situations for many individuals, who may then simultaneously develop similar innovations.

This third scenario, of a more theoretical nature, could be explored in IAS simulations in order to verify first-principles and the consistency and implications of 'new ideas about new ideas'. Questions to address include:

- Are creator agents able to build and transform their situations by reinterpreting unchanged conditions in the system? Can certain type of situations be induced in creator agents by conditions at the idea and social levels?
- Are situations limited to individuals, or can social groups share situations that, for example, help determine the outcome of their selection of new ideas?
- Can we find the implications of certain situations by replicating the entire history of the system, and only modifying the way in which a creator agent gives meaning to its world?

DISCUSSION

Although the approach presented in this paper awaits implementation and extensive experimentation, it represents a well-grounded integrative effort toward the computational study of social creativity. By shifting the locus of attention, it may provide new information and new insights about the complex subject of creativity. In presenting the IAS framework, we have intentionally avoided any definition of creativity as we share Csikszentmihalyi's opinion that the question *"what is it?"* is not as meaningful as *"where is it?"* [10].

The IAS framework has the potential to provide a shared language and a common toolkit for numerous implementations, each of them focusing on specific elements, system processes, or desired outcomes, which will themselves be suitable for comparison and even integration. The IAS framework also moves away from existing sociological, economic or biological complex systems modeling toolkits, which, although quite powerful, have failed to support adequate representations and functions aimed specifically at the study of creativity [32]. The IAS framework presented in this paper proposes a new way of representing creativity-related phenomena, placing idea-agent-society interaction at the centre.

More broadly, this approach may contribute to the philosophical debates about creativity. Each of the existing computational paradigms discussed in Section 1 is based on a specific worldview of creativity. *Individualistic* models, which remain to date the dominant computational approach to creativity, imply that the worth of creative ideas is determined by the Author (with capital A), dismissing the evaluation processes outside the system. The *interactionist* approach acknowledges the role of human evaluation, which is used to provide choices between limited options in order to guide a computational information-intense process. Social simulations have placed creativity as an epiphenomenon of complex systems where individuals interact, mainly portraying the social dimension as an emergent result construed by the human observing a visual display [33].

In more practical terms, the IAS framework enables new tools to inform decision makers in the highly uncertain processes of evaluating the potential worth of new ideas. Today the most reliable ways of estimating the latent creativeness of a new idea include asking peers and experts (patent applications), questioning or observing target users (market research), and small-scale trial and error methods such as prototyping and proof of concept. The IAS modeling of new ideas in explicitly defined conditions may help 'grow' the target outcomes and provide evidence of the likely impacts of such ideas in scenarios where small variations can be repeatedly tested. Although such computational simulations are unlikely to capture every detail and provide complete predictions, they may help us understand the role and importance of certain variables, the type of results that one can expect from given initial conditions, and the range of options available at certain times to encourage different outcomes in such systems.

The computational approach to creativity presented in this paper reifies the idea dimension, and ascribes ideas with the potential to meaningfully interact with creative individuals and their societies, thus forming a complex triad of interactions. In order to understand creativity, hard work will be essential in the future, since, as Morin eloquently realizes [23], "we still are in the prehistory of ideas".

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