CREON: a Creative Ontology based on Psychological and Neuroscientific Studies

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Abstract
As in many interdisciplinary domains, creativity theories are affected by a lack of agreement on the nature of their research objects, e.g., processes, products, people, cultures, and what is their granularity, e.g., social, personal, neurological, etc. Eventually, this problem hinders the possibility of operationalizing creativity research and to establish common datasets and experimental protocols.
This paper presents CREON, an ontology of creativity based on an analysis of the literature spanning from mainstream psychological theories to recent neuroscience results. CREON distinguishes between theories centered on the mental processes of creative individuals, and those focused on the social context, in which creative people interact. The ontology is formally implemented in OWL2 with class hierarchies, axioms, and conceptual relations. It enables semantic interoperability between different psychological and neuroscience theories, preparing the ground to run inferences over different creativity data and to design experiments based on shared definitions of research objects.

Keywords
Ontology; Creativity; Psychological theories; Neural Patterns

1. Introduction: Psychological theories of creativity

Creativity is hard to define. Different theories disagree on the nature of their research objects, e.g., processes, products, people, cultures, and what is their granularity, e.g., social, personal, neurological, etc. Eventually, this problem hinders the possibility of operationalizing creativity research, e.g., by establishing common datasets and experimental protocols. As in other interdisciplinary domains [1;2], an agreement procedure is needed to design a shared ontology, which can highlight similarity and differences, and possibly integrate angles from multiple theories into a novel shared theory [3].

Although it is hard to give a general definition of creativity, in psychology it is possible to highlight two aspects [4]: the cognitive processes related to creative individuals; and the social context in which creative people interact. The two aspects instruct different theories, which address mostly the cognitive aspect (internalist theories), mostly the social one (externalist), or a mix.

1.1. Internalist theories

Concerning internalist theories, in 1926 Wallas [5] explained creativity as a process including 4 phases: preparation, incubation, illumination, and verification. Human creativity is intended as a combination between conscious (preparation, in which a new goal is identified, and verification, in which an idea is verified) and non-conscious processes (incubation, in which there is no conscious attempt, and illumination, or “aha moment”, in which an insight appears in consciousness).

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In 1950 Guilford [6] intended creativity as a process that involves the ability to generate a new idea based on fluency, flexibility, originality, and elaboration. Guilford distinguishes between convergent and divergent thinking. While convergent thinking is aimed at finding a single right answer, divergent thinking is aimed at finding more unconventional and unexpected answers, and it is predominant in creative people. In his studies he has drawn a list of 15 traits that are shared among creative people

In 1995 Smith et al. [7] focused on the cognitive processes that underlie creativity, speaking about "cognitive creativity". The authors state that the same structures and processes involved in non-creative cognition can explain creative thinking, as it involves many aspects of everyday cognition. This theory allows, on the one hand, to verify creativity in a more empirical way, on the other to create computational systems that can improve the human creative process through its simulation.

In another internalist theory, Moruzzi [8], looking at the scientific literature, has outlined 3 important keys to creativity, that are: problem solving, evaluation and naivety. Naivety can be understood as an unconscious elaboration [9] which ignores rigid thought patterns and allows for a more infantile and playful vision [10;11;12].

Margaret Boden [13] in a study of 1994 defined two types of creativity: the "improbabilist creativity" and the "impossibilist creativity". While the first one allows to use traditional information to generate new ideas, the second is related to an exploration and transformation of the conceptual space.

1.2. Externalist theories

Concerning externalist theories and social context, in 1990 Csikszentmihalyi [14], describes creativity as an interaction between a domain of knowledge, a field of experts, and a person. In this sense, creativity needs to be understood within its domain and field: a creative product is not creative by itself, but it depends on the specific domain in which it is included (e.g., music, visual art, etc.).

In this line, Teresa Amabile [15] offered an idea of creativity closely linked to the social context, identifying three main components, namely expertise, that is the basis of creative work which includes knowledge, technical skills and talent; creative thinking, that is based on cognitive abilities to find new solutions to problems; and task motivation, which is divided into intrinsic motivation (deep interest and involvement in the work) and extrinsic motivation (the desire to achieve a goal that is not related to the work itself). These components are influenced by the social environment. For example, task motivation is the component most directly and immediately influenced by the context. In her theory, she states that creativity is linked to innovation within a specific organization, therefore it means that creativity itself is an important but not sufficient condition for innovation.

In relation to context, Sternberg [16] talks about the importance of quality and novelty of the creative product in addition to the usefulness, that are based on the social and cultural judgments. In his theory he talks about three-facet of creativity that are related to intelligence, cognitive style, and motivation/personality [17]. About intelligence, Sternberg distinguishes between the creative intelligence that is utilized to produce new ideas, analytic intelligence that allows an evaluation of the quality and value of one's own ideas, and practical intelligence that is used to explain the usefulness of one's own ideas to others. About cognitive style, he talks of legislative style that represents the possibility of generating new ideas and the liberal style that represents the possibility to try new ways for old things. Last, motivation and personality are related to specific personal characteristics that can be synthesized in self-efficacy, tolerance of ambiguity, and willingness to risk.

1.3. Mixed theories

There are scholars that consider creativity as a process that involves both human mental processes and social context.

Simonton [18] states that creativity is based on three aspects: *originality*, *utility*, and *surprise*, which can be combined based on a multiplicative integration of the probability of a creative idea (p), its final utility (u), and the previous knowledge about the utility (v). In this sense, the creative formula [$c = (1 - p)\, u\, (1 - v)$] is based on an interaction between originality (first factor) and surprise (third factor).

[19;20]. Since creativity depends on social context, Simonton distinguishes between creativity (with a small c) based on the psychological experience of the artist, and Creativity (with a capital C) based on social, cultural, and political aspects [19].

Corazza [21] in his “Dynamic Universal Creativity Process” theory intends creativity as a mental and social process, focusing on the dynamism and unpredictability inherent to creativity. The principles of this dynamics include e.g.:

- Space-Time Dynamic Context: the environment, along with historical and personal experiences
- Knowledge Dynamics: the new information and connections that make knowledge evolve
- Action Dynamics: they influence the creative process and have a feedback effect that guide future decisions and directions
- Evaluation Dynamics: it's continuous and influences both the current creative act and future endeavors
- Emotion Dynamics: they're central to the creative process, influencing motivation, direction, and quality of output
- External Random Events: related to unpredictability in influencing the creative process

The DUCP theory highlights the importance of openness, adaptability, and resilience in creative people.

Last, according to the 4Ps theory outlined by Rhodes in 1961 [22], creativity is something that cannot be reduced to its products jointly with its value and novelty. In his theory, creativity is related to the i) personality traits of creative people (Person); ii) actions that creative people do in order to build a creative product (Process); iii) the creative idea/product (Product); iv) the cultural resonance (Press).

Table 1 shows a synthesis about the main theories related to creativity that are discussed above and modeled in CREON.

Table 1
The main theories of creativity

Author	Domain	Emphasis
Wallas	Personal	Consciousness vs Unconsciousness
Guilford	Personal	Divergent thinking
Smith	Personal	Cognitive Creativity
Boden	Personal	Computational Creativity
Csikzentmihalyi	Social	Field/Domain
Amabile	Social	Expertise/thinking/motivation
Sternberg	Social	Three-facet of creativity
Simonton	Social + Personal	Creativity vs creativity
Corazza	Social + Personal	Dynamic Universal Creativity Process
Rodhes	Social + Personal	4Ps of creativity

2. The Creative Brain

From a neuroscientific point of view, creativity can be defined as the brain capacity to change based on new information and to consider alternative strategies to solve problems [4].

Creativity appears to be related to fluid intelligence [23]. In this sense, creativity is not related to conventional intelligence like personal IQ [24;25], but to a fluid intelligence related to executive functions and associative processes. Executive functions can be understood as a mental process that controls our thoughts and behaviors [26]. They mainly concern set shifting, working memory and inhibition. While, associative processes refer in particular to divergent thinking, understood as the human ability to give a large number of appropriate, interesting and fluid responses to a problem [4].

As shown by the study of Kenett et al. [27] using NeuroSynth [28] on studies related to an fMRI investigation, creativity and divergent thinking are related to the same brain activation, while the novelty allows an activation of different brain areas.

Here, two main brain mechanisms involved in the creative process are examined: the Default Mode Network (DMN), and the Seeking System related to human emotions.

2.1. Default Mode Network

The term "Default Mode Network" (DMN) was used by Raichle et al. [29] and refers to a network of interconnected brain areas that are activated when an individual is at rest and not performing a specific cognitive task. The neural areas that belong to the DMN are medial prefrontal cortex, posterior parietal cortex, anterior cingulate cortex, and medial temporal cortex.

In a recent study, Chrysikou et al [30] using fMRI demonstrated that there is a different activation in the DMN in creative people (eminent thinker) than in a control group of non-creative people (non-eminent thinker). Here, creative people show an optimal neural efficiency in relation to the Alternative Uses Task .

Other EEG studies have highlighted the presence of alpha waves in the DMN, which are associated with situations of relaxation and reduction of cognitive activity. Bhattacharya and Petsche [31] have demonstrated that artists (people with a specific master on Arts) have greater alpha-band desynchronization and delta-band synchronization than non-artists (people without artistic competences), during a spontaneous mental creation of drawing tasks; while in the rest phase artists show a stronger delta-band synchronization than non-artists.

It is possible to explain an increase in creativity in relation to the activation of associative networks [32;4] due to a moderate increase in cortical acetylcholine [33], a decrease in cortical norepinephrine [34] and in the communication between cortex and hippocampus [35] a desynchronization of cortical activity during rest [36].

A specific case in which the DMN is activated is during the REM sleep. Human sleep involves a cycle alternation related to the EEG activity, muscular tone, and eye movements [36]. The REM phase is characterized by rapid eye movement and muscle atonia [36]. In relation to the creativity process, previous studies have shown that REM sleep facilitates associative processing. For example, Stickgold et al. [32] showed an improvement in a semantic priming task after REM sleep compared to N-REM sleep. On the relationship between sleep and creativity, Lewis et al. [37] state that both REM and N-REM sleep facilitate the creative process. While N-REM sleep can abstract rules from previously learned information, REM sleep can promote new associations.

On this line, Wagner et al. [38] have shown an increase in the number reduction task (NRT) after a REM sleep during the night, which suggests an increase in explicit knowledge and insight behavior modulated by sleep. The study of Cai et al [39] has shown that REM sleep enhances creative problem solving in relation to stimuli that appear before the sleeping phase.

In this line, the use of drugs (i.e., alcohol, opium, and hashish) to enhance the creative process is also a known fact. The power of drugs from a neural point of view is related both to the ability to (i) increase dopamine in the striatum and hippocampus that are activated in the reward behaviors [40], as well as in the substantia nigra: high levels of dopamine improve thinking, while low levels of dopamine limit motivation [41;42]; and to the ability to (ii) increase norepinephrine that is associated with hedonic responses [43].

Table 2 shows an example of experimental findings as modeled in CreOn.

Table 2

A few experimental findings in **CreOn**

Study	Method	Activated neural pattern or area	Experimental vs. control population	Creative task

Chrysikou (2020)	fMRI	DMN	Eminent / not Eminent thinkers	Alternative uses
Bhattacharya (2005)	EEG	DMN	Master in art /not	Spontaneous creation of drawings
Stickgod (1999)	PSG /EEG	DMN	People in REM /not	Semantic priming
Wagner (2004)	PSG/ EEG/ EOG/ EMG	DMN	People in REM at night /not	Number redaction
Cai (2009)	PSG	DMN	People in REM /not	Problem solving

2.2. Seeking System

In the recent literature there is a widespread agreement regarding the possibility of defining the concept of creativity on the basis of its constitutive principles such as originality, innovation and utility deriving from a dual process functioning [44], i.e., generative process and evaluative process, attributable to type 1 and type 2 modes of thinking [45]. While the generative process is related to the production of creative ideas or products, the evaluative process is more oriented towards the evaluation of its usefulness [46;47;48]. Several studies have shown an important divergence between these two processes [49], as well as a different involvement of brain areas [50].

For example, recent studies [51;52;53] denoted the activation of the amygdala in the insight phase of the creative process related to an emotional arousal, and the activation of the substantia nigra in the midbrain associated with feelings of reward during novelty processing [54;55].

Specifically, based on the shift between novelty (original and unusual idea) and appropriateness (useful and adaptive idea) in the creative process, Huang et al. [53] used fMRI in order to understand the brain regions responsible for these mechanisms in a chuck decomposition task. Authors show that in the novel process there is an activation of the parietal cortex, postcentral gyrus, and prefrontal cortex, responsible for the mental manipulation of spatial representations; and the activation of the caudate and SN related to the dopaminergic process linked to the novelty seeking [56]. In the appropriateness process there is selective activation of the hippocampus and amygdala. The hippocampus is related to the formation of new associations (i.e. problem solving and insight), while the amygdala seems related to the "Aha!" experience.

Therefore, inducing an emotion with positive or negative valence can modify the artist's normal creative process by improving its originality, flexibility and fluidity [49]. It has been demonstrated that eliciting exciting emotional states favors the human creative process [57;58].

In this line, affective neurosciences have shown the importance of the seeking system to enhance creative process [59]. The seeking system, also known as the “reward system” is a motivational system that drives exploration, the search for information, and the desire for new experiences. This system considers specific dimensions of human experiences such as “drives” and “motivations” [60]. The seeking system is implicated in dopamine activation and connects the lower brainstem and midbrain to higher brain regions such as the frontal cortex. According to this idea, creativity arises from an emotional system, shared with other animals, which, together with the associated learning mechanisms, allows for the generation of ideas about the world. The seeking system enhances creativity by stimulating the search for new solutions and increasing motivation and personal gratification.

3. Creative Ontology

The CreOn ontology initially focused on the 4P theory [22] represented through the classes: (Natural) Person, (Personal) Process, Creative Product and Creativity Press, linked through the relations influenced by, result of, produced in, etc. (see Fig. 1).

Then, we added Simonton's theory [19] about the difference between creativity, related to personal abilities of the users [7], and Creativity, related to the social context in which the user is involved [14;15;21]. This difference is outlined by means of the classes Personal Situation and Social Situation. Simonton's creativity formula is also modeled. All processes, situations, ideas, abilities, and dynamics (Corazza, 2019) are included in the abstract class Creative Situation.

Based on the theory of Sternberg [16;17] and Guilford [6], we have outlined the main personal traits of creative people (cf. the Personal Ability class, including e.g., Fluid Intelligence and Associative Process), correlated to the neural patterns (cf. the NeuralPattern class) of the creative brain [27], like the DMN [29] and the Seeking System [59]. Brain Areas and Neural Patterns are linked to the experimental findings of neuroscientific studies [30;31;32;39] through the classes Experimental Task, Method, and Finding.

The Natural Person class has been reused from the DOLCE foundational ontology [61], in order to distinguish between different agent types (natural vs. social/legal persons, artificial agents, groups).

Relations (object and data properties) as well as axioms for class and property definition have been defined in the OWL version of the ontology, and enable inference and consistency checking of the ontology, and the data that use it.

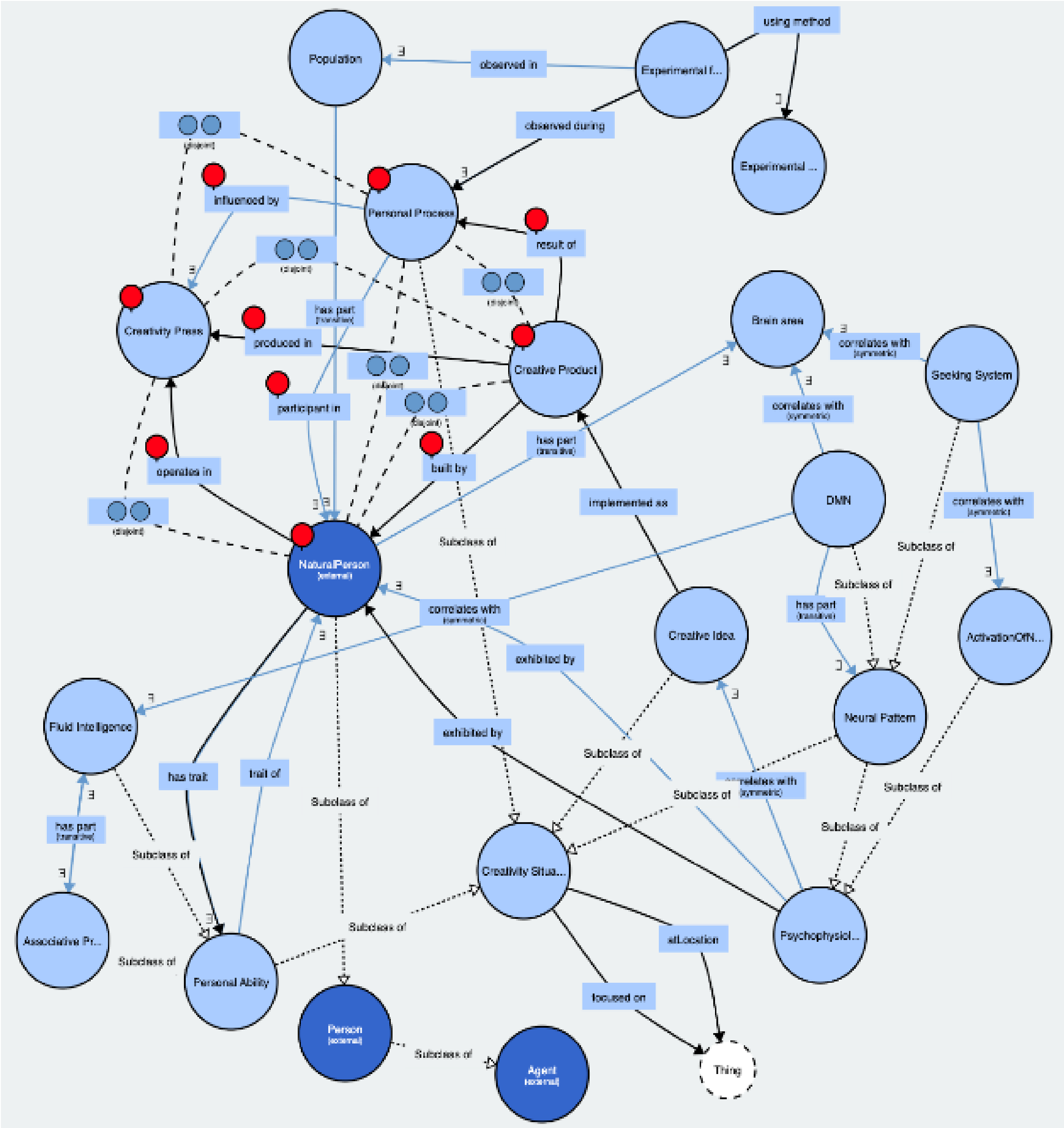

Figure 1: The core part of CreOn with classes, subclasses and their relationships integrating multiple theories and levels (personal, social, neurocognitive, experimental). The red-pinned elements include the classes and relations representing the 4P theory. Diagram processed with WebVowl from the OWL version of CreOn[2].

4. Discussion

Creativity can be defined as the ability to generate original ideas, concepts or solutions, and it can manifest itself in different fields, such as art, science and technology. Creativity is based both on cognitive processes [5;6;7] that involve different functions, and on social processes [10;15;16;17] related to a specific context. On the first point, neurosciences have shown the involvement of different areas, such as the Default Mode Network (DMN), and the emotional process.

[2] http://www.ontologydesignpatterns.org/ont/creativity/creon.ttl

CreOn can be used to compare different theories, entity types, relations, experimental methods and results about creativity. Given our preliminary investigation based on a shared ontology, the current theoretical, experimental and computational state of creativity research does not allow us to draw safe conclusions about functions, methods, neural grounding, or computational simulation of creativity. However, we claim that the availability of a computational framework of theories and experimental results is a precondition to perform shareable, interdisciplinary creativity studies and meta-analyses.

CreOn can also be used to guide hybrid neuro-symbolic AIs, e.g., making trained models interpretable in a cognitive way, or feeding a training model with knowledge structured according to the ontology.

Creativity theories, once formally characterized, contribute to raise questions when we consider creative computational agents. For example: is it possible for computers to be creative? Is it possible for computers to generate something innovative without benefiting from external cues?

Among creativity theories tailored to computer science approaches, Margaret Boden's improbabilist creativity could be studied using Bayesian statistical models, which consider both previous information about an existing state, and relative probabilities of possible future states that are associated with the previous one. In this case, if we understand creativity as the ability of our brain to generate new ideas starting from new information that adds to our previous knowledge, a Bayesian model should be able to replicate it, and therefore create new ideas.

Boden's impossibilist creativity needs computational modeling that defines a geometrical space, which can be explored, updated, or mapped. Data mining can then be used creatively by looking for patterns and rules in the data provided [62]. In this case, predictive methods such as classification and regression can be used to generate creativity from specific examples [62].

Thaler [63] proposed a method for creativity using neural networks that can provide novel output based on known data. This system seems to respect the central dimension of human creativity related to the formation of non-obvious associations related to different domains, usually understood as a "bisociation", and not an association between two different frames of thought that leads to a new meaning [64]

This is the current trend in artificial intelligence with generative models such as GPTs (Generative Pretrained Transformers, cf. [65]), now largely used in creative computational creativity (DALL-E[3], etc.).

Computational creativity has been widely used in multiple domains, e.g., in the generation of music [66] using Markov chains that are stochastic processes with a finite number of states, in which the probability of the next state depends on the current state [67]. They are a popular approach for generative modeling of sequential artifacts such as music and text. For example, Pachet [68] used variable order Markov chains to manage sequences of variable length, to analyze pitch, duration, and speed of a melody. The aim was to allow the system to listen to musical input, and to play with it in real time.

Can we explain computational creativity with the same categories as the ones used for natural persons or groups? Looking at the structure of CreOn's, we firstly need to distinguish artificial agents from persons, but once we accept this, what about artificial creative products, processes, and press?

5. References

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