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Colorful insights supporting the modeling of creative processes across language, music and emotion

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Abstract

In an attempt to unite advances in color science, the creative arts, cognitive psychology and engineering to foster an improved understanding of creative processes, we elaborate on and discuss some recent findings across creative art experiments, cognitive psychology and perceptual color compression. Motivated by a fundamental phenomenon of efficiently managing functional complexity, which has been observed, for example, in design tool development as well as product development in microelectronics, we propose associating functional structures of language and music with perceptual sensitivity to hue, simultaneous color contrast, and color saturation across high dynamic range color processing while simultaneously considering elementary models used in quantum mechanics. A multi-dimensional functional hierarchy not only reveals similarities but also offers a platform towards open questions about creative thinking processes which can be more easily elaborated in a distributive differential context provided by a dynamic spatio-temporal (space-time) model. A suitable test scenario emerges from forward-looking creative experiments utilizing the arts in combination with a highly generic perceptual color compression model. A well engineered verification toolset based on nonlinear control theory appears useful in addressing fundamental challenges in highly complex neuronal tasks across language, music and emotion. We also focus on interfacing between terminologies of cognitive, mathematical and engineering domains together with their underlying functionalities. We present preliminary thoughts and discuss our unconventionally structured approach in multi-modal and multi-sensory contexts via comparison of similarities as well as differences between creativity tasks and perceptual color compression. Ongoing work shall focus specifically on elaborating effective strategies that combine the proposed functional models with promising Deep Learning architectures.

Introduction

With an ambitious vision of eventually providing an interactive set of computer-based tools to assist users -either as an individual user or in a team collaboration environment- in exploring their own creativity efficiently and effectively, we would like to pursue the strategy of combining the best and most simple ideas emerging from color science, deep learning, quantum mechanics, and the cognitive sciences. This ambition arises in part out of a dire need to address the ever-growing disconnect between disciplines and concepts, and more significantly, deep questions underlying such a complex and highly important mental phenomenon as creative thinking. As much as biological systems demonstrate energy and task efficiency in multimodal and multisensory contexts with oscillating regenerative periodicity [1], we would like to elaborate a distributive dynamic space-time model based on discrete (quantized) elementary (atomized) structured phase states with the minimum free energy principle (i.e. Karl Friston) in mind to achieve high efficiency in overall system performance and theoretical optimization. This complex concept will become more easily understood after we have also introduced and discussed various similarities with quantum mechanics.

More specifically, we address the following question: What does spontaneous creativity modeling developed in [2] have in common with perceptual color image compression developed in [3]? As a first pass, there are similarities: (1) both fundamentally rely on human perceptual concepts; (2) both utilize varying degrees of prioritization, detection, and masking strategies for efficiency; (3) both demonstrate hierarchical dynamic functional structure; and consequently, (4) both human creative processes and human vision processes are constantly being challenged to master complex scenarios in real time in order to successfully navigate the world.

Interestingly, very similar concepts can also be found in microelectronics. For example, the smartphone appears to be the most successful device which interfaces with the user more easily than any other 'configurable' device. Enabled through recent advances in microelectronics system architectures, such multi-modal audio-visual and tactile personal communication device with integrated machine intelligence adapts to (1) human perceptual concepts; (2) task switching with an automated sense of varying degrees of prioritization, detection, and masking strategies; (3) hierarchical functional architectures across the embedded subsystems that connect to the physical world; and (4) changing scenarios in real time in order to successfully navigate and serve the user on an individual basis. In this view, the smartphone already plays a significant role in assisting human creative processes leading to improved overall performance in many ways — from instant communication to rapid learning. At the same time, it also captivates the user who pays significant attention to the device while losing focus on the immediate physical surround.

Given these similarities and the current state of microelectronics system architectures, how can we best create a flexible and suitable architecture where human reasoning (i.e. decision-making), emerging from creative behavior, is accompanied by the hierarchical functionality of algorithms derived from human *perceptual* color vision in combination with more general system architectures of microelectronics and computer science?

A Particular Vision

In highly simple and general terms, we would like to pursue a particular vision based on a very simple rule: one should not just follow one thing (quantity) at a time, but also analyze it in synchronization with, as well as in contrast to, something suitably different while staying in a multimodal local context. Under this vision we suggest a general dissection of creative thinking processes and color image compression. With each independent dissection one then combines those quantities to create a useful new quantity at the next level of functional abstraction, enabling a graphical network of structural quantities (data objects) that can be operated on effectively by discrete functions of new, perceptually intelligent hierarchical system architectures emerging from Artificial Intelligence or Deep Learning.

Moreover, the discrete functions shall adhere to a sense of bijective functionality, i.e. an encoder-decoder concept, enabling efficient adaptation to rapidly changing scenarios while the user is exploring his/her own creativity space. Most importantly, such architectures have to well manage top-down knowledge driven processes as they collide, merge, interact with bottom-up data driven sensory processes.

Principal Motivations

> "Not fearing an abuse of comparison, we defend our notion in saying that the cerebral cortex is similar to a garden filled with innumerable trees, the pyramidal cells, that, thanks to intelligent cultivation, multiply their branches, send their roots deeper, and produce flowers and fruits more varied and exquisite every time." (p. 467-468)

poetically writes Ramón y Cajal, father of modern neuroscience, about neurons and glial cells to highlight both their complex architecture and their undeniable similarity to other natural structures [4].

We begin with such a quote because it underscores two key observations perceived and described over a century ago that merit mention in this context of shared structures and principles across multiple biological systems: (1) the mind/brain is extremely complex and a product of nature and nurture (e.g. first descriptions of neuroplasticity) and (2) the mind/brain, as a natural object, is hypothesized to function fundamentally in a similar manner to other biological systems. This becomes paramount to highlight because we are at a point in time where our understanding of the mind/brain is both at its most advanced stage and yet at a stagnant level where dots remain unconnected and, worse still, unperceived. Jump to the computer science and engineering worlds and the building of systems proceeds from the bottom-up — single-tasked entities maximized for efficiency with weak integration of top-down knowledge, emotion, and decision-making processes necessary for system effectiveness, at least at the level of human-like performance. For example, although automated systems are improving with their goal to increase performance reliability, efficiency, and capacity, they still rely heavily on human input for intricate cognitive-behavioral tasks and, in some cases, are too complex even for safe human intervention [5]. Furthermore, human-computer interactive technologies will require an instinctive and ultimately multisensory approach to human recognition systems for complex take-over requests, for example, to be timely and successful [6]. The point we want to highlight here is that the mind, brain, body, and environment are holistically integrated, not separated, and, advancing this concept further, any sort of interface system must be capable of entertaining the resulting structural challenges of such an interconnected relationship.

Emotion, Music, and Creativity

Moving the concept of 'similarity between systems' into the domain of emotion perception and cognition, how much does a multimodal combination of a color space visualization concept and a concept of emotional state representation consolidate or add value to the functional understanding of emotions, as illustrated by the color wheel of emotion? As a point of departure we refer to Plutchik's wheel of emotions in Figure 1 whereby eight basic emotions make the slices of a circle (i.e. in clockwise order from top: joy, trust, fear, surprise, sadness, disgust, anger, and anticipation) that further divide inward or outward to illustrate varying degrees of intensity (i.e. greater inward, lesser outward). As observed in Figure 1, the circular colored likeness to the visible light spectrum (i.e. ROYGBIV) makes a point of relating emotion types and level of arousal to hue and color intensity and vibrancy. This wheel, however, is static despite its continuum of intensities and does not illustrate changing emotional states across time. For example, happy and sad emotions could be placed at opposite ends along a linear axis and mapped into a rotational (circular) dynamic space-time dependency in which sadness can turn into happiness as much as happiness can turn into sadness over time. Time dependencies should also be put in differential context so that subtle changes may accumulate over time until a significantly stable emotional state (with respect to its duration) emerges.

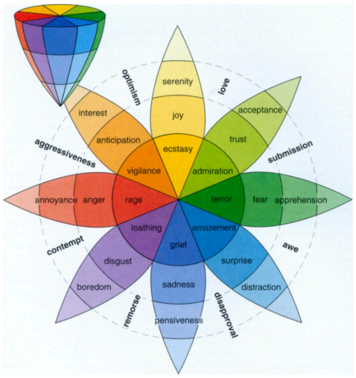

Figure 1. Plutchik's 3D circumplex model of relationships between emotions [7].

Consideration of the flux of emotions across time becomes imperative when, particularly, one examines the very essence of music -i.e. how meaning is derived from such an abstract auditory stimulus that has such emotional power. In musical compositions we often find passages which sometimes elicit sad feelings and later on lead and resolve towards happy feelings or begin happy and lead towards sadness, or any other combination of emotions. In effect, the elicited emotional meaning of the musical passage and composition as a whole presumably results from the combination of musical syntactical expectations -and the breaking of such- within a specific cultural context [8] as well as its interaction with the listeners own internal emotional state(s). The important aspect we would like to open up for discussion is that emotions evolve in a space-time loop — guided by multimodal feedback from a significant amount of distinguishable neurological resources (e.g. auditory, somatosensory, aesthetic goals).

Music offers a very intuitive context in which to dissect space-time situations because its meaning depends on its development across space and time and advancing forward while recalling the immediate past is critical. Under normal operating conditions, emotion processes are most likely well synchronized with regenerative periodicity across all the neurological resources that become available during music listening and/or music producing. For example, in the case of spontaneous creativity or, more specifically, musical improvisation, a single concept or idea can be interpreted in any number of ways musically via the combination, recombination, and transformation of finite elements (e.g. notes, rhythms). What this means is that an emotional state such as happiness, for example, can be represented in an infinite variety of ways within a particular musical idiom and how the improvisor chooses to express that idea depends on a variety of contextual (both internal and external) factors [2]. In simple terms, creative invention can be thus defined as the distance between the unknown from expectation, with the farthest distance being of greater creativity and the smallest being of lesser creativity. We raise this improvisational situation within music because of its contrasting nature to how the engineering and mathematical fields function. Although products are developed for consumers, they are task-specific by definition and usually fail to anticipate an efficient dynamic platform for future functional extensions during the designing of the application. In contrast, during a live jazz performance, for example, the resulting musical experience by the end of the concert is the result of musicians constantly suggesting, anticipating, and integrating the known with the unknown. There is in effect a contrasting mindset at work: the engineering and mathematical areas appear to offer a unidirectional purpose while the arts appear to invite multi-directionality. This inspires a couple of questions: Is this dynamic phenomenon we see in music (and natural language no less) less operational in other human creative behaviors? Can we extend this structurally efficient mindset to other creative domains? And what does this suggest regarding how creative thinking operates in varying situations?

An interesting situation to briefly highlight for its contrastive viewpoint is the winner-takes-all attitude in view of its results on overall single-minded efficiency. Under the winner-takes-all perspective, she who confers the greatest leverage or "amplification" of human talent has the greatest market value -according to prescribed criteria- and thus receives the highest economic reward. Much like the engineering field, management styles of this kind prize the leader who is risk averse and follows a safe but steady and clear pattern of relative success. This stands in stark contrast to many art forms whereby there are no wrong notes, brush strokes, or failed interpretations because every event is an opportunity for the creation of a new idea and risk is, in many circumstances, a way for the artist to promote their distinguishing voice and push boundaries otherwise left untouched. Again, the unknown is a powerful point of artistic departure. Under this artistic perspective is the winner-takes-all scenario an illusion of efficient and effective resolution of the ambiguities of the unknown at a different level of social context? How much is such an attitude actually resolving the uncertainty of situations effectively and efficiently across the open environment it influences? In light of other disciplines' viewpoints we emphasize the need to elaborate efficient structural space-time aware metrics that elicit and support the functionality of creative processes encouraged in the Arts.

Steps Further Ahead

Art and artistic behaviors offer a unique window into how the mind/brain perceives, integrates, transforms, and executes multimodal, space-time information that can be both repetitive and original. Color science and engineering as productive fields offer a powerful concept of plausibility testing through the development of models that mimic the highly nonlinear domain of human visual perception while obtaining instant visual feedback through electronic color imaging devices. Moreover, it is very likely that neurological concepts present in human vision may also be useful in other human brain-body system tasks. Extending this even further, psychological laboratory experiments may soon not only profit from recent findings across art, color science and engineering, but also from a suitable strategy of transferring highly promising concepts of quantum mechanics to human behavior analyses. Quantum mechanics concepts have proven increasingly useful across applications in physics and engineering. For example, the quantum spin hall effect in light [9] suggests a discrete concept at the elementary level regarding how to efficiently model cancelation or neutralization as the superposition of a set of element pairs possessing opposite spin (see Fig. 2 in [9] visualizing a recurring paradigm shift in modeling fundamental phenomena).

Identifying the underlying elementary functionalities would not only enable a multimodal view in space-time, but also the union of -inherited from structural mechanics and physics- a tensor-like structure (vector) attribute with a magnitude (intensity) attribute to better handle structured phase states present in the discrete differential local context of dynamic systems. Highly promising results have already been achieved in perceptual color compression [3] whereby elimination of at least 80% of the image information with an extremely simple concept based on local variance in differential context without compromising visual quality of natural images was achieved.

In view of modeling creative processes so fundamental to human behavior we will elaborate a strategy of integrating elementary functionalities into Machine Learning or Deep Learning-based architectures. To reach a better understanding of the overall context, however, we first discuss a functional model of human creativity that we consider well suited to select the most effective elementary functionalities already present in other engineering algorithms and system architectures.

A Functional Model of Human Creativity

At first, we will zoom out towards cognitive phenomena. Consider the situation in which one has perhaps asked why one sometimes "sees red" or why one may become stressed when someone else looks at a problem in a "black and white" manner. Or more extravagantly, that from a similar shared situation between two people why one innovates enormously traversing new territory along the way while the other remains stagnant unable to move beyond habit. What are these questions fundamentally asking? Are the differences of behavior perceptually based (i.e. entirely dependent on the functioning of bottom-up information processing sensory systems)? Or are they perceptually-cognitively based (i.e. an integrated mix of bottom-up information processing sensory systems *and* top-down knowledge information processing systems)? If the latter, how do we go about breaking down the various elements -such as knowledge, emotion, motivation, ideation, and the like- and their 'percentages' of process engagement, if at all possible? The answers to these questions are not simple and the associated journey of creative thinking is still a highly challenging arena of study.

Figures 2 and 3 illustrate a generalized functional dynamic structure we currently consider particularly relevant to illustrate the key components of a creative process. Inspired by the integrative multimodal experimental work on real-time spontaneous creativity of [2], [10] and [11], the primary elements at work during the dynamic cycle of ideation, problem-solving, and decision-making within the creator's mental space are emotions (single or many motivating and/or elicited in the moment of task performance), goals (task at hand), ideas (incoming, evolving, and/or past thoughts/concepts/images), and knowledge (toolbox of experience that is open to interpretability and transmutability). All these components significantly influence and nurture the creative thinking process as it proceeds, constantly changing in accordance to incoming external sensory influences, the created object's development, and the creator's own internal changes of focus. The core claim is that these four elements are integrated, interdependent, and influenced by each other in a dynamic manner through the time and space occupied by the unfolding creative maneuvering. Moreover, this dynamism underscores the adaptability of the process as each element provides feedback such that creative production is fruitful. Since all the elements are continuously interacting and combining, the process is mathematically nonlinear.

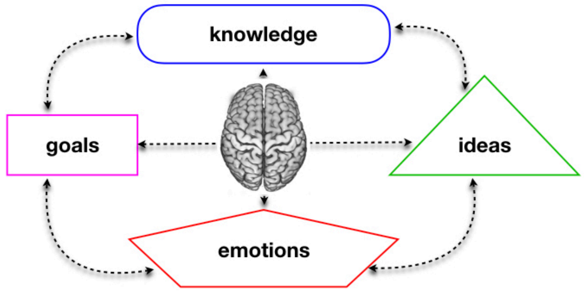

Figure 2. A simple functional model of human creativity.

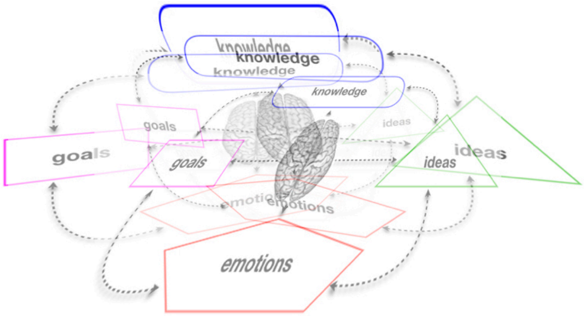

Figure 3. The dynamic nature of creativity as emotions, goals, ideas, and/or knowledge take greater or smaller value as creative thinking and doing proceeds.

A suitable example in which this functional human creativity model can be imagined in action is the challenging task of riding a bicycle while touching the handle bar with one's arms crossed - knowledge of bicycle riding must be challenged, goal is set to ride an alternative way, interest as much as annoyance may be motivating such task, and ideas for how to successfully ride in such a way are emerging. In other words, we present a useful idea enabling functional verification of the proposed creativity model. Eventually, only a carefully designed training/learning program for such a task will enable (re-)learning until successful completion. From a control systems engineering stand point, this example could be useful to measure the most relevant system time constants related to the period of time or response time of (1) understanding the task, (2) thinking about executing the task, (3) executing the task, (4) activating reactions, (5) reaching catastrophic failure (at least over the first couple iterations), (6) achieving the desired task successfully, etc. The dynamics of such functions could presumably fit within the functional human creativity model described to also reflect the concurrent characteristics of space and time changes.

Thus, with such a functional creativity model in mind how do we best combine Art, Science, and Engineering to advance Deep Learning architectures? In particular, how much of recent findings in perceptual color image compression could spark promising new solutions, for example, in artistic computational color image processing (i.e. post production tasks), where Deep Learning could assist human creativity more efficiently than where it stands today?

A Variety of Challenges

To illustrate the variety of applications in which functionalized creative processes could prove highly useful in the near future, we list a small spectrum of diverse challenges.

One fundamental challenge arises regarding the importance of oscillation regenerative periodicity. How important and influential are, for example, inhale-exhale cycles, sleep-action cycles, and mental concentration-relaxation cycles to also better understand and model cycles of emotional states such as happiness and sadness and other such complex human emotions which may also influence creative thinking processes?

Another fundamental challenge arises from prioritization of and sensitivity to relatively weak signals present in multimodal distributive system architectures. For example, a weak signal may come from a circadian mechanism of hormone release which may only occur in hourly periods with very small quantities involved. If such '*subtle*' phenomena are not sufficiently considered from a structural and functional point of view while conducting an experiment, the obtained results may lead to unintended, biased subjective interpretation — even mathematical or statistical analysis may then easily mislead. In color imaging, subtle changes of color contrast across object surfaces can often only be detected if the spatial context is well taken into account. In perceptual color image compression we pursue to better understand how subtle changes of image quality are perceived in local context and what kind of change would result in optimally perceivable image quality as a function of compression ratio. In particular, the precision of structure quantities in the local neighborhood of a pixel appears to be more important than the precision of magnitude quantities [12]. Consequently, one should carefully analyze structural and magnitude quantities in discrete differential context.

Given that the perception of color is a subjective process dependent on a set of varying physical and mental conditions and the production of creative behavior is also a subjective process dependent on a set of varying physical and mental conditions, we can ask the following question: How much could the spatio-temporal color centric perceptual sensitivity to hue, saturation, and simultaneous color contrast help in elaborating significant scenarios of creative processes?

Sometimes the final level of functional abstraction also leads to highly questionable ambiguity with no apparent sound solution on the horizon. In psychological experiments testing for emotional reactions, judgements, and the like, there is a tendency to map emotions across a continuum from negativity to positivity whereby sadness falls on the negative end and happiness on the positive, even in cases where emotion is tracked continuously across time for intensity and real time fluctuations. Additionally, when nonlinguistic labels are employed, emotion is represented via such picture-oriented ways, for example, as the Self-Assessment Manikin (SAM) created in the 1980s to identify pleasure, arousal, and dominance within opposing emotions [13], emoticons, and/or photographs of human faces. With the continued layering of subjective interpretations and an unclear understanding of fundamental elements that constitute valence and intensity, one quickly reaches the limit of reasonable results. In other words, from a system architecture's point of view, one most likely only finds an undesirable local minimum. Instead, what if one were to revisit potential fundamental elements from a dynamic structural functionality that offers a notion of space and time in differential context while simultaneously connecting to higher levels of functional abstraction? In such scenarios it could also be interesting and helpful to apply suitable deep learning strategies and models to resolve ambiguity at such a structural elementary level.

Yet another challenge arises from the winner-takes-all strategy previously mentioned whereby weaker signals present on the loser's end are not carefully followed up on and details that constitute the observed difference are ignored. As such, what would be an efficient approach to highlight the imperative need to look beneath surface outcomes for nuanced underlying causes?

The Functional Parameter-Uncertainty Control Loop

When someone is pursuing a specific goal in creativity, we would like to track the advances of the dynamic creative process with a suitable metric that can well discriminate how far away from the desired goal the current state of the creative process actually is. However, especially in the creativity context, specific expectations related to a specific goal are difficult to define in simple mathematical terms. For example, from an engineering point of view, how and when could we decide that a creative process is heading towards a fruitful outcome? We could imagine a full search of already known outcome scores of other creativity tasks and rate the current creativity task against it. The significance of studying collaborative spontaneous creative environments between humans can precisely aid in understanding how impact assessment (e.g. risk-taking actions) is computed in the moment as outcomes arise [14].

To address this issue in a modeling environment, we suggest to implement a multimodal control loop that tracks different types of functional parameters and their associated uncertainty during the execution of a creative process. For each parameter of interest, we track its magnitude (or variance) in discrete differential quantities, enabling accumulation of magnitude over time. The mean value over time becomes the bias reference value. Variability around the bias is the most interesting element that indicates the dynamics of each parameter in reference to its own mean value. This differential context is comparable to a color contrast in color imaging or an interval in music, for example. Evaluating the variabilities across a set of key parameters elucidates the interdependencies between the observed parameters. Tracking interdependencies between parameters should lead to a better understanding of the importance of crosstalk between parameters. Such crosstalk very likely plays an important role in biological system performance enabling system calibration, differential system stability and robust arbitration among system parameters. For example, how could one estimate relative distance among objects in human vision between left and right eye perspectives without crosstalk evaluation and multimodal feedback, also from past experiences? Very similar estimation processes take place in stereophonic localization of sound sources. Although the auditory sensory system is different from the visual sensory system in the biological system environment, we are not aware of any evidence that the fundamental neurological problem solving strategy should significantly differ. Therefore, assuming similarities in problem solving across different sensory system tasks, a multimodal interdependent analysis of dynamic structure quantities offers a differentiable solution. Moreover, incorporating a statistical error analysis based on uncertainty quantities for each system parameter in dynamic local context helps with estimating the overall robustness of the system. Such a modeling approach differs from an ideal, error free mathematical orthogonalization in n-dimensional space with linearly independent variables that do not consider a certain amount of crosstalk between variables. However, as already demonstrated in perceptual color image compression, a statistical error analysis based on cumulative distribution functions in a nonlinear differential context proved surprisingly stable and useful in predicting overall image quality, independent of local image complexity.

Perhaps we can illustrate the context with a simple practical scenario: imagine a magnificent festival of fountains in motion. How much can a dynamic choreography of water in motion, colorful lighting and music influence an extraordinary experience during a nighttime show? What are the significant functional and cognitive parameters that create an overwhelming experience when droplets of water, propelled into the night sky by dynamically oscillating or rotating fountain jets, appear as a constantly changing colorful sea of lights in three dimensions while their motion is synchronized with musical phrases? For example, we could measure the repetition rates of recurring jet patterns together with the interestingness emerging from patterns of illuminated droplets showing significant local variability.

Do droplet patterns and light patterns interweave, merge, or complement each other? From a mathematical view, a set of sinusoidal wave functions can easily describe a change in synchronicity, dominance versus subordonance, or phase shifts between superpositioned parameters over space and time. Figure 4 illustrates how two signals, A1 and B1, of such functions may interrelate over time. These signals do not need to be independent from each other (enabling further analysis of crosstalk phenomena). Their interdependencies may be evaluated by suitable statistical means in local and global context. Although the functions change their dominance of signal strength rather periodically (at time stamps t1 to t5), a notion of competitive behavior without statistical proof might be misplaced.

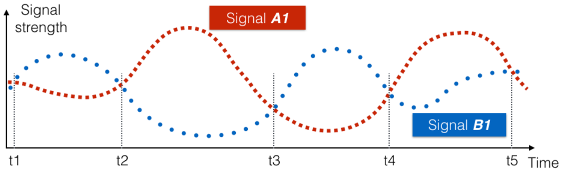

Figure 4. Sinusoidal wave functions illustrating the interrelationship between two signals in differential local context.

How well can fire and water coexist in such an interplay of motion? From a knowledge point of view, would one tend to reason that water would dominate over fire and therefore could not easily coexist? However, from a creativity point of view, how well could structural motion in space and time lead to a better understanding? The idea domain provides the engineering playground to experiment and influence the desired outcome defined by the goal of elegantly combining fire and water that can freely move and dance in aerospace. The input from such experience will accumulate in the knowledge domain to become the new knowledge reference. In the domain of emotions one could perhaps record the variability of admiration and attention, for example. Feedback from the goal domain will enable switching tasks from one goal to the next and [14] illustrates a real life example of the imperative for collaborative feedback in human-human interactions for positive goal outcomes.

We can record the differential changes in each of the four domains already mentioned in the simple functional model of creativity, namely goals, knowledge, ideas and emotions. The number of parametrizable functions for each domain is just limited to one's imagination towards analyzing structural quantities between the four domains that may highlight interrelations in the range from significant to subtle.

How well is the example's multiactuator motion (water, light, music) comparable with oscillating regenerative periodicity like the body's blood stream activated by the heart beat? Any type of contrast metric in differential context will enable analyzing the variability across patterns of multimodal and multisensory quantities in space and time. We can evaluate color contrast variability in comparison with motion variability, musical variability, or even droplet variability (resp. droplet density) together with their synchronizing repetitive patterns and shapes. Furthermore, instead of designing a linear metric, we could also use a nonlinear metric such as ranking (see also [15]) in discrete local differential context enabling very simple intramodal or intermodal comparisons.

From all the above examples together with general functional abstraction in mind we suggest to also analyze already existing system architectures across several disciplines, such as music, science and engineering with the specific goal to better understand similarities as well as differences enabling new pathways towards more efficient interfaces with Artificial Intelligence, Machine Learning, and specifically Deep Learning architectures. With the idea of selecting the most useful system parameters towards modeling creative processes in differential dynamic context, we compare multimodal, multisensory functional properties of hierarchical functionalization across microelectronics, language, music and color imaging. The associated engineering strategies may offer promising building blocks to also master even more complex system architectures present in cognitive science domains.

Hierarchical Functionalization

We first illustrate the most obvious components and functions present across the hierarchical functional architectures of microelectronics, language, music and color imaging. Secondly, we would like to identify suitable candidate functions that could well interface with and also assist in modeling creative processes that are described by our simple functional model of human creativity. We are particularly interested in determining how valuable the functions used in perceptual color imaging are in comparison with the functions of the other domains.

Functionalization of Microelectronics

Over the past decades the microelectronics industry has not only progressed through continuous improvement, but also effectively enabled and stimulated progress in many other industries. Therefore, we would like to present, in sufficient detail, the hierarchical functionalization which occurred in microelectronics while simultaneously focusing on our functional creativity model and Deep Learning architectures.

Table 1 depicts the levels of hierarchical abstraction from a functional perspective. The secret elixir of microelectronics is electron mobility as well as mastering its efficient use (i.e. Moore's law). The first important level of functionalization most likely associates to the diode and the transistor (MOSFET, for example). Next, a group of transistors in discrete electronics creates a logic gate, which represents an elementary functionality enabling the following level of functional abstraction, the famous "bit" of information. One can 'operate on' such a bit to convert its 'meaning' or store and retrieve it over time (using a register or memory cell). The bit also conveniently scales in space and time (enabled by planarization and clock gating technology). Scaling means that the bit can be proliferated to become a group of bits in space and/or time to form a symbol, which constitutes a structurally generic, configurable data quantity. Unfortunately, at this level of functionalization the computer industry created a critical ambiguity. The INTEGER symbol became architecture dependent without a standardized concept of resolving such issue. The default solution was to ignore the dependency on computer architecture and to create files of data sets, in which computer architecture dependency had not been associated with the underlying structural dependency of the INTEGER data type. To resolve the issue, a case by case manual human intervention is required that fully understands the appropriate conversion.

Table 1. Hierarchical functionalization in microelectronics

Level of abstraction	Functional complexity	Examples	Comments
level 0	Electron mobility		physical characteristic, natural phenomenon
level 1	diode, transistor	MOSFET	implementation upon findings in physics
level 2	discrete logic gate	NAND, XOR	technological implementation
level 3	discrete "bit"	0 or 1	space-time modulated elementary data quantity
level 4	discrete symbol	INTEGER, COMPLEX REAL	generic, structurally configurable discrete data quantity - elementary level of functional abstraction
level 5	discrete function	adder, multiplier, selector, switch	transforms a set of structured data quantities into another representation
level 6	system component	Encoder & decoder	
level 7	system peripheral	microphone, camera, touch screen display	interfaces to the 'real world'; human-machine interface

In our view, this example illustrates a significant role of our functional creativity model: if one has only tested the consequences of an ambivalent decision in local context, the underlying weakness will surface later on with a costly impact on unintended consequences. This scenario also leads to a functional creativity model in collaborative context whereby connecting to other people to form a powerful, highly constructive team could lead to sharing expertise and minimizing critical ambiguities in the future. At the same time, if Deep Learning architectures could anticipate the underlying phenomena as well as similarly ambiguous scenarios, the overall system functionality would become much more powerful, reliable and re-usable.

Symbols can be fed to discrete functions, consisting of another group of logic gates in space and time (see also object oriented programming in software architectures). Discrete functions (i.e. adders, multipliers) transform symbols into another type of symbolic representation, again modifiable in space and time. A set of discrete functions may then represent different types of system components, such as encoders together with their associated decoders. And finally, for now, system components can be raised to peripherals connecting to the environment while enabling human-machine interaction, consisting, for example, of microphones, loudspeakers, cameras, and touch screen displays. Interestingly, one can also easily compare a group of logic gates with a neuron of a human brain, where electron mobility is efficiently used in a biological system environment. Therefore, from a functional creativity model's point of view, one could begin thinking of functional as well as structural similarities between the two concepts.

Functionalization of Language

Language has been functionalized for many different types of communication and documentation purposes, long before microelectronics. Table 2 depicts the levels of hierarchical abstraction from a functional perspective. Natural sound of the human voice has been fragmented into discrete quantities of vowels and consonants representing the transformation into letters or characters — the first level of functional abstraction — that could be mechanically carved into stone or written on paper to create visual quantities for reading purposes in the future. Greek and Roman language created letters and then combined letters to form syllables that associate with root meaning, the discrete elementary quantities serving semantics — reflecting concurrent structural embedding (see column 3). The grouping of words leads to sentences expressing a specific thought while following grammatical rules (another type of structural embedding).

Table 2. Hierarchical functionalization in language

Level of abstraction	Functional complexity	Concurrent structural embedding	Examples	Comments
level 0	sound		vocal chord, voice	utterance of vocal chords, controlled by air, mouth, tongue
level 1	letter		vowel, consonant	discrete elementary quantity (symbol)
level 2	syllable		in, con, text	short sequence of letters significant coherence with pronunciation across several roman languages
level 3	word	prefix, suffix	noun, adjective, verb, adverb	sequence of syllables with prefix & suffix variation
level 4	sentence	grammatical rules	framed group of words	sequence of words following grammatical rules (functions)
level 5	paragraph		framed group of sentences	sequence of sentences reflecting an evolution of thought
level 6	section, chapter		framed group of paragraphs	heading followed by paragraphs
level 7	article, book		framed group of sections (chapters)	title followed by sections or chapters

A group of sentences creates a paragraph expressing the context of a thought. The grouping of paragraphs creates a section which is framed by a section title. A group of sections leads to a book chapter or an article framed by its own title. A group of chapters creates a book that is framed by a title and a cover which lets it become an independent object in space. The primary functionalization pattern consisting of grouping and dedicated framing continues to be repeatedly applied across many levels of classification categories. Therefore, the structural approach to functionalization of language also demonstrates a significant degree of stability, simplicity, and repeatability across the functional hierarchy. Again, as with microelectronics, how much is such a structural approach to functionalization an IMAGE of a strategy that is used by our human brain-body system to create efficient processes serving a dedicated goal in biological system context? And how much could we learn to improve productivity across creative processes and creative thinking? In other words, how much does such a concept help build the crutches that could manage human creative processes intrinsically and extrinsically more efficiently while also implementing adaptation to individual needs/talent/aspirations.

Functionalization of Music

Interestingly, multi-modal hierarchical functionalization of music reveals its similarities to language in Table 3. Multi-modal shall indicate that one had to invent a meaningful and simple relationship how a musical instrument functions, how it can be played effectively, and how to create a suitable notation on paper — using concurrent structural embedding (see column 3). The intrinsic physical behavior of a string or a tube defines constraints such as harmonics that should be well reflected by the chosen notation.

Table 3. Hierarchical functionalization in music

Level of abstraction	Functional complexity	Concurrent structural embedding	Examples	Comments
level 0	sound		organ pipe, string, voice	characteristics of an acoustic sound generator
level 1	note	duration, volume	A, B, C, D, E, F, etc.	discrete sound quantity with a characteristic spectral envelop in time domain
level 2	interval	tension, beat, measure, scale, rhythm	A - C	structural relationship of two notes in space (concurrently) and/or time (sequentially)
level 3	chord		A - C - E	a group of intervals; monophonic or polyphonic
level 4	motive	interval paths	. . .	a ‘meaningful’ sequence of intervals and/or chords
level 5	theme	fugue, canon	. . .	a ‘sense-making’ sequence of motives
level 6	movement		. . .	a framed group of themes
level 7	piece		concerto, symphony	a framed group of movements
level 8	genre		jazz, classical, a cappella	a classification function upon a piece of music

Starting from the pure sound generated by vibration of air molecules, we find the first level of functional abstraction as the musical note. A note is a discrete quantity in time domain that is also primarily associated with an instrument, adding a structural functionalization where the sound to be created does not need a complex description of the desired characteristics of the frequency spectrum. The next level of functional abstraction is the interval in sequential context or the time domain. In the spatial domain, the interval transforms into a chord when several notes occur concurrently which we define as a new level of functional abstraction. With the duration of such a chord we create a discrete quantity in space and time. Concurrent structural embedding of duration, volume, rhythm and tension occurs between two or more notes. A sequence (group) of notes forms a motif, somewhat similar to a word or a group of words. A motif expresses an attractive idea that can be developed into a musical theme providing meaningful support for the specific idea. A sequence of themes leads to a movement, framed by a title, similar to paragraphs in language that lead to a section or a chapter of a book. However, in contrast to language, themes carrying key motifs are often repeated, without any or only very subtle variations. Such a framing that uses repetition reminds us of oscillating regenerative periodicity found across biological systems. A particularly interesting example is Ravel's Bolero.

A set of movements creates a piece of music, framed by its title. A piece of music most often consists of one, three (concertos) or four movements (sonatas and symphonies). Here we notice variability and dedicated structure at global scale that also leads to classification towards music genres, such as classical or popular music or jazz.

Music seems to reveal a higher degree of multi-modal structural functionalization than language. The interval is already bound to spectral conformity such as the scale and intended tension. We can perhaps even classify into intrinsic spectral quantities that are a concurrent physical property of the musical instrument and extrinsic spectral quantities that define the space-time evolution. Here we refer to chords played by one or more instruments (space) and the sequencing of notes (time) that altogether produces a motif. Yet another mode accompanies the motif. A motif is not only associated with a beat pattern and a rhythm, but also framed by a measure. These modes appear to be important for synchronizing the musical patterns with the human brain-body system that works upon oscillating regenerative periodicity to stimulate creativity more effectively. We would also like to point out the importance of silence as a framing element or separator that avoids confusion between motifs, for example, and most likely synchronizes to the oscillating regenerative periodicity of the human brain-body system as well.

In summary, via the concurrent processing of multimodal features, music (together with its musical notation) as well as language keep significantly tighter links with the human brain-body system than microelectronics while seamlessly synchronizing to the biological system dynamics. Thus, could this perhaps also stimulate ideas about Artificial Intelligence or Deep Learning system architectures that may adapt to -or assist- human creative processes more easily?

Functionalization of Color Imaging

We would like to also present a simplified version of hierarchical functionalization of electronic color imaging (Table 4), derived from the world of digital cameras that have become a commodity for personal use.

A photosensitive semiconductor device transforms photon flux captured by dedicated optics into an electrical current that can be read and stored in intervals of space and time. Such a discrete quantity that combines space, time, and magnitude is called a pixel, the first level of functional abstraction in our current context of relating to creative processes. The next level of functional abstraction is expressed by local contrast, embedding local structure and magnitude relationships between neighboring pixels (see column 3). At the same time, color filters are used in combination with the pixels to capture sufficient spectral information to generate a discrete color quantity across space and time. A set of color pixels captures an object, framed by an object title, to represent another level of functional abstraction. A set of objects forms an image, framed by an image title and, last but not least, a sequence of images leads to a video, framed by a video title.

From the perspective of effectiveness and efficiency, one could perhaps consider combining finite discrete structural data quantities in local context and hierarchically framed associations among two levels of functionalized hierarchy enabling simple transformations with a tensor like ‘mindset’. In view of creative processes, we would also like to consider multimodal concepts that can more easily resolve ambiguity than in unimodal context. Creating structural associations across several different modes, for example, color-language, color-emotion, or color-music should enable improved memorization and recall of the overall context while strongly reducing the risk of confusion followed by misinterpretation.

Table 4. Hierarchical functionalization in color imaging

Level of abstraction	Functional complexity	Concurrent structural embedding	Examples	Comments
level 0	photon flux		candle light, fire, LED, laser	physical characteristic, natural phenomenon
level 1	pixel		image sensor picture element	discrete spatial quantity (magnitude) of photon flux, integrated over discrete time interval
level 2	contrast	contour orientation, min & max gradient	light & shadow	local structure and magnitude relationship between pixels
level 3	color	hue, saturation, (value)	Bayer pattern color filter set	spectral relationship within photon flux
level 4	object	contour paths, classification	face	a ‘meaningful’ group of (color) pixels
level 5	image	inter-object size, distance	sunset	a framed group of (color) pixels
level 6	video	audio, inter-scene relationship	football game	a framed time sequence of images

As much as tables and spreadsheets quickly reach their limits towards providing a comprehensive graphical overview of a functional architecture, we would like to elaborate a suitable complementary visual representation of functional architectures.

Founding a Suitable Visualization

How to design a useful and easily understandable graphical representation that illustrates the characteristics of discrete structural quantities in dynamic context together with their level of functional hierarchy remains a highly challenging task. For example, how could one remain inspired by the significantly attractive visualization techniques based on color concepts, such as color gamut representations, and transform them into more generic visualization concepts.

We were primarily attracted by two universal symbols, the arrow and the directed graph. The arrow easily signals a direction towards achieving a desirable result. The directed graph with nodes and edges easily visualizes functional hierarchy in a scientific or mathematical context.

We propose creating a composite illustration as shown in Figure 5. The arrow (or vector) symbol appears to be the simplest and most comprehensible construct across many different disciplines that combines structural information and magnitude information (a). By adding a “spin” vector around the main arrow we create a composite symbol that shall illustrate a dynamic process (b). In another step we incorporate the composite vector within a graph node (c) enabling a tight link with a graphical network represented by nodes and edges. Such a graphical network lets us easily transition from one level of functional abstraction to the next, represented by the edge of the graph to illustrate an encoding process, for example (Figure 6), which is often referred to a bottom-up process. The corresponding top-down process is shown as well, illustrating the structural decoding process within a functional architecture.

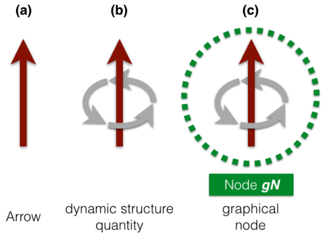

Figure 5. Graphical representation of functional hierarchy with dynamic structural embedding.

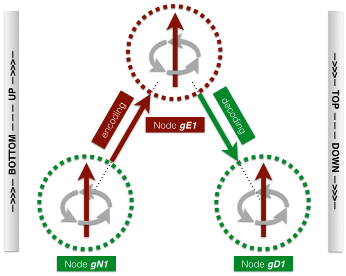

Figure 6. Graphical network with dynamic structural embedding - encoding & decoding example.

Most of the transitions from one level of functional abstraction to the next require some kind of geometric transform that changes the shape of the discrete structural quantities. For example, clustering or segmentation of data quantities, literal associations to classes or categories, etc. change the shape context and the impact of the applied function parameters and/or rules.

Furthermore, variability in differential local context most likely acts as a significant modulator in modeling human creative processes. Several different types of parametric functional variability are depicted in Figure 7: variability D refers to the number of Discrete elements that are part of the dynamic structural embedding, always extendable by at least one more element (dotted arrow). Variability V refers to the variation of the magnitude Value of the dynamic structural quantity, perhaps closest to luminance value in color imaging. Variability P refers to the variation of angular Phase (orientation) of the dynamic structural quantity, perhaps closest to the hue quantity in color domain. Variability S refers to the variation of Strength of the structural quantity, perhaps closest to the color saturation.

With the newly proposed visualization strategy from above we can now also illustrate a different ‘structural’ perspective on LMS cone properties in space and time as shown in Figure 8. Could such a representation somehow inspire new ways of looking at persistent challenges in color constancy?

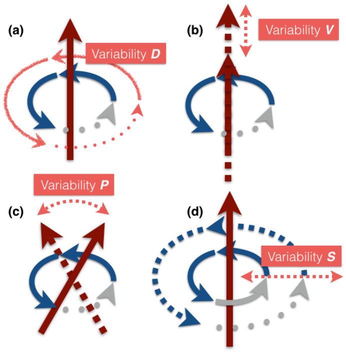

Figure 7. Graphical representation of several types of parametric functional variability across dynamic structural quantities.

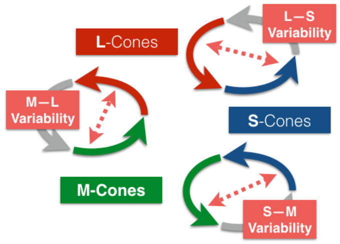

Figure 8. A dynamic structural representation of LMS-Cone interaction.

Discussion

Upon a comparative study based on hierarchical functionalization across microelectronics, language, music and color science, we described how the significance of discrete structural quantities in multimodal local context should be carefully considered while searching for global optimization of human creative processes with well known traditional mathematical strategies. To improve performance, we suggest to evaluate discrete structural quantities in differential local context and build a graphical network that keeps track of multimodal associations among the corresponding structural and magnitude quantities. For example, multimodal similarities between an interval in music and a local color contrast in an image reveal cognitive concepts of ‘data’ analysis that promise to also boost the performance of Deep Learning and Artificial Intelligence architectures. One recent study [3] on perceptual color compression demonstrated the significant correlation between algorithmic masking and perceptual masking of structural and magnitude errors across a wide range of compression factors without compromising visual image quality in local context. Needless to say that once the local context is mastered, global context is mastered as well. Another recent study [2] based on a scientific theatrical experiment revealed the influence of multimodal representation of local context within art while focusing on the interaction between language, music, and emotion within the human creative process. The combination of the two studies could lead to attractive paradigms derived from multimodal structural quantities that may easily stimulate the design of more efficient Deep Learning and Artificial Intelligence system architectures enabling significantly improved 'human centric' human-machine collaboration.

Some Specific Challenges

Subtracting two discrete structural quantities from each other that originate from different space-time instances may easily generate undesirable results. In other words, ignoring the associated structural information, when the magnitude of the two quantities appears equal, leads to an undesirable and often irreversible cancellation. Instead, the structural information should be paired with the number of elements that have been subtracted from each other. Such functional detail enables sufficient traceability and quantifiable structural comparison. We should rather imagine a notion of neutralization potential across the set of structural quantities in local context than its simplified subtraction method. In more general terms, reduction of system information across structural quantities most often generates irreversible errors that also easily mask the underlying potential. For example, when two electrons are next to each other with opposite spin, they may neutralize the electromagnetic field but they are still present as two electrons, playing their role as structural dynamic quantities.

Another Kind of Experiment

Inspired by the graphical illustration of the electron spin in quantum mechanics (for example: [16, 17]) to best reflect the underlying multimodal space-time dynamics that should be considered in any type of dynamic process, we propose to use the vector of angular momentum as a structural component that transforms the discrete dynamic structural quantities of one level of functional abstraction to the next higher level of functional abstraction while primarily sharing the most important structural dynamic context. At the same time, the discrete structural quantities are represented in differential local context of the new level of functional abstraction. The transformation can be implemented as an encoding process similar to encoders used in microelectronics system architectures. Most of those encoders, such as video encoders for example, analyze the incoming data not only in differential context, but also evaluate, track and correct the possible encoding errors by implementing a complete decoder within the encoder. A very simple but powerful concept has been proposed in perceptual color image compression [3] that operates on discrete quantities in local context, pre-dominantly extracting local structure quantities that will be transmitted as the most important information with sufficient precision in differential quantities while preserving other relevant quantities, such as magnitude, with lesser precision. Since such structural concept appears to match the human visual strategies in color image analysis surprisingly well, we propose re-using such a structure oriented concept also across the hierarchy of functional abstraction. Reformulated in mathematical terms, we would like to find a most suitable structural metric tensor (structure tensor) that links two levels of functional abstraction in a bijective association. As shown in perceptual color compression, an integral error correction loop can operate on discrete data while using a closed loop concept -based on an encoder within a fully embedded decoder- with optimal error handling in dynamic local context.

How could such a concept be transferred to creative processes? We start by illustrating the concept in the domain of music. Figure 9 shows the standard linear notation found in music scores (a) of a sequence of two notes that create an interval with a certain tension between the two notes. This tension is more easily described as a vector in rotational (circular) notation (b-d). In a structurally very similar way, the rotational sequence of two notes can be also substituted by a motif or a theme. As the vector then rotates in dynamic context over time, the vector concurrently illustrates the associated differential structural quantity. Such visualization strategy is successfully used in many disciplines of science and engineering where dynamic processes need to be dissected with an efficient strategy to better understand the associated structural complexity. Needless to say, the associated complexity is analyzed with the most plausible cognitive concepts available to the scientific community that addresses such problems, including color representations based on hue quantities, since the human visual system is most sensitive to hue changes.

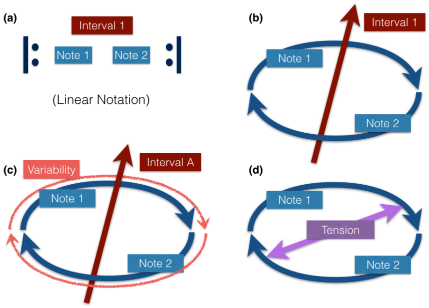

Figure 9. Graphical funtionalization in music.

Here is where new Artificial Intelligence and Deep Learning architectures could help, if the human machine interface eventually matches the associated level of cognitive performance while focusing primarily on a strategy that orchestrates structural regularity efficiently across all levels of functional hierarchy relevant to the simple functional model of human creativity. Eventually, each user could profit from highly improved Artificial Intelligence and Deep Learning assistance on an individual basis with a vision of seamlessly enabling highly efficient support of human creative processes.

A Filmmaking Example

How much do we feel ready to combine color rendering tasks with deep learning methods to let directors of photography, for example, enjoy the art of filmmaking from an artistic point of view? And this without having to learn all about the increasingly sophisticated technical details about color management across the modern processing pipeline from a variety of HDR cameras all the way to dedicated display devices. As a result, human creativity could remain much more enthusiastic about visual storytelling while a Deep Learning architecture assists in exploring the dynamic range of creative options without introducing unexpected results. In fact, musical composition in both the classical and pop worlds is already taking advantage of algorithms to improve compositional efficiency. In those situations the composer chooses, for example, the key signature, speed, and instruments to use for their new composition and relegates the chord sequences and harmonies to algorithms [18, 19]. Although such algorithms are leading to fruitful human-machine collaborations, it would be even more efficient to add Deep Learning functionality in a way that mimics the structural approach found in human creative processes.

Although seamless real-time interactivity appears challenging, we can build upon a structural cognitive concept to facilitate scene rendering that uses a strategy from simple but highly effective modifications such as color cast and lighting or shading with selectable gradient orientations all the way to matte like object color rendering as well as object shadow rendering. Moreover, in view of multimodal influences, one could propose, for example, mood based alignment of scene colors derived from actors movements, voices, music or textual information retrieved from the storyboard. Such strategies may help fine-tune the captured scenes to the producer's artistic intent more easily via automated color rendering control enabled by coherent multimodal processing provided by an adaptive Deep Learning and Artificial Intelligence processor running concurrently as a background process while assisting the production team and creating satisfactorily consistent results much more efficiently. Emerging camera technology already enables remote camera exposure and color rendering control via metadata processing so that artistic intent can be optimally fed into the most important part of filmmaking: scene capture [20]. At least one commercially available tool [21] already tries to hide the technical burden of color management related issues while providing interactive control over the scene content to the user. One research paper [22] demonstrates how to combine textual information with color rendering tasks. Objects within the scene can be re-rendered by taking the associated textual information into consideration.

This example ought to reveal two important paradigms that need to be also met by Artificial Intelligence and Deep Learning architectures to succeed effectively: (1) the structural multimodal and multidisciplinary mental processes of human creativity should be well matched to reach real-time, high quality adaptation to the artistic intent while (2) intelligently tracking and reducing the number of events that generate confusion or conflict. Moreover, interdisciplinary knowledge sharing can be anticipated and provided while focusing on a highly complementary and supportive mindset towards task oriented creativity, instead of trying to follow up on a suboptimal competitive mindset, for example between technical expertise and artistic expertise, often prone to conflictual debate across disciplines.

Another Example: Color Wheel of Emotion

The color wheel of emotion illustrates the usefulness of color concepts for effectively structuring the multi-dimensional context in emotion space. Therefore, when combining textual and graphical descriptors with visualization techniques of color science, the achieved result appears to be significantly more attractive and successful. We argue that graphical representations of color concepts, or music, are efficiently structured to provide powerful but simple mental representations with significantly generic and universal characteristics. These mental representations are much more easily applicable to human creative thinking processes than abstract mathematical representations that quickly appear mentally much more demanding. At the same time, the formal rigidity of mathematical concepts offers Artificial Intelligence and Deep Learning to provide powerful solutions when interfacing efficiently with simpler mental representation that are easily understood by the majority of people to further their creative brain-body processes.

Such a complementary approach may promise increased efficiency through seamless adaptation to the powerful world of human reasoning, learning and understanding to reach a higher level of satisfaction in reference to the undertaken mental and physical efforts. Moreover, this concept may not only be applicable to each individual, but also to collaborative team work scenarios in which each team member plays a different executive role that could interact with and support the other team members more effectively. A challenging component within the new concept emerges from another hypothesis of ours claiming that creative processes may profit from repeatable actions which synchronize with the variability and cross-fertilization (crosstalk) of ideas present in multimodal context which may be similar to regenerative periodicity found across biological systems (in astonishing variety) [1]. Another interesting potential component to be incorporated may come from metaphors helping to conceptualize and visualize promising ideas and thoughts. We already mentioned the phenomenon of "seeing red" or arguing in "black and white patterns." Such metaphors illustrate significant interdependency of different domains such as color interfering with the actual goal of the principal task. Although the metaphoric approach seems to be hardly appreciated in mathematical or engineering context, we argue that an interactive and complementary approach may again achieve increased overall performance in creative brain-body processes.

The Fundamental Engineering Goals

Key to understanding cognitive creative processes is the exploration of (1) information processing 'crosstalk' and (2) interdependencies more efficiently, distributively, and collaboratively (using a dynamic regenerative and iterative periodicity over time) than mathematical concepts or Artificial Intelligence concepts alone. Therefore we propose to carefully analyze the most universal concepts of human cognitive processes (across microelectronics, perceptual color imaging, language, music, and emotion) using the concept of hierarchical functionalization followed by comparison and discussion of the findings.

Modeling human creative processes may reveal a dynamic structural strategy in the cognitive domain enabling orchestration of the yet unknown quantities to transition into the set of known quantities by surprise, admiration, interestingness, and usefulness. Moreover, we would like to also stimulate ideas that could create a more efficient link between human creative processes and deep learning algorithms enabling machines to assist humans in their personal creativity and let them become not only more productive but also entirely more satisfied about jointly achievable results that could be used across a wide range of disciplines — not only online marketing, personal health care, and autonomous driving applications, but also many types of educational and professional disciplines that depend on interdisciplinary collaboration among human experts.

Conclusion

We tried to evaluate how concepts of color imaging and recent findings in perceptual color image compression could offer suitable building blocks in modeling human creative processes as inspired by forward-thinking experimental work across language, music and emotion, from which a simple functional model of human creativity emerged. The multi-sensory and multimodal nature of human creative processes gave rise to also analyzing the engineered functional hierarchy that is observable across microelectronics, language, music and color imaging. In particular, we find functions that show multimodal concurrent structural embedding as a highly generic and useful feature for modeling cognitive processes. We explored the concept of combining color and structure to visualize the most relevant features and functions which could help building and verifying a system architecture dedicated to modeling as well as better understanding human creative processes. We focused also on the rising challenge of seamlessly interfacing with continuously advancing Deep Learning architectures that may play an increasingly important role in effectively and efficiently modeling creative processes.

Our current evaluation also suggests that music and perceptual color image analysis share a significant number of cognitive strategies that appear highly useful to efficiently model creative processes.

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