Creativity: Avalanche in the Sand-pile

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From the Author

This book is a revised and enlarged version of an earlier essay ‘Understanding Creativity: Affect Decision and Inference’, self-published by me in December, 2021, and available at PhilArchive (https://philpapers.org/go.pl?aid=LAHUCA).

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1.1 Creativity: introduction

Creativity is one of those things that make our existence and our life blossom with colors while themselves remaining elusive and intangible. Since antiquity, humankind has never ceased to marvel at its own creative moments. Creativity is one of those things that make us believe that God resides in our soul.

Creativity has many—almost too many—aspects to it. To begin with, there have been anecdotal accounts of it and insightful but essentially conjectural attempts at understanding what the phenomenon of creativity involves. In more recent decades there have been systematic explorations and investigations into numerous aspects of this phenomenon, though the anecdotal—mostly introspective—and the conjectural accounts continue to remain relevant. Even as more disciplined lines of psychological and neuropsychological investigations are opened up, a satisfactory theory of creativity remains essentially elusive and conjectural. However, the conjectures are gradually acquiring more substantive content and creativity is beginning to acquire a less ethereal form.

In this essay I will collect and put together a number of ideas relevant to the understanding of the phenomenon of creativity, confining myself mostly to the domain of cognitive psychology while I will, on a few occasions, hint at neuropsychological underpinnings as well. Though there will be little in these that can be described as my own contribution, I will hope that the the essay as a whole will constitute a useful *point of view* for the understanding of the phenomenon of creativity. In the process, I will include a little (tentative) suggestion of mine regarding the way an apparent non-determinism enters into the making of an inductive inference – one that assumes relevance in the context of creativity as well.

In this, I will steer clear of the vast literature on implementations of features of creativity in *AI systems*. While there remains little doubt that AI systems can indeed replicate many of these features taken in isolation or in clusters, my focus in this paper will be on creativity as it is realized in the human mind.

More specifically, I will adopt the position that a creative act is fundamentally analogous to the making of an *inductive inference* and the exercise of *free will* in that all these are intimately associated with the *self* of an individual. The self (refer to sec. 1.4 is a pervasive psychological engine generated in the entire developmental history of a person, involving such mental ingredients as affect and emotions, preferences, yearnings, memories, personal beliefs, and moral and social views, and is to be distinguished, at least notionally, from shared mental and psychological resources that she possesses in common with members of social groups or communities to which she may belong. The latter may broadly be described as resources shared with her *cultural* environment. At the same time, however, many of the self-linked resources are also imbibed from the *same* cultural environment. Indeed, a near-identical material and cultural environment leaves distinct imprints on different individuals, depending on their widely differing developmental histories where the latter includes the hugely complex succession of psychological and neuropsychological states of a person. Two persons sharing a lifetime of common associations and a common background may yet differ remarkably in their self-resources—this is explained by noting that the neuronal organization (integrated with the underlying biological system) and the emergent psychological makeup of a person are *complex* systems, possessed of unpredictable intricacies in their time-evolution.

We will not, in this book, try to state the defining features of creativity, to enumerate the various different kinds of domain-specific creativity, or to enter into the issue of measuring and comparing creativity. As stated above, this book is meant to be no more than a point of view of looking at what the phenomenon of creativity involves, and will assume that the answers to many basic and specific questions are known, at least in an intuitive and commonsense way. As regards the defining features, we will just assume that creativity stands for the discovery of a *novel* concept in some domain of exercise of the human intellect, by means of which a new set of emergent ideas are glimpsed at, promising to open up an entire new field of investigations, possibly effecting a merger of erstwhile domains. In this, we will mostly consider *scientific* creativity, while occasionally referring to other areas of human endeavor as well.

1.2 A few basic notions

We briefly introduce a number of basic notions relating to cognition. The term 'to think' is a broadly inclusive one covering a wide range of mental activities. Somewhat more specific but of immense significance is the term 'concept'. All our perceptions received as inputs from our outer and inner worlds are in a constant flux of dynamic association with one another. Some of the associated bundles of perception remain stable, being related to stable features of the two worlds—the inner and the outer—that we inhabit. These are the *concepts* in terms of which we make meaning out of these two worlds. The concepts, however, are not static bundles of thought since these are of basic adaptive value, and evolve constantly, gradually acquiring more and more structure (e.g., structure defined by the relative strengths of the perceptual elements associated within a concept). What is more, concepts get bunched into *categories* organized into hierarchies of progressively broader scope, and categories criss-cross into a more and more complex network. A category is, in essence, a concept of a more complex description, and so we will assume that concepts are the basic ingredients of all structured and meaningful thought.

Concepts, moreover, are ingredients of the *conscious mind*, though links between concepts can be established in processes at the unconscious level. The unconscious mind operates on the basis of limited links between perceptual inputs, while concepts are related in a network of far-flung correlations—ones by means of which the conscious mind interprets our outer and inner worlds, thereby *objectifying* perceptual inputs of infinite variety and diversity.

The myriads of concepts formed within the mind of a person may be thought to constitute a *conceptual space* ([8], [18]; see also [19]) of immense complexity, characterized by an equally stupendous extent. Concepts are associated and *correlated* with one another, where a correlation involves a structure over and above the simple association between the entities so correlated since, in order to specify a correlation, one has to specify the manner in which the constituent concepts are related to one another. On the other hand, relatively associations are formed in the mind—to a large extent unconsciously—mostly on the basis of joint occurrence of perceptual inputs at some point of time. While the early stage of the formation of a concept is commonly based on association, subsequent stages pertaining to concepts and categories is by correlation with other entities in the conceptual space.

All these associations and correlations between concepts, and their clustering into categories having a hierarchical structure, are responsible for the enormous complexity of the conceptual space. What is more, this immensely complex conceptual space is in a state of dynamic evolution as an individual receives more and more perceptual inputs from her external and internal worlds.

Correlations between concepts are set up by means of beliefs (sec. 1.3) of various types. Beliefs, to begin with, are correlated concepts of a higher degree of complexity, and the correlations resulting from them are themselves mostly in the nature of new beliefs that appear, in numerous contexts of interest, as end-products of *inference*. Inferences are our way of coping with an uncertain and confusion-laden world where we make use of the inferential process in order to survive and flourish from moment to moment and, at the same time, to avoid harm and disaster. Inferences, in other words, are necessary in order to *act* on the world—one made up, in a manner of speaking, of two components—the outer and the inner worlds. Broadly speaking, an action may itself be in the nature of initiating an inference or, more generally, of embarking upon a train of thought. What is more, an action, on close scrutiny, is seen to have a structure involving a component that may be described as an exercise of *free will* (sec. 1.7).

Beliefs, inferences, and acts of free will are all intimately related to the *self* of an individual. In explaining what the self is made of, we will find it useful to refer to the neuronal underpinnings of psychological states and processes—in particular, of the cognitive ones.

> In this context, *cognition* is a mental phenomenon where there occurs some *processing* of information received as input from the inner or the outer world of an individual, such as the production of an inference or the making of a decision. The processing is performed with the help of the privately possessed psychological ingredients and resources of the person concerned, such as beliefs and emotions, while shared ingredients may also be involved in the processing. Generally speaking, most of such processing occurs unconsciously, possibly with incidental awareness on her part of what is going on.

> The term 'inner' world is used in this book to refer to the mental universe of a person, made up of such ingredients as concepts, beliefs, memories, affect and emotions while, similarly, the term 'outer' or 'external' world denotes her material and human (i.e., social) environment.

1.3 Beliefs: the mind's software

Bertrand Russell observed that belief constitutes "the central problem in the analysis of mind" (quoted in [57]).

> "I argue that beliefs are the mind's software prescribing our behaviours, decision-making, and emotions." Smith [57]

Beliefs are of crucial relevance to the mind, enabling us to navigate through an uncertain world and making us bear the fundamental existential anxiety that life induces in us. As mentioned above, inferences are made possible by the agency of beliefs, and inferences, in turn, generate new beliefs. Beliefs differ in their degree of justification and truth, where the process of justification involves a comparison of the beliefs with *evidence* accompanying experience, and truth signifies universal acceptance of the justification by a social community. There exists a wide spectrum of beliefs in each of us, marked with varying degrees of justification and truth. A belief with a maximum possible degree of justification and truth appears as *knowledge* while, at the other end of the spectrum, there occur beliefs that persist with little relation to justification or truth, and are held together by *emotions*.

> "Our minds were equipped through evolution with an impulsion to create, transmit, and defend beliefs that have utility, whether true or not." Smith [57]

An earlier essay of mine ([36]) outlines the role of beliefs in inference where, generally speaking, inferences are *inductive* in nature. In contrast to a deduction, an inductive inference has to go beyond the evidence (i.e., the information contained in the premises one starts from) or, in other words, the inference is *underdetermined* by the evidence. This is the one great problem that life forces us to face, in virtue of which we are forced to be adaptive, to make bold guesses, and to adopt difficult choices in this world of ours, and this is the one single thing that makes life worth living. Even a deductive inference is never completely free of inductive guesses—a mathematician out to prove a theorem has to guess from time to time as to which lemma or which axiom to invoke in her next step of the proof—the only thing that makes her proof a deductive one is the following: *after* the proof is completed, there remains nothing underdetermined about the conclusion—it can be shown *mechanically* to follow from a set of axioms and unambiguous rules of deduction.

Rules in real life, however, are never unambiguous, nor is life kind enough to offer us a well-trimmed set of axioms to start from. Life is one big guessing game, and we guess *not only* by invoking what we know but also—in most situations—what we *believe*.

Guessing is choosing between alternatives. But, how do we choose? In particular, how does one choose between *disparate* alternatives—even contrary ones? As I ventured in [36], this is where we make use of *self*-linked psychological resources—the choice by one doesn't agree with the choice made by a fellow-man, even one with a near-identical background. What was left implied in [36] is the role of the *affect* system of an individual. This I will spell out in greater details later (sec. 1.5) in the present book.

As outlined in [36], beliefs can be deeply personal things. This requires a bit of explanation (see [37] as well).

All our memories, beliefs, emotions and affect have two components each – a shared component and a personal or self-linked one – though the distinction is not always an unambiguous one.

> The distinction is notional in the sense that the two components do not have separate existence, one independent of the other. The two are inextricably intertwined with each other, while having distinct relevance in our mental world. As an analogy, each of us has an identity as a member of a family and also as a member of a bigger society—the two identities are inseparable but notionally distinct, and each is relevant in its own context.

Right from the moment of birth (and perhaps even before that) every experience of a person (a newborn to begin with) gets associated with some valenced affect, where the affect acts as the core of some emotion and some feeling. Every experience gets stored in memory, imprinted with the affect and the emotion (along with its relation with other experiences and with its degree of salience with reference to the latter). The experiences generate concepts and beliefs. To begin with, all these experiences, concepts, beliefs, and emotions remain self-linked since the self is then the dominant aspect of the being of a person. Gradually, experiences, memories, and beliefs take on an aspect of being shared with other individuals, and entities in the mind start having a dual significance. A belief, for instance, can have a content shared by a larger community of individuals (the family, the peer group, a larger circle of acquaintances, the society, ...) and possesses a significance relating to this larger group and, at the same time, a self-linked aspect that gets imprinted on that elusive psychological entity—the *self* ([10]) of the individual.

A person lost his dear wife on the twelfth of a month. From that day onward, he has *had a deeply ingrained belief implying a dread of the number twelve. He avoids all engagements and assignments on the twelfth of every month.* This belief of his, that the number twelve portends disaster, is an instance of a self-linked one. In contrast, a belief that the number thirteen is inauspicious, is a *shared* one since a large number of people have it. More precisely, a belief usually has both the two aspects (a self-linked and shared aspect) ingrained in it, with one dominating over the other in any given context. With this qualification in mind, I will, in this essay, refer to a belief as being either a self-linked or a shared one.

As other important aspects of beliefs, I mention that beliefs often operate at an unconscious level, and that *beliefs are associated with emotions.* Thus, the acquisition and operation of beliefs often occur without their bearers being overtly aware of those and, moreover, beliefs may not be revised on the strength of evidence.

> "Another significant issue for studying the properties of belief is the degree to which subjects are aware of their beliefs. In pragmatic terms, a person's beliefs are often taken to be what they themselves declare them to be. This type of explicit expression, however, requires insight, reflection, and memory of the belief, as well as linguistic representation. The vast majority of beliefs, however, are not likely to be conscious or reportable, but instead simply taken as granted without reflection or awareness. Such beliefs may be inferred from a subject's behavior, but otherwise remain unconscious and enacted largely involuntarily. This automaticity also applies to the formation of new beliefs. We cannot, for example, choose our beliefs—we cannot choose to believe that it is raining if it is not—and instead often discover our beliefs when we reflect and consider what they are." [9]

Beliefs are often not reason-based. While operating largely at an unconscious level, beliefs are strongly tied with emotions [36]. For instance, when a belief of ours is found to be corroborated by evidence, we experience an emotion with positive valence. This entanglement of beliefs and emotions distinguishes most beliefs from knowledge since, in the process of justification of a belief by evidence and of its transition to knowledge, it is divested of its emotional ties and, in a manner of speaking, gets sterilized into a piece of information, however rich in content. A belief often involves an evaluation of or a judgment on some entity such as an occurrence (*I think that the fall of the conservative government was a deliverance for the country*) or a person or group (*my son is a gem of a boy – I have found none to compare with him*), where the evaluation has an affect-laden and an emotional content. The emotional association of beliefs is relevant in the making of *inferences*, as we see later in this book (sec. 1.6).

> ”Besides helping us to make useful predictions and to achieve greater depths of understanding, some beliefs can evoke profound emotional and creative responses.” [45]

> ”...the believing process is tightly connected with personal relevance, which cannot be understood without the integrating perspective of both cognition and emotion. This notion is subscribed by the findings of cognitive neuroscience.” [60]

1.3.1 Heuristics: rules of thumb

While on the topic of beliefs, one has to talk about *heuristics*. Heuristics are, in a manner of speaking, makeshift beliefs generated and discarded more easily than other beliefs more strongly associated with emotions. The latter are ones resistant to revision under the impact of evidence. Heuristics are ‘rules of thumb’ used by the inferring mind in rapidly connecting between concepts and making possible great flexibility in mental trial-and-error exercises. They often operate at an unconscious level and are responsible for our ‘gut feeling’ ([21]) or intuition.

While beliefs can be strangely resistant to change, heuristics are not usually so, and often prove to be justified bits of knowledge assimilated from various sources, including inferential processes in one’s own mind. These are analogous to lemmas in mathematical literature—one keeps the lemmas stored in a mental toolbox and tries them on when facing an impasse, and is often rewarded with success. For instance, a number of mathematicians, in the course of their career, develop a rich geometrical intuition and build up a huge store of small geometrical tricks of visualization that are found to be of excellent use in times of need. A related set of heuristics involve *symmetry* considerations, not necessarily in three dimensional space, but in abstract mathematical spaces of higher (often infinite!) dimensions. Successful engineers, physicists, and mathematicians have been known to make use of their intuitive but phenomenal sense of symmetry in guessing at solutions of abstruse problems.

Not all heuristics, however, can be said to be foolproof in their content. Most of these are bits of wisdom designed to lend one a supportive hand in a difficult mental exploration—ones that may not lead to correct inference. Thus, an expert chess player has an astoundingly large collection of heuristics at her command, where each of these hints at a possible move in some particular class of dispositions of the pieces on the board and, at the same time, is suggestive of a collection of short successions of moves and counter-moves played out in the imagination. Such a chess heuristic never involves erroneous moves (ones that lead to disaster in the short run) but do not guarantee success either.

> George Polya, the mathematician, has explored in great depth and details the use of heuristics in mathematical reasoning in his celebrated work on the role of inductive inference and analogy in mathematics ([46], [47]; see also [48]). Inductive inference in mathematical work is based on heuristics to a large extent, the latter being of two types: ones that can be deduced on a rigorous basis, and others that can be described as good hunches and are enormously useful precisely because one need not spend a lot of efforts to justify those on solid ground. A large class of heuristics in mathematics, moreover, are in the nature of *analogies*(sec. 2.2.5), the great fountain-head of creativity.

This brings us to the enormous value and power of heuristics in AI systems where these often operate as rules for hopping from one collection of data to another but do not guarantee solution to a complex learning problem in optimum time. The rules can be nested intricately so that one can have rules to generate further rules as a situation demands, which lends great flexibility in the design and operation of AI systems.

Heuristics, like beliefs, can be very much *personal* in spite of the fact that these can often be, in principle, capable of being shared. For instance, there is nothing specifically personal about a mathematical lemma but the store of mathematical lemmas that a mathematician has in her command depends very much on her level of practice, her mental dexterity in quickly figuring out bits of mathematical truth and retaining those in memory, and her overall commitment to explorations in some mathematical domain. Great mathematicians like Ramanujan and Gauss seldom bothered to formally derive the overwhelming number of mathematical truths generated in their mind almost every waking moment of their life. These bits of truth remained as vast repertoires of heuristics that they could use whenever the need arose, and were very much their own, even as each of these would be perfectly intelligible to any other mathematician with whom either of them would care to share, and would be added to the personal repertoire of heuristics of that mathematician. This is also exactly what happens with an expert chess player or with any creative scientist such as a chemist or a biologist. Heuristics, in this sense, are *self-linked* psychological resources of a person—mathematician or not, chess player or not, scientist or not. Even a most ordinary person like me is likely to generate in his lifetime a vast store of heuristics, some of an intimately personal nature and some not so, but all working for him as self-linked resources emphatically determined by his developmental history. Take, for instance, the fact that the young son of my neighbor met with a tragic accident while riding a bike. This has generated in his mind the heuristic *bike riding by young men is sure to lead to danger* (an understandable conclusion, though perhaps stretched too far) and he often stiffens up at the sight of other young men riding bikes.

> What is important to note here is the following. A small mathematical lemma mentally proven by a mathematician in an idle moment of musing is stored in her memory not simply as it would have been written in a book; it would be stamped with at least a little bit of emotion (with a core of affect too, signifying positive valence)—perhaps a tiny bit of privately held pride at having arrived at it in a casual and elegant manner. It is this emotional content that cannot be transferred to another colleague or shared by him, and it is in this sense that even a heuristic clearly possessed of plain truth can be a self-linked psychological resource. Ramanujan and Gauss surely had a lot of such mathematically correct heuristics in their personal stock, of which—one imagines—they must have been secretly proud and possessive.

Thus, generally speaking, a self-linked heuristic is generated in association with an inferential process enacted in one's mind—the success or failure of the inference leads to the generation of a heuristic that associates a positive or negative judgment with a mental summary of the inferential process (*as my young son was suffering from continuing high fever, I called in a herbal expert whose prescription cured him in a few days*—(heuristic)rely on herbal medicine in cases of complicated illness).

1.4 Self-linked psychological resources

The *self* is a concept of central relevance in psychology, though an elusive and slippery one in that it is spoken of in many senses and from many points of view, without one single idea standing out and entailing others. In this essay, as in [37], we use the idea of self as a central engine of our mental activities—the psychological entity that gives identity to our mental being. This, of course, is no solution to the problem of explicitly understanding and explaining what self is, and has a circularity ingrained in it. One hopes that we have a shared and implicit understanding of the idea of self, and discourse from various different points of view enriches that shared understanding even as the latter is not made explicit and precise.

The self as a psychological entity includes such psychological ingredients as preferences and aversions, intimate personal memories, concepts having personal flavor attached to them, and personal beliefs. These, along with privately acquired cognitive faculties, the intimate and private awareness of objects and events (the so-called *qualia*; these form an *implicit* identification of the objects and events concerned), the hopes and aspirations, the drives, cravings, and yearnings, the traits and the changing moods of a person, the quest for *meaning* in experiences of life, all go to constitute her self. All these are associated with emotions and their affect-based core (sec. 1.5.1, where the affect relates to the positive or negative valence characterizing an emotion and the corresponding feeling of pleasure or aversion. At times, though, the feeling may be subdued or even underneath the level of awareness.

While the above refers to the self as a psychological entity or, more elaborately, as a system of entities, one can also refer to the *neuronal* substratum from which it emerges as a distinct entity. Indeed, the self is a *complex system* (refer to [24] for a brief but lucid introduction to the idea of complex systems) that can be described, like other complex systems, in terms of a neuropsychological *hierarchy*, where the so-called default-mode-network is of central relevance ([61], [16], [12]). The neuronal level of the hierarchy is made up of large neuronal aggregates, corresponding to various different regions of the brain, interacting with one another through synchronized electrochemical signals. A more complete and meaningful description of the neuronal level, however, has to take into account a number of other biological systems. In other words, the self emerges from a host of other complex systems in interaction, the latter forming a 'lower' level of the hierarchy. In turn, the self of an individual interacts with other individuals to form various social aggregates at 'higher' levels (the terms 'lower' and 'higher', however, do not have any spatial, geometrical, or value-linked connotation).

In the present book we focus on the *personal beliefs* of an individual as a constituent of major relevance of the self-system, since it is by means of beliefs that concepts in the conceptual space get correlated with one another, inferences are made, the conceptual space evolves in time, and a *restructuring* (see below, chapter 2) of the conceptual space takes place, making possible the emergence of creativity. Along with beliefs, we will have to refer especially to affect and emotions as self-linked psychological resources that remain deeply integrated with beliefs and memories (along with planning and motivation), giving the stamp of individuality to the operations of the self.

As mentioned above (sec. 1.3), beliefs (and memories) of an individual have a shared and a personal aspect to these where the role of affect and emotions is relatively muted in respect of the shared aspects. Shared beliefs and memories arise from the social and cultural environment of the individual, while the personal ones are also imbibed from the *same* environment but are associated with deeply personal affect-based emotions, being linked with the specific developmental history of the individual.

As a matter of special interest, we consider below (sec. 1.5) the *affect system* that operates as an *internal monitor* in the inferential process whenever that process requires a choice to be adopted and a decision to be made.

The self is a constantly evolving neurobiological system, and a good way of understanding the self-system is to try to figure out how it unfolds from the pre-natal (proto-self) through the post-natal to the mature adult, right up to death. The self of an organism is the product of a constant process of differentiation between the organism 'itself' and the 'rest' of the world—the distinction between the two being dependent on the unfolding *context* of the developmental process. In this, the affect system and the emotions occupy an essential and crucial position. For background, I suggest [10], [54]. Also of value is [2].

We will not enter here into more elaborate considerations regarding the origin and development of the self-system of an individual and of the large number of mutually complementary aspects that constitute its complex structure. For background, I suggest [17], [16].

1.5 The affect system and the making of decisions

1.5.1 Affects, emotions, and feelings

The term 'affect' carries a number of different, though overlapping, meanings in the vast literature devoted to it in psychology and neuropsychology. At times, it is meant to stand for emotional feelings in an individual—an awareness of emotions having been activated, often with either strong or subdued bodily reactions such as tearful eyes, faster heartbeat, goosebumps, and tensed muscles. Such bodily reactions are often not under our conscious control, and appear automatically as unconscious and innate mental reaction to inputs received from the external or the internal world of an individual. These appear alongside the valence-based neuropsychological response generated in the context of experiences of diverse types that we will identify in this book as affect.

1. As an instance of an internally generated perception producing a pronounced bodily reaction, one can think of an imagined accident that a dear one may be supposed to have faced (say, son or daughter out on a long drive in the hills and—who knows—perhaps caught in a landslide)—just the supposition is often sufficient to suddenly cause a dry mouth.
2. Antonio Damasio uses the term *somatic marker* [11] to refer to bodily reactions in an affect-based experience.

In other words, we will use the term 'affect' to refer to basic and elemental (i.e., innate) mental responses—ones 'hardwired' into the mind (in virtue of evolutionary processes)—that may or may not produce noticeable bodily reactions (which may nevertheless be there as subdued ones). These mental responses, in turn, activate *emotions*, the latter being complex mental markers that get associated with the experience arising out of a perceptual process. In a subsequent recall of the experience, the emotions are re-enacted (either strongly or weakly) in the mind. Affect, in other words, constitutes the *core* of emotions.

> The term 'experience' used above in explaining the idea of an emotion is to be understood in a broad sense. It includes the context in which the experience is gained, along with the state of mind at the time of it, and an ordering in the salience of the various factors involved. *A child has the happy experience of seeing his mother draped in a red dress singing on the terrace. After the lapse of many years, as an aged person, he sees a young lady draped in a similar red dress singing, and a happy nostalgia floods his mind.*
>
> "Whereas affect is biology, emotion is biography." Nathanson [43]

However, there exist differing accounts of what the 'core' is made of. Thus Nathanson ([43]; see also [55]), following the pioneering work of Silvan S. Tomkins, identifies a number of the innate affects (we use the plural, 'affects', here though for the purpose of the present book, 'affect' is more appropriately referred to in the singular), some of which have positive valence and some negative, where each of these basic affects may occur in a mild form or a relatively strong one.

> Nathanson, in [43], identifies *shame* and *pride* as a pair affects of fundamental relevance in that our psychological *self* entities (refer back sec. 1.4 on the psychology of self) are built around the axis made up of these two.

In the present book, we narrow down the definition of the term 'affect' to a still more basic level, using it to refer to just the bare valence of a stimulus, i.e., a mental marker signifying whether the stimulus is pleasant or unpleasant where, in addition, the *strength* of an affect is often of relevance.

Affect and emotions serve the fundamental function of effecting an *implicit classification* of the complex world around us. The most basic classification is in terms of 'good' and 'bad' – congenial and inimical, based on the affect-related valence resulting from an object or an event. Higher and more complex levels of classification are provided by the associated set of emotions. The sight of mother approaching her child is, fundamentally, a pleasing one to her (the child) and, described more fully, produces joy, excitement and, at the same time, anxiety that the mother's visit may not last long. Here the last named emotion is associated with a mild negative affect while the first two have strong positive valence. The basic affect-based response ('positive'-'negative') is characterized by the feature that *it can be mapped onto a single value-dimension so that it can produce a net resultant valuation* – the child leaps to her mother in joy. A deer standing by a stream in a forest is happy to find drinking water close by and, at the same time, scents danger in the possible presence of a predator—it flees the spot. Classifications—in particular, the dichotomous one in terms of perceptions either congenial or inimical—have great adaptive value and are of fundamental significance in life.

We now come to a feature of affect (in the above narrowed down sense) and emotions that plays a seminal role in a wide range of mental processes. We note, to begin with, that the state of mind of an individual is in a constant process of evolution along multifarious dimensions. In this ongoing complex evolution, emotions (along with their affect-based core) play the role of *amplifying* or *restraining* factors or, put differently, as factors that lead to *instability* or *stability* of a process. *While reading a book on a quiet evening in my living room, I am reminded by a certain passage in it of a happy occurrence that happened long back in my teenage days, and my reading gets disrupted when I set out to relive those bygone days in a nostalgic mood.* This is an instance of a smooth process being de-stabilized by an emotion with a positive valence and a new course of thought being pursued. The fleeting activation of an unpleasant thought, on the other hand, would have forced my mind back to the book.

The instability or the stability mentioned above is of a *local* nature. At any given moment, our mind evolves along very many dimensions, many of those beneath our awareness. The activation of an emotion or an affect with a positive or negative valence relates to only one or a few of those, and only those few strands of thought (often correlated with one another) undergo a de-stabilization or a stabilization, as the case may be. This feature of local stability and instability introduced into our thought process in association with an affect-based valence will later be found to be of great relevance in the making of decisions and in inferential acts.

I close this section on affect and emotions with the observation that a huge literature exists on their *neural* underpinnings. In particular, the *reward-punishment* network or, in brief, the *affect network* continues to be of great interest to neuropsychologists in that it possesses immense significance in almost all unconscious and conscious thought that one can have. In particular, it provides the basis for the affect theory of *the making of decisions*(sec. 1.5.2). I will outline a case that the role of affect in the making of decisions extends to the making of *inferences* as well (sec. 1.6) as well. More generally, the affect network is instrumental in the *establishment of novel correlations in the conceptual space* and, in the ultimate analysis, in *creativity*, where the setting up of extensive correlations results in a *restructuring* of the conceptual space. In all these processes there is an apparent lack of determinism involved, analogous to a similar feature in the exercise of free will(sec. 1.7). I will argue that this can be explained in terms of the self-linked psychological resources of an individual referred to earlier (sec. 1.4.

As an introduction to the neuroscience of affect and the psychological role of the latter, I suggest [33], [5], [6], [52].

1.5.2 The affect theory of decision

Suppose you are going to have to make the following momentous decision: *whether to let your son follow the dictates of his heart and to take up a lifetime career of social work, or to have a showdown and force him to enter the medical profession, which has been your own lost dream in life.*

How do you decide? You have, before you, a choice between *disparate alternatives*. Most of our choices in life, even the most mundane ones, are like this (*with limited money in* *my purse, do I purchase a set of crockery sorely needed for family, or a remote-controlled toy robot to make my daughter smile with delight?*)

Beliefs, emotions, and affect provide for a 'simple' but effective strategy that the mind adopts in solving the impasse. Allow me to be slightly abstract in making this clear. Suppose that I have to make a choice between alternatives 'X' and 'Y'. As I mentioned earlier, X may raise in me a number of emotions (say, 'A', 'B'), possibly linked with beliefs, each with its own valence. The affect-based cores of the emotions activate the affect network to a degree corresponding to the net affect value, say, x (recall the examples of the happy child and the terrified deer). In a similar manner, the emotions (say, 'C', 'D') raised by 'Y' generates an affect value, say, y. The larger of these two would then determine my choice (we observe that each of the two affect-based vales x, y can correspond to either a positive or a negative valence, and that each carries a strength characterizing it).

It goes without saying that the above account can only be a vary vague hint for the actual neural processes—akin to a *computational* procedure—that take place in the complex affect-emotion network in the human mind. Nevertheless the following emerge as general features of the process.

1. In the making of a decision, where one has to choose between disparate alternatives, the mind makes heavy use of *self-linked* psychological resources, namely, beliefs, emotions, and affect. In other words, the computational procedure does not follow a *fixed* algorithm determined by Nature—the algorithm (if we call it that) varies from person to person, though the general scheme followed remains the same and can be assumed to be the product of biological evolution. What is more, the computational procedure resulting in a decision depends on the *developmental history* of an individual in that the self-linked psychological resources evolve throughout her life in a complex manner.
2. Generally speaking, the self-linked resources operate beneath the level of conscious awareness of the person concerned ([13], [59], [63]; see,

however, [44]). Though the process leading to the making of decisions has to be anchored in her neurobiological set-up and hence is not random, it remains, at the same time, fundamentally *unpredictable* to an observer and even to herself. While the general *scheme* that the process follows can be unearthed bit by bit in days to come (the above paragraphs are in the nature of a suggestion), the decision itself cannot be mechanically reproduced.

3. The basic strategy by which the mind makes the decision problem tractable is the one of making use of the activity of the affect network, owing to which the response to a perceived situation (calling for a choice to be adopted), based on the affect-based cores of all the various emotions triggered by it, ultimately reduces to an evaluation that maps onto *a single value dimension*, analogous to the case of a computation whose output is a number having a magnitude and a sign, to be used in adopting a choice among alternatives in the execution of a program. Among the candidate alternatives, the one generating the maximum value is chosen. In other words, the affect network reduces the perception of various different situations to a *common currency* [33], which is an essential pre-requisite in deciding among disparate alternatives.

4. It is perfectly possible that, instead of a number of emotions being activated in a perceived situation, one adopts a reasoned computation based on some particular set of epistemically shared rules and the computation again produces an evaluation that can be represented by a single number (with a magnitude and a sign) for each of the alternatives involved. In that case too it would, in the final analysis, be the affect network that would pick on the numbers and lead to the choice made – this time in a predictable manner. The predictability may, more generally, be probabilistic in nature.

Decision theory, in the last few decades, has taken several turns. Until recent years, the making of decisions was assumed to be free of emotional involvement, and was sought to be described in terms of 'maximization of utility', looked at as a *rational* process. This phase of rationality-based explanation was followed by the 'heuristics-and-biases' approach propounded by Tversky and Kahneman (see, for instance, [22]) where the role of hitherto untapped features of the human cognitive process, including those relating to beliefs and biases, was recognized. This approach ushered in a new era in which the focus shifted somewhat from the account based principally on rational optimization procedures. However, even the heuristics-and-biases approach stopped half-way in giving due recognition to the workings of human psychology, and has more recently been replaced with the affect-based theory of the making of decision, of which an outline—as I understand it—has been given above.

> The role of emotions and the reward-network in decision-making has been discussed in more concrete terms in numerous publications, including [14], [40], [39], [4] (in which other relevant papers are cited), and [52]; [22] provides a detailed survey of the emerging subject of *Neuroeconomics*.

Having said this, I should also like to state that the affect theory can also be viewed as an incarnation of the utility theory where the term 'utility' is to be interpreted in a new context—the one of affect-based evaluation. In the earlier rationality-based theory, utility was introduced as a feature that reduced the response (to a perceived situation) to the much-needed common denominator, thereby eliminating disparities among the alternatives from which a choice was to be made; however, it was left unspecified as to what exactly the utility function was constituted of. Having introduced the utility function by fiat, it was assumed that the making of a decision consisted of a rational optimization procedure in a manner independent of the psychological vagaries of an individual. In the affect-based theory, one has a formal analogy with this rationality-based one in that the 'utility' is now to be interpreted as the valuation resulting from the activation of the affect network and the 'optimization' is now a psychological procedure where the self-linked resources such as the beliefs and emotions are involved. The latter is now no longer 'rational' in the sense of being determined independently of the psychology of the individual. In other words, unlike the utility-based theory, the affect-based one tells us that the 'optimization' can no longer claim to be a normative approach.

1.6 Affect and inference

In the course of our life, every individual has to incessantly face hurdles and problems of some sort or other and is called upon to answer questions and form conclusions, based on given sets of information provided by the world around. The process of arriving at answers and conclusions is referred to as inference. The role of an inference is to take one from an initial set of thoughts or mental perceptions to some other perception by a mental process that may, in a large part, be unconscious. At times the answers and conclusions appear in the form of a *theory*—small or big—that explains some given set of events or phenomena. Such an inference is given the name of *abduction*.

Generally speaking, inferences are inductive in nature ([36]; for background on inductive inference, see [25], [15]), where one has to go beyond the evidence that one starts from, by a process that essentially involves *guessing*—one of *informed guessing*, as it happens to be. Based on an initial set of premises, one arrives at an inferred premise by applying certain *rules*. In the case of deductive reasoning, such as in a mathematical proof, the rules are precise, unambiguous (within the context of the proof, that is) and of general applicability to all inferring individuals.

> However, the context of *examining* a proof and that of *discovering* one are quite distinct. While constructing a proof for a mathematical theorem, or trying to guess at a mathematical truth before attempting to construct a proof of it, even the most prolific of mathematicians has to resort to guessing that may, however, be *informed* guessing.

In most other situations, however, the rules are generally of dubious credentials, being generally in the nature of *beliefs*, associated with *affect and emotions* ([36]). Beliefs and heuristics establish correlations between concepts in the form of 'if-then' suppositions. Only in a relatively small number of cases are the rules precise and explicit, being in the nature of pieces of *knowledge*.

> How the beliefs and heuristics are *represented* in the neurobiological substrate is not known for sure. When one says that a belief is analogous to an 'if-then' type rule, one means that the operation of the belief is of a certain type, there being a substantial vagueness about the statement, whose exact nature is left unspecified. An 'if-then' rule can also be formulated as 'A is B', where 'A' and 'B' are concepts. For instance, 'the king is a tyrant' can be stated in the form 'if *king* then *tyrant*'.

> Whenever one tries to explicitly formulate a mental entity, it becomes vague and imprecise. This is precisely the terrain in the mental world that our *feelings* are relevant in. In contrast to deductive inference—one that can be represented explicitly to a large extent—an inductive inference is essentially dependent on implicit representations and feelings.

It is by means of correlations established by beliefs and heuristics that one makes inferences. An inference generally involves a succession of applications of rules whereby intermediate and sub-ordinate inferences are arrived at, eventually leading to the final conclusion of an inferential act. In the context of such an intermediate stage of inference, the question as to whether the rules are *shared* or *self-linked* ones is often of greater relevance than whether those are justified or not. Let me try to explain how this comes about.

As explained earlier (sec. 1.3), shared beliefs are ones that can be made explicit (in a relative sense, when compared with self-linked ones), their effects on concepts being unambiguous, again in a relative sense—self-linked beliefs, on the other hand, are mostly implicit ones. Referring to the succession of intermediate stages in an inferential process, many of those are based on the application of such shared beliefs and generate unambiguous intermediate inferences. These are analogous to those intermediate steps in a computation where the program does not have to evaluate whether or not some specified condition (or set of conditions) is met with. Such a condition, on the other hand, corresponds to a situation where one can say that a simple progression of the program is punctuated by a *conditional* statement – a tree-like branching of the progression, or a decision juncture where one has to *choose* as to which branch to follow.

If there were no such interruptions of the simple progression of the succession of intermediate inferential stages, then there would be no ambiguity in the final conclusion arrived at, and the inferential act would be akin to a deductive one, in which the evidence (contained in the initial premise(s)) would be sufficient for the conclusion to follow, with no need to go beyond the evidence. In most situations, however, one *has* to go beyond the evidence by guessing as to which of several alternatives or branches of the inferential tree to choose. *This*, as I understand it, is the hallmark of inductive inference.

The question that now arises is the following: *how* does one make the choice? Or, in other words, how does one *decide* which branch to follow? This is where the problem of induction essentially reduces to the problem of making a decision (or, more generally, a series of decisions).

Evidently, the decision cannot be made solely on the basis of shared beliefs because, as observed above, shared beliefs by themselves generate an unambiguous linear progression of the inferential process. In other words, in choosing among alternatives for the subsequent progression of the inferential process, one has to invoke in some way or other a set of *self-linked* psychological resources, the latter being none other that personal beliefs, associated with affect and emotions.

1. The full list of self-linked psychological resources of an individual includes many things in addition to beliefs, emotions, and affect. For instance, there are *drives*, desires, moral and spiritual constitution, aspirations, frustrations, cravings and yearnings, and plans and motivations. Self-linked resources and ingredients may be said to be made up of *cognitive* and *psychic* components. While beliefs and heuristics made use of in inferences are likely to be predominantly cognitive in nature, drives, impulses and cravings are often predominantly psychic. Here I use the term 'psychic' not in the sense of supernatural but in the sense of characteristics that relate, in a manner of speaking, to *repressed conflicts* in the mind of an individual.
2. Shared beliefs are similar to items of knowledge in that their action on premises in an inference is, in a relative sense, unambiguous. For instance, the shared belief that the weather in the month of January is generally cold, tells me (in no uncertain terms) that I should pack a pullover and a windcheater in my knapsack before I set out for hiking in the hills tomorrow. Personal and privately held beliefs do not lead to inferences in a similarly unambiguous manner, and there may arise conflicts between such beliefs. For instance,

> my privately held belief that bald-headed people are clever may prod me to choose a certain dentist to attend to my teeth, while the fact that he has a slight limp may generate a secret suspicion that he is possibly a crook (an idea instilled in my mind years ago as the result of watching a popular TV serial).

A decision to be made in the course of an inference often appears to be insignificant and inconspicuous when compared with the one made in a department store (crockery or remote-controlled toy robot?) or from other more momentous decisions in life, but it is a decision nonetheless since it involves a choice to be made from among alternatives. It does not, on the face of it, call for the activation of identifiable beliefs and does not seem to involve identifiable emotions that can be instrumental in assigning affect-based valuations to the various alternatives involved, but that precisely can be supposed to be what happens beneath the level of awareness of the individual making the inference. Unconscious processing of information is mostly of the parallel and distributed type, and the inferring mind branches out to work out the consequences of the relevant alternatives in the parallel processing of alternative courses of reasoning, in what can be compared with *counterfactual* reasoning since these involve the evaluation of *imagined* consequences of the intermediate inferences in each of these alternative courses. At every step the affect system *evaluates* the consequences and, depending on the result of the evaluation, either propels forward the stream of reasoning or cuts it short, bringing the focus back to the earlier phase of the process, when new courses of exploration can be initiated.

Recall that an inferential process progresses along a single linear course till the rules of reasoning in the form of shared beliefs fail to sustain the progress, when the inferring mind is called upon to employ self-linked resources in choosing between several possible courses to follow. In evaluating the alternative courses, a positive affect sets in a local instability in that the reasoning now flows along a new course that could not be adopted by following the shared rules operative in the earlier phase of inference. In this, the repertoire of personal beliefs is supplemented by the stock of heuristics that can also be counted as self-linked resources, as observed earlier (sec. 1.3.1). Heuristics have a special role to play in inference since these are, in a sense, more fluid as compared with the emotion-laden beliefs—being almost spontaneously active in exploring the conceptual space by establishing correlations among concepts and in generating chains of inferences when aided by the evaluative and monitoring action of the affect system.

> Philip Johnson-Laird [28] has underlined the fundamental importance of choice in creativity (see below for his observations on the close relation (sec. 1.7) between creativity and free will):
>
> ”When a scientist imagines how a phenomenon can be explained, at each point there are several lines of thought that could be explored......In each case the set of choices is constrained by largely tacit mental criteria that determine the genre and the individual's style”.
>
> In these lines the ‘criteria’ referred to by him stand for rules for the setting up of correlations between concepts, represented by beliefs and heuristics, among which he distinguishes between shared beliefs (ones that ‘determine the genre’) and personal ones (‘individual's style’).

While on the topic of inferences, it needs be mentioned that most of the processes making up an inference occurs in the unconscious hinterland of one's mental world([36]). Unconscious inference was highlighted by Helmholtz in connection with sensory (in particular, visual) perception. In more recent decades, the role of the unconscious has been brought to the fore in the case of numerous cognitive functions previously thought to belong to the class of ‘higher’—predominantly conscious— mental activities. For instance, implicit learning ([50], [31]), which involves inferential processes below the level of awareness, has been identified as a major component of learning processes. Numerous, if not most, self-linked psychological resources involved in inferential activity operate predominantly at the unconscious level. In particular, there exist inferential processes entirely in the domain of ‘unconscious intelligence’ ([21]), referred to as *intuitive*(sec. 2.2.1) ones.

At the cost of repetition, I state *in summary* that inferences are made possible by means of beliefs and heuristics that establish correlations among concepts and that can be either shared or self-linked, of which the shared ones are employed in setting up a succession of inferences of an intermediate nature. At certain junctures of this ‘linear’ progression, shared resources fail to set up appropriate correlations (as indicated by a negative affect-based evaluation), and self-linked ones, operating at an unconscious level, are then made use of to set up parallel inferential chains along alternative courses, in all of which the affect system continues to evaluate the inferences generated in a process analogous to counterfactual reasoning. Among the alternative parallel courses one is selected on the strength of affect-based evaluation and the earlier phase of inferential progress gets disrupted by a local instability, leading to an inferential course along a new direction. This—as I understand it—is the basic mechanism underlying inductive inference. In this, the evaluative activity of the affect system, where the latter provides a 'common currency' of evaluation (as to whether or not an intermediate inference is in the right direction) is of basic relevance.

> Peter Medawar, the noted immunologist ('father of transplantation', as he is often referred to) and philosopher of science, spoke of the monitoring activity in inference and hypothesis formation as an 'internal censorship' ([36], [42]).

How does the affect system recognize whether or not an intermediate inferential step is in the right direction? The mind, on embarking upon an inferential process, makes an advance reconnaissance as to what constitute intermediate stages *consistent* with the sought for inference—in which process it makes copious use of results of past inference, mostly in the form of heuristics. In other words, it works *backwards* from the purported conclusion (or one close to it) and constantly performs consistency check between the intermediate inferences obtained in the forward and backward processes. As an analogy, an expert chess player in choosing a move, sets up parallel courses of imagined moves by making use of her stock of chess heuristics and all the while keeps on checking if the moves are consistent with a disposition of the pieces corresponding to a favorable end-game position or one laying claim on some strategic piece of the opponent. Such an approach involving forward and backward inferential chains choose out, from a virtually infinite number of possible courses to be examined, only a limited number of *relevant* ones. This role of the affect system can be described as an 'internal monitoring' of the inferential process, which is essentially the same as the one of 'internal censorship' ([42]) referred to above.

1.7 The exercise of free will

> "One's own free and unfettered volition, one's own caprice, however wild, one's own fancy, inflamed sometimes to the point of madness—that is the one best and greatest good, which is never taken into consideration because it will not fit into any classification, and the omission of which sends all systems and theories to the devil." Dostoyevsky (quoted in [28])

Free will appears to be exempt from cause-effect relationship which, in consequence, seems to violate the principle of determinism. The term 'free' seems to be at variance with the term 'will' since the latter evokes the image of some entity that exerts the will. This, on the other hand, seemingly reinstates determinism and militates against 'freedom'. In other words, 'free will' presents itself as something of a contradiction in terms.

The vast literature that is now available on the issue of free will (see, for instance, [30] for background) illuminates various aspects of the two apparently contrary aspects of it. Following ideas that find such exquisite expression in the above quote from Dostoyevsky, and drawing from the literature on free will, one can develop a fruitful point of view that I have endeavored to put together in [37].

In referring to one's *own* volition, Dostoyevsky puts his finger on the role of self-linked psychological resources of the individual who exercises her free will. By recognizing that the free volition is *unfettered* and does not fit into any *classification*, he acknowledges that it is not explicable in terms shared beliefs, known rules, established knowledge, and normative 'logic'—free will appears to be inscrutable from outside the very private world of the person concerned, so that an observer is apt to describe it as a product of *caprice*.

The absence of identifiable cause-effect relationship in the expression of free will stamps it with an apparent non-determinism—it can indeed be described as non-determinism when one tries to establish the cause-effect relationship in terms of 'external' determinants but has its own causal links in the submerged depths of the psyche, where privately held beliefs, emotions and affect, along with other self-linked psychological resources, exert their causal influences, often in the hidden labyrinths of the unconscious mind.

Johnson-Laird ([28]; see also [29]) has focused on the aspect of non-determinism in the exercise of free will, in respect of which he draws a close parallel between free will and creativity. Having made this observation of fundamental relevance, where he highlights the feature of non-determinism in creativity, i.e., its apparent chance-driven nature, he goes on to look into the possibility of a computational implementation of this non-determinism in AI systems. If, on the other hand, one inquires as to how exactly this apparent non-determinism is brought about in the human mind, one comes face to face with the self-linked psychological resources of an individual, operating mostly at an unconscious level. In this, not even the individual herself has a clue as to how exactly her free will or her creativity emerges, to say nothing of determining or classifying either of these in terms of cause-effect relationships generated (or inferred) by external agents (the 'systems and theories' as Dostoyevsky describes these).

As we have seen in earlier sections, this same non-determinism characterizes the making of decisions (sec. 1.5.2) and of inductive inferences (sec. 1.6) as well. In other words, creativity is fundamentally analogous to the making of decisions and inferences and to the exercise of free will in that all these mental activities involve in their core the self-linked psychological resources of individuals, mostly in the form of personal beliefs and heuristics, emotions, and affect. Of basic relevance in respect of creativity and the making of decisions and inferences, is the role of affect in reducing the perception of disparate entities to one 'common currency' where the mind evaluates the perceptions (recall that a perception is a complex thing made up of numerous dimensions, associated with numerous different emotions) and generates results along a *single* value dimension of pleasure and displeasure (often at an unconscious level), analogous to a number having magnitude and sign.

With all this in mind, we now look at the issue of *creativity*, where we propose a framework for understanding this elusive phenomenon based on the affect theory of decision and of the making of an inference.

Chapter 2

Restructuring of the conceptual space

2.1 The idea of the conceptual space

As underlined at the beginning of this essay (sec. 1.2), *concepts* are the fundamental entities based on which we organize our perception of the world and act upon it. In this, *beliefs* play the fundamental role of establishing correlations among concepts and guide us in the all-important decision-making and inference-making activities—processes of enormous significance in our survival and adaptation. Most of these processes are enacted in our mind beneath the level of conscious awareness.

All the concepts—dormant and active in the mind—make up a stupendously convoluted and complex structure in our mental world that we will refer to as the *conceptual space* ([8], [18], [19]). The structure is convoluted in that the concepts are *mutually and implicitly* related instead of being defined in explicit terms. For instance, referring to the concepts 'round', 'ball', and 'sphere', each depends on the others for its definition, for concepts are defined in the mind in terms of their *mutual associations*. In this, the entire universe of concepts is analogous to a dictionary where the meanings of words are explained by their relations to other words, there being *no fundamental set of words* in terms of which the meanings of all the other words are derived (in contrast, the words themselves are all made up of a fundamental alphabet comprised of a basic set of characters). As another fruitful analogy from mathematics, one can refer to a huge set of *implicit equations* where a large number of variables (say, $x_1, x_2, \cdots, x_N$) are determined in terms of a set of functional relations, each of the functions being determined in terms of *all* the variables taken together.

On the face of it, it appears that if a variable x is determined in terms of y (e.g, $x = y^2$) and y is defined back in terms of x (e.g., $y = x - 1$), then that is enough to send us in circles if we want to determine x and y in numeric terms. In reality, however, the two equations give precisely determined values of x, y though in the example given above, one obtains two instead of one single solution in the pair of variables. In other words, a set of implicit equations is perfectly capable of producing a solution for the variables involved, *provided that* the equations are appropriately framed, since there may remain ambiguities and vagueness in the solutions obtained. For instance, a pair of implicit equations involving three variables x, y, z corresponds, in general, to values of x, y, z lying on a curve in the three dimensional space made up of the three variables. In the case of a large number (say, M) of implicit equations in a large number (say, N, with $N \geq M$) of variables, the former determine one or more regions in a N-dimensional space to which the possible values of the variables get confined. Both in the case of the dictionary and in the case of concepts formed in our mind, this residual vagueness and ambiguity is of vital relevance since it gives flexibility and versatility to our language and to our mental activities.

Incidentally, our use of words in a language and the mental processes operating on concepts are closely related.

> Concepts are not formed on the basis of precise pen-and-paper definitions, but are constructed from the continuing experience of reality. The experience of reality (both the external reality and the inner reality of the mind) perceived at any given point of time or in a short duration cannot be exhaustively, unambiguously, and precisely registered in the mind, far less on pen and paper, if only because that experience has infinitely many aspects—we perceive only a limited number of these, a large part of that perception depending on our current state of mind.

Continuing to refer to sets of implicit equations, let us, for the sake of concreteness, consider a set of two variables ($N = 2$) x, y, satisfying a pair of implicit equations with, let us say, a single well-defined solution $x = a, y = b$. This defines two numbers (analogous to two concepts defined by mutual reference) related to each other by the pair of equations we started with, and a simple *network* made up of two nodes and two links between them. Analogously, the conceptual space residing in the mind of an individual can also be represented, at least notionally, by a *network* made up of the concepts as nodes and their correlations (set up by means of heuristics and beliefs) as links between the nodes. The difference between the two cases is that, in the case of the implicit equations, nodes of the network are located on a single line made up of numbers from $-\infty$ to $+\infty$ (the real line, as it is called; more generally, the network is located in the complex plane) while the conceptual space can be one having an arbitrarily large number as its effective dimension.

Let us now imagine that a third variable z is added to the pair x, y referred to above, and a third implicit equation is added to the pair we started with, and see how the solution to the augmented set is related to that of the earlier smaller set. A more pertinent question is one involving not just two or three variables but a large set of equations relating variable $x_1, x_2, \cdots, x_N$ ($N >> 1$), augmented to a larger set, where a new variable x_{N+1} is introduced and a new implicit equation is added to the set one starts with. The solutions to the initial set of N number of equations and the augmented set of $N + 1$ number of equations form two networks – both, once again, located on the real line. The advantage of referring to networks arising out of sets of implicit equations is that, questions relating to the *geometrical structures* of networks can be discussed in concrete and precise terms, making use of the notion of the *separation* between any pair of points.

One can, for instance, compare the structure of the network obtained as the solution of the N number of initial equations referred to above and the one obtained from the augmented set of $N+1$ number of equations (we refer to the two networks by symbols 'A' and 'B' for the sake of easy reference). For instance, one can refer to pairwise distances between the nodes of 'A' and those of 'B' (this gives $N(N + 1)$ numbers) and look at the minimum and the maximum of the distances so obtained (i.e., the range of separations between the nodes of 'A' and 'B'). In terms of these and other appropriate numerical measures relating to the structures of the two, one can form an idea of the extent of *restructuring* as 'A' gets transformed into 'B'. In the case of large N ($>> 1$), the extent of restructuring is to be specified in statistical terms.

For networks obtained from sets of implicit equations, the restructuring can, in principle, be quite dramatic. In other words, the two solution networks can be markedly distinct from each other as compared in terms of the locations of the solution values on the real axis or in the complex plane, even when one single implicit equation, involving one single additional variable, is appended to the initial set of N equations ($N >> 1$).

This metaphor of solutions to implicit equations can throw some light on the restructuring of the conceptual space that becomes necessary when additional concepts (only a few in number) are sought to be correlated with a large number of existing ones so as to provide an explanation of observed phenomena for which an existing theory fails to provide one. Such a state of affairs corresponds to the replacement of an existing scientific theory by a more effective one in which the conceptual space undergoes a marked restructuring. This is precisely where *scientific creativity* comes in.

Glimpses of the new theory first appear across the conceptual horizon of a lone scientist or of a small group of individuals who may or may not be part of a collaborative team. This happens when an individual (or a small number of individuals; we will, for the sake of convenience, refer to the conceptual restructuring initiated in an individual scientist) seeks to infer new correlations in her conceptual space, trying to find a consistent explanation of observed facts (or anomalies) that could not be explained on the basis of the previously existing correlations between concepts relevant in a problem domain.

2.2 Creativity: Beliefs, inferences, and the self

The conceptual space of an individual is never static—its structure is perpetually in a state of flux due to ever new concepts being formed, and ever new associations and correlations between concepts being established. However, not all of the myriads of concepts lodged in the mind are involved in the evolution of the conceptual space at any given point of time, since only those belonging to a certain domain of inquiry, in which the mind is seeking to arrive at some inference, assume relevance in the inferential effort, in which fresh concepts are formed and fresh correlations are established within the periphery of that domain in the course of the process.

Among the concepts located within the inferential domain, some are well connected with others through existing associations and correlations, but some others may form an isolated island, being uncorrelated with the rest, or having tenuous correlations—established through beliefs characterized by low credibility, or ones that are not coherent with those currently activated in the inferential exploration. Among such uncorrelated concepts one is likely to find those that relate to experimental observations that are not tightly explained by the existing body of correlations among the well-correlated group of concepts.

> It may be recalled that correlations between concepts are set up by means of beliefs and heuristics in inferential processes where an inference can be described as one or more correlations set up in this manner. The correlated concepts often form new beliefs and, at times, lead to concepts of a higher degree of complexity, and myriads of such inferential process give the conceptual space an enormously convoluted and nested structure in an ongoing process of evolution. The process of correlations being set up between concepts, which is essentially an inferential one, is, at times, referred to as an 'exploration' in the conceptual space [8].
>
> Referring to the complex network representing concepts in the conceptual space, a set of concepts tightly correlated to one another corresponds to what is commonly termed a 'cluster' in network theory. A restructuring of the conceptual space corresponds to the setting up of new correlations between such a cluster and a sparsely connected set of concepts when the extant correlations get transformed so as to generate a *consistent* set of correlations among the enlarged set of concepts embracing the ones freshly linked to the previously existing cluster.

Creativity—we are primarily interested in *scientific* creativity in the present essay—consists of a restructuring of the conceptual space with the following features characteristic of it.

(a) It establishes correlations between the mass of already correlated concepts and a few uncorrelated ones forming anomalies or unexplained experimental observations.

(b) In forming these new correlations, it causes a major restructuring among the concepts in the relevant domain of inquiry, whereby a large number of previously existing correlations get modified, for the sake of consistency or coherence, along with new correlations formed afresh.

(c) As the relatively small number of concepts corresponding to the anomalies or unexplained experimental evidence are correlated with the previously correlated set (these earlier correlations considered collectively constitute a *theory*—one that now gets revised through the restructuring of the conceptual space), an early indication is, *at the same time*, obtained that an entirely new terrain of concepts lies *beyond* the ones representing the anomaly that initiated the restructuring in the first place and that get coherently correlated with the entire set of previously existing concepts. A new theory with a broader scope is thereby made visible where the relevance of a new set of conceptual correlations now becomes apparent.

The mind and many of its constituents are instances of *complex systems*. A vast literature has emerged on complex systems in recent years, illuminating a terrain of stupendous extent, made up of distinct subjects ranging from physics, through biology, to economics and various social sciences. Generally speaking, complex systems are fruitfully represented in terms of *networks* made up of *nodes* and *links* (the latter establishing correlations between the former), where these networks are, moreover *multi-layered* in nature — nodes are connected by links of various distinct types.

The concepts lodged in our mind constitute a system of vast complexity, and the conceptual space can alternatively thought of as a multi-layered complex network where concepts are correlated by various distinct layers of beliefs

> acting as links. In a major restructuring of the conceptual space, fresh *layers* of correlations are set up between distant regions, with extant layers reorganized into new connective patterns—existing correlations get removed or modified, and new correlations are set up.

All these supposed features of scientific creativity, that often bring in a major revision of existing theory and make visible the outlines of a new theoretical scheme, constitute a *plausible* description of how creativity is likely to be related to a restructuring of some relevant domain of the conceptual space. We recall that the fundamental process leading to such a restructuring is the 'exploration' of the conceptual space—a term that stands for an extensive inferential effort on being faced with an anomaly, i.e., unexplained evidence that cannot be explained on the basis of the previously existing set of correlations among concepts in the relevant domain of inquiry. We recall further that inference is precisely the cognitive-psychological process of explaining new evidence by the one of establishing correlations by means of the existing body of beliefs and heuristics. The restructuring, in turn, brings in an extensive process of *belief revision*, equivalent to the formation of new theory.

The only 'justification' of the new set of beliefs, i.e., of the emerging theory, is that the unexplained evidence in question is explained in a coherent manner. There is no guarantee that the restructured beliefs will be sufficient to explain *further* unexplained evidence as those are encountered in subsequent practice and experience. Let us, at the cost of being a bit abstract, call the set of beliefs generated in the restructuring process as 'B' and refer to the unexplained evidence that this set of beliefs makes explicable as 'U'. The only justification for 'B' is that it should explain 'U' and, at the same time, form a coherent set.

> However, 'coherence' is often a deceptive concept, being partly a matter of facile appearance, where emotions and affect play their role in causing an impression of coherence. Generally speaking, coherence depends on some *yardstick* against which it is judged, and that yardstick itself is likely to be an enveloping belief appearing as a *mindset* that makes a set of beliefs (such

as 'B' referred to above) appear to cohere among themselves while the coherence with some *larger* set of beliefs is left unexplored. In other words, coherence is not a sure guide to justification. What is more, explanation of hitherto unexplained evidence is also an equally fallible guide, since the appraisal of evidence is itself theory-laden [36].

Now suppose that some *new* evidence (call it 'U′') is unearthed, requiring a further revision of the belief system whereby 'B' gets transformed to 'B′'. Within this scenario, consider the two sets 'B' and 'B′' in reference to the evidence 'U', i.e., the one that was considered to be anomalous prior to the observation of 'U′'. Evidently, 'B' and 'B′' are *both* sufficient to explain 'U', i.e, 'B' is *underdetermined* by 'U', but it still appeared to be acceptable *in the context where* 'U′' did not appear in the horizon of experience. In *that* context, the more inclusive revision to 'B′' was not on the cards (imagine Newton to have discovered quantum theory, bypassing the classical theory altogether—quantum theory, after all, is supposed to be inclusive of the classical theory—Newton did not lack in the talent but had to be, by necessity, consistent to his *context*). In other words, the belief revision corresponding to a restructuring of the conceptual space is dependent on the *context* of that revision.

Evidently, the above hypothetical scheme of conceptual restructuring and belief revision is essentially conjectural, but it generates a useful *point of view* in terms of which the phenomenon of creativity becomes, to some extent, amenable to concrete analysis, thereby shedding some of its elusive character.

2.2.1 Intuition, insight, and creativity

As mentioned earlier (sec. 1.3), our beliefs have two aspects inherent in them—an aspect of being shared inter-subjectively, and one of being private and personal. Among these, beliefs that are predominantly inter-subjective are mostly accessible to the conscious mind, where the holder of a belief can be aware of it. On the other hand, predominantly self-linked beliefs are not always open to being accessed consciously, since one can be only dimly aware of those, and that too after much soul-searching.

We have also observed (sec. 1.6) that beliefs may act as 'if-then' type rules for the establishment of correlations among concepts and that such activity of beliefs may take place in unconscious depths of one's mind.

Finally, the process of establishing correlations among concepts commonly appears as inference, leading to the evolution of the structure of the conceptual space. A certain type of major restructuring of the conceptual space ([8]), as outlined in the present chapter can then be associated with creativity.

In this context, it may be of interest to briefly explain the terms 'intuition' and 'insight' before continuing with our attempt at understanding the phenomenon of creativity.

Generally speaking, the process of inference has both a conscious and an unconscious component, where the former involves the use of inferential rules – mostly in the form of beliefs shared inter-subjectively – that one can access by conscious reflection though, in reality, even these operate automatically in most situations, i.e., below the level of awareness. On the other hand, it is likely that the beliefs of a deeply personal nature operate at a more submerged level of the mind. Referring to the progression of an inferential process that commonly consists of sequential parts punctuated with decision junctures where the sequential progression branches out and one of the branches is chosen in a process similar to the adoption of a choice, the simple sequential progression is effected by means of inter-subjective rules of which one has at least a minimal awareness.

Intuition is the name given to an inferential process that takes place entirely beneath the level of awareness and indicates that sound reasoning rules may be accessed and made use of even without a vestige of conscious control. It seems likely that this is achieved by means of heuristics [21] that have a solid content, many of which may have been acquired in the course of evolution—examples being sophisticated navigation techniques used by aquatic animals, insects and birds and even by humans under diverse conditions. We will not enter here into detailed considerations regarding heuristics having sound and highly effective content and how such heuristics may have been made part of our unconscious inferential process.

> There may be deep and subtle aspects to the acquisition and use of 'higher' cognitive functions that operate in the unconscious hinterland of the mind. For instance, one possible mechanism may involve the so-called 'gut-brain interaction' (see, for instance, [41]), based on the enteric nervous system (ENS). In other words, our mind is a product not of our brain alone, but of the biological system as a whole.

Thus, intuition is 'intelligence of the unconscious', where we don't have a cue as to how we arrived at a correct inference. Insight and creativity share this one feature with intuition: these are overwhelmingly dependent on unconscious processes, with little realization on our part of the way these lead to success—at times quite awesome—in hitting the bull's eye.

While inferences result in the setting up of correlations among concepts, most of those do so, in a sense, on a 'microscopic' scale where the concepts so correlated are not remote from one another. This statement makes sense when one has in mind some metric specifying the separation or distance among concepts in the conceptual space. We will not dwell on this difficult issue in this essay, partly because no satisfactory metric appropriate for our present context is known (see [18] for a penetrating approach in this regard), but mostly because the structure of the conceptual space with all its tangled and nested features and all its mutual correlations at multitudes of levels is still not sufficiently clear for a quantitative description and analysis. Instead, we will assume in a qualitative sense that a notion of separation or distance between concepts and conceptual domains is defined, at least in some given context and within some given region in the conceptual space.

> Recalling our earlier reference to network in the present chapter, there exist notions of separation between a given pair of nodes in a network in terms of the number of links traversed in the shortest route from one of the nodes to the other [62]. However, there may exist a multitude of links of diverse *types* between nodes in a possible network representation of the conceptual

space, owing to which the notion of distance in the conceptual space becomes problematic. Still, it makes sense to refer to sets of nodes as being sparsely or richly connected, where such an evaluation appears to be meaningful between domains of the conceptual space as well—two domains may be close to each other or remote, depending on how densely these are correlated and how stable these correlations are (recall that new correlations are constantly in the process of being established between concepts, and old ones get revised by means of inferential processes).

When an individual arrives at an inference intuitively, she does not know how that inference came to be formed, but such an inference does not commonly establish a correlation between *remote* regions of the conceptual space. More often than not, such an intuitive inference makes use of tacitly acquired cues that are made use of in the setting up of heuristics which then get involved in establishing the requisite correlations among concepts. For instance, *an experienced driver, on hearing a strange sound while driving a car, immediately locates the cause even without conscious thought, and reaches for his toolkit in order to set the offending machinery right.*

This is why all instances of intuition cannot be described as insights, since an insight is distinguished by the fact that it establishes correlations between remote concepts in some given context.

I lost my denture that I took out one day and kept on a shelf while cleaning my mouth and subsequently taking bath. Forgetful of setting it back where it belonged, I came out of the bathroom and became aware of having lost it a couple of hours later. I then spent half an hour in a vain search of it, wondering all the while where I could have lost it. Suddenly, in a flash, I recalled having taking it out in the bathroom and was certain that I must have absentmindedly put it in the medicine cabinet when I had taken an aspirin tablet from it and then put the denture there instead of the medicine bottle—and, sure enough, on going back to the bathroom, I found the bottle on the shelf and the denture in the cabinet.

A patient suffers from strange fits of weakness and depression that a number of physicians are unable to diagnose and cure. One of them, after observing several episodes of the malady, one day orders a rare blood test that the other physicians—even renowned *ones—did not even think of, and the cause of the affliction was immediately identified.*

Insights may be more or less remarkable in their result (the medical diagnosis certainly more so than the retrieval of my lost denture) but all have the common feature that they establish correlations between remote concepts (denture and bottle of medicine, or fits of depression and rare blood condition). However, in most cases these correlations do not have a *cascading* effect, i.e., they remain confined to isolated sets of concepts and do not result in any major (or 'macroscopic') restructuring of the conceptual space.

Such major restructuring is, however, a characteristic feature of creativity (recall that our focus in this essay is on *scientific* creativity). In other words, an act of creativity does not remain confined to establishing correlations between a limited number of concepts in a limited region of the conceptual space. What may be initiated as an act of setting up of such limited correlations, may quickly result in a precipitous effect. To start with, the correlations set up initially give a sudden glimpse of an entire major region of the conceptual space that was hitherto unconnected with an existing region (a well connected cluster of concepts between which correlations had been set up in an earlier phase) from which the conceptual exploration got started. This is then followed up by numerous correlations being tried between the two conceptual domains (the previously explored domain and the one that is now accessed through new correlations), all of which are found to be relevant (and themselves productive of fresh correlations) in the context of the exploration. At this stage, the individual scientist engaged in the mental exploration experiences the much-discussed 'aha!'-effect—a surge of startled ecstasy. The creative act is then followed up by groups of workers, subjecting it to exacting tests, and then giving it the stamp of a new and improved *theory*.

In other words, scientific creativity often results in partial or complete replacement of an existing theoretical framework in some domain of inquiry with a new and improved theory. This phenomenon is, at times, referred to as a 'conceptual revolution'. A conceptual revolution often introduces a new mode of discourse in the domain in which it occurs. We will briefly touch upon this issue later (sec. 3.2.4) in this essay (see also [38]).

2.2.2 Affect and inference in creativity

All along the process of restructuring of the conceptual space, it is inference that constitutes the principal mechanism underlying creativity. As indicated earlier (sec. 1.6), inference is made possible by the activity of the affect system, where the latter acts as an *internal monitor* in the onward progression of the inferential process, with inter-subjective and personal beliefs establishing correlations between concepts in some domain of the conceptual space. What happens in an act of creativity is that remote domains get correlated and a 'macroscopic' restructuring sets in.

The importance of the 'internal monitor', even though completely invisible to the conscious mind, can hardly be overemphasized. The ever vigilant steering it provides forms the essential precondition of all goal-directed activities of the human mind. In particular, the evolution of conceptual space that takes place by means of incessantly occurring inferences is made possible by the imperceptible and silent activity of the affect system where the evolution itself occurs in two discernibly distinct ways—one of a gradual change by means of inferences that establishes correlations only locally, and the other of a major restructuring that occurs through the setting up of remote correlations, not only between isolated concepts but between entire domains where a cascading effects takes place with one correlation almost spontaneously leading to numerous others, thereby opening up an entire new terrain in the conceptual space. It is this cascading that finds an analogy in the avalanche set up in a sand-pile as the latter reaches a *critical state*.

In order that such cascading may be made possible, the inferring mind, equipped with the unique ability of the affect system, has to *evaluate* the relevance of the conceptual correlations being set up in quick succession. *This* requires a trained mind, where the training consists of generating a vast repertoire of heuristics relevant to the task at hand—one of generating an explanation of an anomaly that defies a satisfactory resolution even when the resources inherent in an entire conceptual domain, richly endowed with correlations existing within it, are brought to bear upon the problem.

It may so happen that the 'problem' at hand is apparently rather a 'small' one—say, like the explanation of the spectral characteristics of atomic hydrogen or the explanation of the spectrum of black-body radiation, or even an anomaly in the expressed traits in samples produced in successive generations of a species of plant seeds. To start with, the problem remains hidden behind a big mass of 'success' of the existing theory within the domain under consideration. But it distinguishes itself by being strangely recalcitrant to the authority of that theory, even when the full power of the latter is brought to bear upon it. The hugely successful classical theory made up of Newtonian mechanics and Maxwell's theory of electromagnetism proved to be inadequate in explaining the hydrogen spectrum and the spectrum of black-body radiation.

As an analogy, one may think of the detection of a small error in the solution of a set of equations—let us say, a set of implicit equations in a large number (N) of variables. Commonly one attempts to find a solution by starting from a set of plausible values of the variables (in the so-called complex plane) and then initiating an iterative procedure that is expected to converge upon the exact solution. However, even when the initial values are chosen close to a likely solution (with only a small error showing up when the values are substituted in the equations), the iterative process, instead of converging, may begin to diverge with successively larger errors showing up in the process. This tells us that even a 'small' error may hide a large discrepancy when compared to the actual and exact solution. On the other hand, when the iterative process is initiated from a set of assumed values in a distant domain of the complex plane, it may be found to converge quickly. In order to find an appropriate domain (the 'basin of attraction' pertaining to the iterative process) in which the initial set of values is to be chosen, the computation is to be carried out for a relatively large set of initial values (the process of 'exploration') and every time one has to *check* whether the iteration is still diverging or is showing signs of convergence. In all likelihood, the right domain may be away by a large separation from the one from which the process was initiated to start with even when the initial values in that domain showed only a 'small' error on being substituted in the given set of equations. In the case of a set of equations involving a large number of variables, small errors may be particularly deceptive in accepting a purported set of values of the variables as the true solution, which may lie in a domain remote from the initial one by a large measure.

> In all this reference to sets of implicit equations in large numbers of variables, I only speak loosely and without sound mathematical theorems in my knowledge—I hope that this analogy with what can conceivably constitute to be a scenario involving implicit equations may be instructive in an attempt at understanding how the mind closes in on the solution to an anomaly that defies explanation in terms of the large number of correlated concepts within a given domain, and seeks out relevant correlations with concepts in a distant domain.
>
> The basic idea in invoking the analogy with systems of equations in large numbers of variables is that the latter requires *a large number of consistency conditions to be satisfied simultaneously*. It is then conceivable that a small overall error (defined in some appropriate manner) detected in a purported solution may not be amenable to correction by making small changes in the values of the variables and such small changes may increase rather than decrease the overall error. In other words, the basin of attraction of the exact solution with reference to the iterative process of locating it may lie in some distant domain referred to the domain one starts from.
>
> This, however, is difficult terrain in mathematics, and I am not competent to deal with these questions on rigorous basis.

Of vital relevance in the above computational approach to locating a solution to a set of equations is the process of continuously checking whether the intermediate succession of initial values in the various domains lead to a diverging or converging process of iteration. This requires a succession of *decisions* to be taken in executing the algorithm of the computational process where, each such decision depends on the output value of a certain number (with a magnitude and a sign) indicating the error in some stage or other of the iteration. *Additionally*, the algorithm is to compare successive error values to decide whether the iterative process is a diverging or a converging one. In other words, a *huge* set of decision processes (including the generation of error values and comparisons between successive errors) becomes necessary in order to relocate from one domain to another in the space of possible values of the relevant set of variables. In the case of a numerical algorithm under consideration this checking is performed in terms of the numerical value of an intermediate output that tells the program whether to go ahead or to adopt a different course altogether.

In the absence of such evaluation and monitoring, the computation may prove to be wholly *intractable*—more so when the solution to be arrived at is located in a remote region as compared to the starting point. A numerical algorithm often proceeds through an apparently random choice of successive initial points (the so-called *Monte-Carlo* approach) but even so, the continual checking for convergence is essential for the actual success of the process.

The inferring mind may conceivably adopt a 'Darwinian' approach of establishing random correlations and selecting out the ones that seem to be favorable to the solution of the problem at hand, but it appears that the mind lacks the wherewithal necessary for a truly random search ([28]) in the conceptual space.

> However, this last statement needs to be qualified. Creativity requires that the mind should go into *incubation* once it settles upon the job of solving some problem and realizes that the solution is not forthcoming when looked at from known angles and the exploration for the right concept needs to be carried out over a broader terrain. A relatively short incubation phase is also frequently involved in insightful inferences but such a phase features more prominently in an act of creativity. It is possible that some degree of spontaneous and uncorrelated neural activity may be involved during such incubation phase, but a more likely explanation of the necessity of incubation involves other essential aspects of creativity, as we see below (sec. 2.2.3).
>
> At the same time, it may be mentioned that spontaneous and uncorrelated activity may occur on two different scales—one of these involves *microscopic* fluctuations in the activity of single neurons or small groups of neurons in the brain, while the other refers to fluctuations in the correlated activity of large scale neural aggregates that determine the multitude of unconscious and conscious mental states and psychological functions of an individual—such fluctuations may be termed 'macroscopic' ones. Microscopic fluctuations occur incessantly within the neuronal assembly of the brain and have little psychological relevance, if any. Macroscopic fluctuations, on the other hand, may possibly be involved in the Darwinian process of exploration of the conceptual space referred to above.

Commonly one finds that reference to the affect system in the literature is confined to the role and significance of the 'aha'-effect as it is experienced in the process of conceptual restructuring in creativity. However, the present essay gives center stage to the affect system in the entire inferential process leading to conceptual restructuring, as it occurs in creativity.

> A correct inference has an obvious adaptive value—correct inferences, indeed, constitute the driving force of life. It is also not too far-fetched to conjecture that finding an unexpected short-cut in a difficult job was a rewarding experience for early humans as it is in modern man, and is possessed of adaptive value too. Taken together, the two may explain the conspicuous expression in the form of the 'aha'-effect, where the associated emotions may partly be of evolutionary origin.

2.2.3 Constraint and freedom in creativity

An act of creativity always takes place in some *context* as does any and every act of inference – deductive or inductive.

> Major acts of creativity may also occur serendipitously, to which the discussion in the present essay applies only in parts. Serendipity and purposeful search for an explanation mostly go hand in hand, one or the other of the two being the dominant feature in any given situation. An individual or a group may be engaged in a research program with some purpose in mind, during which there takes place an evolution of their conceptual network, when a chance observation suddenly connects up hitherto uncorrelated conceptual domains, and a related but somewhat different issue gets flooded with illumination, almost too dazzling to bear.

Most inferences are of the inductive type where one has to go beyond evidence and choose between alternatives in which one is helped in a major way by the affect system, mostly in the search for new domains in the conceptual space to which links are set up, to be pursued further on receiving 'approval' from the affect system. However, the process never assumes the form of a wild and blind search, as no inductive inference ever does—inferences are highly constrained by context and are domain-specific, since otherwise the mind would have to make a choice between too many alternatives and the process would be too heavily underdetermined—it is psychologically costly and unnecessary to conduct a search among chemical species while trying to solve a problem on gravitation. It would be equally out of the context to zero in on categories like ‘bleen’ and ‘grue’ (Goodman’s paradox) while inferring on the color of emeralds from the observation of a number of green ones.

But too much of domain-specific constraint is suffocating and lethal where creativity is concerned – much like the case of the globe-trotter facing visa problems.

In order to explore distant domains and establish remote correlations, the mind needs to be set in the *default mode*, where it desists from outwardly directed purposive action and engages in intrinsic activity based on the default mode network (DMN) of the brain (see, for instance, [49]), congenial for long term planning and prediction, imagination, and *creativity*. This has been referred to as the *incubation* phase in reference to acts of insight and creativity and has been mentioned in introspective accounts of numerous original thinkers, notable among whom having been Henri Poincare ([8], chapter 2; [56], chapter 2). Such an incubation mode, often akin to ‘day-dreaming’, is perhaps even more of a necessity in the case of creativity in literature and the arts where domains are not always demarcated clearly and where internal, self-linked psychological resources are engaged not in establishing correlations between specific concepts but in setting up associations between whole clusters of psychological ingredients mostly buried deeply in the unconscious.

> Creativity in literature (including, specifically, poetry), music, painting, sculpture, and the like is related mostly to what have been referred to as the *psychic* components of the self earlier (sec. 1.6) in this essay, as distinct from the *cognitive components*. While cognitive components principally involve beliefs of diverse types, the psychic components include such ingredients as drives, yearnings, cravings, unfulfilled aspirations, moral and ethical beliefs, poignant memories, and a host of similar other constituents of the psyche—ones that are managed by our *soul*—lest they may disrupt our existence itself ([**?**]). Both the psychic and the cognitive components are, without exception, soaked to a greater or lesser extent in emotions and affect. It is affect that, in the ultimate analysis, steers us through the incredibly complex maze of life, at times leading us on to acts of creativity.

It is in the incubation phase that the domain-specific constraints on inference are released and the mind engages in the *free* exploration of the conceptual space, where freedom too is to be constrained appropriately. Creativity needs 'freedom' on two counts—one of these is the freedom to explore distant domains in the conceptual space while the other is the freedom from knowledge-based, socially induced and inter-subjective rules of inference so that the self-linked beliefs may get into the act. The latter kind of freedom appears as a fundamental *non-determinism* in creativity since determinism is the name commonly given to *predictability* in terms of identifiable causal effects (refer to [37]).

> A system is *self-determined* if there is no external system or agency that determines its behavior, and it evolves in accordance with rules that can be expressed in closed form, say in the form of a set of autonomous differential equations or an unambiguous code that does not need external inputs during run-time. Thus, for instance, a cellular automaton is self-determined even though it evolves according to a code set up by an external agency (an AI system or a human intelligence)—once the code is given, the behavior of the system made up of the automaton and the code does not depend on an external agency. The question, however, arises as to whether and to what extent such a self-determined system is *determinable*, i.e., how far its future behavior can be predicted in advance. The description of the rules of evolution of a *Turing machine* may be completely known, making it a determined system—nonetheless, given an arbitrary input string, it is not *decidable* whether the machine will ever halt. More generally, the behavior of the machine or of a self-determined system at an arbitrarily distant future may be indeterminate to a large extent. In a sense, predictability is the *foundational* issue behind all attempts at theory building. It underlies all our attempts at understanding *reality* ([38]).

Creativity is intimately dependent on freedom from recognizable causal relations precisely because it is made possible by self-linked psychological resources—ones that remain hidden to an onlooker (even, to a large extent, to a psychologist) and mostly to the individual too who engages in the creative act. In this, creativity is analogous to the exercise of free will ([28]; see also [37]) that appears to be non-determinable in a large measure.

At a fundamental level, the freedom from constraints in the exploration of distant domains in the conceptual space and the freedom from inter-subjective casual effects in the making of a decision in an inferential process, are not too different from each other. Because, conceptual domains are, to a large extent, demarcated from one another by means of knowledge-based and inter-subjective categorization. In order that domain boundaries may be dissolved in the conceptual exploration, one has to suspend to a large extent the inter-subjective criteria underlying the demarcation of domains which is precisely why the incubation phase is so necessary in an act of creativity. What is more, the crossing over from one domain to another needs a choice to be made (and, equivalently, a decision to be adopted) in the same way as in an ordinary inferential process.

In other words, creativity is at heart a spectacular inferential act where the inference is freed from the constraints of some specific domain or other.

> In any given line of inquiry, concepts may have proliferated to such an extent that what was a conceptual domain yesterday is divided into sub-domains and even more restricted regions today. This is the natural course of evolution of the conceptual network – by the creation of new concepts, new correlations, and new clusters (densely correlated groups of concepts). Routine inferences take place in some tiny region within a larger domain. Creativity would then require that the constraints imposed by a fixed and limited region be relaxed and a conceptual exploration be carried out in some appropriately larger region.

2.2.4 Creativity: heuristics and non-determinism

We have made a qualified distinction between beliefs in general and heuristics, in an earlier section (sec. 1.3.1). Heuristics are beliefs of a special kind—they often have good credentials in being justified to a larger degree when compared to the majority of beliefs of other kinds that we hold, are more readily subjected to the test of evidence and revised accordingly, and have a better 'turnover rate'—being produced and discarded with greater facility, depending on their efficacy in the this or that inferential process. While we may be aware of many of the heuristics held in the vast store of these tiny and active bits of belief lodged in our mind, many others remain hidden in the unconscious depths of it and presumably play a prodigious role in the conceptual exploration undertaken in acts of creativity.

As the examples of heuristics based on symmetry-related concepts held by engineers, scientist and mathematicians indicate, along with a huge number of others rendering good service to artisans, technicians, athletes, car drivers (men and women from almost every walk of life)—we are most of the time unconsciously guided by heuristics in all activities that have some degree of automaticity built into them. Most of these heuristics—though justified to no small degree—are included in our self-linked psychological resources since these are produced in a manner intimately related to our developmental history and are associated to some extent with emotion and affect, though this feature of the heuristics may be less pronounced than what applies to other beliefs entrenched in the mind. In any case, an individual's store of heuristics is often specific to her and depends on her occupation, habits, temperament, and commitments in life. Above all, heuristics constitute a dynamic component of the mental world of a person and are highly active in establishing correlations among concepts, much like efficient enzymes in biochemical reactions.

It is the dynamics of the conceptual network, to which the fluidity of the heuristics contributes in a large measure, that is a major contributing reason behind the *non-determinism* inherent in creativity. The application of heuristics to the establishment of correlations among concepts occurs on such a short time scale compared to the time characterizing an act of creativity (including the incubation phase) that the latter essentially becomes *history-dependent* (for background on history-dependent processes in complex systems, see [62]), i.e., if the process is imagined to occur a number of times under identical conditions (i.e., with the context of the process remaining the same), the outcome would differ from one occurrence to another.

This, in a sense, distinguishes the non-determinism characterizing acts of free will ([28],[37]) and that relating to creativity. An exercise of free will depends in a major way on the activity of self-linked psychological resources that remain outside and beyond known causal relations, owing to which the act appears to defy the principle of determinism. In contrast, the heuristics that make a major contribution to an act of creativity are mostly ones based on justifiable principles (and hence appear to be inter-subjective ones when considered in isolation from their person-linked features) that can be identified as having contributed to the act, but only *after* it has occurred—the fact of its occurrence appears to be a random event owing to the exceptionally dynamic nature of the activity of the heuristics. Having said this, I have to add that the self-linked nature of the heuristics is also relevant in conferring a degree of non-determinism to acts of creativity (and, likewise, the fluidity of heuristics must also be responsible in some measure for the non-determinism characterizing the exercise of free will). As we have seen, heuristics may have a good measure of justification in them but are still dependent on the details of the developmental history of an individual, such as the level of rigorous practice in some particular domain that she goes through, the mode of thinking that she adopts in her past stages of development, the types of sources that she exposes herself to, and very many other factors of a similar nature. The items of knowledge and inter-subjective beliefs that a person acquires in the course of her life are pretty much the same when compared to another individual with a similar background, but her store of heuristics may be vastly different.

> As indicated earlier (sec. 1.3), *all* beliefs, including ones in the nature of heuristics, have shared and self-linked aspects to them – it is the one or the other of the two that acquires relevance in any given context.

I conclude this section by noting that the issue of non-determinism in our mental activities is a deep one, only a few aspects of which have been touched in this essay of mine. All our mental activity is a result of conjunction between our 'states of mind' and states of the world external to it. Both the mind and the external world are exquisitely complex systems, with stupendously complex modes of evolution, and it is no wonder that the conjunction between the two is bestowed with a great deal of unpredictability. It is only in a coarse or 'macroscopic' sense that one finds predictability in the activities of the mind.

2.2.5 Analogy in creativity

The foundational ingredient in creativity—and indeed in much of our mental life—is *analogy*. And, it is analogy that is primarily responsible for the triggering of a major restructuring of the conceptual space, so typical of an act of creativity.

The crucial relevance of analogy in our thought process in general, and in inference and creativity in particular, has been discussed by numerous authors (see [32], [8], [23], [26], [20], [64])—making up a vast storehouse of ideas on how much of a subtle and universal role does analogy have in creative thought.

Analogy can truly be identified as the most effective means of establishing correlations among concepts. In broad terms, it can be formally described as a mapping from one concept (the 'source') to another (the 'target') and, as such, can indeed be looked upon as *the* universal means of correlation, since some mapping or other can always be defined regardless of what the two concepts (the source and the target) are. In this sense, analogies among concepts do not intrinsically reside in the concepts themselves as much as these are generated and employed to relate them by the inferring mind. The setting up of an analogy is itself an act of inference where the former plays a role similar to a belief. However, this way of defining an analogy is too broad to be of use unless one takes into account the fact that an analogy can be either shallow or deep depending on whether or not it *simultaneously* tells us something of the way the two concepts are related to *other concepts* correlated with them. In other words, a deep analogy is one that tells us something interesting about the properties of the target-concept from those of the source-concept, thereby setting up a densely correlated *cluster* around the target concept in our mind. However, whether this cluster of concepts is 'interesting' or not depends delicately on the context. In this respect, a good analogy is like a metaphor or a joke that has to be tuned to the context to be of genuine interest since otherwise it falls flat. Just as a joke or a metaphor does not reside inertly and intrinsically in the situation it lights up but has to be discovered by an acute mind (though not invented by it), a fertile analogy is likewise one to be discovered within a given context to be useful in setting up new correlations. Analogy is a complex thing that results from a conjunction of the concepts involved (the source and the target), their context, and the store of ideas and heuristics in the exploring mind. All this owes its origin to the fact that an analogy sets up correlations over a wide domain in an *implicit* manner—one that cannot be unambiguously described in explicit terms, unlike a similarity that can be recognized more explicitly.

The important thing about analogies in the context of creativity is that their production and use is not directly dependent on the contiguity of the concepts involved. In this, an analogy once again resembles a good metaphor or a good joke, both of which are capable of connecting up *remote* ideas—the more distant these are, the more effective and potent the metaphor or the joke is. Run of the mill analogies depend on the contiguity of the source and target concepts that offer easy means of being correlated through their common or shared correlations. While two such concepts can be linked in an almost trivial manner, they can also be correlated through a distant route that can more often than not throw light on other concepts lying on that route, whereby the analogy becomes an 'interesting' one—a potent source for further correlations.

> While an ordinary belief or heuristic correlates a source and a target concept by means of a relation of implication (where the implication may even be a vague one), analogies operate predominantly by means of association, owing to which these have an amazing power to link up remote concepts.

For instance, when one is asked the question *in what respect is a glass analogous to a bottle*, he may respond by saying, *both are made of glass*, which would be a rather uninteresting and flat observation. On the other hand a response such as *both start flying in the late hours of a party* would be more interesting in establishing a correlation through a rather long and circuitous route, thereby suggesting a revealing picture of a party in an advanced stage of dissolution—a picture impregnated with a host of associations of a telling nature.

In other words, analogies generated by a fertile mind (equipped, let us say, with a huge store of relevant heuristics) can be effective in establishing *long range* correlations across domains, somewhat resembling the case of a *phase transition* in the physical sciences.

1. We have to keep on reminding ourselves that we do not have a precise definition of the notion of distance between concepts, the major reason underlying the failure being that concepts are often linked in a complex manner by correlations of multiple types. We hope that our tacitly held and common-sense notions of contiguity and separation between concepts are adequate to meet the requirements of the present discourse.
2. In a phase transition of a material from, say, the liquid to the solid phase, an analogous phenomenon is observed, where states of atoms at distant locations become correlated even though the interaction between any pair of atoms is of a much shorter range. In particular, a *critical state* observed in phase transitions of diverse types, is characterized by correlations over an *infinite* range—it may be mentioned that phase transitions are possible, in principle, only in systems of infinitely large volume.

Invoking deep analogies is a profoundly personal ability—presumably dependent on self-linked psychological resources (including the repertoire of heuristics at one's command), operating at an unconscious level ([51]).

Chapter 3

Self-organized criticality: avalanche in the sand-pile

3.1 Introduction: lessons from nonlinear differential equations

Phase transitions in physics refer to transformations in *equilibrium configurations* of systems. More generally, complex systems undergo *dynamic* phase transitions involving qualitative changes in their behavior patterns. Such changes are brought about by the joint effect of the intrinsic interaction among the components of a complex system and of changes (commonly, small and slow alterations) in the state of its environment. Referring to a notionally defined state space (commonly referred to as the 'phase space') of the system, dynamic transitions can be described as changes in the (geometrical) patterns of sets of trajectories in that space.

1. The above description of dynamic phase transitions is a notional one in that a state space (or, more specifically, a phase space) cannot always be defined in precise terms, to say nothing of trajectories in that space or of the geometrical pattern of bunches of trajectories. Precise and rigorous definitions exist for non-linear ordinary differential equations with 'reaction functions' (i.e., ones representing the rates of changes of relevant variables) belonging to certain acceptable types. Nonlinear partial differential equations are also amenable to precisely formulated analysis to some extent. Such analyses are, in the main, applicable to (CPS). Behavior patterns of (CAS), on the other hand, are more commonly described in qualitative and non-mathematical terms. While computer-generated descriptions and simplified math-

ematical models are available in abundance for adaptive systems as well, the results obtained in the theory of non-linear differential equations act as powerful analogies for broad classes of complex systems.

2. For a brief introduction to complex systems of the CPS and CAS types, see [24].
3. There is no general method of solution to nonlinear differential equations. However, the so-called *qualitative theory* for such equations is a highly developed one, where the topological features of trajectories in the phase space are of central interest. This theory is the result of remarkable contributions from mathematicians, physicists, and engineers over the last hundred years.

Invoking the analogy to nonlinear differential equations, one refers to sets of *Lyapunov exponents* (we use the symbol λ to denote a Lyapunov exponent; a complete set of Lyapunov exponents will be denoted by Λ) in various distinct regions of the phase space. Imagining a trajectory initiated at some given point (say, P) in the phase space, a positive λ indicates that a trajectory initiated from a point (say, P′) slightly shifted from P in some particular direction in the phase space will deviate progressively from the trajectory initiated from P (*sensitive dependence on the initial condition*). A negative value of λ, on the other hand, implies that the two trajectories will progressively come closer.

The complex dynamics of the system under consideration depends crucially on how Λ varies from point to point throughout the phase space,since this determines the patterns traced out by bunches of trajectories in the various regions of that space. As a result of this variation, the behavior pattern of a complex system, as revealed in the disposition of bunches of trajectories in the various regions of the phase space, differs markedly (and often spectacularly) in the respective regions, constituting what may be termed a ‘complex behavior pattern’—for instance, in some part of the phase space, there may exist a steady configuration, around which trajectories reveal a periodic or quasi-periodic behavior, while in some other region the behavior may be chaotic. In the latter situation, the behavior may be termed ‘stable’ in that the chaotic trajectories may get confined to a ‘strange attractor’— a region in the phase space that all trajectories initiated in the ‘basin of attraction’ eventually reside in.

Added to this complexity depending on initial conditions in the phase space, there arises the fascinating complexity resulting from an alteration in the *context* where the context is commonly taken into account in terms of boundary conditions and, additionally,in terms of sets of parameters characterizing the evolution of the system under consideration (for instance, the Rayleigh number or the Reynolds number in the case of fluid flow—a host of such parameters characterize the flow under various different physical conditions). Here the paradigmatic phenomenon is *bifurcation* that reveals a change in the geometrical disposition of trajectories in the various regions of the phase space as certain threshold values of the relevant parameters (including those specifying the boundary conditions) are crossed.

> I repeat that this entire mode of description of the evolution of a complex system is based on the analogy with what one finds in the qualitative theory of nonlinear differential equations (referred to as the theory of *dynamical systems*), which acts as the paradigm in much of our current view on complex dynamics. The mathematical notion of the phase space or, more generally, of the 'state space'—the term 'phase space' applies to the special case of Hamiltonian systems—does not, strictly speaking, apply to any and every complex system. Once again, we use the term 'phase space' in the sense of a paradigm. The term 'Lyapunov exponents' then refers to factors in the system behavior that tend to amplify or to suppress small deviations in its state in the course of its subsequent evolution.

In a broad sense, the dependence on initial conditions in the phase space can also be looked upon as context effect, and one can speak of the sensitive and complex dependence of the system behavior on context. Within this broader interpretation, the dependence on initial conditions may be referred to as an 'intrinsic' effect and that on the context (in the narrower sense where initial conditions are not included) as 'extrinsic'—the evolution of a system depends on how the intrinsic interactions get expressed under extrinsic ones—where one has to keep in mind that the distinction between the intrinsic and the extrinsic is only conditional—in a broad sense.

The distinction between the intrinsic and the extrinsic is largely determined by *time scales* of evolution—interactions that operate on relatively small time scale are taken to be intrinsic ones while evolutionary processes occurring on a larger time scale are considered to be arising due to extrinsic interactions—indeed the very definition of the constituents making up the system depends on the time scale thought to be relevant in describing the system dynamics. Considered over a relatively long time scale, extrinsic factors play a role analogous to intrinsic ones, and it may be worthwhile to include some of these factors in defining the components the system is made up of (i.e., the ‘system’ itself may have to be redefined).

In summary the dynamical evolution of a complex system may be of an exquisitely intricate nature, involving co-existence of regular and irregular behavior patterns of various kinds and transitions between stable and unstable regimes of evolution where an instability implies that the behavior pattern may change markedly and new modes of behavior make their appearance. Here the term ‘behavior pattern’ refers to both the temporal evolution and *spatial* structures describing the system under consideration.

3.1.1 Self-organized complexity

The transitions between distinct behavior patterns induced by instabilities in the system may often take place over a relatively small time scale as compared with the intervals over which stable modes of behavior remain dominant. Since, over such short time scales, it the intrinsic interactions that dominate over the extrinsic ones, the generation of novel modes of behavior through instabilities in complex systems is referred to as *self-organized complexity*. The role of extrinsic factors in this context is to *steer* the system to the *edge of instability*. Since the instability often leads to an irregular (‘chaotic’) behavior pattern, the point of occurrence of the instability is correspondingly referred to as the *edge of chaos*.

Self-organized complexity may involve varied and diverse types of bifurcations in the system behavior, where I repeat that the term ‘bifurcation’ is used as an analogy, by invoking the paradigm of nonlinear differential equations that may or may not be of strict applicability to the system under consideration.

One such bifurcation scenario in nonlinear differential equations and nonlinear mappings (analogues of differential equations, where time is assumed to vary in discrete steps) is referred to as *intermittency*. The pattern of intermittent and recurrent transitions to some novel mode of behavior has been found to occur over a wide range of real-life phenomena involving complex systems and is referred to as self-organized criticality.

3.1.2 Self-organized criticality

As a system is pushed to the edge of instability by the operation of extrinsic factors over a relatively long time scale, it makes a rapid transition to a new regime of stability where, however, the state of stability is slowly altered by the operation of extrinsic factors that again steer the system to the edge of instability, thereby inducing another precipitous transition to a new—slowly evolving— stable regime. This recurrent pattern of slow evolution to the edge of stability, succeeded by rapidly changing phase of instability, is observed over a fascinatingly wide range of real-life situations, such as the stick-slip process in dynamic friction, the recurrent generation of neuronal voltage spikes, forest fires, earthquakes, and the generation of *avalanches in sand-piles*. Such recurrent alteration of a system configuration between stable and unstable regimes involving two distinct time scales is the hall-mark of self-organized criticality (SOC). In other words, the occurrence of SOC can be described as a recurrent phenomenon involving a slow 'accumulation of strain' in a system, followed by a rapid 'relaxation' or 'burst' when the strain gets released.

The sand-pile has been widely studied as a prototype model of SOC ([62], [27]). As grains of sand are slowly added (extrinsic factor) to a growing sand-pile, nothing noticeable happens at first (slowly evolving stable regime) till some critical height is reached when an avalanche is generated (rapid transition induced by instability) and part of the sand-pile collapses. If the process of addition of sand grains is continued, then a similar collapse occurs once again, and the avalanche gets repeated in a recurrent manner.

SOC is typically characterized by the occurrence of *power law distributions* in the statistics of numerous physical features relating to the dynamics of the process. In the sand-pile example these include the duration of an avalanche relaxation event, and the size of the avalanche. The occurrence of the power law distribution is independent of the actual speed of addition of sand grains to the pile, provided only that it is sufficiently slow—hence the name *self-organized* criticality. The occurrence of power law distributions is indicative of the absence of any particular *scale* associated with the critical transition, analogous to the case of a critical state in an equilibrium phase transition of a thermodynamic system (the so-called ferromagnetic transition in the Ising model constitutes a particular instance). In contrast to equilibrium phenomena, SOC represents a non-equilibrium process where, in the critical transition, no particular spatial or temporal scale is selected by the system, i.e., in a large number of occurrences of the transition, spatial and temporal structures (e.g., the avalanche size and the duration of avalanches in the case of a sand-pile) at all scales can be identified.

3.2 Creativity as an instance of SOC: the sand-pile of the mind

3.2.1 Complexity and emergence

The evolution of a complex system involves *emergent phenomena*, i.e., the appearance of novel structures and behavior patterns at certain junctures in the process of evolution. As the overall configuration of the large number of components making up the system (represented by nodes in an evolving network) changes, generating changing patterns of vast complexity in the mutual interactions among all these components, there appear the emergent modes in the system determined by the overall configuration of components and the resulting mutually determined interactions.

While the emergence is fundamentally based on the interactions among the components, it is impossible to predict or to determine how and when it is destined to occur. What is of crucial relevance here is the *enormously large* number of *implicitly* determined mutual interactions (as in the case of a set of implicit equations referred to earlier) among the components, reminiscent of phase transitions of infinitely large systems in equilibrium statistical mechanics. The configuration of components, in other words, is determined by a vast number of mutually determined conditions, in consequence of which, the prediction of an emergent phenomenon is an intractable problem.

Emergence is based on *collective* functioning of large aggregates formed of components in a complex system (see, for background, [7]). Referring to the network representation of the system made up of nodes (components) and links (interactions), the large aggregates correspond to *clusters* with rich internal connections—ones that interact with other clusters not through the state variables pertaining to their individual components considered independently of one another, but predominantly through *collective* variables pertaining to the clusters as aggregate entities. In other words, the individual components and the clusters as large assemblies are in a mutually complementary relation—these may be referred to as the 'microscopic' and 'macroscopic' entities pertaining to a complex system. As the macroscopic entities are assembled in the course of the complex evolution of the system, these acquire an identity of their own, when collective state variables become pertinent in determining their mutual interactions, and 'microscopic' variables, in a relative sense, lose relevance (collective excitations of diverse types are known to appear in condensed matter theory close to phase transition configurations).

All the collective interactions are fundamentally based on the microscopic interactions among individual components, but can only be understood in terms of the collective variables, in which the state variables of the individual components, considered independently of one another, lose significance—the relation between the newly emergent collective variables and the microscopic variables becomes indeterminate because of the vast size of the relevant set of interactions.

3.2.2 The brain and the mind

The mind is an *emergent property* of the brain. As the neuronal organization of the brain reaches a certain stage in the process of biological evolution, collective functioning of large neuronal aggregates and their interactions through neural pathways take control over a large part of the interaction between the human organism and its exquisitely complex environment. The collective states of these aggregates and their interactions appear as mental states and mental processes, steering us through in our perilous journey in life.

The set of mental states, and the processes through which those states evolve with time—the latter arising out of the interactions among the mental states, that take place along with the interactions with the environment—make up a complex system in itself. In other words, the mind, considered as an emergent entity, is a complex system whose functioning is complementary to the functioning of the individual neurons in the brain—the system from which the mind emerges in the first place. In other words, the brain constitutes, in a manner of speaking, the complex *substratum* from which the mind emerges.

Considered as a complex system, the mind is made up of a large variety of *mental resources* such as the memories, preferences generated by affect, emotions, beliefs, opinions, concepts, intents, fantasies, cravings, and so on. Each such mental resource such as, for instance, each item of belief, can be looked at as a *collective variable* whose specification goes to specify the collective *state of the mind* at any given instant. The 'values' of all these variables taken together jointly determine the mutual interactions among the various components of the mind (a 'component' is specified in terms of each of the variables referred to above) and the way the mind interacts with the world it finds itself in.

3.2.3 Creativity as a critical transition in the conceptual space

In the present context of attempting to understand the nature of (scientific) creativity, we will be especially concerned with the vast store of *concepts* lodged in the mind of an individual, of which we have spoken above, referring to the conceptual space that can alternatively be described as an enormously complex network in which the concepts (nodes) are correlated by means of beliefs (links). The conceptual space is incessantly in a state of being restructured, with new concepts being formed and new correlations being set up by means of ongoing processes of inferences that we have referred to as an 'exploration' of the conceptual space. It is in this process of exploration that previously unconnected domains in the conceptual space ('clusters' in the network representation) get connected and a critical state is reached at some juncture—one that cannot be predicted or determined beforehand—when there follows a rapid phase of generation of an immensely fertile conjecture in the form of some remarkable analogy, and the subsequent realization of the possibility of setting up of a cascade of hugely potent novel inferences, illuminating an entire new terrain that had so long remained unexplored.

Referring to the incubation phase (sec. [**?**]) involved in a creative act as remarked by Poincare and others, a creative act more often than not involves,first, a slow process where the conceptual exploration is made to reach a tipping point when a crucial conjecture (commonly, based on some deep analogy) provides for a critical configuration in the conceptual space, followed by a rapidly cascading proliferation of meaningful inferences that illuminate a whole new terrain in the conceptual space.

The slow preparation and incubation phase consists of the following processes: (a) an intake of facts and ideas from the common pool of knowledge and viewpoints available in the society of peers and fellowmen, (b) the shutting off of the mind from external sources so that an elaborate exploration of the conceptual space may be made possible, largely released from constraints imposed by shared modes of thought and reasoning, (c) a continuous process of 'monitoring' in the said exploration, guided by affect-driven self-linked processes where a stupendous number of decisions are made, all pertaining to the issue of whether or not the exploration process converges on to some novel and fruitful explanation sought for in the creative act. As the exploration approaches a grand culmination, an existing cluster of closely correlated concepts gets linked with some relatively remote cluster that is likely to be a loose one, only sparsely correlated with the rest of the conceptual space. This process of setting up meaningful links between remote clusters appears essentially as an act of setting up a deep analogy that suddenly makes visible a new conceptual terrain beyond the horizon hitherto limiting the conceptual space. This is the critical state marking the 'Aha' moment, marking the onset of a rapid cascade of highly productive and interconnected inferences whereby a whole new set of beliefs is formed, linking the concepts that were so long residing in remote domains. A reasonably coherent framework for an emergent *theory* becomes dimly visible. It then gets transferred to an epistemic community to subject it to rigorous deliberations and fact check, making use of shared beliefs, knowledge, and views so that the community may finally find acceptable the emergent theory as a new way of looking at the world.

Creativity, in other words, constitutes an instance of self-organized criticality (SOC) and is analogous to the generation of an avalanche in a sand-pile.

3.2.4 Conceptual revolution

Scientific creativity, at times, gives rise to *conceptual revolutions* in the world of science. Such revolutions may lead to the emergence of a new theoretical framework in some domain of scientific inquiry – often expanding that domain almost beyond recognition – or may remain confined to some given domain, causing a major development within it, generating a fresh surge of ideas.

Such conceptual revolutions were highlighted by Thomas Kuhn [35] according to whom the historical course of scientific progress may be described in broad outline as an alternating succession of phases of so-called ‘normal science’ and ‘scientific revolution’. Kuhn’s description of normal science drew attention to a phase defined by a ‘paradigm’, which loses relevance as a ‘revolution’ breaks out. Normal science progresses by relatively slow accretion of ideas that steers scientific activity in some given domain to a critical state when a conceptual revolution breaks out, somewhat like an avalanche.

Such a scheme of the course of scientific progress leaves many questions unanswered and even raises some doubts, but itself serves as a useful paradigm in looking at the historiography of science. I have referred to a number of such questions and doubts elsewhere ([36]; see also [38] for my take on Kuhn’s scheme of things in the context of scientific *realism*) – even so, the paradigm of scientific progress that Kuhn outlined fits with the idea of self-organized criticality within the universe of scientific ideas which, in turn, dovetails with the scheme outlined above of the restructuring of the conceptual space within the mind of an individual.

> It has even been asked if Kuhn’s scheme relating to theory revision runs counter to the very concept of scientific progress. Kuhn’s idea relating to the acceptance (by members of a scientific community) of an emergent scientific theory over a pre-existing one has been seen as a philosophy leaning towards what is referred to as *social constructivism*. I have reservations about such branding of a point of view with a name, sharply demarcating it from alternative and apparently

contrary points of view, and giving it either a thumbs up or thumbs down sign which – though useful at times for the development of specific ideas – is, at the end of the day, uncongenial to progress as it is commonly interpreted.

Terms like 'progress' or retrogression are value-loaded and are likely to be inimical to the spirit of inquiry. Reality knows no such thing as progress or retrogression – it knows only of *incessant change* – what appears as progress in some terrain is likely to be associated with 'retrogression' somewhere else.

It is in this spirit that I include the next few lines below in this little book of mine. It may be mentioned, however, that such apparent value-neutrality is not inconsistent with taking ethical and moral stands on specific issues relating to the practice of science.

As the conceptual space of an individual engaged in an act of creativity gets restructured, their occurs a major revision in her belief system when she sees things in a new light in something like a gestalt switch. Her account of things (within the expanded conceptual domain) changes, and she starts 'talking a new language'. This eventually culminates in the emergence of a new theory that an entire community of scientists accepts after adequate scrutiny and tests against hard evidence. Analogous to the case of the individual scientist seeing things in a new light, the entire fabric of the emerging new theory seems to differ in major ways from the earlier theory. Kuhn (and Feyerabend too; however, the two were not tuned to the same wavelength in their discourse) referred to this aspect of theory change as *incommensurability* (see [58] for background). The idea of incommensurability has been severely questioned on the ground that it reduces to denying the ground for a rational choice between theories succeeding one another and for the acceptance of one over the other as a better representation of reality.

This book is not the place to examine the thesis of incommensurability or to pronounce upon it. It needs only to be stated that the relation between succeeding theories is a *complex* one – it does not pay to be too hairsplitting and to sharply pose one viewpoint against another in the midst of complexity. What is often more rewarding is a genuine interpenetration of sets of ideas perceived to belong to such opposed viewpoints. It may be argued that the idea of incommensurablity certainly says something important about theory change, though it need not be taken in the literal sense to mean a fundamental incongruity – names are no replacements for *meanings*, and meanings in this complex world of ours interpenetrate one another to a degree that often makes a mockery of abounding philosophical disputes.

> *The contrary faces of scientific creativity:* Scientific creativity engenders the eternal conflict between *irrationality* and *objectivity* that leads to the generation of a huge tension within the viewpoint of *scientific realism*. The creative process in the individual is irrational in that it makes fundamental use of self-linked psychological resources, but then, *almost simultaneously* it has to make a volte-face so as to generate an effective representation of reality—a sober 'scientific' representation, that is. Creativity in literature, arts or music, on the other hand, presents a different face.
>
> Incommensurability, in a sense, reflects this contrariness in scientific creativity.
>
> Here, incidentally, is a relevant observation by Baggott in [3]:
>
> "Theorizing involves a deeply human act of creativity. And this, like humour, doesn't fare well under any kind of rational analysis."

Incommensurability, indeed, *resides at the heart of creativity*.

Incommensurability – as opposed to incompatibility – between a revised theory emerging from an earlier one through an act of creativity is understood by referring to the conceptual space which has a *multi-layered* structure (refer to [62]), where there ar multiple types of correlations between the concepts, in which the various different types can be imagined to be stacked one above another. For instance, the term 'malfunctioning of the circulatory system' contains a number of concepts connected by means of plain English language, overlaying which is a set of correlations having specific physiological connotations. Likewise, sets of scientific concepts are typically organized in a tightly knit layered structure. For instance, when one speaks of a 'particle', one can refer to a point-like mass or, alternatively, to a wave-packet in quantum mechanical theory, or even to a certain state of a quantum field, such as a photon in the context of the quantum mechanical electromagnetic field. All such multiple layers of interconnections result in an enormously complex structure of the conceptual network and, simultaneously, in a correspondingly stupendous complexity in the evolutionary dynamics of the conceptual space.

In an act of creativity, as distant domains get correlated, mostly by analogical heuristics, not all of the multiple layers of correlations get replaced with newly emerging ones. Some of these layers are retained to a large extent, some are modified to a considerable degree, while some new layers are formed, as a result of which the restructuring of the conceptual space assumes a complex character, and the newly emerging theory appears to be related to the earlier one in contrary ways. On the one hand, it shares to a large extent earlier layers of conceptual correlations characterizing the previous theory while, at the same time, novel layers of correlation make their appearance that give an entirely new texture to the revised theory. The earlier theory can be interpreted in terms of the emerging one by referring to the layers of conceptual correlation that are shared in common by the two theories, but the converse relation does not hold—essential aspects of the emerging theory cannot be interpreted by remaining confined to the concepts as correlated in the earlier theory. In an act of creativity, the scientist pays no heed to extant layers of correlations between concepts and, experiments with new layers of meaning, as if in a fit of caprice.

This, in brief, is how incommensurability is inherent in the process of creativity.

> I repeat that in the present essay, we have mostly been concerned with creativity in science. In the case of fields such as literature, music, art and sculpture, incommensurability in creative work resides in the emergence of new genres that have different qualities, different structures, and different appeal to people, in whose minds novel combinations of emotions and other psychic ingredients are evoked.

3.2.5 Creativity at all scales

Finally, we add the important observation that creativity can be identified *at all scales* in the dynamics of the conceptual space, which is inherently an exquisitely complex one. Thus, a creative act may connect distant conceptual domains and open up the possibility of a large number of meaningful correlations between remote concepts, thereby inaugurating a new theory supplanting an existing one, or else, may generate a whole new lot of correlations *within* a domain thereby adding fresh layers in the conceptual network pertaining to that domain, giving it a new look wherein it is flooded with fresh ideas. In other words, a creative act may cause a remarkable enrichment of a conceptual domain rather than expand it in new directions. As an instance, the development of the theory of biological evolution by Darwin was without doubt a supremely productive creative act that not only changed the face of the science of biology but added a new dimension to the entire cultural world of mankind. Compared to this, the development of the idea of evolution by genetic drift was an event of a smaller magnitude where the outlines of the theory of evolution were not altered in a major way, but led to a substantial enrichment of that theory, introducing a new perspective into it. We are all familiar with highly original solutions to ordinary-looking problems developed by friends and colleagues in workplaces and other commonly occurring situations—ones recognized as results of *insight*, a phenomenon that we discussed in sec. 2.2.1 earlier. In the present context we may draw a distinction between insights that generate surges of new ideas from ones that succeed only to a limited extent, and describe the latter type as instances of creativity, though on a relatively minor scale.

> It seems likely that, apart from creativity, many other psychological phenomena in the human mind constitute instances of self-organized criticality. One other instance that comes to mind relates to—conjugal fights! These too occur on all scales, analogous to avalanches in a sand-pile.

Put differently, the creative process can take place within the confines of conceptual domain of limited extent, in which fresh layers of correlations are established across sub-domains, signaling a conceptual restructuring within the confines of the domain or else, it can cause a major restructuring, significantly altering the multi-layered structure of the conceptual space.

Creativity, in other words, can be compared to a special type of evolution of a complex network where the creation of fresh links between clusters of nodes in the network results in further links being set up in and around these clusters and in fresh layers of correlations being added to extant ones, where a restructuring of the conceptual space can take place over an extent that may be large or small. It is this phenomenon that makes it resemble a process of self-organized criticality, where we recall that self-organized criticality can occur on all scales in a complex network (sec. 3.1.2).

Chapter 4

Summing up: affect inference and analogy driving the sand-pile of the mind

In this essay, we have had a close look at creativity, mostly in the context of *scientific* creativity, and have tried to put together a framework aimed at understanding and analyzing this elusive phenomenon.

At a fundamental level, creativity consists of a complex mix of *inferences*—one of a very special kind—involving a *restructuring in the conceptual space*. The latter has a tangled and nested complex structure that can be notionally represented as a network of concepts correlated with one another by means of a web of *beliefs*, including a huge repertoire of *heuristics*.

Beliefs and heuristics active in the mind of an individual have both a shared and a self-linked aspect, where the former refers to beliefs possessed in common by a larger community while the latter are specifically associated with the developmental history of the person, making up a component of her psychological self.

Concepts are correlated with one another by means of these beliefs and heuristics, where the correlations keep on being built and rebuilt by means of an incessant succession of inferences that results in an exquisitely complex evolution of the conceptual network. An inference, launched from one or more initial premises—each made up of a number of correlated concepts to start with—proceeds through a succession of consecutive correlations established by means of beliefs and heuristics, to finally end up in a conclusion, once again comprising of a number of correlated concepts. In the process, shared beliefs are made use of in setting up a simple 'linear' chain of intermediate inferences, where the simple succession is punctuated with a number of decision junctures at each of which a choice is to be adopted among more than one disparate alternatives. This choice, and the entire chain of intermediate inferences is made possible by means of the affect system. Affect constitutes the core of emotions that plays the all-important role of reducing varied and diverse experiences to a 'common currency' corresponding to a single value-dimension, analogous to a number with either a positive or a negative sign, and a magnitude.

The reduction to a single value-dimension provides the pivot over which the entire complex of psychological processes of an individual keeps going smoothly, resolving conflicts and clearing blockades. A disruption in this causes a major disintegration of the entire mental fabric of a person. The affect system, emerging from a long evolutionary process, works equally well for the shared as well as self-linked psychological resources of an individual, and gets involved at every stage in the making of an inference. In this context, we mention that creativity in such genres as poetry, music or art involve the so-called self-linked psychic ingredients (like, for instance, the drives, desires, aspirations and frustrations of an individual) in the place of the cognitive ones like beliefs and heuristics though, once again, emotions and affect are involved as essential components in the creative process.

Scientific creativity involves a restructuring of the conceptual network whereby a cluster of concepts and beliefs, all tightly correlated with one another so as to form a theory, gets linked with a *remote* set of concepts, where the latter corresponds to one or more phenomena not explained by the theory in question. As a result of the restructuring, there takes place an extensive belief revision whereby the correlations among the previously existing cluster and those linking the remote clusters are set up, with extant correlations modified and new layers of correlations appear in the form of beliefs that make up a potentially coherent system. The previously existing domain in the conceptual space, to which the earlier theory was applicable now expands into a larger domain, in respect of which the modified correlations along with the newly established ones constitute a revised theory.

An inference takes place in some *context*, where the latter constrains the process of setting up the chain of intermediate inferences leading to a conclusion. Without such constraint restricting the exploration of the conceptual space, the making of an inference would have been an intractable process. This is analogous to the set of constraints necessary to assemble a successful search program in computation. However, a creative exploration needs to connect remote domains in the conceptual space, for which the constraint is to be relaxed so that a more effective and free exploration may be possible. This phase of free exploration in a creative act is commonly referred to as 'incubation' where the mind is predominantly in the default mode. Such a phase of exploration in the default mode is also involved in what is referred to as 'insight' where, however, the remote concepts correlated in the process belong to a relatively restricted domain. What is more, creativity is characterized by a 'domino effect' where the links set up between remote concepts quickly lead to a further set of correlations and there finally appears a whole new domain to be linked up in a major restructuring, with the emergence of a revised and expanded theory. The revised theory is given a solid foundation by an entire community of scientists on the basis of critical examination against evidence, while eliminating possible inconsistencies.

Creativity involves an apparent *non-determinism* in that it cannot be explained rationally in terms of an accepted set of principles based on a theoretical framework existing prior to the conceptual restructuring. Such non-determinism, which characterizes acts of free will as well, arises in virtue of the involvement of self-linked psychological resources in the exploration of the conceptual space by means of a huge succession of inferential processes, since these self-linked resources are specific to the developmental history of an individual and cannot be accessed by means of shared inter-subjective rules.

Further, the involvement of heuristics in the conceptual exploration makes the latter a history-dependent one since the formation of new heuristics and their activity in an inferential process take place without the inertia characterizing the more emotion-laden beliefs. Such history-dependent evolution of a complex system is known to generate an effective randomness—one that characterizes an act of creativity.

> In this context, I mention a revealing passage from [53] where the noted mathematician and mathematical physicist David Ruelle refers to the self-linked psychological resources of Newton and speculates on the role that these played in the great creative achievements of that intellectual colossus:
>
> ”The interplay between Newton’s various intellectual interests is fascinating. These interests range from the greatest achievements in mathematics and physics to disreputable speculations (by present-day standards) about alchemy, history, and religion. It is tempting to apply censorship to Newton’s intellectual production and decree that some is good and the rest better forgotten. If, however, we want to understand the process of intellectual creation in Newton’s mind, we cannot forget his disreputable speculations. In his desire to grasp the meaning of the universe the research on the prophecies or alchemy was not less important than the work on gravitation or differential calculus. A lot, obviously, remains to be understood on how Newton’s mind functioned.”

Of fundamental relevance in the process of correlation of remote concepts are heuristics based on *analogy*. In a broad sense, every inferential activity is in the nature of an analogy since, speaking in general terms, an analogy is a mapping from a source concept to a target concept. Analogies have the ability to connect remote concepts as much as they can connect contiguous ones in the conceptual space. Those connecting remote concepts appear as deep ones since these throw light upon additional clusters lying on the routes between the source and target concepts. Analogies, in other words, constitute the very essence of creativity, making possible major restructurings in the conceptual space by means of the cascade effect found in self-organized criticality (SOC).

Scientific creativity makes possible the emergence of a revised and expanded theory replacing a previously existing one that has failed to explain some particular set of facts by means of the conceptual correlations characterizing the earlier theory, where these correlations were confined to a restricted domain in the conceptual space. Such episodes of theory revision are referred to as conceptual revolutions and raise the question as to whether and in what sense the revised theory can be said to be *incommensurate* with respect to the earlier theory. As we have seen, incommensurability is related to the multi-layered structure of the conceptual space, where not all of the layers get modified to an equal degree in the conceptual restructuring while, additionally, new levels of correlations are set up among the concepts in an expanded conceptual domain.

Finally, acts of creativity can occur on various *scales* in the conceptual space – not only connecting up distant domains in it, but connecting sub-domains within a domain, or enriching the correlations within a domain and generating a new set of concepts along with a new layer of correlations within it. This accords with the idea that creativity may be looked at as an instance of self-organized criticality (SOC) in the conceptual space, where we recall that critical processes are known to be scale-free. SOC involves time-scales of widely differing magnitudes, with a phase of slow build-up to a tipping point and a subsequent phase of rapid reorganization to a new configuration with a novel emergent structure. In this, avalanches in a sand-pile—where a slow addition of sand-grains leads to a critical state that gives way to an avalanche—constitute a model of the phenomenon of creativity in the human mind.

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