Mapping Human Creativity

Hussein Zedan[*]
Antonio Cau, Keno Buss and Sascha Westendorf
Software Technology Research Laboratory
De Montfort University, Leicester, U.K.
www.cse.dmu.ac.uk/STRL/

Andrew Hugill and Sue Thomas
Institute of Creative Technologies
De Montfort University, Leicester, U.K.
www.ioct.dmu.ac.uk/

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Abstract

- *Is it possible to map Human Creativity in a way similar to that of the Human Genome?*
- *Do mechanisms of the creative processes cross the boundaries of disciplines?*
- *Are there optimal conditions that may enhance human creativity?*
- *How does cooperation/collaboration affect creativity?*

To shed some light on all of the above questions, we provide a unifying framework within which the creative processes (and hence creativity) can be understood and analysed. The unification here is in the sense that the proposed framework is discipline-independent. Co-creation and the effect of collaboration on the creative processes are properly addressed as concurrency is treated as a fundamental dimension within our theory. Being formally sound, the proposed allow us to reason about temporal properties which governs the nature of creative processes. The approach is supported by a tool set, known as the De Montfort Creativity Assistant which consists of two major pluggable components: (1) De Montfort Collaborative environment, an integrated tool support which allows real-time collaboration between creators; and (2) the Creativity Mapper which maps the creativity process of a creator. Creativity maps from a number of disciplines (art and engineering) are produced as illustrative examples of the approach.

Keywords:

Creativity, Creative process, Unifying theory, Generalised Transition System, Co-creation, De Montfort Creativity Assistant, Creativity Mapper.

[*] *To whom all correspondences should be made: Software Technology Research Laboratory, De Montfort University, Gateway Building, The Gateway, Leicester LE1 9BH (zedan@dmu.ac.uk)*

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1 INTRODUCTION

1.1 Motivation

Conceptual advances have always been the driving force behind progress. This in turns relies on *creativity* and the ability to continue the production of new insights and novel ideas. For example, in *science* we can see many accounts of breakthroughs that dramatically affected our lives:

- *Medical* discoveries such as Fleming's Penicillin and Salk's Polio vaccine;
- *Chemical* discoveries such as Mendeleev's formulation of the Periodic Table of Elements;
- *Cosmological* discoveries such as Newton's formulation of the General Law of Gravitation, and Einstein's Law of Relativity.

To set up the scene and motivate our work, we take an example from biological sciences and another from mathematics where the notion of *mapping* has proved successful.

Biological sciences have been particularly revolutionised by insights such as the discovery of the DNA double helix. Such a discovery has led to the identification of key genes, relating to organ development and programmed cell death, and has proved vital to the understanding of what happens when certain bacteria and viruses, such as HIV, invade cells or when neurological disease occurs. As a consequence of these advances, the *Human Genome Project* started in 1990 to determine the complete sequence of the 3 billion DNA subunits (bases), identify all human genes, and make them accessible for further biological study. The project was considered one of last century's Grand Challenges and was planned to last 15 years, but rapid technological advances accelerated its completion to 2003. Consider the following:

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gttgaggggtgttgagggcggagaaatgcaagtttcattacaaaagttaacgtaacaaa
aatctggtagaagtgagttttggatagtaaaataagtttcgaactctggcacctttcaat
tttgtcgcactctccttgtttttgaca

atgcaatcatatgcttctgctatgttaagcgtattcaacagcgatgattacagtccagct
 M  Q  S  Y  A  S  A  M  L  S  V  F  N  S  D  D  Y  S  P  A
gtgcaagagaatattcccgctctccggagaagctcttccttcctttgcactgaaagctgt
 V  Q  E  N  I  P  A  L  R  R  S  S  S  F  L  C  T  E  S  C
aactctaagtatcagtgtgaaacgggagaaaacagtaaaggcaacgtccaggatagagtg
 N  S  K  Y  Q  C  E  T  G  E  N  S  K  G  N  V  Q  D  R  V
aagcgacccatgaacgcattcatcgtgtggtctcgcgatcagaggcgcaagatggctcta
 L  R  P  M  N  A  F  I  V  W  S  R  D  Q  R  R  K  M  A  L
gagaatcccagaatgcgaaactcagagatcagcaagcagctgggataccagtggaaaatg
 E  N  P  R  M  R  N  S  E  I  S  K  Q  L  G  Y  Q  W  K  M
cttactgaagccgaaaaatggccattcttccaggaggcacagaaattacaggccatgcac
 L  T  E  A  E  K  W  P  F  F  Q  E  A  Q  K  L  Q  A  M  H
agagagaaatacccgaattataagtatcgacctcgtcggaaggcgaagatgctgccgaag
 R  E  K  Y  P  N  Y  K  Y  R  P  R  R  K  A  K  M  L  P  K
aattgcagtttgcttcccgcagatcccgcttcggtactctgcagcgaagtgcaactggac
 N  C  S  L  L  P  A  D  P  A  S  V  L  C  S  E  V  Q  L  D
aacaggttgtacagggatgactgtacgaaagccacacactcaagaatggagcaccagcta
 N  R  L  Y  R  D  D  C  T  K  A  T  H  S  R  M  E  H  Q  L
ggccacttaccgcccatcaacgcagccagctcaccgcagcaacgggaccgctacagccac
 G  H  L  P  P  I  N  A  A  S  S  P  Q  Q  R  D  R  Y  S  H
tggacaaagctgtag
 W  T  K  L  *

gacaatcgggtaacattg
gctacaaagacctacctagatgctcctttttacgataacttacagccctcactttcttat
gtttagtttcaatattgttttcttttctctggctaataaaggccttattcatttca
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This sequence is known by geneticists as *gene expression*. Important characteristics of this expression is that it is articulated only using a small and fixed numbers of letters a, c, t and g. The expression is divided into three distinct sections: a header and a footer (identified here by the colour red) signifying the beginning and end of the gene. Between these two sections lies the actual representation of the gene. The whole expression *maps* a gene known as SRY which is responsible for human sexual organ characteristics and identification. Geneticists also tell us that both the header and footer contain information relating to the origin of our ancestor's sexual origin, including how it evolved, etc[1]. The SRY gene is a fraction of the whole human genome which was mapped using only those four letters.

Our second example is taken from mathematics and, in particular, mathematical proofs or reasoning. By reasoning we refer to *logical* reasoning, not of common-sense reasoning.

Fundamentally, reasoning is the process of systematically drawing *conclusions* from a number of given *facts* by applying a series of logical steps. There is no doubt that those steps, by their brevity and unexpected turns, may strike its reader as being very ingenious constructions. Dijkstra [4] has observed that:

> *"...many of those steps that may seem surprising, at first sight, are, in fact, (almost) dictated, as they are the only (or by far the simplest) transformation that will enable to exploit one of the givens that has to be taken into account." [sic]*

In this connection, he recommended that:

> *" ...we maintain as fine grained a bookkeeping as possible of what of the givens we have used: what has not been used yet often indicates the direction in which the proof should be completed. " [sic]*

Here we are interested in *"automated" reasoning*. The object of automated reasoning is to construct computer programs that assist (fully or partially) in solving problems and in answering questions requiring reasoning. The assistance provided by an automated reasoning program is available in two different modes: The program may be used in an iterative fashion; that is, instructions are given to draw some conclusions, and then, based on the user's analysis of the conclusions, it can in the next run execute a new set of instructions and so on. Or such a program may be used in a batch mode; that is, the entire reasoning task is provided and the final result is awaited.

The steps involved in the proof and their sequence of application form what is often known as proof plan or strategy which can be re-used or be the basis for the formation of another plan (e.g. same steps with different sequencing or ordering) for a different conclusion. Such a plan together with the mood and rationale of its creator is what we call here *proof map*.

Building an automated reasoner involves the provision of an algorithmic description to a formal calculus so that it can be automated to prove theorems of the calculus in an efficient manner. Important aspects of this exercise involve: (a) defining the class of problems the program will be required to solve; (b) deciding what language will be used by the program to represent the information given to it as well as new information inferred by the program; (c) specifying the mechanism that

the program will use to conduct deductive inferences, and (d) figuring out how to perform all these computations efficiently. For example, using the equational prover EQP[16] and the following set of axioms

a1 $x+y=y+x$ (*commutativity*),

a2 $(x+y)+z=x+(y+z)$ (*associativity*) and

a3 $-(-(x+y)+-(x+-y))=x$,

[1] In fact this gene mapping has indicated that the *female* sexual organ is the default and that the male counterpart is its mutation!

we are able to prove:

$-(-x+y)+-(-x+-y)=x^2$.

While basic research work continues in order to provide the necessary theoretical framework, the field has reached a point where automated reasoning programs are being used by researchers to attack open questions in mathematics and logic, and to solve problems in engineering. It is important to observe that the existence of such automated reasoners or theorem provers did not hinder the creativity of neither the mathematicians nor the logicians; on the contrary, the research area remains extremely active.

Therefore, given the importance of creativity and creative thinking, is it possible

- to *map* Human Creativity, in a way similar to that of, for example, the Human Genome?
- for the creative processes, behind a given discovery and within a given discipline, to rely on mechanisms that are similar across disciplines as diverse as art and science?
- to create optimal conditions in an (research) organisation with the aim of enhancing the creativity of its staff? and
- to discover the effect of cooperation/collaboration on creativity[3]?

In this paper we provide a theoretical framework together with a sound notation with which creativity and the creative processes can be understood and analysed. The framework provides a unifying theory for creativity in the sense that it is discipline-independent. As the nature of creativity strongly depends on the ‘cultural environment’, such an environment is treated in our framework as one of the many *viewpoints*[4]

Concurrency is an important dimension in our theory as it allows the analysis of *co-creation* and the effect of collaboration in the creative processes. Our unifying theory of creativity is sound allowing us to reason about (temporal) properties governing the nature of the creative processes. It is also supported by a tool set, known as *the De Montfort Creativity Assistant*. The construction of creativity maps is illustrated using two creations from the art and engineering domains.

1.2 Paper structure

The paper is structured as follows: the next section articulates some of the forces, challenges and models used for creativity and gives a set of premises which we put forward as *Axioms of Creativity*. Section Three gives an overview of our *creativity mapping* model. In this section the treatment is given informally and provides the intuition behind our approach. Section Four gives the formalisation of the approach. A generalisation of the traditional transition system is presented and a formal treatment of the *creative structure* together with our proposed *creativity mapping* notation are given. In this section we give some algebraic laws (*Laws of Creative Processes I & II*) which provide the needed machinery for analysing and reducing the complexities in the creativity maps. Section Five describes the De Montfort Creativity Assistant, a tool support for our unifying approach. Our supporting tool has two fundamental and pluggable components: De Montfort Collaborative Environment (allowing a real time collaboration) and the Creativity Mapper which maps creativity. Section Six provides illustrations of our approach by conducting a number of experiments from Music and Software Engineering domains. The paper ends with some conclusions and modest auguries to stimulate further insight.

[2] For brevity, we eliminated the proof map, however a proof could be found in [10]

[3] The cooperation/collaboration may be, in some circumstances, restricted or constrained , in some ”forms“, to further enhance creativity.

[4] *Viewpoints* of a similar nature are often grouped into categories. In this paper we sometimes use the terms *(sub)activity* and *viewpoints* interchangeably.

2 FORCES, CHALLENGES AND AXIOMS

Understanding and analysing *creativity* and the *creative processes* is hard and has been for a long time a major concern of many scholars across the spectrum, from the arts and literature to the sciences and engineering. *Identification, cultural* and *evaluation* are just a few of the challenges that characterise creativity and its processes.

The identification of creativity has been most commonly through its *products*. For example, in architecture, music, writing, fine art, puzzle solving and scientific discovery, the presence of a creative product(s) is a fundamental prerequisite for considering creativity.

Anecdotal descriptions have been also used to identify processes that are considered creative. Many discoveries (specially in the sciences) were linked to a sudden realisation or unexplained *divine intervention* associated with what is known as the *AHA! response*[5]. For example, Newton's falling apple (which has been since disputed!), Archimedes' "Eureka" moment in a bath or Mendeleev's dream are well known examples. Would it have been profitable if we had some records of what Isaac Newton was thinking, together with, his moods "before" and "after" the fall of that apple? Equally, it would have been extremely interesting and useful to have known Archimedes' moods "before" and ''after" he went to that famous bath! And surely, knowing Mendeleev' states "before" and "after" sleeping might have shed some lights on his discovery. The ''before" and ''after" states of mind are very powerful mechanisms to analyse creativity and the creative processes.

Outside of the creative product itself and the AHA! response, the kinds of concrete evidence that point to the process of creativity are indeed very few.

At its core, creativity is both *subjective* and *domain-oriented*. What is creative to one, in a domain, may not be perceived as creative (at all) by another, even in the same domain! A creative theorem prover may be meaningless to an artist. Software engineers have begun to talk of a ''beautiful" system design and that computer programs have aesthetic features. To a composer, such aesthetics may not be even noticed nor comprehended Even within a single domain, subjectivity is so overwhelming! Take, for example, (creative) writers. Some will adamantly reject the existence of a number of writing styles. Yet they are more than willing to judge others of writing in the style of this or that writer.

Both *novelty* and *value* have often been attributed to creativity. These attributes are very hard to evaluate. Two products/artifacts, for example, can be compared only if they have been intended for the same, or similar, purposes and had been created within appropriate context (including cultural context). One can easily and randomly put together a set of not previously seen shapes, words, tones, colours or chemicals and produce a product/artifact. Just because they are new, or have not been seen before, it does not make them valuable pieces of art, architecture, music, or synthetic compounds. The value of the creative product is measured by the society that **receives** the product.

Adding to the challenges is that creativity has a *temporal* dimension. What is judged being creative ''now" may not be so at the time of its creation. In the domain of artistic creativity, many examples of *masterpieces* were deemed to be highly creative well after the artists died. Furthermore, the value attributed to a product may be a function of when it materialised and emerged. Just as their novelty may be determined by other already existed products at the time of their creation, their value is also a function of what other products are deemed valuable. For example, the value of Fossil fuels discovery has clearly raised as it was put in the context of the automobile and aviation technologies. In the absence of these drivers, the value associated with the discovery would have been probably trivial or even not recognised at all.

[5]The AHA! response is the manifestation of a "surprise" element that results in the discovery of a new problem description or frame of reference, which theretofore was not available. Often, this discovery leads to the emergence of the problem solution. The phenomenon seems to be more important for the socio-psychological aspects of discoveries and creative inventions, than for the cognitive psychology of creativity.

Over the past century or so, there have been many models for creativity. Some dismiss the notion that creativity can be described as a sequence of steps in a model. For example, Vinacke [2] insisted that creative thinking in the arts does not follow a model. In a similar vein, Gestalt philosophers, like Wertheimer[8] , assert that the process of creative thinking is an integrated line of thought that does not lend itself to the segmentation implied by steps in a model. But while such views are strongly held, they are in the minority.

In business, where models are used for quality improvement, strategic planning, re-engineering, and so on, are well-positioned to deal with this apparent controversy. Whilst models may appear to be useful and helpful in guiding our efforts, they should not be used too rigidly for that is perceived, by some, to constrain creativity. On the other hand, even if we deviate substantially from a model in a given situation, this does not render the model useless. It is also important to understand that we should not be too rigid about when one step of a model ends and the next begins.

Arieti [1] reviewed eight models of the creative thinking processes that were proposed during the period 1908 to 1964. Many other additional models have been since proposed. Most of these models have a common characteristic: they depend on a balance between *analytical* and *synthetic* thinking and usually describe the *creative process* as a sequence of phases that alternate between these states. For example, the often cited Graham Wallas' Model [6, **?**] has four phases:

- *Preparation* (definition of issue, observation, and study)
- *Incubation* (laying the issue aside for a time)
- *Illumination* (the moment when a new idea finally emerges)
- *Verification* (checking it out)

The implied theory behind Wallas' model (and similar older models) is that the creative thinking is a *subconscious* process that cannot be directed, and that creative and analytical thinking are complementary and is reflected to varying degrees in other models of creativity.

Modern models however tend to imply *purposeful* generation of new ideas, under the direct control of the thinker as is reflected in Paul Plsek's *Directed Creativity Cycle* model [12].

And that the total creative process requires a drive to action and the implementation of ideas. We must do more than simply imagine new things, we must work to make them concrete and real.

2.1 Axioms of Creativity

We start our study by formulating three premises which we believe are *fundamental* to understand and, hence, analyse the notion of *creativity*. We call these the **axioms of creativity**[10]. These are:

A0. Creativity is identified only by its product. How can we possibly identify creativity that was involved in the production of a painting or a musical composition without seeing the painting or hearing the music? Identifying the effect of creativity is similar to demonstrating the existence of electricity, which we can only realise through many of its uses including a switching on a light bulb or a washing machine! The precondition of creativity lies in its manifestation in a concrete and tangible product[6].

[6] The "origin" of a creation is an issue that will concern authentication authorities and that the proposed creativity maps may be of some benefits. However this issue is outside the scope of the paper.

A1. The value of creativity is determined only by the society it receives it. The valuation of creativity seems to have created a drift in the community. Some reject the idea of evaluation altogether as it can be seen to hinder creativity. The notion of evaluation leads naturally to the question of how we can judge that one creation is *better* than another within the same domain of creations: a painting X is better than Y or a piece of literary work A is more creative than another. Perhaps the price tag associated with painting X is higher than that associated with Y. Or the judges of a particular *Booker Prize* committee decided that A involved more creative thinking/efforts than other literary works. Whatever metric is used, it is best left to the society that receives the creation[7].

A2. Creativity is an emergent phenomenon. There is no doubt that creativity is an *emergent* phenomenon in which the *whole* (i.e. the creative process) is larger than the sum of its *parts*.

The emergence of a new steady state in a *dynamic system* occurs abruptly as it passes a particular threshold. The system was not designed to exhibit such a behaviour *a priori*. The important aspect here is that the new state was *unexpected*. Such a new state could be a desirable one but it could be also chaotic state. Being an emergent behaviour, we would have no idea of which type it would be.

As the creative process describes a complex system, that results in a creation, it exhibits emergent behaviours that occur abruptly, spontaneously and suddenly resulting in a creative insight. Some of those behaviours could be chaotic (in the literary world, it is manifested by a complete dislike of the work). The difficulties with emergence is that it is an environment-dependent: what is chaotic in one environment may not be so in another. It is important to note that emergent is different from the *divine-intervention* phenomenon (i.e. the AHA response!).

3 CREATIVITY MAPPING MODEL: AN OVERVIEW

In this section an outline of our *Creativity Mapping Model* is given. The outline is kept rather informal and is given from an operational viewpoint as a means of rationalising its basic components.

We focus here on the behaviour(s) of the *creator* albeit a writer, composer, painter, engineer or a scientist, and not on the *creation* itself. We place no value judgments on what is being created, as such value is normally placed by the society that receives the creation (c.f. Axiom **A1**).

Let us begin by considering the *zone* of creation which is a space where the *observed* behaviours of the creator are recorded. Initially, the zone is 'empty'. Unlike, for example, a canvas, a score sheet, a paper or a piece of clay, the creation zone contains a faithful recording of the creator's *moods* and their *dynamics*, see Figure 1.

Moods represent the *states* of the creator. The creative process is thus captured through observing the changes in the states. Clearly, what it can not be observed, can not be recorded.

In Figure 1, the states are represented as black dots and the changes from one state to another is represented by lines connecting those dots. Those are known as *transitions*.

The double arrow is pointing to the state where the recording of the creative process(s) has started. We call this the *initial state*.

Collaboration/cooperation can also be represented as illustrated in Figure 2. Here the creation zone is split into two sub-zones, one for each creator, and initially, the creative process starts at both a_1 and b_1 simultaneously. The creative processes are recorded, in the normal fashion, each in their allotted sub-zone. We note that the two

[7] We assume here that fairness and transparency/openness are implicit characteristics of their judgments!

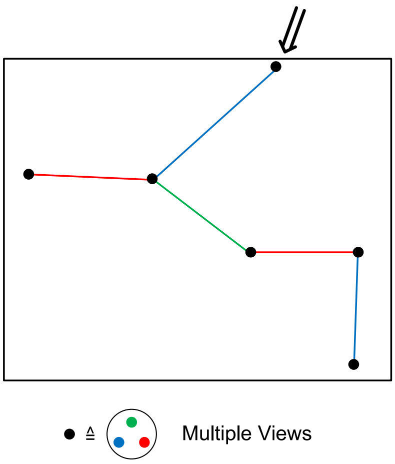


Figure 1: Creation Zone

creators may share common moods. The important issue here is that both creators share the state of the creation itself which has to be kept consistent in both zones and throughout the creation life cycle.

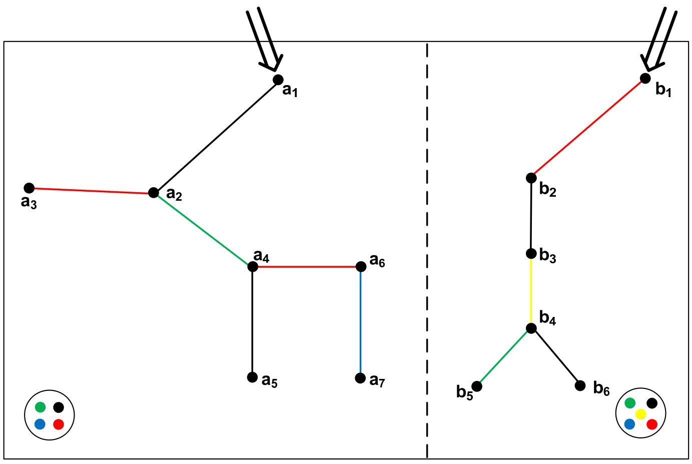


Figure 2: Collaboration/Cooperation Zone

In our setting, and unlike traditional finite state machines [21], we have no distinct final state. Indeed every state may be considered, by the creator, as a final state. Our rationale stems from the fact that any state in the creation's life cycle may be considered, by the creator, as a final state (although it might not be so by others).

Transitions in the creation zone represent different *viewpoints* of the creation process(es). In Figure 1, for example, four distinct views can be seen: the red, black, green and blue views. Identifying the various distinct *views* of the creation is crucial in capturing and recording the creative process(es). The effect of these views are encoded in the states. States becomes rather complex as each carries multiple views of the creator. These views are represented by smaller dots inside the black dot and are colour-coded. Each colour represents a particular view of interest[8]. For example consider *time, knowledge*, and *contemplation* to be some particular views of a creator representing the passage of time, the acquisition of knowledge and the act of thinking, respectively. A "knowledge" transition here means a change in the creator's "knowledge" mood and hence change in the "knowledge" state.

[8] It may also include the state of the creation itself.

Transitions may also be directed to add further clarity to the dynamism of the creative process, as illustrated in Figure 3.

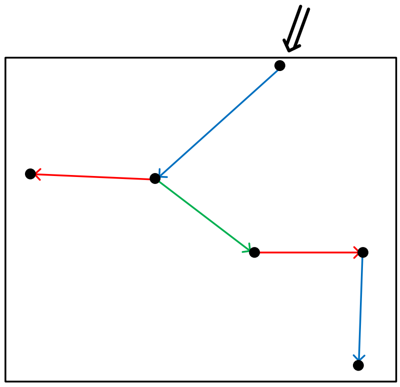


Figure 3: Directed Transitions

In many circumstances, changes in more than one view at the same time can occur. For example , in Figure 4, if the 'green' view represents time consumption, then we can infer that every transition consumes time. Similarly, the creator may have *contemplated* whilst *acquiring knowledge* and both have *consumed time*. All three transitions occurred at the same time!

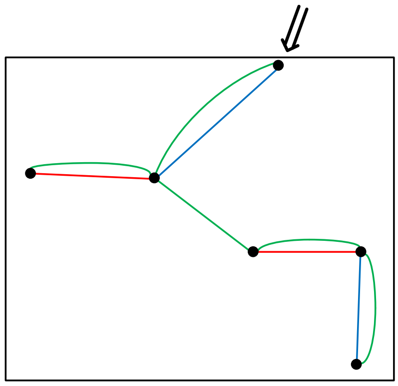


Figure 4: Multiple Transition

The figure also shows a snap-shot of a *creativity map*. Various analyses, such as optimisation, tagging, clustering and classification, could be performed over such a map. For example, given a creator in a particular domain, we may store a number or all of her/his maps and, using existing data/text mining technologies, we can explore the existence of particular pattern(s) which will identify unique characteristics about the creator. Similarly, we can perform the same analysis to discover characteristics about creators from different domains; hence studying how creativity crosses the boundaries of disciplines.

Viewpoints may be classified into two major classes: *External* viewpoints which are forces in the environment within which the creation is being made, and may indeed influence the creator directly. These forces include, social, political, psychological and even religious forces. A deadline for completing a creation is an example of an external force. The second type of viewpoints is what we call *local* which are directly related to the various activities in which the creator will be engaged. The choice of viewpoints is hard as it necessitates a process of abstraction, i.e. hiding viewpoints which are deem to be irrelevant, and we have to be mindful of the fact that these may have an affect on our analysis.

In some circumstances, a creator may choose a certain transition more (or less) often than another. Such a situation could be modelled in an extended version of our current framework by labeling transitions by a probabilistic metric measuring the probability of taken a transition. For example, given creator we may study and analyse all of his/her creative maps and infer that a particular transition is taken with a probability of, e.g. 0.6. However, in the current version of the model, we place no such probabilistic measure and thus we assume that transitions carry equal probabilistic chance of being taken.

As a creativity map represents a discretisation of a creative process, the elapse time is also discrete and that each transition consumes one clock tick. Each map has a global clock (an oracle) which is updated once a transition is completed.

Furthermore, *hopping* is another important phenomenon in the creative process. In the process of creation, creators usually and continually hop, mentally and physically, from one creation zone to another which may result in an enlargement of its state space, as depicted in Figures 5 & 6.

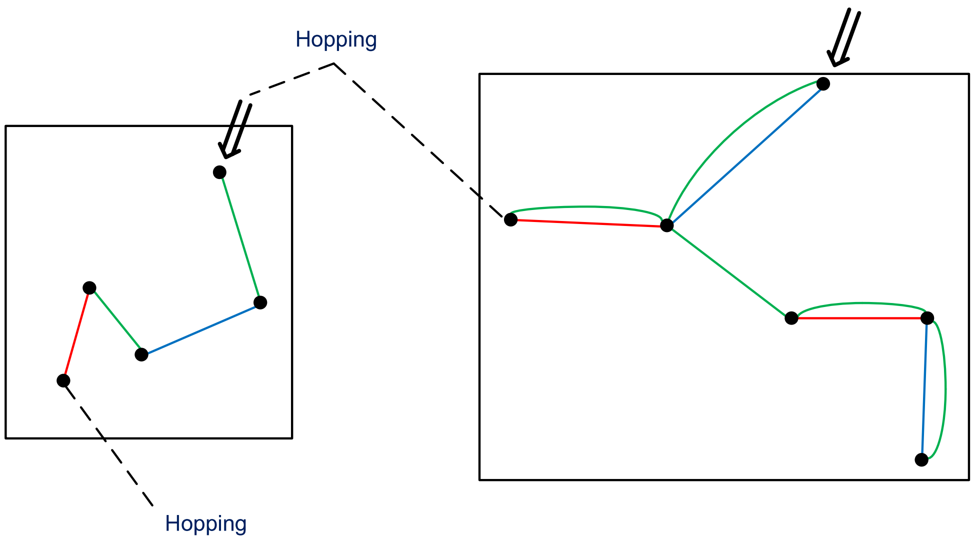


Figure 5: Hopping between domains

Hopping provides a conceptual model for interaction and collaboration amongst individuals which is critical to creativity. Creative activity often grows out of the relationship between individuals and their work, and from the interactions between an individual and others (perhaps in different field). Because complex problems require more knowledge than any single person possesses, participation, communication and collaboration between stakeholders is necessary.

Hopping may also end in what we call the *black hole* of creativity. This models the situation where the creator decided that the current process will not lead to a productive creation. It represents the *death* of creativity if that particular path is followed!

States and transitions within the creation zone will ultimately end with a complex structure similar to that of a *tumbleweed* structure. In Figure 7, some of those structures are visualised. In a tumbleweed, a "tweak" represents one or more transitions. A tumbleweed may continually grow until the creator is satisfied with the creation.

In such a visualisation, given two tweaks from two different tumbleweeds, we can study and analyse the complexity of both with respect to particular views, for example contemplation and time. Such a comparison can also serve as a useful tool to adequately characterise creative process maps.

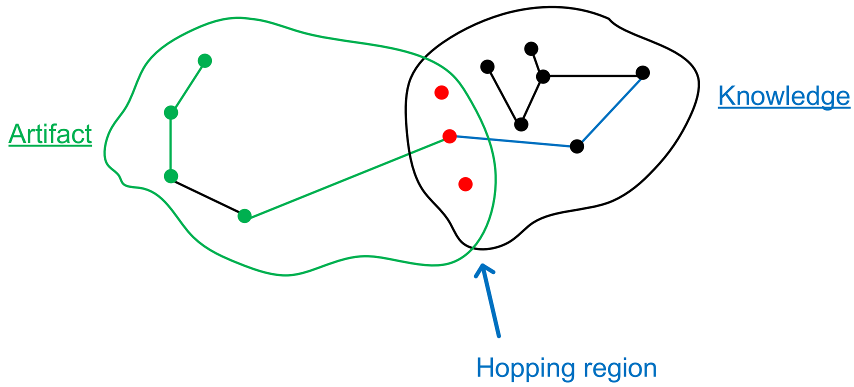


Figure 6: Hopping region

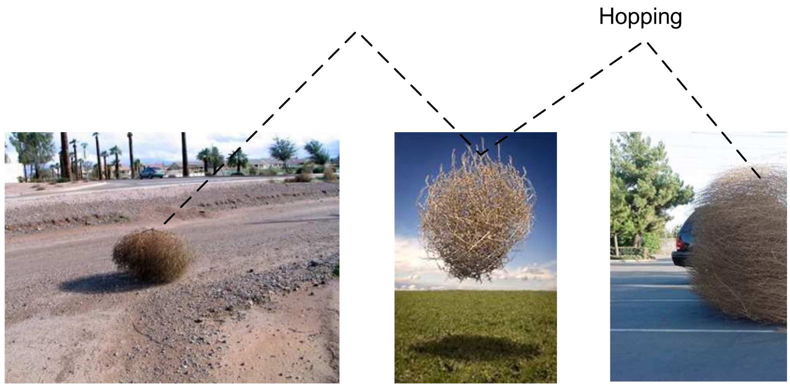
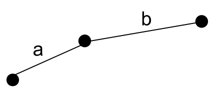


Figure 7: Tumbleweed structure

4 CREATIVITY MAPPING MODEL: A FORMALISATION

In this section we give a formal underpinning of our *Creativity Mapping Model* outlined above. Our formalisation generalises the traditional *transition system*. The classical notion of a transition system uses a *fixed* relation between states and every system has its own set of *actions* which are used to label transitions.



For example actions a and b are used in the above system to control the dynamics of the system. Such a traditional view does not adequately model the creativity process. What is needed is a semantic model with *multiple* relations and each is associated with its own set of actions; as depicted in Figure 8.

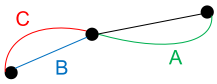


Figure 8: Generalised Transition System

In this *Generalised Transition* System, there may be more than one relation between states (the *red, blue* and *green*) and actions vary from one relation to another (in this case we have A, B and C).

4.1 Generalised Transition Systems

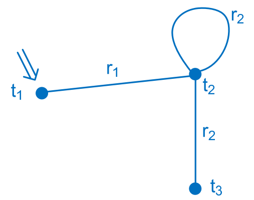
Let *Var* and *Val* be a set of possible variables of interest and *Val* be a set of their values. Let Σ be a set of *states*, that we are interested in observing, and that σ_i is an element: $\sigma_i \in \Sigma$. A state maps a variable to its value, i.e. $\sigma_i : Var \rightarrow Val$.

A *transition* r (sometimes denoted by $\rightarrow_r$) is a relation between two states, $r \in \Sigma \times \Sigma$

Let R be a set of transitions, i.e., $R \in P(\Sigma \times \Sigma)$, the structure consisting of Σ and R, (Σ, R), is called a *Generalised Transition System*.

4.1.1 Examples

Example (1) *Clock transition systems.* In this system we have a clock with only one hand. It has four states and the advancement from one state to another depends on the transition it will take.

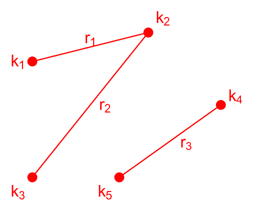


There are two relations: r_1 moves the hand by *exactly* one tick, whilst the other relation r_2 can either stay stationary (i.e. don't move the hand at all) or moves it by an unknown numbers of ticks. This Clock system is defined as follows: let $Var = Clock$ and $Val = \mathbb{N}$. The two transitions are:

$\rightarrow_{r_1} ::\ t_i\ r_1\ t_{i+1} \mathrel{\widehat{=}} (t_{i+1} = t_i + 1)$

$\rightarrow_{r_2} ::\ t_i\ r_2\ t_{i+1} \mathrel{\widehat{=}} (t_{i+1} \geq t_i)$

Example (2) *Knowledge transition systems.* Here we have two creators each with her/his knowledge set. Here, the state space of interest contains three states for the first creator and only two states for the second.



For the first creator, there are two relations, r_1 and r_2, which describe the dynamics of acquiring knowledge. These are given as follows:

- $k_2\ r_2\ k_3 \mathrel{\widehat{=}} (k_2 = k_3)$
- $k_2\ r_1\ k_1 \mathrel{\widehat{=}} (k_1 > k_2)$

Note that r_1 maintains the creator's level of knowledge (i.e. there is no changes). However, the second relation, r_2, increases the creator's level of knowledge by an unknown quantity. Measuring the acquisition of knowledge is left unknown.

The dynamics of the second creator's knowledge is described by the relation r_3 which can either maintain its level or decline , i.e.:

- $k_4\ r_3\ k_5 \widehat{=} (k_5 \leq k_4)$

4.2 Special Transitions

There are a number of special transitions which are useful in the analysis of creativity maps. These transitions have algebraic properties allowing us to manipulate and study equivalence relations between different maps.

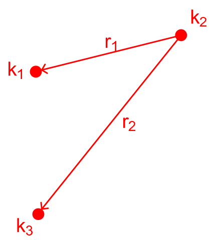
To begin with, let us formally define the *start* and *end* of a transition. For a given transition $\sigma_i\ r\ \sigma_j$, we define the *start* (*St*) and *end* (*Et*) of a transition as two functions:

$$St : \Sigma \times \Sigma \rightarrow \Sigma \ \cdot$$
$$if \ \ \sigma_i\ r\ \sigma_j \ \ then \ \ St(r) = \sigma_i,$$

and

$$ET : \Sigma \times \Sigma \rightarrow \Sigma \ \cdot if \ \ \sigma_i\ r\ \sigma_j \ \ then \ \ Et(r) = \sigma_j.$$

For example, in the *Knowledge* system above, we have



$St(r_1) = St(r_2) = k_2$, $Et(r_2) = k_3$ and $Et(r_1) = k_1$

St and *Et* provide a powerful means of defining the *direction* of a

transition and hence the dynamic flow of creativity maps. Obviously $St(R) \widehat{=} \bigcup_{r \in R} St(r)$ and $Et(R) \widehat{=} \bigcup_{r \in R} Et(r)$.

Some special transitions are now identified:

1. ε-transition. For any Σ, an ε-transition, Figure 9, is defined as:

$$\forall s \in \Sigma : \quad s \;\; \varepsilon \;\; s.$$

Figure 9: ε−transition

The ε transition may be used to model the situation where the creator has "chosen" not to make any progress at all in all the viewpoints that are directly related to the creation. We can think of the ε transition as a particular moment where the creator has decided to stop creating but may return to it at some future time.

2. ***ANY*-transition.** For any Σ, an *ANY*-transition is:

$$ANY \;\widehat{=}\; \Sigma \times \Sigma.$$

The *ANY*-transition represents the *maximal* transition, or the set of *all possible* transitions.

3. ***NULL*-transition.** For any Σ, a NULL-transition, ϕ, is defined as follows:

$$\forall \sigma_1, \sigma_2 \;\in\; \Sigma : \;\; \neg\,(\sigma_1 \;\phi\; \sigma_2),$$

where $\neg\,(\rightarrow_r) \;\widehat{=}\; (\Sigma \times \Sigma) \setminus \rightarrow_r$. Unlike *ANY*, ϕ is the *minimal* relation. ϕ is a transition that does not exist within the space of all possible transitions for that creation. We observe here that Σ and ϕ represent the top and bottom (respectively) of a lattice structure, under the inclusion,$\subset$, relation that is formed by all transitions in the creative processes of the current creation.

4.3 Operations

Operations over transitions are important for they allow us to compose and hence describe the dynamic nature of the creative process. Here we define the minimal set of operations; namely *choice* (denoted by $+$) and *sequential* composition (represented by ;). Later, we will introduce concurrency operations and demonstrate their use in analysing the effect of collaboration/cooperation on creativity.

4.3.1 Choices ($+$, $\widetilde{+}$, $\underset{\sim}{+}$)

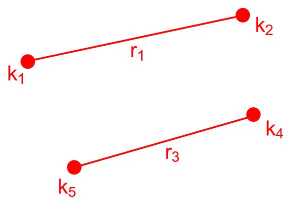
Capturing alternative creative paths is fundamental to the creative process. Here we identify three types of choice: branch, merge and general choice.

- **General Choice.** The general choice operator $+$ is defined as follows:

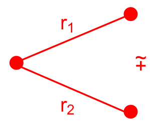
$$\rightarrow_{r_1} + \rightarrow_{r_2} \widehat{=} \{(\sigma_i, \sigma_j) : (\sigma_i \rightarrow_{r_1} \sigma_j) \vee (\sigma_i \rightarrow_{r_2} \sigma_j)\}$$

The choice operator produces a set of transitions that are induced by one relation or the other. For example in the *Knowledge* system we have a disjoint choice between r_1 and r_2:

$\rightarrow_{r_1} + \rightarrow_{r_3} \; = \; \{(k_2, k_1), (k_4, k_5)\}$



- **Branching.** It is also natural for a creator to reach a state from which a *branching choice* may be taken. Similarly, from two states, a *merge choice* may be taken. These are formally defined as follows.



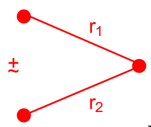
Branching

$\rightarrow_{r_1} \widetilde{+} \rightarrow_{r_2} \widehat{=}$

$$\begin{cases} \rightarrow_{r_1} + \rightarrow_{r_2}, & St(\rightarrow_{r_1}) = St(\rightarrow_{r_2}) \wedge \\ & Et(\rightarrow_{r_1}) \neq Et(\rightarrow_{r_2}) \\ \phi & otherwise \end{cases}$$

As you can see the branching operator is defined as choice with the start point of the branches being identical.

- **Merging.** Similarly, merging is defined as:



Merging

$\rightarrow_{r_1} \underset{\sim}{+} \rightarrow_{r_2} \widehat{=}$

$$\begin{cases} \rightarrow_{r_1} + \rightarrow_{r_2}, & Et(\rightarrow_{r_1}) = Et(\rightarrow_{r_2}) \wedge \\ & St(\rightarrow_{r_1}) \neq St(\rightarrow_{r_2}) \\ \phi & otherwise \end{cases}$$

Again the merge operator is defined as a choice in which the end points of the branches are identical.

4.3.2 Sequential composition (;)

The sequential operator glues transitions in a linear fashion. We first define the sequential operator for two transitions and generalise it for multiple transitions (which is known as a **path**).

For any Σ and $\rightarrow_{r_i}$,

$$\sigma_1 \rightarrow_{r_i} \sigma_2 \; ; \; \sigma_3 \rightarrow_{r_j} \sigma_4 \widehat{=} \begin{cases} \sigma_1 \rightarrow \sigma \rightarrow \sigma_4, & \sigma = \sigma_2 = \sigma_3 \\ \phi, & otherwise \end{cases}$$

4.3.3 Creative Path ($\rightarrow^*$)

A **path**, $\rightarrow^*$ is recursively defined as a sequential composition of zero or more transitions. For any Σ

$$\rightarrow^* \; \widehat{=} \; \varepsilon + \rightarrow ; \rightarrow^*$$

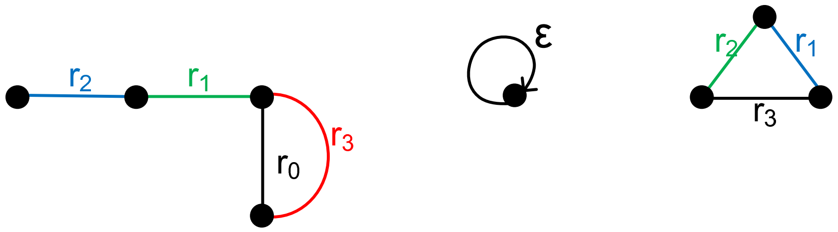


Figure 10: Paths

Let us also define the *length* of a sequential path to be the number of transitions that it is made of. In Figure 10, we show a number of possible paths of length four, one and three respectively. Note here that a path may contain transitions from different type of transition system. For example, the first path is made of four transitions representing four different viewpoints of interest; here they are represented by the colours blue, green, red and black. The path in the middle contains a transition from one viewpoint only. The choice of the various viewpoints depends on what we wish to analyse about the particular creator and creation. The Figure also shows a visual notation for encoding creativity processes.

Given a domain of creation and a fixed set of viewpoints, we can compare between two different paths. For example, the society which receives a particular creation may consider the *length* of a path or the number of, for example 'red' transitions as a meaningful comparator between two creations. We shall return to this point in subsequent sections.

4.4 Laws of Creative Processes - I

The above operations form an algebra over the set of transitions and hence enjoy some algebraic rules which we use to manipulate creative maps. Here we only give a small subset of the laws that were used in our evaluation case study. Laws that deal with co-creation are given in a subsequent section. A full set is given elsewhere [9]. Let τ be the set of all possible transitions in the creative map, the algebraic structure $< P(\Sigma \times \Sigma), +, \phi, ;\ , \varepsilon >$ is an algebra which enjoys the following sound algebraic properties.

4.4.1 Identity/Units.

The ϕ and ε transitions are the *units* of the choice and sequential composition operators respectively: The choice between a given

transition and ϕ will result in taking that transition; similarly, the sequential composition of a given transition with the ε is equivalent to taking that transition [9]. These are expressed as:

(U-1) $\phi + \rightarrow_r = \rightarrow_r = \rightarrow_r + \phi$

(U-2) $\varepsilon;\ \rightarrow_r = \rightarrow_r = \rightarrow_r;\ \varepsilon$

4.4.2 Zeros.

The choice between the *ANY* transition and any other transition in τ will yield the *ANY*; and that composing the *NULL* transition sequentially with any other transition in τ will result in the *NULL* transition.

(Z-1) $ANY + \rightarrow_r = ANY = \rightarrow_r + ANY$

(Z-2) $\phi;\ \rightarrow_r = \phi = \rightarrow_r;\ \phi$ (finite)

4.4.3 Commutativity, Associativity and Distribution.

The choice operator is a commutative and distributes over itself.

(C-1) $\rightarrow_r + \rightarrow_t = \rightarrow_t + \rightarrow_r$

(C-2) $\rightarrow_r + (\rightarrow_t + \rightarrow_w) = (\rightarrow_r + \rightarrow_t) + \rightarrow_w$

The ; operator can distribute over the choice operator and itself (but it is not commutative).

(C-3) $\rightarrow_r;\ (\rightarrow_t + \rightarrow_w) = (\rightarrow_r;\ \rightarrow_t) + (\rightarrow_r;\ \rightarrow_w)$

(C-4) $\rightarrow_r;\ (\rightarrow_t;\ \rightarrow_w) = (\rightarrow_r;\ \rightarrow_t);\ \rightarrow_w$

[9] This is equivalent to the fact that 0 and 1 are the *units* of the *addition* and *multiplication* operations, respectively, in the arithmetic algebra.

4.4.4 Star and General Rules

The **star** notation means a zero or more of its operand. So let $X \in P(\Sigma \times \Sigma)$ be a transition, X^* means that there is a choice between a zero or more of X transitions! The following rules are valid:

(G-1) $\phi^* = \varepsilon$

(G-2) $\varepsilon^* = \varepsilon$

(G-3) $ANY^* = T \qquad (T = (\Sigma \times \Sigma)^*)$

(G-4) $\rightarrow_r^* = \varepsilon + \rightarrow_r; \rightarrow_r^*$

$$= \varepsilon + \rightarrow_r{}^*; \rightarrow_r$$

(G-5) $(\rightarrow_t + \rightarrow_r)^* = \rightarrow_t^*; (\rightarrow_r; \rightarrow_t^*)^*$

(G-6) $\rightarrow_{r_1} + \rightarrow_{r_1} = \rightarrow_{r_1}$

4.5 Creative Behaviours

The traditional view of a behaviour is one of a *sequence of states*, see for example [22] and [20], where the behaviours $< \sigma_1\ \sigma_2\ \sigma_3 >$, and $< \sigma_1\ \sigma_3\ \sigma_2 >$ and $< \sigma_1\ \sigma_1\ \sigma_2 >$ are all different behaviours. However, due to the multi-views nature of creativity, a single sequence of states will not adequately describe creative behaviours and hence the creative processes. Instead, in our generalised transition system, a behaviour is treated as a *set of sequences of states*, where the elements of the set reflect the various viewpoints of interests. We therefore define a behaviour in our creative processes, B, as $B \subset (\Sigma \times \Sigma)^*$. For example, the behaviour

$$\{ < Contemplating\ Creating\ Contemplating\ Acquiring >, < Contemplating\ Creating\ Acquiring\ Contemplating > \}$$

is equivalent to the behaviour

$$\{ < Contemplating\ Creating\ Acquiring\ Contemplating >, < Contemplating\ Creating\ Contemplating\ Acquiring > \}.$$

And that the behaviours

$$\{ < Contemplating\ Creating\ Contemplating\ Acquiring >, < Contemplating\ Creating\ Contemplating\ Acquiring > \}$$

and

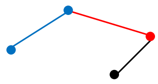


Figure 11: A behaviour in a creative process

$\{ < Contemplating\ \ Creating\ \ Acquiring\ Contemplating\ > \}$
are identical. It is obviously clear that a *creative path* is a single behaviour, as depicted in Figure 11.

Note here that a behaviour contains all or some of the viewpoints of interests. The behaviour in Figure 11, for example, contains a recording of only three viewpoints: red, blue and black. We could have included (or indeed removed) extra viewpoints. This leads us to define $(\Sigma \times \Sigma)^*$ to be the set of *all possible behaviours* (or *all possible creative paths* in our creative system). The "*all*" here is rather important, as it captures both observed and non-observed behaviours.

4.6 Creative structures and Their Construction

As we mentioned earlier that a *viewpoint* is a perspective on a given creation as seen by an external observer including the creator. The numbers of these viewpoints can be very large depending on how fine-grain is the observation we wish to make. For example a piece of music could have a *timing* viewpoint which represents the length of time it took the composer to complete the whole piece, or it may also represent the elapse time to complete one note. The result of these observations produces what we call *the creative map* and is a recorded using the transition notations given above.

Thus, let $V = \bigcup_i V_i$ be the set of all possible viewpoints of interest. We define a *creative structure*, $< C, \rightarrow_c >$, as

$$< C, \rightarrow_C > \hat{=} < T, \rightarrow_T > \times \bigcup_i < V_i, \rightarrow_{V_i} >$$

where

$< A, \rightarrow_A > \times < B, \rightarrow_B > \hat{=} < A \times B, \rightarrow_A \times \rightarrow_B >$, and
$< A, \rightarrow_A > \cup < B, \rightarrow_B > \hat{=} < A \cup B, \rightarrow_A \cup \rightarrow_B >$ such that

$\rightarrow_A \times \rightarrow_B \hat{=} \{ < < a_1, b_1 > , < a_2, b_2 > > :\ a_i\ \in\ A, b_i\ \in\ \ B \wedge a_1 \rightarrow_A a_2\ \wedge\ b_1 \rightarrow_B b_2 \}$

Our rationale is that that the elapse time is a fundamental component in the mapping of the creativity process as time does not stop whilst activities are being performed. To some creative domains (such as writing, composing and designing) recording the elapse time is needed. These viewpoints can be as refined/detailed as the observer wishes to be.

Let us for example consider three specific viewpoints of interest: *Time, Knowledge* and *Artifact*. These are independent of any discipline. *Time* denote the elapse time of the creation, *Knowledge* represents the fact that the creator has gained knowledge (either by hopping from zone to another, contemplating, etc.) and *Artifact* represents the process of creating or the production of the particular artifact. These three viewpoints of interests form three separate transition systems. These are: $< T, \rightarrow_T >$, $< K, \rightarrow_K >$ and $< A, \rightarrow_A >$, respectively.

The resulting creative structure is thus defined and can be formed as:

$$< C, \rightarrow_C > \widehat{=} < T, \rightarrow_T > \times [< A, \rightarrow_A > \cup < K, \rightarrow_K >]$$

Here for example a piece of music could have a *timing* viewpoint which represents the length of time it took the composer to complete the whole piece, or it may also represent the elapse time to complete one note. The result of these observations produces what we call *the creative map* and is a recorded using the transition notations given above.

The creative process maps can be represented graphically as well as be expressed algebraically. For example, Figures 12 depicts two creative process maps, P_I and P_{Ins}.

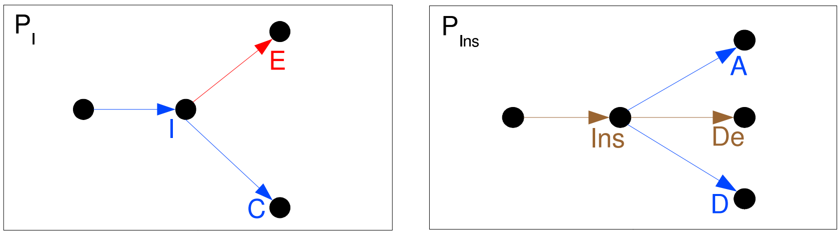


Figure 12: P_I and P_{Ins} Creative Process MapsMap

The P_I map describes a process, consisting of three transitions, I, E and C, in which the creator has begun with an I transition. This is followed by either an E transition or a C transition. The following algebraic expression correctly describes the same map:

$$P_I \widehat{=} \rightarrow_I ; (\rightarrow_E + \rightarrow_C)$$

Similarly, the $P_I ns$ map can be expressed as

$$P_{Ins} \widehat{=} \rightarrow_{Ins} ; (\rightarrow_{De} + \rightarrow_A + \rightarrow_D).$$

4.7 Operations Over Creative Structures and Co-creation

The Operations over transitions presented above can be lifted over creative systems. The operands for those operations are creative systems themselves. So the sequential and choices operations are between creative systems rather than transitions. Another important operation between systems is **parallel** composition which can be used to study collaborations between two or more creators, i.e. **co-creation**.

Let $\Omega_1 \widehat{=} < A, \rightarrow_A >$ and $\Omega_2 \widehat{=} < B, \rightarrow_B >$ be two creative systems. These systems may represent either two different creative processes or a collaborative creative process which was made by two different creators. There are two basic operations to compose these systems: *sequential* and *parallel* compositions.

Sequential Composition. Composing Ω_1 sequentially with Ω_2 (denoted to by $\Omega_1; \Omega_2$) is naturally done by composing a path from Ω_1 and sequentially compose with another in Ω_2 such that both share a transition, i.e. the last transition of $(\rightarrow_A)^*$ is the first transition in $(\rightarrow_B)^*$. Such an intuition help in modelling the hopping phenomenon that was discussed above (see Figure (4)). Sequential composition can be thus derived from the above algebraic laws:

$$\begin{aligned}\Omega_1 \;;\; \Omega_2 \quad \widehat{=} \quad & (\varepsilon + \rightarrow_A; (\rightarrow_A)^*) \quad ; \quad (\varepsilon + \rightarrow_B; (\rightarrow_B)^*) \\ = \quad & \varepsilon \quad + \\ & (\rightarrow_A; (\rightarrow_A)^*) \quad + \\ & (\rightarrow_B; (\rightarrow_B)^*) \quad + \\ & (\rightarrow_A; (\rightarrow_A)^*) \quad ; \quad (\rightarrow_B; (\rightarrow_B)^*).\end{aligned}$$

One can observe that the composition could either be *empty* (ε), A, B or composition of two paths. If the composition is either A or B, hopping does not occur.

Parallel Composition. There are two kinds of semantics that we can define: (a) true parallelism (denoted by $\|$) and (b) interleaving (which is written as $|||$):

> **True parallelism semantics.** For a true parallelism we have all possible combination from the two transition systems:
>
> $\Omega_1 \;\|\; \Omega_2 \quad \widehat{=} \quad < A \times B, \rightarrow_A \times \rightarrow_B >$.
>
> **Interleaving semantics.** Interleaving semantics is simply a representation of parallelism by non-determinism. A transition is taken from either A, B or both $((\rightarrow_A \wedge \rightarrow_B))$:
>
> $\Omega_1 \quad ||| \quad \Omega_2 \quad \widehat{=} \quad < A \times B, \rightarrow_A \;|||\; \rightarrow_B >$, where
>
> $<\rightarrow_A \;|||\; \rightarrow_B> \quad \widehat{=} \quad (\varepsilon_A \wedge \rightarrow_A) \vee (\varepsilon_B \wedge \rightarrow_B) \vee (\rightarrow_A \wedge \rightarrow_B)$, and
>
> $\rightarrow_r \wedge \rightarrow_t \quad \widehat{=} \quad \neg \quad (\neg \;\; \rightarrow_r + \neg \;\; \rightarrow_t)$

4.8 Laws of Creative Processes - II

The above two operations are governed by a number of useful rules which can be used to manipulate a given creative map. Here we give only a few:

It does not matter if one observes the first creator (Ω_1) followed by observing the second (Ω_2) or the other way round. The resulting map will be the same:

(P-1) $\Omega_1 ||| \Omega_2 = \Omega_2 ||| \Omega_1$

(P-2) $\Omega_1 \| \Omega_2 = \Omega_2 \| \Omega_1$

Similarly, observing the first and second creators (in any order) then the third will produce the same map as that when observing the first and then the second and third creator (in any order).

(P-3) $\Omega_1 ||| (\Omega_2 ||| \Omega_3) = (\Omega_1 ||| \Omega_2) ||| \Omega_3$

(P-4) $\Omega_1 \| (\Omega_2 \| \Omega_3) = (\Omega_1 \| \Omega_2) \| \Omega_3$

The ; operator can distribute over the both parallel operators and itself (but it is not commutative).

(P-5) $\Omega_1; (\Omega_2 ||| \Omega_3) = (\Omega_1; \Omega_2) ||| (\Omega_1; \Omega_3)$

(P-6) $\Omega_1; (\Omega_2 \| \Omega_3) = (\Omega_1; \Omega_2) \| (\Omega_1; \Omega_3)$

Sequential compositions are distributed:

(P-7) $\Omega_1;\ (\Omega_2;\ \Omega_3) = (\Omega_1;\ \Omega_2);\ \Omega_3$

4.9 Examples

In this section we give a few simple examples to demonstrate the use of our algebraic laws in pruning and collapsing the creativity process maps.

1. Single Creator. We recall one of the examples in Section 4.6. In particular, the P_{Ins} map in Figure 12:

$$P_{Ins} \widehat{=} \rightarrow_{Ins};\ (\rightarrow_{De} + \rightarrow_{A} + \rightarrow_{D}).$$

This map was originally created from the *composition* of two sub-maps:

$$P_{Ins1} \widehat{=} \rightarrow_{Ins};\ \rightarrow_{De}$$

and

$$P_{Ins2} \widehat{=} \rightarrow_{Ins};\ (\rightarrow_{A} + \rightarrow_{D}).$$

using the distribution role of ; over the $+$ which results in

$$P_{Ins} \widehat{=} P_{Ins1} + P_{Ins2}$$

We can also use this rule for decomposing a given map. For example the map in Figure 12 can be *decompose* into two simpler maps:

$$P_I \ \widehat{=}\ \rightarrow_I;\ (\rightarrow_E + \rightarrow_C) \ = \ (\rightarrow_I;\ \rightarrow_E) + (\rightarrow_I;\ \rightarrow_C)$$

The application of rules such as the above, helps in identifying patterns (i.e. sub-maps) and hence reducing the inherent complexity of the generated creativity process maps, as we illustrated later in Section 6.

2. Multiple Creators. Let us consider a collaboration between two creators, A and B, where a portion of their creative process, P, is depicted in Figure 13.

The creative process maps of A and B can be also described algebraically as follows:

$$A \ \widehat{=}\ \rightarrow_{a_1};\ (\rightarrow_{a_2} + [\rightarrow_{a_3};\ (\rightarrow_{a_5} + [\rightarrow_{a_4};\ \rightarrow_{a_6}])])$$

and

$$B \ \widehat{=}\ \rightarrow_{b_1};\ \rightarrow_{b_2};\ \rightarrow_{b_3};\ [\rightarrow_{b_4} + \rightarrow_{b_5}]$$

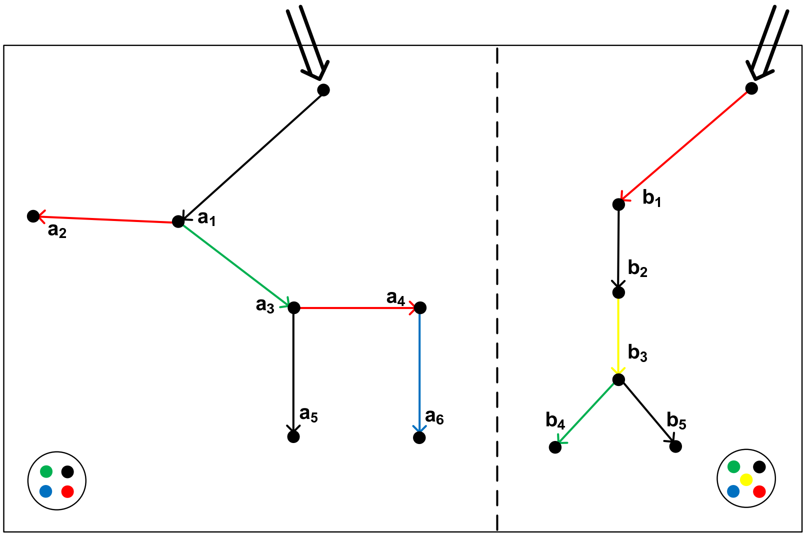


Figure 13: Two Collaborating Creators: $P = A|||B$

A careful examination of A indicates that it consists of three distinct paths:

$$A_1 \widehat{=} \rightarrow_{a_1};\ \rightarrow_{a_2};$$

$$A_2 \widehat{=} \rightarrow_{a_1};\ \rightarrow_{a_3};\ \rightarrow_{a_5}$$

and

$$A_3 \widehat{=} \rightarrow_{a_1};\ \rightarrow_{a_3};\ \rightarrow_{a_4};\ \rightarrow_{a_6}.$$

A can be expressed as

$$A = A_1 + A_2 + A_3.$$

Similarly, B has two paths:

$$B_1 \widehat{=} \rightarrow_{b_1};\ \rightarrow_{b_2};\ \rightarrow_{b_3};\ \rightarrow_{b_4}$$

and

$$B_2 \widehat{=} \rightarrow_{b_1};\ \rightarrow_{b_2};\ \rightarrow_{b_3};\ \rightarrow_{b_5}.$$

B can be also rewritten as

$$B = B_1 + B_2.$$

The whole process can be described as either

$$P_1 = A|||B$$

or

$$P_2 = A||B.$$

Collaboration in P_1 is assumed to have taken place in an *interleaving* mode, whilst in a non-interleaving fashion (i.e true concurrent semantics) in P_2. The choice between the two options will depend on the type of analysis required. In interleaving semantics however, the number of all possible paths can become so large that computationally degrades the performance of the analysis.

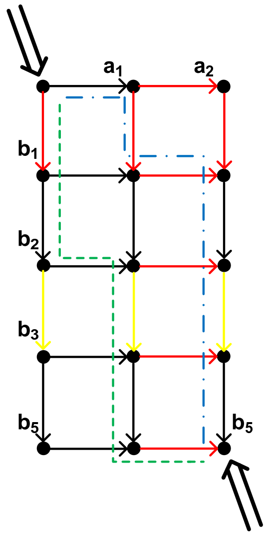


Figure 14: Interleaving Semantics

A visual illustration of an interleaving semantics can be seen in Figure 14. It shows all possible execution trajectories between only two creative sub-processes A_1 and B_2 (i.e. $A_1 ||| B_2$[10]). The following are examples of two interleaving paths (highlighted as "dashed" lines in the figure):

$\beta_1 \;\widehat{=}\; \rightarrow_{b_1};\ \rightarrow_{b_2};\ \rightarrow_{a_1};\ \rightarrow_{b_3};\ \rightarrow_{b_5};\ \rightarrow_{a_2}$ and

$\beta_2 \;\widehat{=}\; \rightarrow_{a_1};\ \rightarrow_{b_1};\ \rightarrow_{a_2};\ \rightarrow_{b_2};\ \rightarrow_{b_3};\ \rightarrow_{b_5}.$

To study the "effect" of collaboration on creativity, interleaving semantics give us a rich set of data on which to base *creativity static analysis*:

Let us assume that there exist a formulation of such an "effect" in the form of a desirable property (which should normally be made by the society which receives the creation). A static analysis should be conducted to show that all possible interleaving behaviours (paths) satisfy such a property. For example, if we place a particular importance on, say, the red-coloured transition over other transitions, for example, the red transition "signifies" the death of creativity. Let us now assume we have the predicate $last^{\beta}_{red}$ which means that the last transition in the β path is red. An example of a desirable property can be $\neg(last^{\beta}_{red})$,, i.e. a bahaviour/path should not have a red transition as its last element. A creativity static analysis should therefore show that all possible behaviours/paths satisfy the property. In the above example, we can see that β_1 fails to satisfy the property. It is important to note that properties could be also as complex as to, for example, express a desired relationship between the various viewpoints of interest, an expected range of densities of particular transitions, and so on.

[10] A valid execution trajectory begins from the top left hand corner and terminates at the bottom right hand corner in the figure. A total number of valid execution trajectories is, in this case, eight.

5 THE De Montfort CREATIVITY ASSISTANT

The De Montfort Creativity Assistant is a tool set which was built to support the analysis of creative behaviours and processes. It has two major components:

- **De Montfort Creative Environment** and
- **De Montfort Creativity Mapper**

Each component can be used as stand alone software or in an integrated fashion. Independently of any software system that may be used by a creator, the Creativity Mapper can be used to capture the various viewpoints and then generates the creativity process map of the current creation. The map is then appropriately tagged and stored ready for further analysis.

5.1 Overall Technical Requirements

In [11], Ben Schneidermann highlighted a number of high level requirements for creativity support systems. These include ''*...the necessity of low thresholds (easy entry to usage for novices), high ceilings (powerful facilities for sophisticated users), and wide walls (a small, well-chosen set of features that support a wide range of possibilities). The need for easy exploration of multiple alternatives (Support many paths, many styles) and powerful history-keeping (convenient backtracking and undo) emerged repeatedly.*"

The philosophy for designing our De Montfort Creativity Assistant follow similar principles and in particular it enjoys a number of specific requirements; including:

- *Web-Enabled.* It is well acknowledged that a Web-enabled application is one that requests services and/or resources via an HTTP (and more specifically TCP/IP) request; this request may or may not be granted. The requested services and/or resources may perform an operation or return data to the requester. The request may be one made over the Internet or a private network. The requests might be made by a Web browser, a Visual Basic (VB) or Java application. The De Montfort Creativity Assistant is a web-enabled application which can run from any browser or launched from any website. This gives it the added benefit of allowing it to be platforms- and workplace- independent.
- *Data Centric.* Data plays a crucial role in creativity support tools. The overriding characteristic of traditional design methodologies is that a distributed application is seen as a set of processes (implemented as procedures or objects). Data in those approaches are designed and treated as second-class citizen and is assumed to be contained within each of the processes. Addressing the issue of moving data between processes is often addressed well after all of the processes have been defined. As data plays a vital role in creativity and its supporting tool, a data-centric approach provides a much more natural alternative of such tools. Such a methodology focuses on the data that is moving and transforming in the system, rather than the processes that are performing those actions. The De Montfort Creativity Assistant adopts a data-centric approach in which we adhere to the following principles:
  - Data is exposed and is visible to the entire system.
  - Code is hidden thus allowing data to be shared across the entire distributed application, as well as the ability to modify and enhanced the application during its life cycle.
  - Clear separation between data-handling and data-processing components. Data-processing components are likely to be stable while data-handling allows for differing data formats, persistence, and timeliness.

- Modularisation and loose coupling of code. This is achieved through well-defined interfaces and abstraction.

- *Collaboration.* It is well recognised that any creativity tool support should foster cooperation and collaboration between creators. This implies the sharing of ideas, innovation, tricks and techniques. In addition, it is widely acknowledged that the creative processes are not normally supported by a single tool, but rather requires the orchestration (initiated by the creator) of a variety of tools each serves a needed function in the creative activities. These must be seamlessly integrated *if and when it is needed*. Such functionalities include importing and exporting data from existing conventional tools set such as spreadsheets, word processors and data analysis.

  The De Montfort Creativity Assistant provides an integrated platform that enhances cooperation and enriches collaboration in *real-time*. Facilities such as chat, white-board, posted note and Internet navigation are all provided in an integrated fashion (i.e. in a single login!).

5.2 The De Montfort Creative Environment

The Creative Environment is an integrated tool set allowing the management of projects, instant messaging and white-board facilities, pend-it notes with reminder, and sharable and real-time collaborative text-based editor. The environment has a simple and familiar desktop interface which depicted in Figure 15.

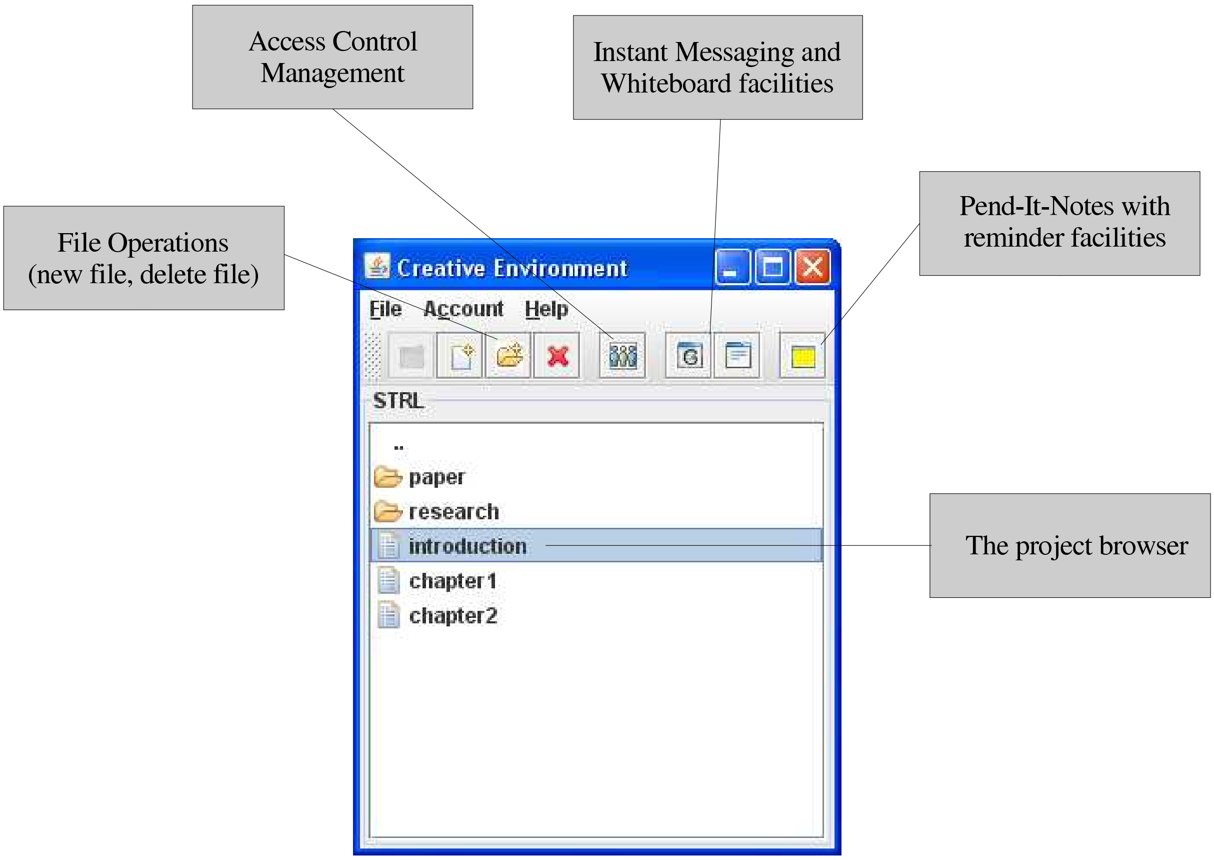


Figure 15: Creative Environment and its Facilities

5.2.1 Architecture

De Montfort Creativity Environment has a layered architecture with a clean interfaces between each layer allowing for pluggability and hence extensibility, see Figure 16. The layers are briefly desriped below, but details of the design and implementation may be found in [13] and [14].

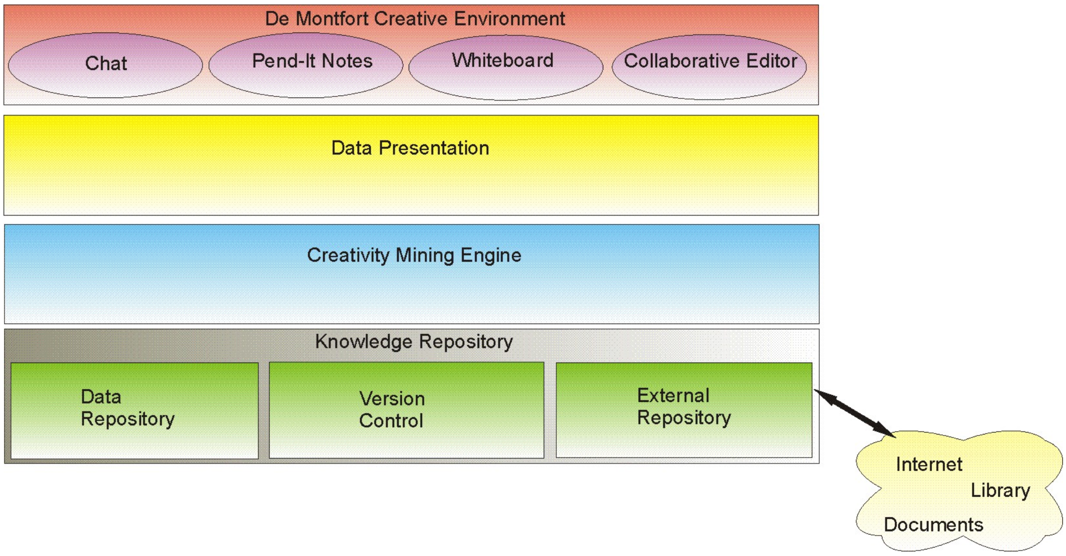


Figure 16: Overall Architecture of the De Montfort Creative Environment

- *Knowledge Repository*. This is the repository for all data handled by the Creativity Assistant. The Data Repository stores the logged data from the Creativity Environment and/or Creativity Mapper. A version Control System is used to store all different versions of a creation and makes them available for analysis and tracking/tracing progress. The External Repository component allows for a dynamic connection to existing knowledge-based systems which can be dynamically and at run-time queried for needed artifacts which are outside the current creativity zone.
- Creativity Mining Engine. The engine does all required processing and analyses, from building up the current creativity map, mining for similarities between maps to identifying specific structures/patterns and analysing specific text or design.
- Data Presentation. The Data Presentation layer brings the user input to a standard format that can be processed. It is bidirectional as it brings the data from the Knowledge Repository in a format that it can be displayed to the user and vice versa.
- The (real-time) Collaborative Editor/Environment. It is an interface to the whole application (see Figure 17).

  The Collaborative Editor/Environment provides editing facilities. Currently it is a textual editor but it can integrate other editors of interests. It is important to note that the design and implementation of our editor was not to create yet another text editor as there are many similar on-line systems exist (e.g. GoogleDocs [15], Writer[**?**], etc.), and to our knowledge, there have been no reports that these enhances creativity.[11]

[11] It is often claimed that Web 2.0 concepts and principles can revolutionise and that indeed are the new long waited silver bullets for the software industries! To-date there have been no serious application that is implemented with Web 2.0 technologies. Instead, Java and Java Web Start technologies or C# are currently still the common choice for serious software development.

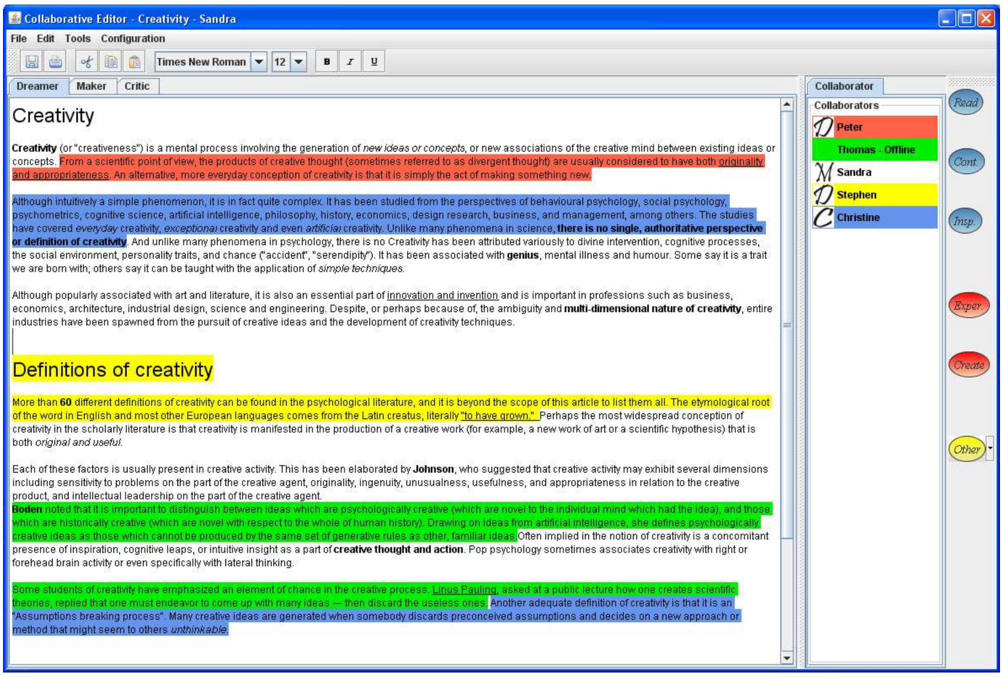


Figure 17: Real-time Collaborative Editor

However, our rationale here was to enable real-time collaboration and to have a tighter control over what the creator produces rendering it to much further analyses including the exploration of the effect of collaboration/cooperation on creativity.

The Collaborative Editor/Environment supports three different modes or views of the creation. These views reflect the modes of creator. The collaborator list is shown and each is identified by a distinct colour together with their current status and a history tracking system showing who was responsible for any changes in the creation. In addition, a facility to invite more collaborators is also available. The Editor tracks the history of a document and creates a new version each time the document is saved. This older revisions can be reviewed later and compared using the editor's statistics facility, Figure 18.

The revision analysis compares the different versions of the creation's history, both textually and visually. The two documents that were compared are shown side by side with the statistical analyses are shown. Usual text analyses are provided. The statistical comparison gives an overview of both compared revisions based on characters, words and paragraphs. It creates diagrams based on this data and displays the amount of change in various charts.

5.3 Creativity Mapper

The Creativity Mapper calculates and incrementally generates a creativity map for the current creation. It can be used as an integrated facility within the De Montfort Creative Environment or as a stand-alone application along with any other creativity software or working environment. The mapper provides various buttons representing the mood of the creator (e.g. *Contemplation, Inspiration, Experimenting, Creation*. The creator is required to press a button that most accurately describes her/his mood at the time. The action system of the Creative Mapper is extendible as it allows customised actions. This is represented by the 'Other' button which if pressed, will open a

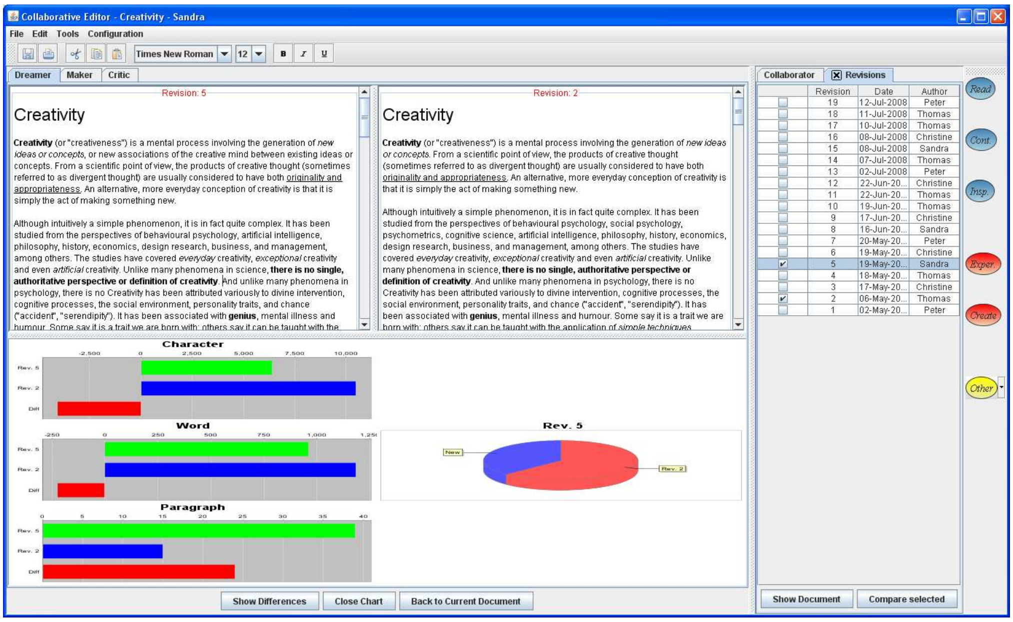


Figure 18: Statistical Analysis

pop-up menu with former individually generated actions and the ability to create new ones too. Figure 19 shows the Creativity Mapper with its six default buttons. The buttons are grouped into the Knowledge (representing the acquisition of knowledge), Artifact (reflecting the creation of an artifact) and Other group.

Figure 19: Creativity Mapper

The Creativity Mapper is based on a Client/Server architecture (Figure 20). An Action Listener, which is part of the client, listens to any action performed by the current creator.

Once the Creativity Mapper is invoked, a creativity mapping session will start and would be linked to the server side of the system. The Transition System Manager (TSM) is responsible for building and/updating the creativity map for the current creator. If the current session is for a new creation, then a new one with a single initial state is created and incrementally constructed.

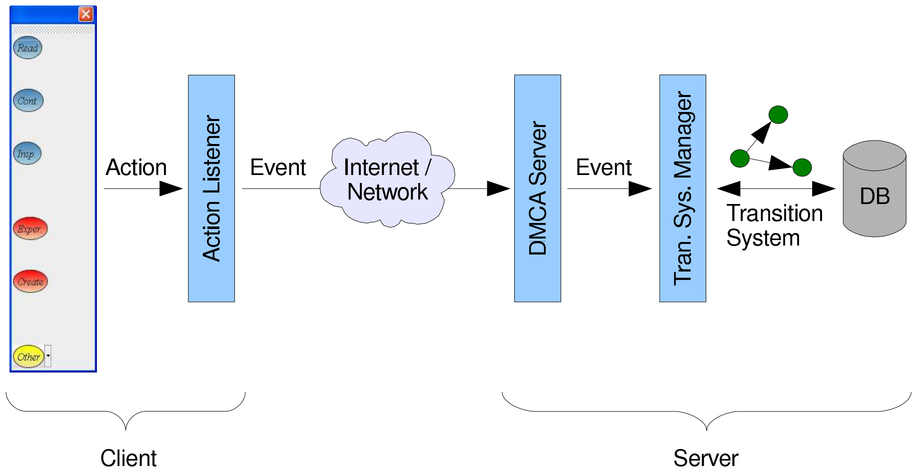


Figure 20: Creativity Mapper Architecture

6 EXPERIMENTS

We present a number of experiments from the art and engineering domains to illustrate the construction process of creative maps. Each was for one creation within each one domain. The first is a music composition and the other is software design.

6.1 Experiment 1: Music Composition - Secret Garden

6.1.1 Description

Secret Garden is a multimedia installation[12] takes the form of an interactive public artwork using sensor technology. A large cylinder will have eleven viewpoints distributed around its circumference, Figure 21. Peering into one of the viewpoints will trigger a view of an idyllic scene in the garden, generated in three dimensions.

Secret Garden is an attempt to recreate a contemporary version of Eden in the midst of an urban space using the stories of the Fall. Two human figures dressed from head to toe in robes of blue (Male) and red (Female) will enact the story of the Fall, combining video vignettes with 3D generated environments, each scene distributed to a different viewpoint. Each viewing port will contain two loudspeakers, through which will be heard settings of eleven texts for solo voices (one male, one female).

The composer recorded his working processes and decision-making on a dictaphone and provided the resulting 40-minute tape as usable documentation to the Creativity Mapper, with an undertaking to follow this up with further tapes as the composition unfolds. The tape reveals the following creative decisions. What follows is an account of the early stages of composition of the music.

A first step was to research the texts. The voices are unaccompanied and the character of the music will be appropriate to the meanings of the words. These are mostly mystical in nature. e.g.:

[12]It is being created by the artist Martin Rieser and the composer Andrew Hugill, in conjunction with the Institute Of Creative Technologies (IOCT) and the Fused Media Lab at De Montfort University, Leicester, UK.

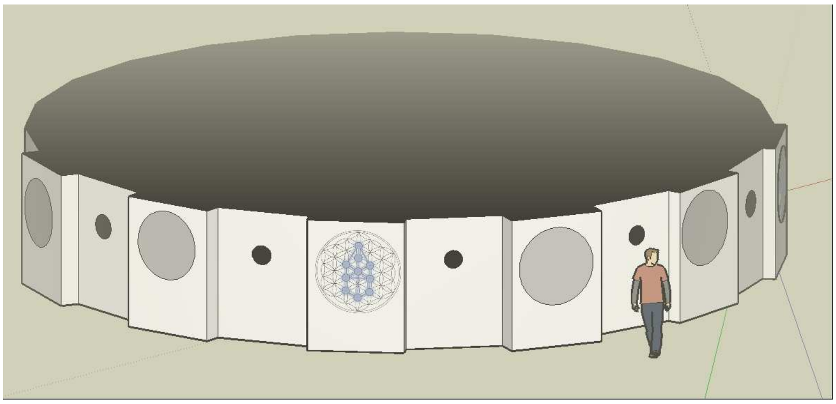


Figure 21: Secret Garden

```
The birds are
Spilling the morning
In liquid song
The trees are still,
And mist is rising
In slow smoke
If you see with the heart
The world is full of light:
The mind's knife cannot cut it
Or deliver it in pieces
For scrutiny.
It flows like the rivers, opens out its music like a bird:
The waking world
Pierced by the risen sun
In a golden minute.
```

There are ten such poems, and a further one, making eleven: a numerological configuration which offers possibilities for organising musical materials.

The composition was begun in Aldeburgh, Suffolk, famous as the home of the composer Benjamin Britten. This location also offered some early inspiration for the music.

A crucial first musical decision concerned the modality. A Western classical scale (major-minor mode) was not appropriate, but neither would it be satisfactory simply to borrow a non-Western mode. The modality would have to sound both ancient and geographically unlocatable. It also had to serve as a framework for the entire composition, thus providing unity of experience as the viewers moved from hole to hole. The numerology helped with the creation of a new mode of ten intervals and eleven pitches, as shown in Figure 22.

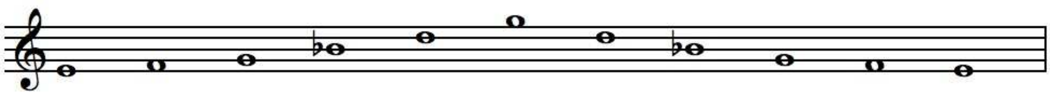


Figure 22: Mode: Interval and Pitches

These eleven pitches expand by a semitone step each on the ascent, and contract similarly on the descent. The central seven pitches describe a chord of G minor, but the modal approach and the centring on E will tend to unsettle any implication of tonality. The high G will form the centre of the eleventh opening, and the other pitches will fan out symmetrically from there. Each poem will, therefore, have its own 'home' pitch, which will dominate. These sit comfortably within the vocal range, while allowing plenty of room for expressive writing.

This mode also allows for the possibility of music in eleven (x 2) simultaneous voices, if all the viewing portals are simultaneously occupied. The objective here is that a casual listener should always hear an harmonious and aesthetically satisfying whole, regardless of how many portals are active and what stage of the musical process each one has reached. This presents a considerable compositional challenge, for which a modal approach is ideally suited.

There are still a few questions to answer: will the tenor simply follow the soprano, or will he mirror by inversion? Will the vocal line be chromatic or remain fixed to the gamut described by the mode? Should there be any digital processing of the sound? May the performers be allowed hand-held percussion with which to punctuate the verses?

These compositional decisions will all be made as the music itself is written down. At this stage, however, the entire piece is conceived and mostly audible within the composer's mind. The next step is transcription and working with the singers to achieve the best results. It is always an important decision whether to write something that enhances the voices or works against them. In this case, much will be learned from a planned studio session.

6.1.2 The creativity Structure and Map

To begin with we have identified the various viewpoints of interest. Obviously these will vary from one analysis to another and will be *goal-directed*: For example we may wish to study the relationship between the acquisition of knowledge, the production of the artifact and the consumption of elapse time. In that case we may only record those dimensions.

In our current scenario, we observe that the composer has gone through various activities during the composition: From *Reading*, *Experimenting* and *Creating* to *Contemplating*. We also learn that the composer has changed his environment (sometimes physically) to gain *Inspiration*. This has led to the identification of six viewpoints of interest which we grouped into three distinct categories:

The first of those is what we call *Knowledge* (K) in which the composer was learning and acquiring appropriate and much needed knowledge about the Secret Garden. We observed the composer has read, contemplated and modified/changed the environment to gain inspiration. In this category, three transition systems are identified and constructed:

$$R = < Reading, \rightarrow_R >, \ , C = < Contemplate, \rightarrow_C > \text{ and } \ I = < Inspiration, \rightarrow_I >.$$

Each of these systems represents a sub-viewpoint of interest within this category. The K set of states is simply:

$$K = Reading \cup Contemplate \cup Inspiration$$

The second category is what what we call *Artifact* (A) where the composer is actively composing and experimenting with the music. Here we have two extra transition systems:

$$C =< Creating, \rightarrow_C > \text{ and } \quad E =< Experimenting, \rightarrow_E >.$$

The *Artifact* states are drawn from the set

$$A = Creating \cup Experimenting$$

Our final category is the time that denotes the passage of time. For this category we have our last transition system

$$T =< Time, \rightarrow_T >$$

and its set of states is $\mathbb{N}$ (set of natural numbers).

The entire *creative process*, C_M, can now be formed from those six subsystems as we described in Section 3.6:

$$C_M \; = \; T \; \times \; (A \cup \; K)$$

As expected, the creativity Mapper initially generated a rather complex structure of which a portion is depicted in Figure 23 below.

Observe here, the black cross indicate death of creativity. Invariably, every $\rightarrow_C$ will lead either to the *death of creation* or to $\rightarrow_{CR}$ transition.

The structure was submitted for a further analysis, utilising some of the creativity laws given above. The analysis has yielded the discovery and identification of various patterns which were repeated in an interleaving manner. These four distinct sub-structures are depicted below and are labeled P_E, P_C, P_I and P_R, Figure 24.

Each of these sub-structure should be read from left to right. For example, in the sub-structure P_C, every time a contemplation phase has ended, the composer has chosen to either conduct some more experiments, sought inspirational activities or read more; and in the P_R sub-structure, a contemplation always followed a reading activities.

Each transition should be substituted with its corresponding sub-structure. For example, whenever the $rightarrow_E$ transition appears in a substructure, say in the P_I sub-structure, then it is replaced by the P_E sub-structure and the $rightarrow_C$ is repalced by the P_C sub-structure, and so on. It is interesting to note that the four sub-structures correspond to the chosen viewpoints. However, if these viewpoints are further refined to introduce more sub-categories to, for example *Inspiration* and/or *Reading* categories, then we would reasonably expect these to be reflected in the resulting sub-structures.

The whole map can be easily described by the following algebraic expression

$$C_M \; = \; [T \parallel [R \; ; \; \; (C \; ||| \; I \; ||| \; E)]]^*$$

As we can see, the composer started with a phase of reading and acquiring knowledge, then went into two concurrent phases of creation and experimenting. Note here that inspirational activity is an integral part of both creation

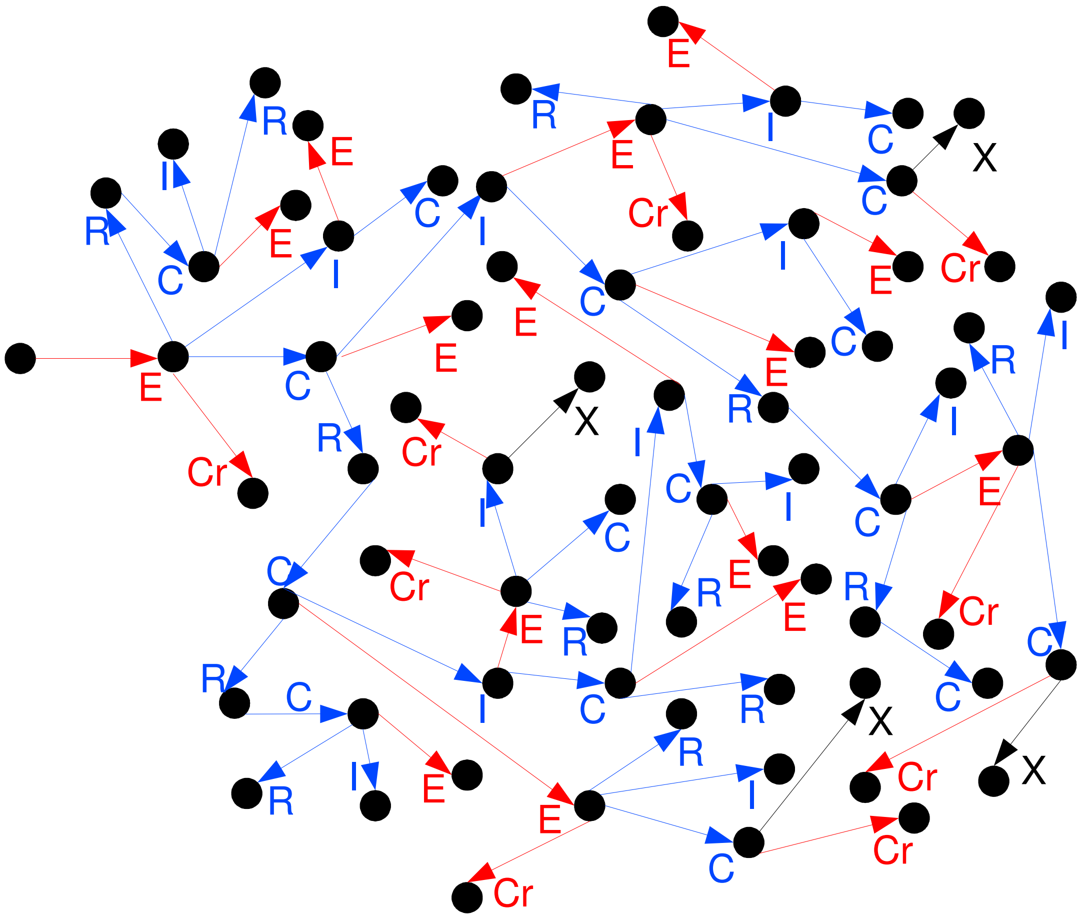


Figure 23: C_M Map

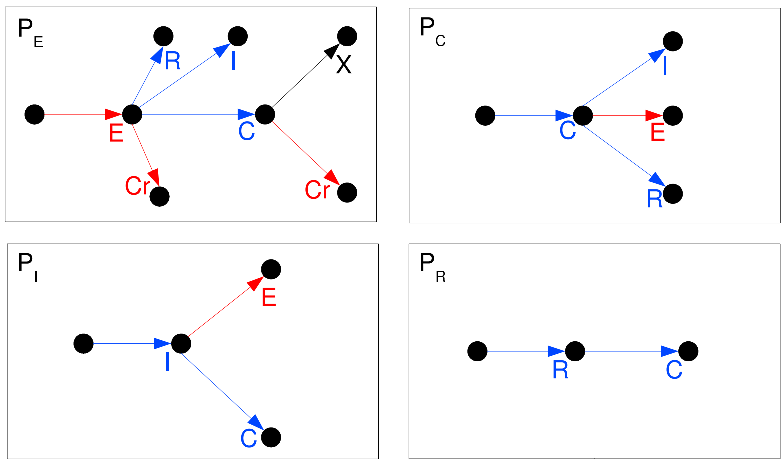


Figure 24: C_M Map: Patterns

and experimental activities. Figure (7) below depicts the final map. We notice here that time, T, is composed in a true parallelism with the other three sub-structures (P_C, P_E and P_I) whose composition is interleaved. True parallel composition may be used in a situation where further refinement to our chosen viewpoints are deemed necessary.

For example we may refine the sub-category *Inspiration* into physical inspiration ($Inspiration_P$) to denote physical activities, such as walking, jogging, driving, swimming, etc., and spiritual inspiration ($Inspiration_S$) such as meditation. In this situation we may discover true parallelism in the sense that the composer was experimenting whist gaining inspiration. Parallelism may also be found in the situation where the composer decided to collaborate with another. In which case we may find one composer is contemplating whilst the other is experimenting, etc.

An important observation can be made about elapse time which is associated with each transition and activity. In the above map we only considered the global elapse time for the whole creation but we could have also considered the elapse time for each $\rightarrow_I$ and $\rightarrow_R$. This would have allowed us to infer, at least statistically, the duration of elapse time needed for P_I and/or P_R before the action of creation itself.

Further, as we mentioned earlier, the above map is for that particular composition and that particular composer. By mapping sufficiently large number of compositions produced by the same composer we will be able to discover common processes which represent the *finger print* of the composer. If we conduct the same experiment for as many composers as possible we will be able to uncover some commonalities amongst compositions. we will have to resolve issues relating the choice of terminologies used by different composers when describing their moods. These could be resolved using current Natural Language Processing techniques.

6.2 Experiment 2: Software Design - FermaT

6.2.1 Description

Software *evolution* is an activity which results in producing new version of the current software. These changes are made with the purpose of adding/removing certain functionalities, migrating it from one platform to another, modernising it by transforming it to a new language, increasing its comprehensibility and/or making it more maintainable. The key to comprehending, analysing and ultimately reengineering large scale systems is to meet the need for generating appropriate abstractions of the system. It is vital to be able to eliminate details which are unimportant to the task at hand and focus on the essentials. The FermaT transformation system[13] together with an extended transformation catalogue, forms the core of the commercial FermaT Migration and Comprehension Workbench produced by Software Migrations Ltd. (SML). The Workbench includes a number of tools for assembler analysis, comprehension and migration including data flow analysers and program slicing.

The system uses formally sound program transformations, which preserve or refine the semantics of a program while changing its form. These transformations are applied to restructure and simplify the legacy systems and to extract higher-level representations.

By using an appropriate sequence of transformations, the extracted representation is guaranteed to be equivalent to the original code logic. The Wide Spectrum Language, called WSL is a logic-based formal method used for the transformation. Over many years a large catalogue of proved transformations has been developed, together with mechanically verifiable applicability conditions. These have been applied to many software development, reverse engineering and maintenance problems.

The theoretical work, on which FermaT is based, originated in research on the development of a language in which proofs of equivalence for program transformations could be achieved as easily as possible for a wide range of constructs. A program transformation is an operation that modifies a program into a different form that has the same external behavior (i.e. it is equivalent under precisely defined denotation semantics). Since both programs and specifications are part of the same language, transformations can be used to demonstrate that a given program

[13]FermaT was designed and implemented by Martin Ward, the Chief Architect of the Software Migration Ltd., which is available under the GNU GPL (General Public License.) from: http://www.cse.dmu.ac.uk/ mward/fermat.html

is a correct implementation of a given specification. WSL is the 'Wide Spectrum Language' used to support program transformation and includes low-level programming constructs and high-level abstract specifications within a single language. This has the advantage that it is not necessary to differentiate between programming and specification languages: the entire transformational development of a program from abstract specification to detailed implementation can be carried out in a single language. During this process, different parts of the program may be expressed at different levels of abstraction. So a wide-spectrum language forms an ideal tool for developing methods for formal program development and also for formal reverse engineering.

FermaT has applications in *forward engineering* (developing provably-correct software from high-level specifications), *reverse engineering* (determining the high-level specification of an existing software system) and *language migration*. FermaT has been used in several large-scale migration projects, transforming over a million lines of low-level assembler code into high-level structured and maintainable C.

It is important to observe that there are two different experiments where creativity could be studied.

- The usability of FermaT itself to migrate a given legacy system, and
- The original design of FermaT,

The former may lead to the articulation of a number of guidelines or conditions to increase/improve the efficient use of FermaT. The later will shed some light on the creativity involved in the engineering of a major industry-strength system which in turn would be beneficial for many software designer. Here we shall report on the later deferring the former to a forthcoming paper.

6.2.2 The Creativity Structure and Design Map

As a discipline, Software Engineering enjoys a number of well established life-cycle models which are being currently used by software designers and developers across the sector. Some of these have become de facto standards, including *Waterfall* and *Spiral* models. By large, these models have fixed and well known phases: requirements, specification, design and implementation. Other models may have extra and more refined phases such as architecture, detail design, testing, maintenance, etc. The implementation of these phases are often done in an interleaving and iterative fashions and depends on the application domain. These life-cycle models are often taken as general guiding principles and that creativity and the creative processes reside in their usage for the development of software products. The production of FermaT had gone through similar life-cycle phases but we shall focus here on the creativity processes involved in the early stages of its development, namely *requirements* and *specification*.

We begin by realising a number of viewpoints of interest, particularly at the requirements and specification phases. Given the fact that the sector was suffering from the lack of automated techniques that helps to maintain legacy systems and that over 70% of development cost was spent on maintenance alone, we will certainly be interested in the creative processes involved in capturing that need and how the designer arrived to the formalisation of its specification

We categories the viewpoints of interest into three major categories: *Need*, *Invention* and *Creating*. This is in addition the temporal category *Time*.

- The first of those categories, *Need*, involved a number of sub-activities: *Discussion*, *Inspection*, *Acquiring*, each forming a transition system:

$$D = < Discussion, \rightarrow_D >, \quad I = < Inspection, \rightarrow_I > \text{ and } A = < Acquiring, \rightarrow_A >.$$

The state-space of the *Need* category is $N = Discussion \cup Inspection \cup Acquiring$. The need transition system is thus:

$$< N, \rightarrow_D \cup \rightarrow_I \cup \rightarrow_A >$$

- The time category which denotes the passage of time has the usual transition system

$$T = < Time, \rightarrow_T >$$

and its set of states is $\mathbb{N}$ (set of natural numbers).

- The *Creating* category, C, involves a further subcategories: *Prototyping* and *Testing* with a state-space $C = Prototyping \cup Testing$ and transition systems:

$$P = < Prototyping, \rightarrow_P >, \quad \text{and } Te = < Testing, \rightarrow_T >.$$

This lead to the *Creating* transition system

$$< C, \rightarrow_P \cup \rightarrow_{Te} >$$

- The *Invention* category, *IN*, involves the development of the transformation theory that underpins the FermaT system. In turns this involved two sub-activities: *Development* and *Inspiration*. The *Invention* state-space is $IN = Development \cup Inspiration$ with transition systems:

$$De = < Development, \rightarrow_{De} >, \quad \text{and } Ins = < Inspiration, \rightarrow_{Ins} >.$$

The *Invention* transition system is therefore,

$$< IN, \rightarrow_{De} \cup \rightarrow_{Ins} >.$$

The entire *creative process*, $FermaT_C$, can now be formed from those subsystems:

$$FermaT_C = T \times (N \cup C \cup IN).$$

Figure 25 shows a fraction of the $FermaT_C$ map which is obviously a complex structure[14].

Once again we could identify some basic patterns in the behaviour which can be extracted which are depicted in Figure 26.

The whole $FeramT_C$ creative process can also be described as an expression in our algebraic setting as

$$FermaT_C \;=\; [T \parallel [N \;;\; (IN \parallel\!| \; C \parallel N)]]^*$$

[14]It is interesting to note that $FeramT_C$ map has demonstrated the widely accepted software engineering principle: It is better to develop the "right" thing than developing the thing "right".

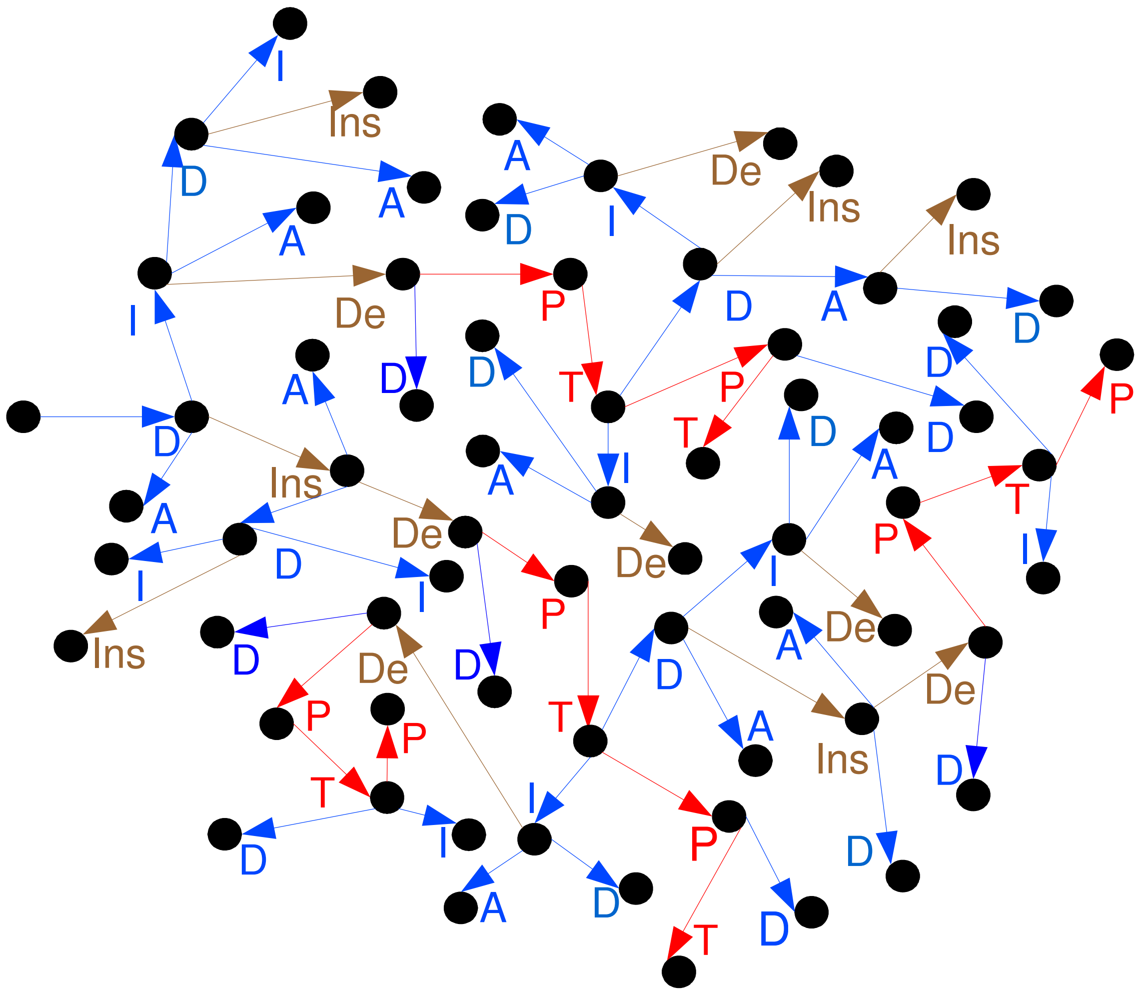


Figure 25: *FermaT$_C$* Map

6.3 Discussion

Creativity maps are discrete representations of creative behaviours providing the necessary basis for analysing the *creative processes* and hence enhancing our understanding of the *creative* phenomenon. A number of observations are however in order:

- We have not shown the time transitions as this will have further complicated the map. However it is implicit that every transition is associated with a time-transition.
- In the construction of a creativity map, The choice of viewpoints will vary depending on the type of analysis that is required. For example in the *FermaT$_C$* map above we may have wanted to explore the creativity that was involved in the development process itself. In this situation we would have been only interested in the *Creating* viewpoint and prune the map to eliminate *Need*. Further, we may have also refined the *Prototyping* viewpoint which would have allowed us to study the relationship between productivity in coding and creativity when prototyping is involved.
- The maps produced in the above two experiments *only* represent the creativity maps of two creators for two specific creations (FermaT and the Secret Garden). Obviously we can not draw general conclusion about

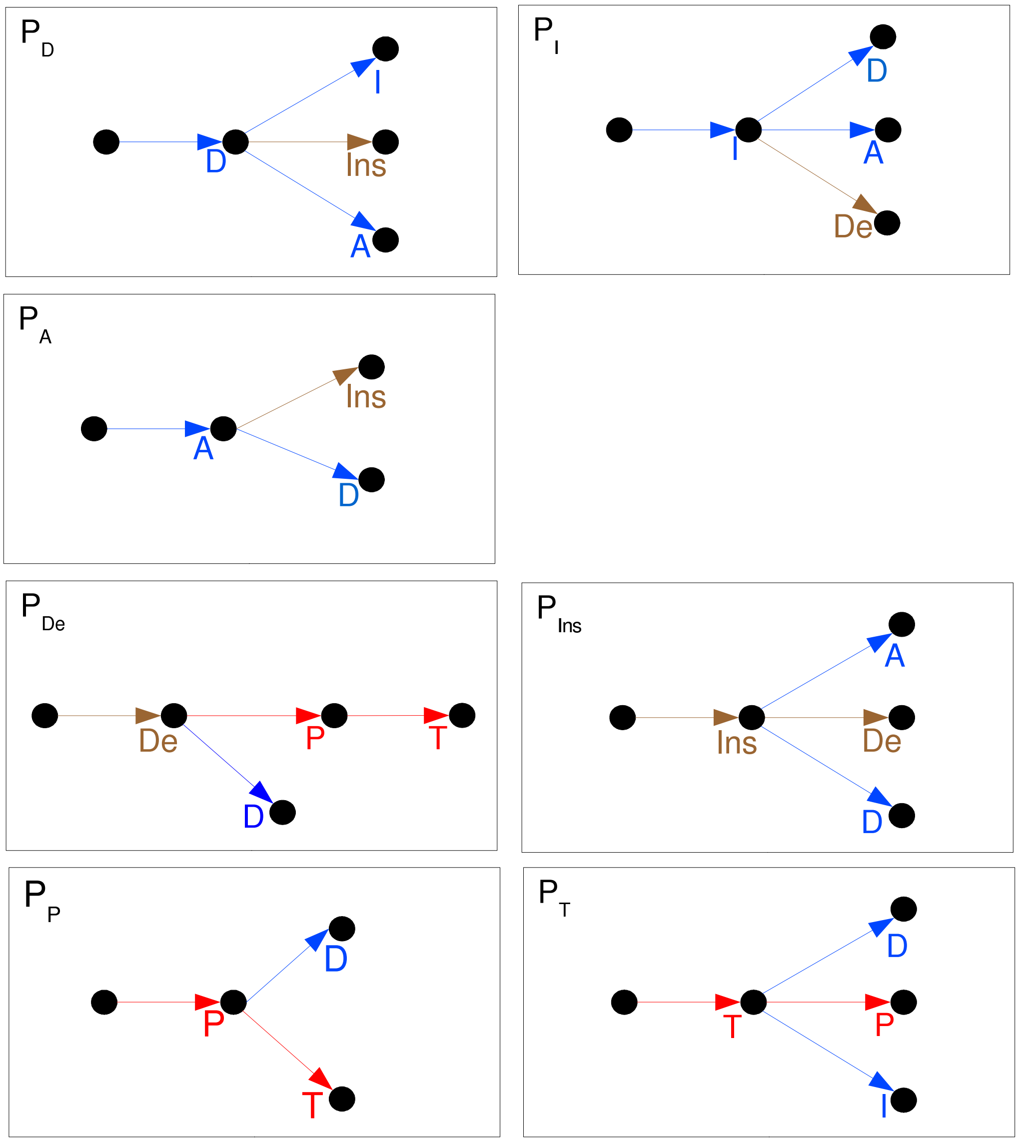


Figure 26: *FermaT$_C$*: Patterns

the two creators, for that we need a statistically valid number of creations. This in turn will require *power analysis*[18] to determine sample size. The creator however is able to learn, in an incremental fashion, about the creative processes involved and may be able to alter some activities in order to optimise them.

- One of the most powerful characteristics of any creativity map is that it contains a rich amount of information which can be utilised to enhance our understanding of creativity and may assist in improving its processes. For that we need to distinguish between three fundamental components: *data, information* and *knowledge*. The three components form a trajectory in which "data" is placed at its bottom. Further, it is commonly known that "knowledge" is often produced as a result of adding semantics to data (both locally and globally). "Information" is often the product of both data and knowledge. In our case, we note that creativity maps encompass all three components: transitions represent data, a path (or a behaviour) is indeed behavioural knowledge and the boxes which we produced following the analysis of the map represent information obtained about the creator, e.g.*De* and *Ins* in the *Fermat$_C$* map above. The analysis which is performed over a map is in fact a process of discovering information given the rich data and knowledge about both the creation itself and its creator. For example the *I-box* of the C_M map provides us with the information that once the composer is inspired, he either contemplates or experiments. Similarly in his *R-box*, the composer creates after reading.

Creativity maps with their rich and large amount of data form strong infrastructure for Creativity Assistant tools support. The next generation of De Montfort Creativity Assistant will support the extraction of creativity boxes which are the basis for creativity knowledge mining.

- For a particular creative map we may assign, as part of the analysis, an 'importance' to a particular box and study the frequency of its occurrence in that map and in other maps of the same and/or other creators within the same discipline. Similar findings may be obtained across different disciplines. This may reveal important knowledge about the creator, in addition to allowing us to build a taxonomy of creative processes. Once a statistically significant data set, a probabilistic creativity map for a given creator can be produce. Such a map will assign a probabilistic attribute to boxes and be able to infer some probabilistic properties about the creativity map.
- The choice of the labels that describe the mood of the creator is done in a rather non-intrusive fashion so as not to hinder creativity. This however presents us with the difficulties of terminology alignment. There are many existing techniques that can be use to address this issue utilising for example self organising map or alignment algorithms in the ontology domain.
- Each transition system in a creative map can be associated with an *action* set, which in turns adds more expressive power to our formalism.

  At a particular level of analysis, we may only be interested in discovering, for example

  1. the order of transitions, i.e. a $Create$ activity is followed by three inspirational:

  $$\rightarrow_{Create}\ ;\ \rightarrow_{Inspiration}\ ;\ \rightarrow_{Inspiration}\ ;\ \rightarrow_{Inspiration}$$

  2. in the occurrence frequency of a particular transition (i.e. over the duration of the creation, 40% of transitions was $\rightarrow_{Prototyping}$).

  But at a more deeper level of analysis, discovering that the transition $\rightarrow_{Create}$ has occurred twice over a particular interval, is not enough, and we may wish to identify/distinguish between those occurrences. For example, in (1) above it may beneficial, at a detailed level of analysis to exactly know their types.

  This is achieved by decorating the transition by an appropriate action: $\rightarrow^{A}{}_{\alpha}$ (This is read as: *this creator has taken the transition* $\rightarrow_{\alpha}$ *in which its particular action A has been performed.* For example, $\rightarrow^{Jogging}_{Inspiration}$ is followed by $\rightarrow^{Praying}_{Inspiration}$ which is followed by $\rightarrow^{Sleeping}_{Inspiration}$. Those three inspirational transitions would have appeared at a particular level of analysis as three identical transitions whilst at a more detailed level of analysis they will appear different. Here the *action* set of $\rightarrow_{Inspiration}$ is {Jogging, Praying, Sleeping}.

  We may also hide that level of details for some transitions. For example we may have

  $$(\rightarrow^{Jogging}_{Inspiration}\ ;\ \rightarrow^{Praying}_{Inspiration})\ ;\ \rightarrow_{Development}\ ;\ (\rightarrow^{Sleeping}_{Inspiration})\ ;\ \rightarrow_{Development}$$

- As we mentioned earlier, c.f. Section 4.7, *co-creation* is modelled using the parallel composition operators which provide both true and interleaving semantics. The type of analysis discussed in the above point can be used as a basis to study the effect of collaboration/cooperation on creativity. For example, if we assign an importance (on a particular behaviour or a set of behaviours composed in a particular fashion), that represents an increase enhancement to creativity, then we can establish the frequency of its occurrence and may infer benefits from the collaboration under study.

7 CONCLUSION AND FINAL REMARKS

There is no doubt that throughout history, *creativity* has been a central phenomenon to human activities and thoughts. It has been also the driving force for most, if not all, known innovations and discoveries. Furthermore, some of the well known inventions and breakthroughs often occured at the boundaries of disciplines.

Whilst the literature is full of explanations ranging from the simple, or even trivial, to the highly complex, *creativity* and the *creative processes* still suffer from a lack of precise definition and, perhaps more importantly, a systematic and holistic study (scientific or otherwise) that is based on a firm theoretical foundation, allowing us to uncover its nature and properly understand its processes. Moreover, within such a theory, at least if *scientifically-based*, it should be possible to show that any finding is both *generalisable* and *reproducible*. We believe that the study presented here offers a starting point for such an endeavour. Antagonists will, as they always do, continue to reject the necessity of a theoretical underpinning to creativity, even more so if such a theory purports to be scientifically-based. What we have proposed is not a formalisation of creativity itself but of its processes. Our belief here is that by formalising the "process", we can gain greater understanding of the phenomenon itself.

In this section we briefly summaries our findings and the basis for a scientific theory that underpins further investigations. This is then follows by some insights for subsequent explorations and future work.

7.1 Summary

There are obvious difficulties in reaching a general definition of creativity. Every discipline has a different notion or understanding of what constitute creativity. Worse still reaching an agreement amongst creators within the same discipline prove to be almost impossible. It may be then more profitable to understand the anatomy of creativity through uncovering its processes which subsequently could lead to the identification of some ingredients/dimensions that give rise to a definition which may be acceptable to the community at large.

The most useful starting point is that creativity depends on a conceptual shift in thinking [3]: *Directly* through divine intervention (the AHA! response) or by *indirect* means via the creative product itself; both have traditionally been seen as approaches to identifying the creative process.

The rationale of the former stems from the belief that the occurrence of a clear behaviour like the AHA!response has been taken as an evidence that creative activity has taken place. I.e., the AHA!response is a pre-condition to creativity and innovation. Whilst it may be reliable diagnoses in some cases, it is hardly a guarantee to be repeatable in every case of creative activities neither to be absent from the more mundane processes that somehow involve a surprise element. Clearly, the "AHA!response" belief fails to satisfy one of the fundamental criteria of a theory; namely the *reproducibility*.

A crucial factor in the creative process appears to be a shift in the structure of the task at hand. A shift involves the alteration of the problem space or a direct manipulation in the problem representation. This has been demonstrated in both scientific, design and mathematics discoveries. The fact that the creative process requires the discovery of a new problem space necessitates that it must be conducted in at least two distinct search spaces: one of solutions and the other of problems[15]. This means that the creative individual must have skills not just for problem solving but also for defining new problem spaces.

An important, and perhaps may be an obvious, observation is that creative processes have somewhat close ties with most of cognitive processes. The evidence considered, here and elsewhere, suggest that cognitive processes related to creativity share a great deal with ordinary cognitive acts such as the acquisition of knowledge, identifi-

[15] In some art discipline, the term 'problem' is not adequate. The term 'need' may be more acceptable.

cation of needs, and the separation of concern. This is not to say that there are no significant distinctions between ordinary cognition and creative processes.

We have begun this investigation by concentrating on an indirect mean of creativity, i.e. creative processes, for their comprehension will lead to precisely articulated definition of creativity. Our vision was that human creativity could be *mapped* in a similar way as that of human genes. In doing so, we will be able to study the similarities of creative processes across the various disciplines which vary from the sciences and engineering to mathematics and the arts. Such a mapping can also facilitate the exploration of the effect of *diversity* (in the form of collaboration and/or cooperation) on creativity. It will also give us a rich data-set from which, given a domain or an organisation, we can formulate a set of optimum attributes/conditions that, if applied or adhered to, will increase chances for enhancing creativity.

Our starting point was to establish a set of hypotheses, *Axioms of Creativity* (c.f. Section 2.1, page 8). We have given a sound general framework which is supported by a notation that allows us to encode the creative processes. The resulting is what we call "creativity process map" which is a complex geometrical structure and required to be further *pruned* and simplified. For that reason we have given a set of sound algebraic rules (known as *Creativity Laws*) which preserve the semantics of the structure. The structure is constructed by considering a number of viewpoints of interest. At the analysis phase, we can either hide some of those viewpoints and/or study the effect of one viewpoint on another.

Furthermore, the presented approach is supported by a tool set, known as De Montfort Creativity Assistant which consists of two major pluggable components:

1. De Montfort Collaborative environment. An integrated tool support which allows real-time collaboration between creators and
2. Creativity Mapper. A tool which, by applying our creativity laws, generates the creativity process maps and extracting creative process patterns.

We have also evaluated our techniques on a number of creations drawn from the art and engineering domains. In the remainder of this section we give some observations and outline few insight for further investigation.

7.2 Observations and Future Insights

7.2.1 Viewpoints and Creativity Data Bank

As we mentioned earlier, viewpoints are perspectives/dimensions that form the creative activities. The *temporal* aspects of the creation, the *acquisition* of knowledge (or needs for the particular creation), *contemplation* and the act of *inspiration* are all examples of viewpoints that might be of interest. These viewpoints form a layered structure where the viewpoints in one layer is a *refinement* of those that reside in the layers above. For example, the actual elapse time (or the physical duration of time) consumed by the creator and the virtual time[16] are both two refinements of the temporal viewpoints.

The choice of viewpoints depends on the type of analysis that is required to be made. This by definition, implies the adoption of a notion of *abstraction*[17] which means hiding some viewpoints which are deemed to be irrelevant. We need however to be extremely aware of the fact that what is deemed to be irrelevant might have an indirect

[16]Virtual time is that which is controlled by the creator unlike the physical time which the creator has no control over, i.e. clock ticks. Virtual time may be slower or much faster than that of physical time

[17]*Abstraction* here is taken to be the inverse of *refinement*

effect on other viewpoints. As we mentioned earlier, social, economic and religion are examples of dimensions that may indeed affect or constrain creative processes.

Another important observation is related to what we call *term unification*. The choice of "terms" that adequately describe the moods of the creator is left completely to the creators themselves. It is inevitable that a creator may choose a term that s/he feels accurately describes her/his mood at one particular time and choose different term to describe the same mood at another time! Additionally, creators from the same discipline may choose different terms to describe identical mood. Naturally this present us with the problem of unifying those terms. Natural Language Processing provides many sophisticated text analysis techniques which can be utilised to resolve such a problem. For example, to resolve an ambiguity of a particular term, the context within which the creator is working could be inferred from other terms, chosen by the creator, which in turns reduces the number of senses of that term. This could be done iteratively until the conflict is resolved. On the other hand, the society of creators in a particular discipline may agree a set of terms that adequately describe their moods. We anticipate that it is more likely that such an agreement could be formulated in disciplines such as mathematics, engineering and life sciences; it might be harder however in other art-related disciplines.

As part of the Creativity Mapper, we have a complex database management system (which is known as Creativity Data Bank (**CrDB**)) which stores tagged creativity maps. The vision here is to create a public **CrDB** that allows creators to deposit their Creativity Maps which can then be further analysed and studied by others from the same or different discipline. We also have to be mindful of the fact that any analysis will require a sufficiently and statistically valid population for us to reach an unbiased and meaningful conclusion.

7.2.2 Legacy Creations

The creativity maps can be built in an incremental, interactive and a non-intrusive fashion (i.e., as the creation is being developed).
However, for legacy creations, the maps can also be constructed *a posteriori* but only if adequate information were available. For example, in music, a composer like Mozart was known to have developed his compositions completely in his head and then transcribed them onto paper. In such a case, Mozart's creativity map can not be re-produced, even at a simple level of detail. On the other hand, Beethoven used to labour carefully, and with such a precision, over sketches and drafts of his compositions. In fact, it is widely believed that his first ideas were so crude that scholars and analysts marveled at how he could have produced from them, at the end, such miraculous results as seen in the many of his master pieces. Indeed Beethoven's extensive sketchbooks (which total over 8,000 pages) and the autograph manuscripts, covering several stages of development, reveal the composer systematically exploring and evolving his musical ideas. Indeed, in [19], Lockwood, through close investigation of individual works, has traced the creative process as it emerges in Beethoven's sketches and autograph manuscripts, which in turns may provide us the basis for constructing his creativity map[18]. Lockwood's lucid analysis enhances our understanding of Beethoven's musical strategies and stylistic developments as well as the compositional process itself. Altogether it provides a valuable basis for a complete construction of Beethoven creativity map *a posteriori*.

7.2.3 Creativity, Emergence and Diversity

As we discussed earlier, creativity can be seen as an *emergent* phenomenon in which the *whole* (the viewpoints involved in the creative processes) is larger than the sum of its *parts* (the conditions, facts and assumptions) that started it.

[18] Four studies address the composition of the Eroica Symphony from various viewpoints. The chamber works discussed include the Cello Sonata in A Major, Opus 69, the string quartet Opus 59 No. 1, and the Cavatina of the later quartet Opus 130.

Emergence in complex systems depends on the dynamic interactions between the individual agents within the system. In creativity, by ‘system’ we mean the final creation and ‘agents’ are collaborators involved directly or indirectly in the production of a single creation. We would expect that creativity therefore to greatly benefit from such interaction which is central to both *diversity* and *collaboration*.

However, in order to support the principles of a *“freedom to try new things”* and a *“free-flowing hierarchy”*, these interactions must be done flexibly and without central control. This leads to an important question of how a social group designs a shared basis of authority and thus, a governance system.

Biologically-inspired and Open-Source Software systems may provide us with some intuitions. For example, in [17] an examination of the emergence of a governance system in an open source software community showed how a community uses a formal bureaucratic basis of authority to reinforce the community’s meritocratic norms. However, this approach depends upon democratic mechanisms that not only limit that basis of authority, but allows the system to adapt with members’ changing interpretation of leadership. One of the finding was that while technical proficiency is an important criteria for leadership in such a group, it is not sufficient. Despite espoused preferences for ‘hands-off leaders’, skill in building the organization becomes increasingly important over time. Recent scholarship on open source communities suggests that any governance system introduced must be meritocratic in order to attract “high quality” (as perceived by the community itself) contributions from voluntary members.

7.3 Epilogue

Mapping human creativity is a complex task. It requires close and “committed” collaborations between a wide range of disciplines, including the arts, engineering, computer science, mathematics, physical sciences, social sciences, psychology, sociology, philosophy and education. Advances in technologies will no doubt facilitate such endeavours. Whilst it should not be seen as, and certainly we are not claiming it to be, a panacea, the mapping itself should serve as a powerful tool to understand and further reveal, at least, some aspects of the nature of creativity: allowing therefore the possibility of enhancing its processes. The approach presented here provides a sound framework within which creativity process maps can be constructed, compared and analysed.

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