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Emergence and Dissolvence in the Self-organisation of Complex Systems

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Abstract: The formation of complex systems is accompanied by the emergence of properties that are non-existent in the components. But what of the properties and behaviour of such components caught up in the formation of a system of a higher level of complexity? In this assay, we use a large variety of examples, from molecules to organisms and beyond, to show that systems merging into a complex system of higher order experience constraints with a partial loss of choice, options and independence. In other words, emergence in a complex system often implies reduction in the number of probable states of its components, a phenomenon we term dissolvence. This is seen in atoms when they merge to form molecules, in biomolecules when they form macromolecules such as proteins, and in macromolecules when they form aggregates such as molecular machines or membranes. At higher biological levels, dissolvence occurs for example in components of cells (e.g. organelles), tissues (cells), organs (tissues), organisms (organs) and societies (individuals).

Far from being a destruction, dissolvence is understood here as a creative process in which information is generated to fuel the process of self-organisation of complex systems, allowing them to appear and evolve to higher states of organisation and emergence. Questions are raised about the relationship of dissolvence and adaptability; the interrelation with top-down causation; the reversibility of dissolvence; and the connection between dissolvence and anticipation.

Keywords: property space, emergent properties, dissolvence, information, self-organisation, complex systems, complexity.

> "He escapes from his ego by this merger and acquires an impersonal immortality in the association; his identity *dissolving* into greater identity." [1] (italics added).

1. Introduction

Complex adaptative systems (simply referred to here as complex systems) have become a major theme of inquiry and speculation in some scientific circles and more generally among scientists with an interest for broader issues. The study of complex systems focuses on their essential characteristics such as the emergence of new properties, self-regulation and adaptative behaviour, all of which are easily observable in complex systems (e.g. living organisms) and in computational models (e.g. cellular automata) [2-17]. Given the epistemological and philosophical implications of complex systems, these have also become an object of investigation for some philosophers of science [18].

In the study of complex systems, little attention is paid to the fate of ingredients caught up in the process of synergy, in the forming of a system of a higher level of complexity. Indeed, one may wonder about what is left behind in the domain of properties when components become subsumed in a higher order. The reality and the attributes of this neglected but essential aspect of complexity are explored in this writing.

2. The Synergetic Process

2.1. Describing a System

We begin this examination by reconstructing with words and diagrams the synergetics of complex systems interacting and becoming integrated to create complex systems of higher levels. A system can be described from a triple viewpoint. First, it has a structure (here called form) approached in formal descriptions. Further, a system exhibits a pattern of behaviour called function and characterised as properties. This is the static description of a system, leading to models that neglect the temporal dimension. Indeed, form and function of a system are not static but change with time -- they fluctuate within a probability range. This is described as the fluctuation of a complex system.

It was Prigogine who clearly saw structure, function and fluctuation as the three essential attributes of complex systems [9, 19, 20]. He also recognised that form, function and fluctuation cannot be ordered causally or hierarchically. Rather, they must be viewed as being of equal significance and feeding on each other. Indeed, form and function influence each other, as do form and fluctuation, and as do function and fluctuation. In other words, form, function and fluctuation are interdependent. They depend on each other in a quantitative manner, and in some cases even qualitatively. Fluctuation of form and function in a system generates a number of formal and functional states, which are thus the expression of the mutual interdependence of form, function and fluctuation. The ensemble of all possible states of this system will span a range of values which delineates a property space. The latter can also be viewed as the basin of attraction of all possible states of a given system. Figure 1 offers a schematic representation of such a conceptual description of a complex system. This is the representation we used in another paper to describe molecular structure [21].

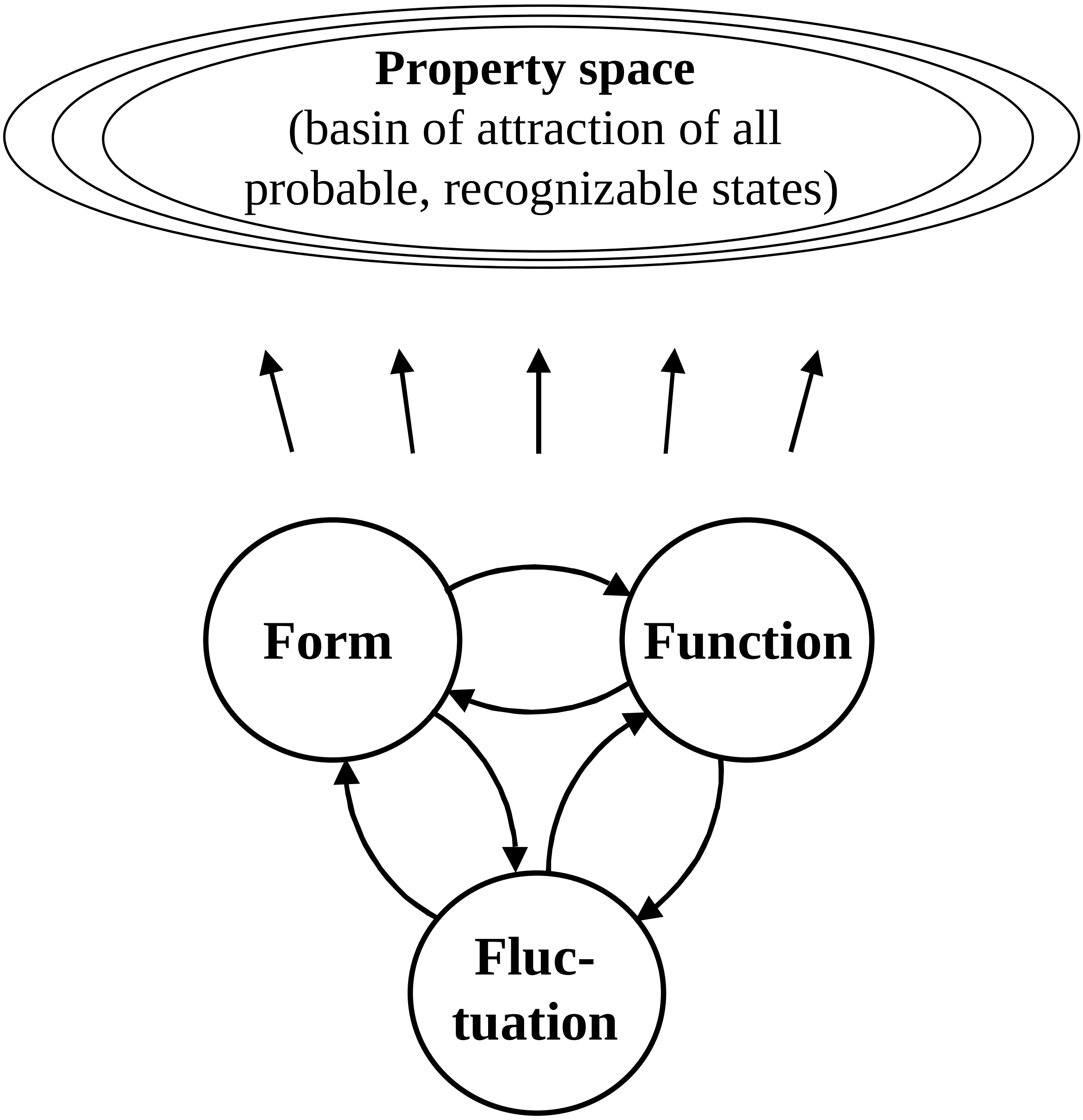

Figure 1. Form and function of a system fluctuate to produce a number of formal and functional states. The ensemble of all probable states defines the property space of the system.

It is through the functional states, or rather through their properties (the observables) that a system is accessible to an observer. How many discrete and distinct states can be recognised for a given system depends of course on its intrinsic nature, and also on the criteria of discrimination applied by the observer.

2.2. Forming a System of Higher Level

Let us imagine a number of systems of level **M** that co-exist independently and without interaction but are synergistic in their potential to merge to form a system of higher level **M+1**. Initially, these systems of level **M** are each in an isolated state, as shown schematically in Figure 2 for two systems of level **M** where the actualisation of any interaction has not yet occurred.

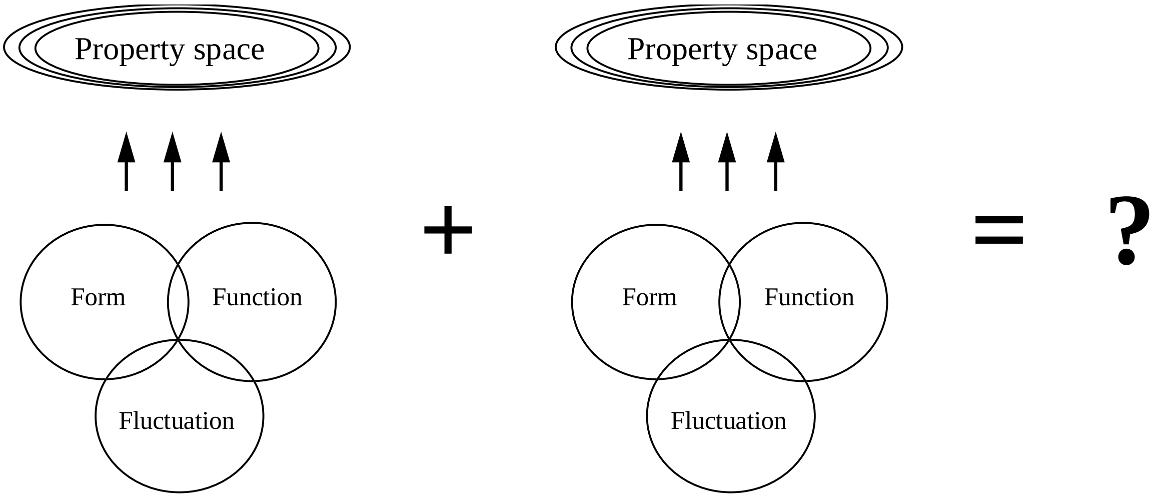

Figure 2. What happens when (sub)-systems come together to form a complex system of higher level?

When systems of level **M** acquire the ability from mutual recognition and information processing to engage each other in weak interactions, an embryonic higher level system **M+1** emerges in a nascent state. A relationship, a synergism is born and the nascent system of higher order evolves as schematised in Figure 3. At this primitive degree of interaction, system **M+1** is characterised by a small, partial blending of property spaces with a concomitant small loss of conservative identity characteristic of the primordial **M** systems. As illustrated later, we call such a constraint, a process of dissolvence, a concept that is the central argument of the paper.

When more extensive interactions occur among systems of level **M**, further changes in the architecture of the evolving **M+1** level system are brought forth. As portrayed in Figure 4, moderate interactions produce a more integrated **M+1** system having with an emergent property space of progressively broader extension, whereas further constraints affect the property spaces of the sub-systems. The process underway here is reversible, the temporal course being dependent upon the robustness of the two levels of complexity.

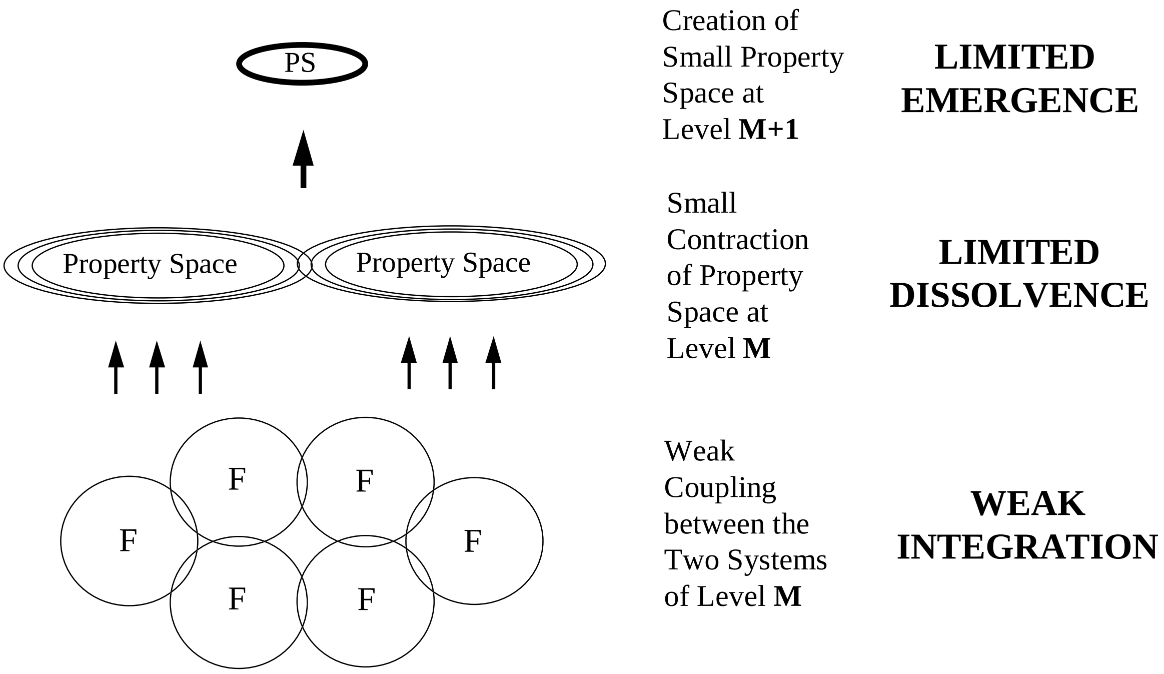

Figure 3. Schematic representation of weak coupling among sub-systems, resulting in limited dissolvence of their property space, and limited emergence of new properties.

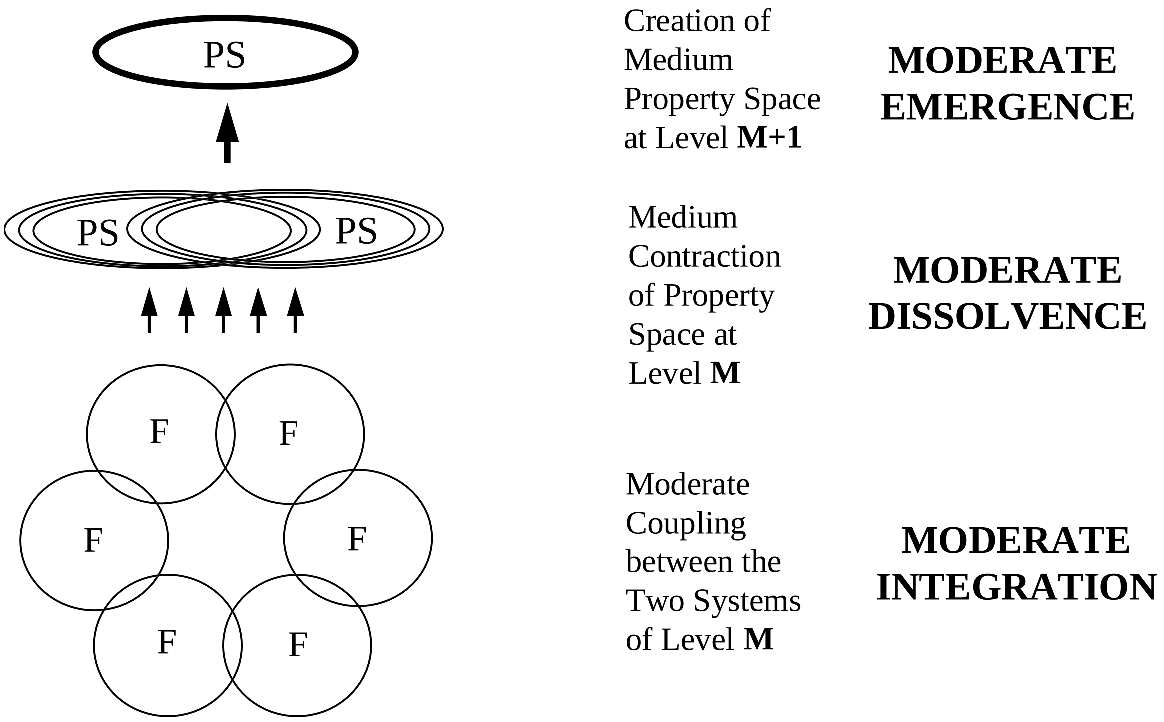

Figure 4. Schematic representation of moderate coupling among sub-systems, resulting in moderate dissolvence of their property space, and moderate emergence of new properties.

At certain points in the course of the increasing synergy among **M**-level systems, a trifurcation may occur. This is shown very schematically in Figure 5 which relates the extent of synergy to an internal information exchange driving the progress curve. This exchange is postulated by Carvalho-Rodrigues and Dockery [22] to define more accurately a system state than a statement of ingredient attributes would do. This information exchange arises from the accumulation of information which Crutchfield [23] calls intrinsic emergence. The first possibility at the trifurcation (arrow A) is that the evolving synergism may no longer be supported by the available information exchange. The system then reverses its progress, collapsing to a lower level of synergy; possibly even reverting back to the field of conservative **M**-level systems.

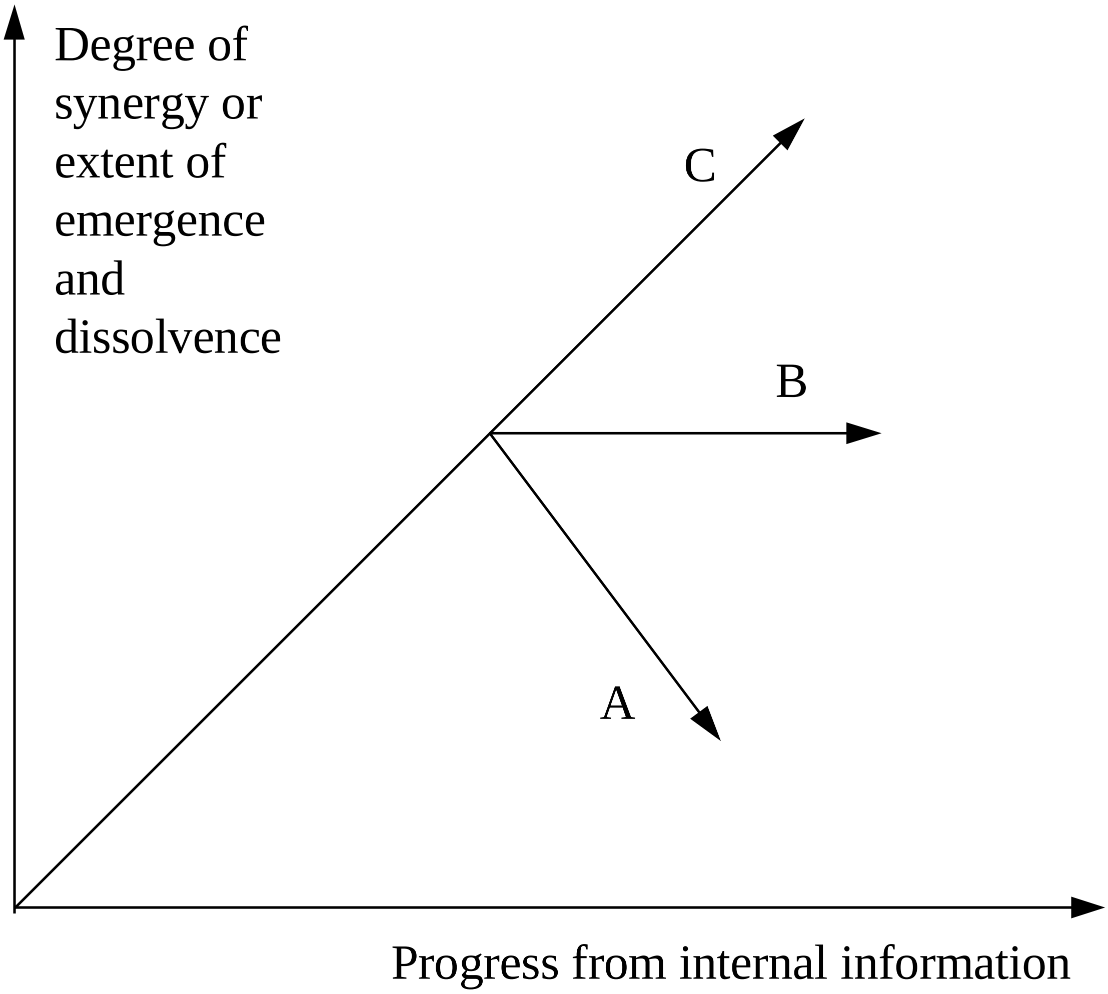

Figure 5. Trifurcation faced by an evolving complex system. The first possibility (arrow A) is for the system to reverse its progress, collapsing to a lower level of synergy. A second possibility (arrow B) in the progress of synergy is the balancing of internal information with synergetic stability, producing a metastable complex system bearing the hybrid character of **M** and **M+1** level systems. A third possibility (arrow C) is for the progress to continue from the generated information and to evolve towards a higher level of synergy with strong interactions between the components.

A second possibility (arrow B) in the progress of synergy is the balancing of internal information with synergetic stability. This produces a metastable complex system bearing the hybrid character of **M** and **M+1** level systems. At this level there is created a niche in which the complex system resides for a protracted period of time as a stable entity.

A third possibility occurring at a trifurcation (arrow C) is for the progress to continue from the generated information and to evolve towards a higher level of synergy with strong interactions (transactions [24], symbiotic union [14]) between the components. The development of extensive emergence defines a higher level of stability in the highly organised and integrated **M+1** complex system. Such a highly integrated, complex system is schematised in Figure 6. A number of authors have stressed the essential role of adaptiveness in, and complementarity of the components to generate networks of interactions [25-27].

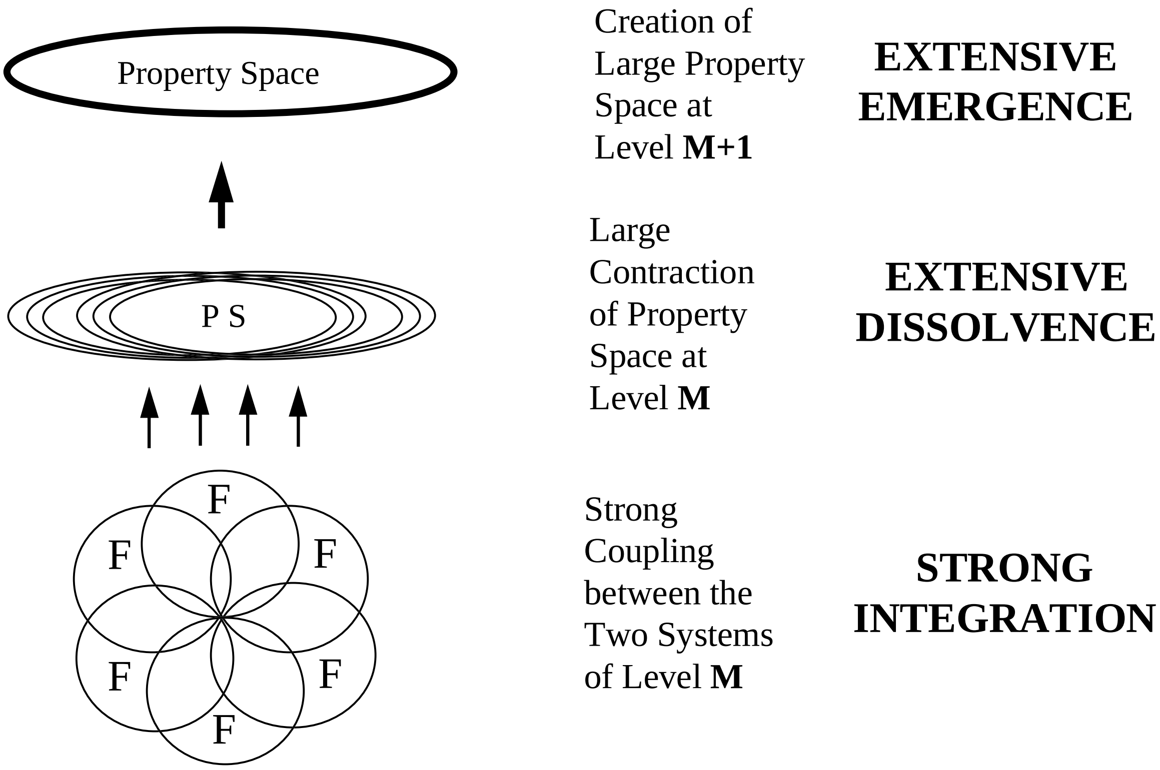

Figure 6. Schematic representation of strong coupling among sub-systems, resulting in extensive dissolvence of their property space, and extensive emergence of new properties.

At this point, we have presented a hierarchy of system types starting with isolated states symbolised by **M** in Figure 2, evolving to a nascent system and then complex systems of increasing integration as depicted in Figures 3, 4 and 6. It is assumed that this evolution is driven and controlled by an internal information exchange. Thus the evolving systems correspond to a hierarchy of synergies linked to information processing, as discussed by Fleissner and Hofkirchner [28]. How this exchange of internal information might be linked to emergence and dissolvence will be hypothesised in the last part of this writing.

3. Dissolvence -- the Word and the Concept

When examining the highly symbolic representations in Figures 3, 4, and 6, we observe that the creation of a complex system at level **M+1** is accompanied by the emergence of properties. These emergent properties define the property space of the new system. Simultaneously however, we hypothesise that the interaction, coupling and integration of the systems of level **M** is accompanied by constraints resulting in an alteration, often a reduction, in their property space. At this stage of the discussion, such effects are presented as a postulate, to be exemplified and evidenced later in this writing. Here, we reflect on possible characteristics of the phenomenon in order to focus awareness and help recognise it in nature.

The phenomenon we call dissolvence is viewed as a reduction in the number of probable states of a system, and/or in an alteration of the relative probability of these states, as it engages in productive interactions and synergy with fellow systems to form a system of higher level of complexity. Stated differently, a system merging into a higher system experiences a decrease or alteration of choice and options, coupled with a partial or total loss of independence. This is pictured in Figure 7, which gives a two-dimensional representation of the energy landscape (basin of attraction) of a system **M**.

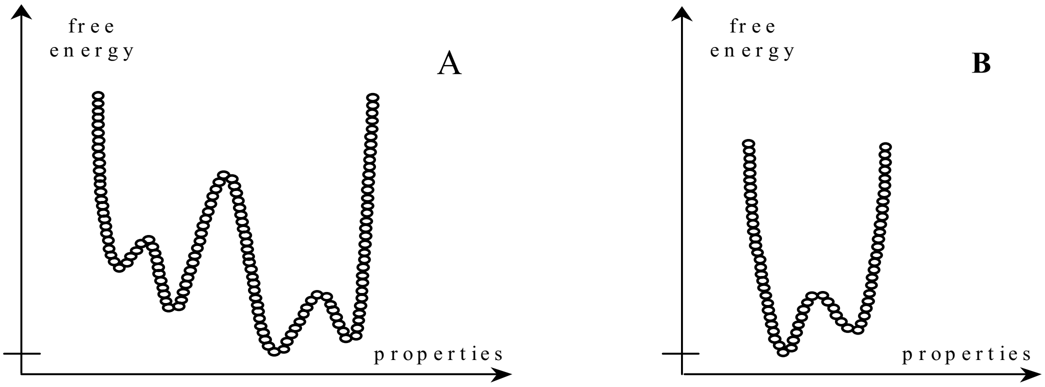

Figure 7. Two-dimensional energy landscape (basin of attraction) of a complex system in a free condition (**A**) or incorporated and constrained into a complex system of higher order (**B**). The abcissa is a one-dimensional projection of the multidimensional property space of the system. Each recognisable state is symbolised by a small circle in the energy landscape. The curve drawn by the ensemble of all formal and functional states that the system can occupy represents the energy lanscape of the system. The system in the constrained condition can occupy fewer states than in the free condition, and the energy (probability) of these states is altered.

The abcissa is a one-dimensional projection of the multidimensional property space of the system, and each recognisable state is symbolised by a small circle. The curve drawn by the ensemble of all formal and functional states that the system can occupy represents its energy landscape. When the system **M** is in a free, isolated condition, it will experience no constraint and will be able to exist in all its probable states, as schematised in Figure 7A. When in contrast system **M** becomes integrated and constrained into a complex system of higher order **M+1**, its energy lanscape should not remain unaffected. What we envisage is schematised in Figure 7B, namely that the constrained system is able to occupy fewer states than in the free condition, and that the energy (probability) of these states is altered.

The partially lost propensities do not disappear, they dissolve into the higher system, to use the same word as Wells, Huxley and Wells [1]. To speak of dissolution would be trivial and too material. For reasons of parity with emergence, the word dissolvence is proposed.

Dissolvence is an aspect of the formation of a complex system that has received little explicit attention. Interestingly, the seed of the idea can be found in a number of writings, e.g. (italics added) :

- "…we simply do not know what the inner relations and *restrictions* between the parts of a complex molecule are." [25].
- "For example, water is not present in a mixture of hydrogen and oxygen. It has a new unity which, in effect, *sacrifices* the "parts" hydrogen and oxygen." [29].
- "Each higher stage of organization occurs by fusion and by internal rearrangement of the component parts …" [30].
- "Fusion involves more than a simple addition of several individual units. *A melding takes place, a reworking of the material* to produce a new and larger whole with properties that transcend those of its parts." [30].
- "The subsidiary systems themselves do not gain any higher characteristics and may even *lose* some …" [31].
- "Hierarchical control systems […] involve *specific constraints* on the motion of the individual elements. […] The control constraints […] *limit the individual cells' freedom* […]. [The] structural constraints *reduce the possible number of states* available to a system of particles […]. A control hierarchy *constrains the behavior* of the elements of a collection so that they perform some coherent activity." [32].

We submit below that emergence and dissolvence are coexistent and coordinate phenomena. However, they do not involve the same properties, meaning that the properties lost during dissolvence are not the same as those arising in the emergence process. Thus we cannot strike a product balance of gain and loss, and indeed the complexity of the **M** and the **M+1** systems mitigates against such a reductionist exercise. Because the two processes are coincident in the above sense, they could both be associated with information processing leading to the manifestation of externally observed properties, as hypothesised in Section 7.2.

Now, we turn our attention to well-recognised occurrences of emergence in nature, and examine whether dissolvence can also be identified as a natural and universal phenomenon, harmonious with emergence.

4. Dissolvence at the Chemical and Biochemical Levels

4.1. The Level of Molecules and Aggregates of Molecules

In previous writings [21, 33], we have used a number of examples to demonstrate that the phenomenon here called dissolvence is a constant occurrence at the levels of chemical and biochemical systems. Thus, electrons and nucleons when interacting strongly to form atoms lose much of their properties and freedom, relative to a "free" state.

Similarly, the union of atoms forms molecules which are complex systems in their own right [21, 34-36]. In our representation, a molecule can be viewed as a level **M+1** system in our Figures 3, 4 and 6, whereas the ingredient atoms are level **M** systems. When the synergy of atoms occurs to form molecules, there is a well-known emergence of molecular properties that do not exist in isolated atoms. Such emergent properties and structural attributes include among others molecular topology, stereoisomerism, conformational freedom and flexibility. Emergence in molecules thus involves their form, function and fluctuation.

This view is incomplete in that it neglects the fate of the constituting atoms. Many of the properties characteristic of isolated atoms are lost in molecules. Indeed, the dissolvent properties of atoms when forming molecules are those associated with their external layers of electrons, the so-called valence electrons. These electrons no longer belong to the atom, but form the molecular orbitals which account for so many emergent molecular properties and structural attributes including chemical reactivity and wavelengths of absorption of electromagnetic radiations [34-36].

To repeat the above with different words, the synergetic process accompanying molecular formation is accomplished through electron sharing among the constitutive atoms, thereby producing a dissolvence of some atomic properties together with a concurrent emergence of molecular properties. One further aspect of dissolvence at the atomic/molecular level is its reversibility. Given proper conditions (e.g., when enough energy is supplied to the system), a molecule can be decomposed into its constituting atoms.

It is also important to note here that the synergetic process that accompanies molecular formation is in some sense anticipated since there are only a limited number of ways by which atoms may combine to form stable, discrete molecules. As discussed later, we submit that this anticipation is mediated through the information generated in the process of dissolvence. The anticipatory phenomenon is expressed in terms of valence, forces, affinities, attractions, to name a few.

Aggregates of atoms or molecules offer other, fascinating examples of mergent properties resulting from a coherent collective behaviour. As the word "coherent" implies, all atoms or molecules in an aggregate (or a region thereof) have lost their freedom and must behave identically. The laser offers the most spectacular illustration of coherent behaviour. Also, in liquid water the molecules oscillate between an incoherent phase (molecular ground state as observed in the gas phase) and a coherent phase in which the water molecules interact coherently with a large classical electromagnetic field to occupy a larger volume and display an ice-like structure. This behaviour appears central to the properties of liquid water so critical in biological processes [37, 38].

The phenomenon of phase transition is intimately related to that of coherent behaviour, as seen in solidification, magnetisation and conductivity. Here, symmetry breaking occurs, a more complex phase is formed, and an emergent property appears. As for the individual constituents and sub.processes, they "are guided by the system as a whole to conform to a coherent pattern of behaviour" [39]. This is seen as another case of dissolvence.

4.2. The Level of Biological Macromolecules

In the biosphere, the formation of molecules from atoms is just one step, albeit an essential one, in the open-ended ladder that leads to macromolecules, membranes, organelles, cells, tissues, organs, organisms, societies, and beyond [9, 12]. Macromolecules are polymeric composites of a large number of molecules linked by covalent bonds. The molecules that react to form macromolecules are known as monomers prior to the reaction, and as residues once they are incorporated into polymers. This is in itself a revealing terminology, indicating that chemists and biochemists are well aware of the changes in chemical properties that accompany the monomer-to-residue transformation.

Natural macromolecules are mainly sugar polymers, proteins, glycoproteins and nucleic acids, and they may contain a single or different types of residues (e.g., cellulose and proteins, respectively). The emergent properties of biomacromolecules include flexibility, adaptability, and mostly a large array of functions (transport of compounds and electrons, enzymatic catalysis, formation of molecular "machines", etc). Here, we examine the coordinate changes in the properties of the monomeric units as they are incorporated into macromolecules [21]. First, biological monomers become residues by undergoing chemical alterations such as loss of -H and -OH (in macromolecules formed by a reaction of dehydration, e.g. proteins and polysaccharides).

But there is more than mere chemical alterations when we compare monomers and residues. Indeed, monomers behave as any other chemical compound, possessing a property space defined by their form, function and fluctuation. As residues, their property space is severely altered and restricted. For example, their conformational space, their lipophilicity and the ionisation of side-chains are strongly influenced by the macromolecule and its macromolecular fields. In other words, residues differ from their monomeric precursors not only chemically, but also by major constraints (i.e., dissolvence) in form, function and fluctuation. In a recent computational study, we demonstrated the alterations in their property space accompanying the incorporation of amino acids into peptides [40]. An understanding of the process called dissolvence could thus lead to better prediction of future events and rational molecular design.

Here again as with molecules, reversibility of dissolvence can be achieved given enough energy and proper conditions. In fact, it is often easier experimentally to decompose a polymer into its monomeric units than a molecule into its atoms.

4.3. Biological Aggregates

Dissolvence-emergence can be seen in the aggregation of protein molecules to form functional, macromolecular aggregates known as molecular "machines" (e.g. enzymes, transporters, receptor systems with their transduction units). The molecule of hemoglobin is an example of such a system. Four hemoproteins combine through a variety of forces to become a functioning tetramer with emergent properties that optimise the binding, transport and delivery of O_2. Each macromolecule of hemoglobin exhibits dissolvence as the synergy occurs. This manifests itself as masking of certain side-chains, hydration patterns, and so forth. In general terms, biomacromolecules are regulated ("constrained") in their form, function and fluctuation by the functional aggregates of which they are sub-systems.

Biological membranes offer other clear examples of simultaneous dissolvence-emergence. The emergent properties of these multifunctional systems are compartmentalisation, the control of transport processes, coupled or hypercyclic enzymatic activities, and transmission of information, to name some of the most important functions. The constituents of biological membranes are the phospholipids that form the anisotropic bilayers, cholesterol, and various functional proteins and glycoproteins. All of these constituents experience marked limiting (i.e. dissolvence) in their property space. Thus, their packing and intermolecular interactions restrict their conformational space, while their functions are subordinated to higher-level regulations. We also note that dissolvence at the level of biological aggregates appears as a reversible phenomenon.

Ligand-macromolecule complexes are another case in point. The phenomenon of induced fit is of central significance in enzymatic reactions. Here, the enzyme selects a particular conformation of the substrate while the substrate induces a change in the conformation of the protein. The phenomenon allows additional specificity and regulatory control in the reaction [41, 42]. The same phenomenon plays a essential role in molecular pharmacology, with conformational selection in the ligand contributing to selectivity, and allosteric transition triggering the receptor's response [43-45].

An additional phenomenon occurs in enzymology, where the emergence of catalysis may be associated with electronic constraints on the substrate and/or cofactor. Consider for example the glutathione transferases [EC 2.5.1.18], which have evolved to play a critical role in the detoxification of reactive compounds and metabolites. The cofactor of these enzyme is glutathione, a tripeptide containing a cysteinyl residue whose thiol group is the nucleophile that reacts with the substrate. Because a thiol group (pKa 9) is a weak nucleophile which would react inefficiently, part of the catalytic mechanism involves a more than hundred-fold increase in the acidity of the thiol group of glutathione (pKa < 7). The result is that glutathione in the catalytic site is constrained to the anionic state whose nucleophilicity is much greater than that of the neutral state [46]. In other words, the cofactor is forced into an improbable state, allowing the enzyme-cofactor complex to be a highly effective detoxifying agent.

5. Dissolvence at the Biological Levels

A practically infinite repertoire of emergent properties is to be found in biological systems. In the previous section, we have discussed biomacromolecules which are considered to be the simplest biological systems and whose functionalities, adaptability, resilience and high propensity to enter higher-level systems make them the essential building blocks of living systems [36, 44]. The highest biological levels are organisms, populations, ecosystems, up to the global ecosystem of planet Earth [47]. Some of these levels will be examined here for the evidence of coupled dissolvence-emergence.

5.1. The Subcellular Level

The basic living unit in organisms is recognised to be the <u>cell</u>, which is made up of ingredients ranging in complexity from protein molecules to <u>organelles</u>. The latter are of particular significance here, being units endowed with specialised, emergent functions, and separated by a membrane from the rest of the cell. Examples include nuclei, mitochondria, lysosomes, chloroplasts, and the endoplasmic reticulum with its ribosomes.

Organelles are incapable of surviving or even functioning outside the cell, where they find the matrix to which they are adapted, or outside artificial media that very closely mimic these intracellular conditions. Inside the cell, they receive the energy and material to operate and the information to regulate their functions, while they export their products and wastes. One telling example of dissolvence is that of <u>mitochondria</u>, the organelles whose major function is to supply energy to the cell in the form of ATP (adenosine triphosphate). The fact that mitochondria retain the genetic information coding for some of their proteins has suggested that they could be distant descendants of independent microorganisms which during evolution entered into synergy with primitive cells, progressively losing their capability for independent life, and ending up being enslaved cellular constituents.

In other words, organelles are open systems whose survival and functioning are entirely dependent on higher-level systems (cells) via a permanent influx and efflux of information, material, energy, products and wastes. Not only the organelles, but each ingredient participates in the synergetics forming the cell, thereby loosing some aspect of its form, function and fluctuation, and participating in the process of dissolvence. Interestingly, at this biological level dissolvence must be seen as having a low degree of reversibility since organelles are not viable outside the cell, as noted above.

5.2. The Levels of Cells, Tissues, Organs and Organisms

At higher levels of biological complexity, the eukaryotic cell becomes a participant in the synergy leading to tissues, organs, and organism. At each level emergence is manifested by a variety of specific properties. But what about dissolvence?

Cells belonging to pluricellular organisms live a highly constrained life. They seldom have the capacity for independent survival and multiplication, in contrast to prokaryotic cells (e.g. bacteria) which possess these essential functions but do not associate to form pluricellular organisms. Just like organelles, eukaryotic cells are open systems whose survival and functioning are entirely dependent on and controlled by higher-level systems (tissue, organ and organism) via a permanent influx and efflux of information, material, energy, products and wastes. Thus, their differentiation, development and controled death (apoptosis) are entirely determined by external signals which, directly or indirectly, act on the genome (e.g. by switching genes on) or on post-genomic (metabolic) functions. This complete dependence for survival, this control and subjugation, are all expressions of dissolvence.

Similar controls and regulations by higher levels are apparent in tissues and organs. This is also interpreted as dissolvence, but there is a difference. Indeed, our examination of cells is based on a comparison between prokaryotic (capable of independent existence) and eukaryotic cells. No such comparison is possible for organs, since we are not aware that there exist primitive systems of this type able to assume independent existence. This point however is left open for experts to answer.

In sum, organisms are highly complex systems whose form, function and fluctuation emerge from a hierarchy of sub-systems having surrendered some of their properties. The dissolvence experienced by sub-systems is the grist for the mill of emergent property formation. In many cases (organelles, cells, organs), this dissolvence has a low degree of reversibility since the sub-systems are not viable outside the higher system.

6. Dissolvence at the Social Levels

Beyond individual organisms, we enter the realm of vegetal, animal and human societies, ecosystems, and higher human federations [48, 49]. At these social levels, the phenomenon of emergence is omnipresent and amply documented. As shown by the few examples presented below, emergence and dissolvence can again be found to coincide.

6.1. Social Insects

A number of animal societies such as colonies of social insects, schools of fishes, flocks of migrating birds and packs of carnivores show behaviour patterns of great survival value which are characterised by a marked to extreme degree of coordination and coherence. This can only be achieved through severe, genetically evolved constraints on the behaviour of the individual animals. In other words, emergence and dissolvence are again found to coincide in these animal societies.

Social insects (e.g., bees, ants and termites) live in highly integrated and complex colonies which have always fascinated humans. The emergent properties of these stable societies have allowed the social insects to occupy new ecological niches, to undertake breathtaking constructions, and to achieve unique evolutionary successes [50]. But what about the insects themselves? These were molded by evolution to be highly specialised animals able to fulfill only one or a few tasks (workers, soldiers, genitors, etc.), and unable to survive without the colony's support. Thus evolution has created insect colonies endowed with emergent properties, but has simultaneously deprived the individuals of many capabilities. This example of emergence-dissolvence is not without analogy with the formation of pluricellular organisms. One aspect of this analogy is the irreversible character of dissolvence, since individual social insects cannot survive for long away from their colony.

In Section 3, we have indicated that dissolvence could also take the form of a constraint towards an improbable state. This fact is illustrated in a spectacular manner by the recent demonstration that queens from eusocial insects (ants, termites and honeybees) have a 100-fold increased life-span compared to all solitary insect species examined. This shift to an improbable state is concordant with the evolutionary view that average lifespan in a species should increase as the rate of extrinsic mortality decreases [51].

It is interesting to note at this point that some species of ants may be evolving towards yet a higher level of organisation, with the colonies (themselves formed of a number of nests) becoming integrated in a type of "supercolony". Such a "nation" of the ant *Formica lugubris* was discovered in 1973 in the Swiss Jura mountains and has undergone little change since then [52]. This supercolony is formed of 1200 highly integrated nests linked by a network of paths extending 1000 km, covers about 0.7 km^2, and numbers 200 to 300 million individuals! According to the entomologists who are busy studying this supercolony, its evolution represents a strategy for survival in a hostile environment. Emergent properties at this level of organisation involve an optimised use and distribution of limited resources, and the exclusion of competitors. Dissolvence can be found in tight regulations of the activities and population of each nest. Food is shared between nests, migrations are organised, and some nests contribute only male or female genitors.

6.2. Human Societies, Nations, and beyond

Human families, societies, companies, associations, groups, clans, tribes, states, nations, etc., are among the innumerable types of social constructs outside of which no newborn can become fully human [53], and no human person can hope to live or survive. Some of these organisations are highly structured and tie their members tightly (e.g. armies), others are loose and impose little (e.g. scientific societies). All of them however display emergent properties in the sense that they can achieve more (quantitatively and qualitatively) than the sum of the efforts of isolated parts, be they individuals or lower-level organisations.

Yet there is another face to the functioning of these organisations, namely the obligations and duties accepted by or imposed on their members. No organisation can function or even exist without its members accepting some restrictions to freedom, e.g. executing designated tasks, obeying schedules, and collaborating with strangers. These obligations and restricted options can be seen as the human aspects of dissolvence. Obviously this level of dissolvence is often a highly reversible one, since humans in many cases -- but not always -- can leave an organisation without harm.

There is also another human aspect of dissolvence that we wish to mention, one that is seldom recognised and accepted but whose study by psychologists and sociologists might be quite revealing. What we have in mind here is the behaviour of humans in crowd or mobs. Crowd psychology was seemingly first analysed in detail by the French scientist Le Bon [54]. In human gatherings, collective emotions and even collective behaviours may arise which can be seen as commendable (e.g. in religious ceremonies, artistic performances or sportive events) or offensive (e.g. collective expression of fanaticism), or may even be downright destructive and murderous (history recent and old is replete with mass assassinations).

As far as crowds are concerned, such collective emotions and behaviours are emergent phenomena. But the picture is quite different at the level of the individuals forming the crowd. Indeed, most of these humans are now under influence. Their emotions are channeled and directed, and their gestures are no longer entirely free. In extreme cases, they will act as puppets, losing all critical and moral sense and behaving as less-than-humans. We feel strongly that these phenomena are manifestations of dissolvence.

Many historical paths exist for a nation to form and prosper. Thus, our two respective nations, whose official names testify to their formation as a federation of states, were created when small yet free republics joined their destiny. The point of relevance here is that both the American States and the Swiss Cantons freely abandoned partly or completely many of their prerogatives in order to create a viable federation. Examples of total abandon include foreign diplomacy and the military. Partial transfer of authority involved education, taxes, justice, police, communications, and others. The birth of the European Union is another example of freely accepted loss (dissolvence) of rights as a strategy to thrive.

This bottom-up creation of some nations can be constrasted with the much more common top-down path where a nation grows by political pressure and military conquest, and then grants some political privileges to its constituent units (e.g., provinces and towns). Here, the loss of rights is more imposed than freely accepted, but it is just as genuine.

A comparable argument can be made of the planet-wide mental network that has evolved explosively in recent years. We are of course referring to the Internet. A high density of four components is necessary for such a highly complex system to emerge and develop. First and above all, we need intelligent agents (humans) capable of creativity and free will. Given the modest capacity of the human brain for storing, computing and retrieving large databases, mental tools were necessary to compensate these limitations. These tools are the computers, which represent the second component in the Internet. The third component must fulfil the task of transmitting information with extreme capacity, speed and reliability. Modern telecommunications (the information "highways") offer these functions. And finally we need the fourth component, namely the immaterial products of this mental activity. These form a dynamic memory without which no mind can exist.

The global result is a network of nodes (humans and computers) and edges (the telecommunication channels) with emergent properties that humans as components of this system can apprehend partly but not completely. But what about dissolvence in this emerging, planet-wide sphere of mind (noosphere)? This is presumably a topic of utmost psychosocial significance and one well worth contemplating, but we feel that any discussion would at present be too conjectural.

7. Emergence, Dissolvence, and Self-organisation

The above examples taken from across a vast span of levels of complexity are all compatible with the concept of dissolvence, and they all illustrate the coincidence of emergence and dissolvence as presented above in conjectural form in Section 2.2. In some nascent systems where the integration between constituents is a weak and loose one, limited emergence and dissolvence are deduced. In highly integrated systems where the interactions are strong, extensive emergence and dissolvence are seen. This hypothetical link between the degree of coupling and emergence-dissolvence is schematised in Table 1.

Table 1. Relations between coupling of components, dissolvence of their properties, and emergence of properties at the higher level.

	Level M	**Level M+1**
Weak Coupling	Limited Loss of Properties Small Decrease in Number of States Small Contraction of Property Space ⇒ **Limited *Dissolvence* in Properties and Complexity**	A Few Emergent Properties A Few Emergent States Creation of Small Property Space ⇒ **Limited *Emergence* in Properties and Complexity**
Strong Coupling	Large Loss of Properties Large Decrease in Number of States Large Contraction of Property Space ⇒ **Extensive *Dissolvence* in Properties and Complexity**	Many Emergent Properties Many Emergent States Creation of Large Property Space ⇒ **Extensive *Emergence* in Properties and Complexity**

Below, we enter the realm of hypotheses and propose a plausible role for dissolvence during the creation of complex systems (Figure 8).

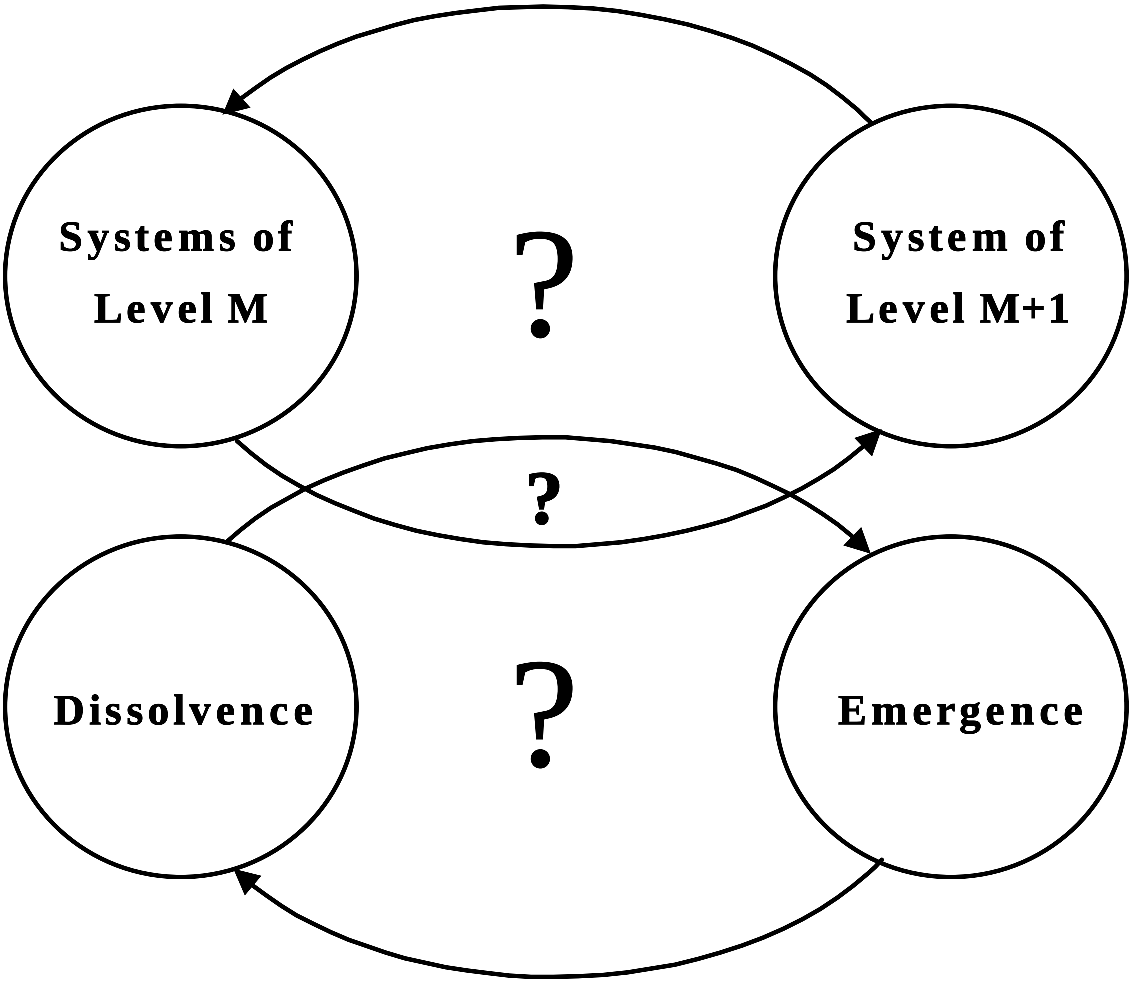

Figure 8. How is the creation of a higher-level system connected with dissolvence and emergence?

7.1. Dissolvence is not Destruction

A first point to be made forcefully is that dissolvence as presented here is not a destructive process. What accompanies the destruction or death of a complex system is its own decomposition, and not dissolvence at the level of its constituents. Dissolvence as we understand it is not implicated in the destruction of a complex system. On the contrary, and as amply illustrated above, it is coincident with the emergence of a complex system. How can dissolvence be understood to be a creative process?

7.2. Dissolvence is Part of the Creative Process of Self-organisation

It has been proposed that information is a basic property of the universe along with matter and energy [55]. Information is defined in terms of its capacity to organise a system, and a system is said to contain information if it exhibits organisation or non-random patterns of components. Thus, the information of a system reflects the internal alignment or coordination of its components so that the production of change in any form is facilitated, enhanced or made more efficient [56]. In this sense, the system's information is a source of the synergy that we have illustrated in our figures. The information amplifies in a non-linear way the effects of ingredient interactions, leading to the familiar characteristic of self-organisation [57] and emergent behaviour -- the whole is more than the sum of the parts.

Information is also concerned with a selection from alternatives [59]. This again is in accord with the concept of dissolvence, which as stated implies a loss of options (Section 3).

Information is generated when causes in a system are exceeded by effects [28]. This happens when there are changes in the structure or state of a system, as resulting from dynamic interactions. Information is created during the organisation of a system, and this information fuels the creation of new features in the structure or state which we observe as emergent behaviour. We propose to carry this concept a step further by recognising that dissolvence is an information-generating and hence a creative process. Far from being a loss in terms of information, we view the reduction in the number of states at level **M** as creating the information that fuels the creation and self-organisation of the system at level **M+1**. In other words, dissolvence at level **M** is transformed into information passed to level **M+1** where it appears as emergence (Figure 9). Such an exchange of information could be progressive, emergence deriving information from dissolvence in order to allow first the birth of a nascent system. As dissolvence progresses, the extent of the transformations produces an enhanced level of organisation and drives the **M+1** system to higher levels of integration and complexity.

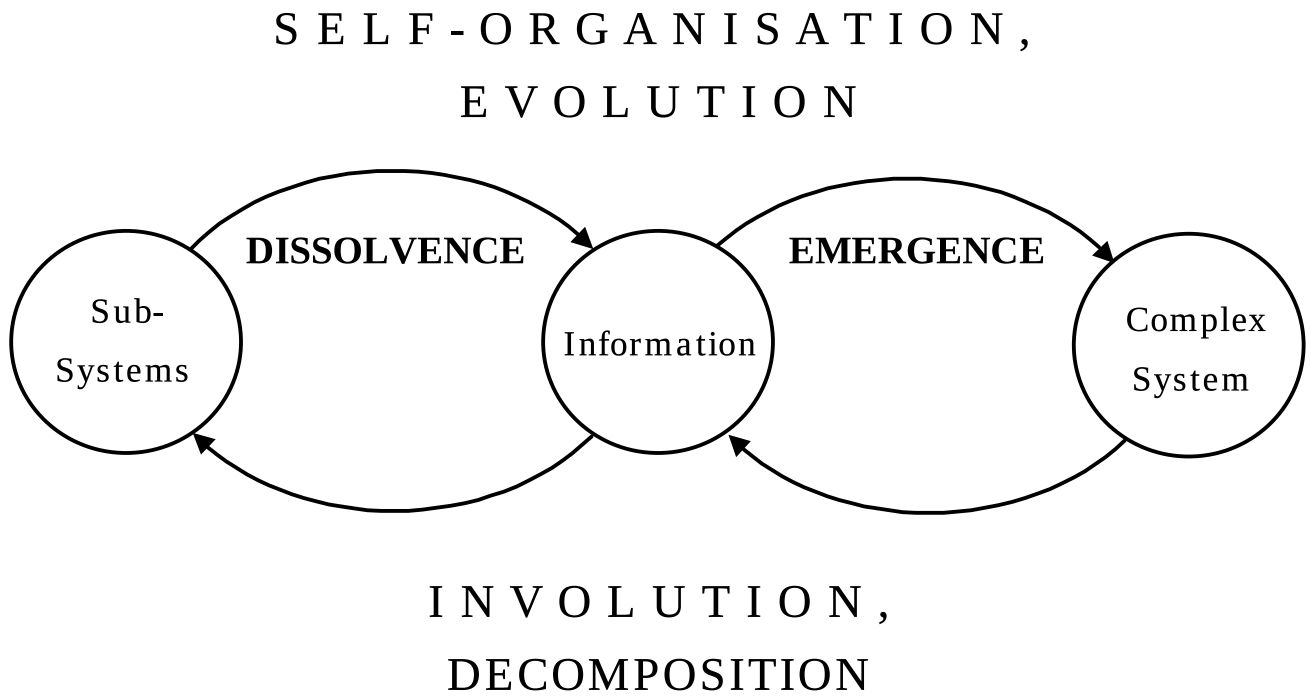

Figure 9. Schematic representation of dissolvence as the process generating the information to fuel the creation and self-organisation of a complex system at higher level.

The consequences of this idea is that the greater the episodes of dissolvence in a system, the greater the generation of information and hence the more emergence and greater complexity. Such a concept fulfills the premise that an increase in a system's information is more likely if its initial level of information is higher [60]. In this perspective, dissolvence is placed at the core of emergence and complexity, serving as a fuel for the evolution to higher levels organisation.

7.3. Dissolvence and Top-down Causation

Top-down causation (downward causation, top-down influence) signifies that the nature of a complex system influences or determines the nature and function of its components [61]. This concept comes close to the idea of dissolvence presented here, but there is a difference if it is understood narrowly [62].

Indeed, the concept of top-down causation correctly acknowledges that a complex system constrains the behaviour of its parts, but the view it offers is a static, *post-hoc* one. In contrast, the concept of dissolvence we have presented here is suggested to be a dynamic one intertwined with emergence and fuelling the self-organisation of a complex system as it appears and matures (Figure 9). It is this creative, evolutive, information-generating aspect that, we propose, makes the concept of dissolvence more general and potentially fruitful than top-down causation.

A related view is that of catalytic closure, which is understood to mean that the "whole is maintained by the action of the parts; but by its catalytic closure, the whole is the condition of the maintenance of the parts" [63]. Here, the concept of top-down causation is expanded to include the bottom-up creative role of interacting parts, as stressed throughout this essay. Top-down causation is also strengthened to imply that the parts have relinquished so much of their individuality and separateness that they are no longer viable outside the higher system. As discussed in Section 5, this is indeed the situation prevailing in the biological levels.

7.4. Synchronisation

Another facet of dissolvence, and one we merely mention here, is the synchronisation between parts that characterises many complex systems. A number of authors have noted the different time scales exhibited by complex systems at different hierarchical levels. From the law of temporal hierarchies [58] to the hierarchy of dynamical time scales [32] and the hierarchy of frequencies [64, 65], there appears to be a consensus that an association exists between levels of complexity and the time scales at which complex systems function. Allen and Hoekstra go as far as stating that "[l]ow frequency behavior allows the upper level to be the context of the lower level" [64].

A consequence of this association between levels of complexity and time scales is that sub-systems must synchronise when merging to form a higher system. Such a phenomenon, which has indeed been recognised by a number of authors, is easily understood as a manifestation of dissolvence. It is for example referred to as entrainment or interactional synchrony [66, 67], and is seen when oscillators respond in synchrony [39].

The connectedness between entrainment and coupling, and hence with dissolvence, is encapsulated by Hall's words, "if you can't entrain, you can't relate" [66]. In addition, there is a top-down aspect to entrainment, in that higher systems also constrain the rates/frequencies at which their components behave, relative to their unconstrained state [68].

8. Conclusion

In this writing, we have viewed from an unexplored perspective, the creation of complex systems and the emergence of their specific properties. Specifically, we have examined the property space of the components as they come together and enter coupling and synergy to create a complex system. What has been found is that the formal and functional states of the components are altered and often decreased in number during this creation. This phenomenon we call dissolvence, and it can be recognised in the formation of complex systems ranging from atoms to nations.

The idea of parts being contrained by the complex system to which they belong is not a new one. The quotations at the beginning of this essay and in the text can be interpreted in the light of the concept of dissolvence. The concept of "top-down causation" [61] discussed above is also worth remembering.

In sum, the twin concepts of dissolvence and emergence characterise the interplay between matter, energy and information as fundamental ingredients of nature. A number of aspects of dissolvence remain to be clarified in future explorations:

- Complex systems are adaptable, meaning that their evolution is driven by their environment. The relation between the adaptability of a complex system and the dissolvence experienced by its components has not been examined here and should be established. However, it can be noted that the sequence leading from a weakly integrated to a strongly integrated system (Figures 3, 4 and 6) can or must be context-driven. This would suggest that dissolvence is one of the mechanisms that allow adaptability.

- A system can break down or simply revert to a lower state (Figure 5). Whereas dissolvence is seen as a forward process, its reversibility must be elucidated. Throughout the examples discussed above, we have hinted at cases of either facile or improbable reversibility. This is equivalent to considering the degree of autonomy of the parts, i.e. their degree of independent existence [69, 70].

- Another aspect to be examined concerns the capacity of complex systems to anticipate the future [8, 60]. How anticipation connects with dissolvence appears as a challenging problem.

These ideas are now brought forth for the appreciation of the scientific community.

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