

## Chapter 5

### MULTILEVEL RESEARCH: EXPLORING NATURAL ROOTS OF SOCIO-ECONOMIC ORGANIZATIONS

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*This article is a part of a collaborative, interdisciplinary research effort to develop multilevel models of organization in living systems, with a broader aim to develop new scalable solutions to enable multilevel sustainability between economics and ecosystems. To facilitate further interdisciplinary collaboration and research, an initial scaffolding of multilevel ideas and observations has been put out. It presents a multilevel view of organization in living systems that spans across molecular, cellular, ecological, and social systems. In developing the scaffolding, some definitions of key organizational characteristics have been put forth. An examination of multilevel living systems through the lens of these definitions reveals two common multilevel level organizational patterns (CMOP). These CMOPs provide new insights into the possible natural roots of our socio-economic human society. The research also points to possible organizational and role similarities between subsoil Mycorrhiza networks, gut bacterial networks, and our financial investment networks. New insights from the CMOPs have been discussed, important implications outlined, a possible new direction for multilevel sustainability between economic and ecosystems has been presented, questions and areas for further research have been put out.*

#### 1. Introduction

*Some of the most pressing ecological and social problems facing us today are known to arise through interactions between self-organizing processes across two or more different levels in organization [Joshi 2015]. For instance, ecological changes and ecosystem degradation [[World Wildlife Fund 2014](#)] that accompany socioeconomic development are often attributed to interactions between our socioeconomic organizations and underlying ecosystem organizations [[Daly 2007](#)]. A deeper understanding of such multilevel phenomena requires efforts to develop organizational models and insights that span multiple levels.*

This article is a part of a collaborative, interdisciplinary research effort to develop multilevel models of organization in living systems, with a broader aim to develop new scalable solutions to enable multilevel sustainability between economics and ecosystems. To facilitate further interdisciplinary collaboration and research, an initial scaffolding of multilevel ideas and observations has been put out in the form of common multilevel organizational patterns (CMOP).

This paper presents two important common multilevel organizational patterns (CMOP) in organization of living systems that point to the possibility that some key organizational aspects of human socio-economic organizations could be an extension of a larger multilevel pattern in organization in living systems. These CMOPs provide new insights into the possible natural roots of our socio-economic human society. They also serve as multilevel “scaffolding” of ideas and observations for new research aimed at exploring similarities in organization and underlying processes across multiple levels in living systems. Such research could eventually help us better understand how our socio-economic organizations fit into the larger scheme of organization and evolution in living systems.

Prior research across different levels in natural organization has revealed that organization in living systems at one organizational level leads to the emergence of new entities that enable organization at the next higher level. For instance, organization in molecular systems in the course of prebiotic evolution leads to the emergence of living cells [[Morowitz and Smith 2007](#); [Pratt 2011](#); [Luisi 2014](#)]. Organization in living cells then gives rise to their multicellular forms [[Bonner 1998](#); [Furusawa and Kaneko 2002](#)] and ecosystem networks comprised of autotrophic and heterotrophic species [[Ulanowicz 2009](#); [Solé and Bascompte 2006](#)]. Organization in heterotrophic species populations (including humans) then leads to social organization comprised of families, communities [[Hamilton et al. 2007](#)] and eventually leading to the emergence of formal businesses, and a socio-economic system of exchanges and organization that is described in economic, social and organizational theories [[Padgett and Powell 2012](#); [Hordijk 2013](#); [Scott 2011](#); [Searle 2010](#)].

It has also been previously observed that certain multilevel organizational patterns arise in living systems. For instance cooperation [Stewart 2014; Axelrod and Hamilton 1981] has been observed as a multilevel organizational pattern in living systems. Autocatalysis is another multilevel organizational pattern in living systems [Ulanowicz 2009; Hordijk 2013]. In order to look for common multilevel organizational patterns in the organization of living systems, one needs to first develop useful definitions of general organizational characteristics of systems that could be applicable across multiple levels. A multilevel view using such defined organizational characteristics can then be used to look for multilevel patterns in the organization of living systems.

For instance, in the widely studied common multilevel organizational pattern involving “cooperation” [Axelrod and Hamilton 1981; Stewart 2014], systems belong to the class of unitary systems (like atoms, unicellular organisms or species individuals) “cooperate” or share their dynamic to give rise to the class of composite systems (like molecules, multicellular organisms, or species social groups). In multilevel systems, it is only when one looks at such systems using an organizational characteristic of “unitary systems” across multiple levels giving rise to systems with an organizational characteristic of “composite systems with a shared dynamic” across multiple levels, that cooperation as a multilevel organizational pattern becomes evident.

In this article, new definitions of classes of coupled-composite systems, decoupled-composite systems, alphabetic catalysts, and the concept of modulatory systems have been used to capture important characteristics of internal organization in living systems across multiple levels. Such a definition allows one to look for organizational similarities across multiple levels; hence allowing for a multilevel comparison of organization across three different levels molecular level, cellular level and social level.

An examination of multilevel living systems through the lens of these definitions and concept reveals a common pattern in organization of living systems across multiple levels. The CMOP extends across levels from molecular organization in cells, to cellular organization of species in ecosystems, and the organization of people in human society.

## 2. Definitions

*First the idea of a “composite system” in the context of multilevel organization in living systems is presented and then used to define two classes of systems called “coupled-composite systems” and “decoupled-composite systems”. These definitions are then used to reveal a common multilevel organizational pattern in organization of living systems.*

From a systems theory perspective in its broadest conception, a “system” may be described as a complex of interacting components together with the relationships among them that permit the identification of a boundary-maintaining entity or process [Laszlo 1998]. A composite system in living organization then is a combined system that is comprised of two or more systems at the same level in organization (i.e. each system is now a sub-system of the composite system), such that the organization of the entire composite system fulfils the boundary maintaining condition.

At different levels in living systems internal organization that constitutes a composite system is based on relationships (or bonds) between elements based on sharing or exchange. For instance, composite systems in the form of molecules arise through relationships (bonds) between atoms through sharing of electrons. Cellular composite systems in the form of multicellular species arise through relationships or bonds between cells through sharing of biomolecules and biochemical pathways. Social composite systems in the form of families, communities, and businesses arise through relationships or bonds between species individuals through sharing of species resources for work in the course of collective adaptation. A summary of composite systems at different levels in organization of living systems referenced in this study is presented in Table 1.

In such exchange-based relationships that give rise to composite systems, the dynamic of exchange is sometimes asymmetrical, in that one sub-system acts as a *donor* and other acts as an *acceptor* of the medium of exchange (i.e. shared resource) at that level. For instance, in molecules that are formed through the exchange of electrons, differential electron affinities [Sanderson 1988] between atoms can make some atoms (or atomic groups) act as electron donors and some act as electron acceptors within the same molecule. In such a case of asymmetrical exchange two classes of composite systems can be defined: (1) The class of coupled-composite systems, and (2) The class of decoupled-composite systems.

### 2.1. The class of coupled-composite systems

*Composite systems that are comprised of both donor and acceptor sub-systems (at a given level in organization), within the same composite system organization are said to belong to the class of “coupled-composite systems”.*

For instance, a water molecule (H<sub>2</sub>O) that is comprised of an electron donor atom (H) and an electron acceptor atom (O) in the same molecule belongs to the class of “coupled-composite systems” at the molecular level. Carbon dioxide (CO<sub>2</sub>) molecule that is comprised of an electron donor (C) and an electron acceptor (O) in the same molecule is also said to belong to the class of coupled-composite systems at the molecular level. Similarly, multicellular autotrophic or multicellular chemoautotrophic species are coupled-composite systems at the cellular level, because the biomass producing donor cells (photosynthetic cells or chemosynthetic cells) and biomass acceptor cells (non-photosynthetic cells or non-chemosynthetic cells) are present within the same multicellular system. Likewise, kinship based social groups are coupled-composite systems at the species level because species producing groups (i.e. reproducing members or families) and functionally specialized species deploying working groups are present within the same family or kinship-based community composite system comprised of many different related families.

## 2.2. *The class of decoupled-composite systems*

*When donor and acceptor sub-systems exist in separate composite systems, such composite systems are said to belong to the class of “decoupled-composite systems”.*

For instance, carbohydrate (CH<sub>2</sub>O) molecules are produced in the course of photosynthesis from oxidized molecules like CO<sub>2</sub> and H<sub>2</sub>O by separating electron donor Hydrogen atoms from electron acceptor Oxygen atoms through the photolysis of water and the release of electron acceptor Oxygen. Carbohydrates are reduced molecules and have a deficiency in the electron acceptors (compared to CO<sub>2</sub> and H<sub>2</sub>O) hence such reduced molecules belong to the class of decoupled-composite systems at a molecular level.

Similarly, unicellular and multicellular heterotrophic species are decoupled-composite cellular systems at a cellular level, because unlike multicellular autotrophic species that have both net biomass producing photosynthetic (donor) cells and net biomass consuming non-photosynthetic (acceptor) cells, heterotrophic multicellular species do not have net biomass producing photosynthetic cells within their cellular organization. Hence they have an internal deficiency in biomass production (in the context of a production-consumption dynamics) [[Yodzis and Innes 1992](#)] and belong to the class of decoupled composite systems.

Likewise, non-kinship based social groups are decoupled-composite systems at the species level, because unlike kinship based social groups that internally produce their own human resources (or species resources), non-kinship based social groups like formal businesses do not have species producing groups (i.e. reproducing families) within their internal organization. Hence, non-kinship based social groups, like modern day formal businesses must depend on kinship based social groups for their human resources (or species resource) needs, hence they are classified as decoupled-composite systems at the level of social organization.

## 2.3. *A comparative definition*

*It is important to clarify that the classes of coupled-composite systems, and decoupled-composite systems are not absolute definitions of composite systems, but they are distinct classes of systems that arise through a comparison between organizations of two sets of species. Hence both H<sub>2</sub>O and CO<sub>2</sub> as molecules do not belong to the class of coupled-composite systems in any absolute sense. Both H<sub>2</sub>O and CO<sub>2</sub> molecules have a very different internal balance between electron donors and acceptors. However, it is only through a comparison of molecular organization of related coupled-composite molecular systems – H<sub>2</sub>O and CO<sub>2</sub>, and decoupled-composite molecular systems – carbohydrates, that the organizational distinction between coupled-composite systems and decoupled-composite systems becomes evident.*

## 2.4. *Alphabetic catalysts*

*Another common multilevel pattern in organization in living systems is the emergence of catalysts and networks of such catalysts that operate at different levels in organization. At the molecular level, enzyme proteins are known to catalyze transformations between molecules [[Alberts et al. 2002](#)] in living cells. At the cellular level, DNA catalyzes cellular and multicellular organization in species. Finally, at the level of organization of species populations, human language allows collective social “rule making” that creates preferred behavioral paths in society and “catalyzes” social organization [[Knight 2005](#); [Searle 2010](#); [Logan 2007](#); [Padgett and Powell 2012](#)].*

In defining catalysts here we have used an extended definition of catalysts and catalysis. It is proposed that a catalyst is a system that enhances the rate of transformation of a set of input objects into a set of output objects, without itself undergoing any permanent change. In this way a catalyst creates preferred paths in the transformation of

input objects into output objects. Such an extended definition of a catalyst and catalysis to include all sets of objects not just molecules and their reactions, allows for the extension of the concept of catalyst and catalysis beyond chemical reactions, and to any process that involves the mediated transformation of input entities into output entities. Similar extended definition of catalysts and catalysis have also been attempted elsewhere [[Cabell 2011](#); [Padgett and Powell 2012](#)].

Further, in all these cases such catalysts are known to evolve to have a certain alphabetic character [[Ji 1999](#)]. Protein catalysts are made up of alphabets of 20 amino acids, DNA is made up of alphabets of 4 nucleotide base pairs, and human languages have their own phonetic and alphabetic character. For the sake of drawing organizational similarity across multiple levels in this study such catalysts have been termed “alphabetic catalysts”.

The coupled and decoupled-composite systems across multiple levels and alphabetic catalysts (that are referenced in this study) are tabulated in Table 1.

Table 1. A summary of composite species that arise through sharing of resources at different levels in organization in living systems is presented. Further, coupled-composite systems and decoupled-composite systems and alphabetic catalysts (that are referenced in this study) at different levels in organization of living systems are presented.

Org. level	Systems	Shared resource	Composite Systems	Coupled-composite systems	Decoupled composite systems	Alphabetic catalysts
I	Atoms	Electrons	Molecules	Oxidized molecules	Reduced molecules	Proteins
II	Living Cells	Bio-molecules	Multi-cellular species	Multicellular autotrophic species	Heterotrophic species	DNA
III	Species individuals	Species resources	Families, extended families, business entities	Kinship based social groups (like families)	Non-kinship social groups (like formal businesses)	Human language based collective social rules

## 2.5. Characterizing modulator systems

*Modulation is a term that has been often used in the context of communication technologies. Frequency Modulation (FM) and Amplitude Modulation (AM) are two popular technologies in radio (RF) communication [[Hudson and Luecke 1999](#)]. In each case there is a “carrier wave”, a radio wave that defines the base level dynamics of system, which is altered or “modulated” by a modulator wave to encode new information like music or news in the carrier wave. Such systems are essentially comprised of two independent dynamics: (1) the dynamics of the carrier wave (base dynamics) and (2) the dynamics of the modulator system. The resultant dynamic after modulation represents the combined effect of the two dynamics. In such a system, a “modulator” is a device whose input is used to “modulate” the dynamics of the carrier wave [[Hudson and Luecke 1999](#)]. Similarly, modulation is also possible where a light beam acts as a carrier. Using a similar conceptual framework in optical systems, an optical modulator is defined as a device that is used to modulate a beam of light [[Ramaswami and Sivarajan 2002](#)].*

In the brain as well, a number of “neuromodulators” like dopamine, and serotonin, are known to change (i.e., modulate) the patterns of flow of stimulus through neural networks [[Arias-Carrión et al. 2010](#); [Weiger 1997](#); [Doya 2000](#)]. A neuromodulator is defined as something (as a polypeptide) that potentiates or inhibits the transmission of a nerve impulse but is not the actual means of transmission itself. The dopamine system in the basal ganglia in the brain is one of the most widely studied neuromodulator networks. Every dopaminergic neuron is extensively branched and a single dopaminergic neuron can synapse with a very large number of target neurons [[Arias-Carrión et al. 2010](#)]. Here again the neuronal network system can be represented through two different dynamics. The first is the base level dynamic of stimulus flow in the neuronal network that is enabled through the release of neurotransmitters, and the modulation of this dynamics by the modulator system is based on dynamics of the release of neuromodulators like dopamine. The combined effect of the two determines the overall dynamics of stimulus flow in the neuronal network.

In the case of the dopamine system this helps an organism choose between different behavioral choices and learn to choose those that predict a reward [[Arias-Carrión et al. 2010](#)].

For the sake of the discussion in this article, we define a modulator system, as a system whose input modulates the dynamics of the base system. The base system is assumed to have its own dynamics independent of the modulator system. The combined dynamics of the entire system is then a combination of the two.

### 3. Common Multilevel Organizational Patterns (CMOP)

A multilevel view of organization in living systems, using the definitions in the previous section reveals two common multilevel organizational patterns. The first CMOP appears in the form of a triad comprised of interacting systems. The second CMOP is seen in exchange networks at three different levels in organization.

#### 3.1. CMOP in molecular, cellular and social organization

The first CMOP in the form of a triad is seen at three different levels of organization in living systems. At each organizational level this triad is comprised of interactions between three classes of systems- coupled-composite systems (1), decoupled-composite systems (2) and a network of alphabetic catalysts (3), as presented in Fig. 1 (numbers in parenthesis refer to those in Fig. 1).

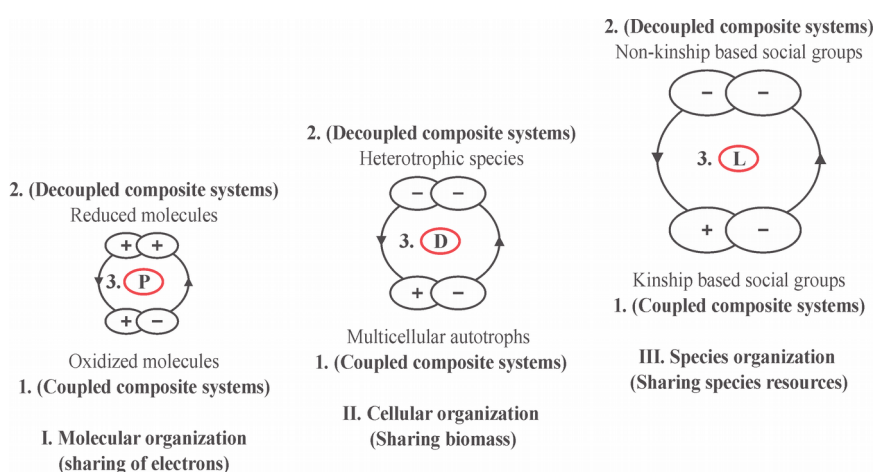


Fig 1. Common multilevel organizational pattern of a triad of interactions between coupled-composite systems (1) decoupled-composite systems (2) and alphabetic catalysts (3), across three levels of organization in living systems, as described below.

At the first level of molecular organization into autotrophic or chemoautotrophic living cells (I), the interacting triad is comprised of coupled-composite systems in the form of oxidized molecules (1), decoupled-composite systems in the form of reduced molecules (2), and enabled by (3) networks of alphabetic protein catalysts, shown in red as (P) in Fig. 1. The interactions between elements of this triad are found in the autocatalytic molecular “metabolic core” [[Morowitz and Smith 2007](#); [Smith and Morowitz 2004](#); [Luisi 2014](#)] within living cells. The metabolic core is one of the earliest autocatalytic molecular systems in the evolution of chemoautotrophic living cells, and is now universally found in living cells. The metabolic autocatalytic core is further coupled with other cellular metabolic pathways that expand metabolic range and sustain living cells [[Smith and Morowitz 2004](#)].

At the second level of cellular organization (II), the interacting triad is comprised of coupled-composite systems in the form of multicellular autotrophic species (1), decoupled-composite systems in the form of heterotrophic species (2), and is enabled by a (3) network of alphabetic DNA catalysts, shown in red as (D) in Fig. 1. The interactions between elements of the triad are found in autocatalytic networks of autotroph-heterotroph interactions within species ecosystems [[Ulanowicz 2009](#)].

At the third level of organization of heterotrophic species (III), the interacting triad is comprised of coupled-composite systems in the form of kinship based social groups (1) like families, extended families and kinship based communities, decoupled-composite systems in the form of non-kinship social groups like formal businesses (2), and enabled by a (3) catalytic network of (alphabetic) linguistic rules, shown in red as (L) in Fig. 1. The interactions between elements of the triad are found in autocatalytic networks of human resource exchanges between families and business entities within socio-economic human societies.



The common multilevel organizational pattern hence comprises interactions between coupled-composite systems, decoupled-composite systems and alphabetic catalysts, and gives rise to “autocatalytic core networks” at that level in organization through these interactions.

### 3.2. CMOP in exchange networks

The second CMOP observed is based on new research findings from soil microbiology, and gut bacteriology. These research findings reveal interesting organizational similarities between sub-soil Mycorrhiza networks, gut bacterial networks in heterotrophic species, and financial investment networks in socioeconomic communities. When examined together with the multilevel organization of living systems outlined in Fig. 2, this research reveals a common pattern where at each of the three levels of exchange networks (Level I, II, and III in Fig. 2) Mycorrhiza networks, gut bacterial networks and financial investment networks modulate the flows of exchange materials across exchange networks comprised of competing species. At three different levels these networks are known to modulate the growth rates of species, and hence increase or decrease the salience of different network paths that comprise the total flow of resources through the entire network. These modulator networks have been marked as “M” (Mycorrhiza), “G” (gut bacteria), and “B” (Banks and financial networks) in Fig. 2. Current research that presents organizational and role similarities between modulator networks that operate at three different levels in organization in living systems has been compiled below.

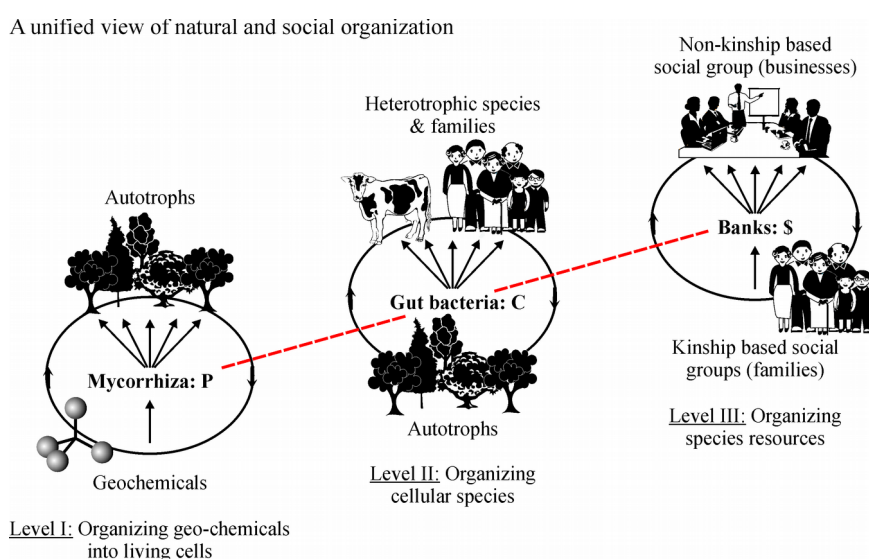


Fig. 2. Three levels of exchange networks seen in living systems. The organization at the third, social level is based on the previously proposed CMOP (section 3.1). The first level (Level I) involves organization of geochemical molecules into autotrophic species and gives rise to networks of exchange between autotrophic species and bio-geochemical cycles, the second level involves ecological networks of exchange between autotrophs and heterotrophs. The next level involves species organization into socio-economic society and gives rise to networks of exchange between kinship based and non-kinship based social groups. Research points to the existence of three levels of modulator systems: the Mycorrhiza networks (M) in roots of terrestrial autotrophs, gut bacterial networks (G) in guts of heterotrophic species, and banks and financial networks (B), as discussed in section 3.2 and 3.3. The red-dotted line illustrates the possibility of synergizing across the three levels of organization as discussed in section 4.7

### 3.3. Important research findings supporting Mycorrhiza, gut bacterial, and financial investment networks as modulator systems

#### 3.3.1. Arbuscular mycorrhizae (AM)

Arbuscular mycorrhizae (AM) are ancient fungal habitants going back more than 400 million years [Parniske 2008]. They are mainly involved in the transfer of water and mineral nutrients, in particular phosphate (Pi), to their host plants. Roots of over 90 % terrestrial plant species can associate with AM fungi, establishing endosymbiotic relationships [Van Der Heijden and Horton 2009]. AM exchanges are estimated to consume up to 20 % of the photosynthetic production of terrestrial plants (approximately 5 billion tonnes of carbon per year) [Parniske 2008]. Therefore, AM symbiosis contributes significantly to global phosphate and carbon cycling and influences primary productivity in terrestrial ecosystems [Parniske 2008].

AM fungi are coenocytic, that is their hyphae have a continuous cytoplasm (without cross walls) in which thousands of nuclei coexist, forming a syncytium. The nuclei encode surprisingly diverse genomes and several lines of

evidence indicate that the nuclei themselves are diverse, that is AM fungi are heterokaryotic [Parniske 2008]. This suggests that AM fungi could have a wide range of metabolic and symbiotic capabilities. Its long evolutionary history, its highly conserved primitive cellular form, combined with its ubiquitous symbiosis with terrestrial autotrophs leads us to believe that AM probably occupy an important ecological niche in the subsoil ecosystem comprising plants, bacteria and geochemical cycles [Johnson et al. 2005].

Subsoil networks of AM fungi are known to interconnect multiple species of autotrophic plants [Van Der Heijden and Horton 2009; Heijden et al. 2015]. They modulate [Van der Heijden et al. 1998] and influence plant community structure [Montesinos-Navarro et al. 2012] and alter plant-plant interactions by supplying and recycling nutrients [Van Der Heijden and Horton 2009].

AM fungi symbiotically provide phosphorous (and Nitrogen) from the soil in exchange for carbohydrates from plants. The extent of symbiosis in the plant root system is dependent on the plants Phosphorous and Nitrogen status and its photosynthetic capacity (carbohydrate production) [Van Der Heijden and Horton 2009]. Since AM exchange subsoil Phosphorous for Carbohydrates from plants, they are able to simultaneously sense the status of subsoil geochemical cycles, and the photosynthetic productivity of the associated plant species. Through their modulator effects AM fungi are known to have both positive and negative effects on plant growth [Van Der Heijden and Horton 2009], hence modulate flows in interspecies networks comprised of autotrophs, bacteria, and biogeochemical cycles [Bonfante and Anca 2009].

While Phosphorous is predicted to be the major limiting element in terrestrial ecosystems high-energy Carbon is the limiting element for decomposers [Cherif and Loreau 2009]. Hence by exchanging Phosphorous for high-energy Carbon (carbohydrate) from plants, AM could be able to allocate growth limiting Phosphorous to modulate overall production of carbohydrate across networks of competing species of autotrophs and their subsoil bacterial ecosystems [Walder et al. 2012].

### 3.3.2. Gut Bacterial networks

*The bacterial-host mutualism is ubiquitous and is seen even in the simplest of heterotrophic species [Thomas et al. 2010]. The pervasive and extensive mutualism between gut bacteria and their heterotrophic hosts points to the possibility that gut bacteria could play an essential role in enhancing environmental adaptation of their hosts [Norris et al. 2013].*

From the point of view of their role in the host-food dynamic, gut bacteria occupy a strategic position in the autotroph to heterotroph flow of biomass. The flow of biomass in the exchange between autotrophs and heterotrophs occurs through the guts of the heterotrophic species. From this unique vantage point gut bacteria can sense the changing nature of food supply from autotrophs (i.e., changing diets of heterotrophs) as well as the internal states of the heterotrophic species [Norris et al. 2013]. This could enable them to modulate the absorption and utilization of resources in the gut of the host based on changing composition of food supply and internal states of the host. Hence, gut bacteria can determine how much of the consumed food-energy the host can assimilate and how much passes out back to the ecosystem.

Gut bacteria are known to modulate host appetite as well as their internal state of satiety [Norris et al. 2013]. Research provides evidence that gut bacteria can even determine metabolic phenotypes in humans [Li et al. 2008]. Gut bacteria have also been shown to modulate growth rates and reproduction rates in some species [Storelli et al. 2011]. The species composition of gut bacteria biome can influence the level of absorption of nutrients. For instance, in human populations certain species of bacteria are associated with higher fat absorption and lead to obesity in their hosts [Turnbaugh et al. 2006; Ley et al. 2006].

One of the most prominent food classes whose absorption is influenced by gut bacteria is carbohydrates [Hooper et al. 2002; Flint et al. 2012]. Most mammals cannot digest and absorb complex polysaccharides from plants. Gut bacteria digest these sugars in the gut and break them down into short chain fatty acids that are readily absorbed by the host. By modulating carbohydrate metabolism gut bacterial biomes can significantly influence the calories available to a species [Flint et al. 2012].

The species composition of gut bacterial biome is known to be dependent on the diet of the host [Jumpertz et al. 2011]. Further, changes in diets produce changes in species composition [David et al. 2014]. Such changes in species compositions of gut bacteria could be associated with changes in growth rates in host species [Storelli et al. 2011]. Hence it is possible that the bacterial colonies in the gut can sense changing patterns in food production (from changes in dietary intake of its hosts) and change its species composition and growth rates of species. Gut bacteria can also affect the nutritional state, motivational state [Norris et al. 2013] and activity levels in host species.

Certain species of gut bacteria also produce plant hormone like substances when faced with nutritional stress and such signaling could influence metabolic states in plants [Goffin et al. 2010]. Recent findings suggest that gut bacterial

compositions play a vital role in the evolutionary emergence of new species [Brucker and Bordenstein 2013], hence defining metabolic niches for species in an ecosystem. Interestingly, gut bacterial biomes show geographical variation even within the same species [Suzuki and Worobey 2014]. This evidence broadly suggests that ecological factors could influence composition of gut bacterial biomes and such biomes could play a role in defining metabolic niches for species.

Evidence presented above suggests that changes in the composition of colonies of gut bacteria can significantly modulate the energy and nutrients available, activity levels, and reproduction rates in heterotrophic species. In doing so, could gut bacteria serve to modulate species compositions in autotrophic-heterotrophic exchange networks in ecosystems? Further, could this also modulate the distribution of plant production between competing heterotrophic species, so as to maximize the overall benefit to the entire autotroph-heterotroph ecosystem? While definitive answers require further research, preliminary findings point to an important role of gut bacteria in modulation of flows of biomass between competing ecosystem exchange networks.

### 3.3.3. Banks and Financial Investment Networks

*Banks and investment institutions provide money to such businesses that not only require investment for growth, but also present the best promise for profit, and hence provide good returns for the investment. Businesses in turn use this money to generate profits by providing ever-changing repertoire of products and services to fulfill changing needs of its customers [Werker 2003; Schumpeter 1934]. In economic models it is hence believed that banks and equity markets, dynamically modulate the flows of human, material, and other resources across networks of competing business entities in an economy by changing the levels of investments across businesses entities and economic sectors based on their growth rates and predicted returns. Hence, in doing so banks and financial investment networks serve as community level modulators by investing across a mix of competing business entities and sectors of the economy to derive optimum overall growth for the economy as a whole. Growth in banking and financial markets is hence often correlated with growth and development in an economy [Boot and Thakor 1997; Schumpeter 1934; Levine 1997].*

### 3.4. Common characteristics of modulator systems – Mycorrhiza, gut bacterial and financial investment networks

*There are a few common features of network modulator systems across multiple levels:*

- (1) They differentially modulate growth rates across dependent species in an ecosystem or economy. Hence at the first level in organization sub-soil Mycorrhiza networks are known to modulate growth rates of different autotrophic species across groups of competing autotrophic species in ecosystem networks [Van Der Heijden and Horton 2009; Walder et al. 2012]. At the next higher level, gut bacterial networks are known to modulate growth rates and activity levels in across different heterotrophic species [Turnbaugh et al. 2006; Storelli et al. 2011]. At the next higher level, banks and financial investment networks are known to invest across competing business entities and hence modulate growth rates across competing business entities [Boot and Thakor 1997].
- (2) They modulate growth rates by “differentially altering” the flow of rate-limiting scarce resource (s) across different dependent species in exchange networks. Mycorrhiza networks are known to differentially allocate phosphorous across different competing autotrophic species [Van Der Heijden and Horton 2009], hence modulating growth rates across competing species of autotrophs. Since phosphorous is an important constituent in the energy metabolism of autotrophs, and a rate limiting resource in ecosystems [Cherif and Loreau 2009], changing the availability of phosphorous, alters growth rates of autotrophs. Gut bacterial networks are known to modulate the growth rates in heterotrophic species by modulating the availability of carbohydrates and small chain fatty acids that provide energy for species growth and activity [Hooper et al. 2002; Flint et al. 2012]. By modulating these flows, they can alter growth and size in heterotrophic species [Storelli et al. 2011; Ley et al. 2006]. Finally, banks and financial investment networks modulate growth in businesses by altering the availability of money and financial resources across competing business entities [Schumpeter 1934; Boot and Thakor 1997]. Altering the availability of money changes growth and activity levels in business entities.
- (3) They appear to “invest” the rate-limiting scarce resource across species networks giving rise to community effects and enabling group level adaptation and group learning. Mycorrhiza networks appear to allocate (or invest) phosphorous to such species of plants that in the given environment, provide the highest growth and hence highest return of carbohydrate to the Mycorrhiza network across a community of plants [Walder et al. 2012]. The differential allocation of phosphorous across competing autotrophs gives rise to community effects, and could enable group adaptation [Van der Heijden et al. 1998;



[Montesinos-Navarro et al. 2012](#); [Van Der Heijden and Horton 2009](#)]. Similarly, banks and financial investment networks allocate money (or invest) across such businesses and sectors that in a given environment provide optimum financial risk/reward proposition for the bank or investor. At the level of the entire economy the differential allocation of financial capital across business entities and economic sectors gives rise to community effects by dynamically allocating financial resources to produce optimal overall economic growth and financial returns for the investor. While, gut bacterial networks are known to modulate the availability of carbohydrates in heterotrophic species [[Hooper et al. 2002](#); [Flint et al. 2012](#)] whether they give rise to community effects, and facilitate group adaptation across species in ecosystems is still unknown and merits further research.

- (4) They occupy a strategic position in the flow of nutrients into the dependent species organization hence being able to effectively modulate resource flows.

Mycorrhiza networks occupy a strategic vantage in the “roots” of plants, where they alter the absorption of geochemical molecules by modulating the availability of phosphorous [Walder et al. 2012]. Gut bacteria occupy a strategic vantage in the guts of heterotrophic species, where they can sense the availability of nutrients in the food, and also alter their absorption [[Storelli et al. 2011](#); [David et al. 2014](#)]. Finally, banks and financial networks are said to be the “roots” or the “stomach” of business organizations [[Duisenberg n.d.](#)] and modulate the availability of finance to the business [[Levine 2004](#); [Boot and Thakor 1997](#)]. In doing so they can modulate the availability of human resources and other human controlled resources to business entities. It is interesting to note that within the social context, people do not require to be paid money to work within kinship based social groups (like in one’s own family), however money is required to work in non-kinship based social groups like businesses. Hence money can be said to play an important role in sustaining non-kinship based social groups (like businesses), and banks and financial investment networks play an essential role in enabling modern day socio-economic organizations.

- (5) They create highly branched networks that connect to a large number of dependent species in the base system network.

Mycorrhizae are known to interconnect to a large number of terrestrial plants through their sub-soil network [[Van der Heijden et al. 1998](#)]. This forms a subterranean network for the flow of nutrients across terrestrial plants. Banks and financial investment networks are also known to connect to a large number of business entities, and give rise to highly branched networks where banks form key nodes in such networks [[Vitali et al. 2011](#)]. Gut bacteria are ubiquitously present in guts of heterotrophic species from the simplest heterotrophs [[Taylor et al. 2007](#)] to human beings, and there is a rapid exchange of genetic and environmental information between communities of gut bacteria [[Jacob et al. 2004](#)]. While it is possible that such exchanges between gut bacterial communities across heterotrophic species can give rise to community effects, a definitive answer to the question ‘do gut bacteria enable inter-species community effects between heterotrophic species?’ requires further research.

## 4. Discussion

### 4.1. Common multilevel organizational pattern in organization of living systems

*The common multilevel organizational pattern presents kinship based social groups like families, non-kinship based social groups like formal businesses, and human language in social organization as an extension of a larger multilevel pattern the organization of living systems. The notion that businesses, families, communities and exchanges that constitute our modern society could be a part of a larger pattern in living systems serves to initiate new thinking towards a unified view of organization in social and natural systems.*

The two classes of composite systems defined in this study reveal an important pattern in the form of “core networks” comprised of a triad of interactions at each level in organization of living systems. Across ascending levels of organization in living systems, the triad involves interactions between coupled-composite systems, decoupled-composite systems, and alphabetic catalysts that give rise to autocatalytic organization with increasing spatial and temporal scales. The sub-microscopic scale molecular triad of interactions comprises the autocatalytic core metabolic molecular network [[Smith and Morowitz 2004](#); [Morowitz and Smith 2007](#)] in living cells. The triad of interactions at the cellular level gives rise to an autocatalytic species ecosystem organization [[Ho and Ulanowicz 2005](#); [Ulanowicz 2009](#)] that has a greater spatial and temporal scale, and finally the triad of interactions at the species level gives rise to our autocatalytic socio-economic society [[Padgett and Powell 2012](#); [Hordijk 2013](#)] that is organized at even greater spatial and temporal scale.

#### 4.2. *Stability and ecological scope of coupled and decoupled composite systems*

*It is important to point out that for self-organizing living systems that are dependent on a constant flow of materials and energy for their sustenance [Prigogine 1997], producing decoupled-composite systems that must depend on other systems for their source of energy and exchange resources is a major evolutionary feat. From an energetic perspective, the evolution of living cellular species from chemoautotrophic or autotrophic unicellular systems to multicellular (chemo-)autotrophic systems extends the flow of energy and materials from producing photosynthetic cells to consuming (non-photosynthetic) cells within the same composite system organization (coupled-composite system). However, the evolutionary emergence of cellular heterotrophic species that must depend on their relationships with (chemo-)autotrophic species for their sustenance extends this flow of energy and materials across different species to create a new level of ecosystem dependence between producing and consuming species.*

[Yodzis and Innes \[1992\]](#) have shown that autotrophs, and multicellular autotrophs, where producing and consuming sub-systems exist within the same composite systems organization (coupled-composite systems) have a larger ecological scope (i.e., they are ecologically more stable). Heterotrophic cellular species (decoupled-composite systems) that do not produce their own high-energy biomass have a smaller ecological scope (i.e., they are ecologically less stable). Further, within heterotrophic species the ecological scope decreases with growing deficit between production and consumption of high-energy biomass. Hence, cold-blooded heterotrophic species that are less deficient in high-energy biomass are ecologically more stable than warm-blooded heterotrophic species that require a higher rate of flow of high-energy biomass per unit species mass.

[Yodzis and Innes](#) provide an important conceptual framework to understand stability differences between coupled- and decoupled-composite systems in ecosystems. This raises the question can these ideas be generalized to examine the scope for coupled and decoupled-composite systems across multiple levels in the organization of living systems?

According to the species-class definitions in this paper, non-kinship based social groups and heterotrophic species both belong to the class of decoupled-composite systems, and kinship based social groups and multicellular autotrophic species both belong to the class of coupled-composite systems. If ideas presented by [Yodzis and Innes](#), on the differences in ecological scope between autotrophic and heterotrophic species are extended to social ecosystems, then kinship based social networks like families, extended families and kinship based communities that produce and deploy human resources within the same composite system should be ecologically more stable than non-kinship based social networks that must depend on external sources of species resources to fulfill their organizational needs.

Evidence suggests that this might indeed be the case. It is interesting to observe that Dunbar and others in their study of social networks in human society have found that bonds between individuals in kinship based social networks are stronger than those between individuals in non-kinship based social networks [[Roberts and Dunbar 2011](#); [Curry et al. 2013](#)]. Generally speaking, stronger bonds between elements are usually associated with more stable organizations. Could this mean that kinship based social networks are more stable than non-kinship based social networks? The higher ecological stability of Kinship based social networks like families, and communities is supported by the observation that kinship based social networks for species reproduction are found across many species of heterotrophs, and have existed much before the emergence of non-kinship based formal social groups in human society. Behavioral evidence also points to important differences in affinity between individuals in kinship and non-kinship based social groups. For instance, one does not require an external reward like money to take care of ones own family (i.e., a kinship based social group), whereas people require external rewards like money to work within non-kinship based social groups (like businesses). This lends support to the idea of higher relative stability of kinship based social groups. Could this mean that, like in ecological organization, in social organization also the decoupled-composite systems also have a lesser ecological scope (or are less stable) than the coupled-composite systems? This is a question that requires further research.

#### 4.3. *Autocatalysis in exchange networks*

In living systems the emergence of new levels of dependence, is also accompanied by the emergence of autocatalytic networks between coupled and decoupled-composite systems at each new level in organization. Hence, the emergence of dependence between oxidized molecules and reduced molecules in an autotrophic or chemoautotrophic living cell is accompanied by the emergence of an autocatalytic metabolic core that is highly conserved and seen across living species [[Smith and Morowitz 2004](#)]. The emergence of dependence between autotrophic species and heterotrophic species is also accompanied by the emergence of an autocatalytic species networks in ecosystems [[Ulanowicz 2009](#)]. The emergence of dependence between kinship based social groups (like families) and non-kinship based social groups (like businesses) is also accompanied by the emergence of autocatalytic networks of exchange between

businesses and families [Padgett and Powell 2012]. The question is why and how does the emergence of dependence give rise to autocatalytic networks? This is a question that requires further research.

#### 4.4. *The role of alphabetic catalysts*

*Alphabetic rule-making catalysts are known to enable interactions between decoupled and coupled-composite systems at two different levels in organization of living systems. Alphabetic protein catalysts are known to catalyze transformations of coupled molecular systems like Carbon dioxide, and water into decoupled molecular systems (like carbohydrates, and other cellular biomolecules) within living cells [Alberts et al. 2002]. Similarly, another alphabetic catalyst, human language, is thought to enable social rule making that enables the emergence of rules-based non-kinship based social organizations in human society [Bingham 2009; Knight 2005]. Is it possible that alphabetic catalysts also play a role in the emergence of dependence between autotrophic and heterotrophic species in ecosystems? Extrapolating the common multilevel level pattern prompts a speculation that DNA could have an important role to play in enabling the emergence of cellular heterotrophy and in enabling ecological relationships between autotrophic and heterotrophic species. Could the emergence of DNA have allowed cellular systems to decouple producing and consuming metabolic pathways to give rise to heterotrophic cells that do not produce their own biomass? Recent research reveals that extensive areas of external DNA are dynamically inserted into species DNA through viruses [Witzany 2012], and points to significant DNA exchanges across species through viruses. Could this be an outcome of the role of DNA as an ecosystem level rule-making catalytic system that is similar to the role of human language in social organization, as suggested by inter-level similarity considerations? This is a question that requires further research.*

While catalysts enable dependence between coupled-composite systems and decoupled-composite systems, autocatalysis in exchange networks are also thought to shape networks of catalysts. Recent research suggests that autocatalysis in prebiotic cellular metabolism, could have a role in the selection of only one enantiomer in amino acids in proteins [Kafri et al. 2010]. Autocatalysis has been suggested to play a role in the emergence of human language as well [Logan 2007]. Could autocatalysis have a role in the emergence of the alphabetic character in alphabetic catalysts in living systems? This is a question that requires further research.

#### 4.5. *Common multilevel organizational pattern in exchange networks*

*Observations suggest a common multilevel organizational pattern in organization of living species across levels-ecological and social. They point to the possibility that financial investment networks and banks could belong to a larger class of modulator systems that arise in the course of organization of exchange networks within both ecosystems and socio-economic systems. Further research could provide new insights into the roots of financial and investment networks in the larger scheme of organization in living systems.*

#### 4.6. *Modulator systems in multilevel alignment*

*Aligning and synergizing self-organizing exchange networks across multiple levels, like aligning economic exchange networks with ecosystem exchange networks, is one of the most difficult challenges we face today. Here we look at how connections between modulator systems at two different levels in ecosystems could play a role in aligning and synergizing exchange networks across two different levels in ecosystems.*

Within ecosystems there are two levels of energetically and materially coupled exchange networks. At the first level of exchange networks geochemical molecules are organized into different autotrophic species (Level I). Different autotrophic species then become food for the different heterotrophic species hence giving rise to the next higher level of exchange networks in ecosystems (Level II), see Fig. 2.

At Level I, Mycorrhiza networks are known to modulate growth rates across different autotrophic species by providing phosphorous to different autotrophic species in quantitative exchange for carbohydrates [Van Der Heijden and Horton 2009; Heijden et al. 2015]. Autotrophic species (or groups of autotrophic species) that provide more carbohydrate hence get more phosphorous. Hence carbohydrate production influences phosphorous allocation across different autotrophic species connected to a Mycorrhiza network. At the next higher level in the exchange networks between different autotrophic species and different heterotrophic species gut bacteria use carbohydrates to modulate energy availability to heterotrophic species [Hooper et al. 2002; Flint et al. 2012].

Hence carbohydrates seem to play a role both in influencing dynamics in exchange networks at Level I, as well as in influencing dynamics in exchange networks at Level II. Could such an organization where carbohydrates are a

common influencing factor in exchange at both levels serve to align both levels towards increasing overall carbohydrate production in ecosystems (hence increasing the overall primary production in ecosystems) by synergizing dynamics across both levels? Could this two-level role of carbohydrates provide new insights on aligning the third level of exchange networks (economics) with underlying ecosystem exchange networks at Levels I and II?

#### 4.7. *New avenues for aligning ecosystems and economic systems*

*It is interesting to note that at each of the three levels modulator systems use a scarce resource to modulate species growth rates across competing networks of exchanges. Mycorrhizae use Phosphorous which is an ecologically scarce resource [Cherif and Loreau 2009] that limits the growth in autotrophs, gut bacteria use carbohydrate which is a growth limiting resource both for soil bacteria [Cherif and Loreau 2009], and heterotrophic species, and banks and financial investment networks use money, which is a growth limiting scarce resource for business entities [Lietaer 2001]. This multilevel view points to the possibility that using a scarce, rate-limiting resource to modulate network dynamics could be a larger pattern in modulatory systems of using different scarce resource as “currencies” for “investment” across competing exchange networks at different levels.*

In such a scenario, can it be possible to envision a system for currency exchanges that could allow for the equitable exchanges and reciprocity between human economics and natural economics? For instance, can human currencies be made exchangeable for the mycorrhizal “currency” of phosphorous?

A simple way to imagine how such a currency exchange could work is by using an analogy from global trade. For instance, when people from country A that use pounds (£) as their currency, exchange goods or services with people from country B that use dollars (\$) as their currency, a global system of currency exchanges enables a cross-border transaction between people in two different economies. Similarly, can one imagine two different exchange networks or “economies” (for a lack of a better word): (1) A “natural economy” that operates on an embedded phosphorous currency and mediated through “bankers” in the form of Mycorrhizae, and (2) a human economy that operates on human currencies (like a dollar, pound, and others) mediated through banks and financial investment networks?

In such a case, can one think of a system for currency exchanges that can allow for “cross-border” trade and investments between natural economy and our human economy? Could digital currencies that mirror phosphorous flows through mycorrhizal networks capture the dynamics in subsoil ecosystems? Can human exchanges with ecosystems be “valued” in terms of such a digital ecosystem currency? Can people and human organizations be incentivized to grow the subsoil economy through an exchange between the two currencies? Can such a strategy create new employment in ecological regeneration? These questions capture both the problems and possibilities brought forth by new insights from multilevel research.

Undoubtedly there are many unanswered questions, however ideas like an economic-ecosystem exchange are unique new perspectives that arise through a multilevel worldview. A multilevel worldview could provide new insights that lead to solutions that cannot be envisioned in the current two-system worldview that completely separates economics and ecosystem dynamics. It is important to note that what is presented above are only possible directions for further exploration and are presented only to illustrate possibilities for further discussion and collaborative exploration.

## 5. Conclusion

*The chapter presents two important common multilevel organizational patterns (CMOP) seen in organization of living systems. The first pattern is revealed when one looks at systems and their interactions through the lens of the definitions of the two types of composite systems presented here. The second CMOP is seen in exchange networks at different levels in organization.*

The first CMOP presented here, reveals important similarities in organization between natural and social systems and paves the way towards the development of multilevel organizational models that can provide a unified view of both natural and social systems.

The idea that our socio-economic organization, comprised of formal businesses, families and their shared communities, and enabled through language based rule-making, could be a part of a larger pattern in the evolution of living systems provides new insights into the natural roots of our socio-economic systems.

The CMOP also serves as a conceptual scaffolding to facilitate multilevel and cross-disciplinary scientific research to explore if there could be common processes underlying the CMOPs. The CMOP leads to important new questions that provide opportunity for further research [Joshi 2015] to explore the organization of multilevel living systems, and sustainability in such multilevel systems.



The second CMOP presented here points to high-level organizational similarities between exchange networks at three levels. A comparison is drawn between modulator systems operating at three different levels. New insights on how ecosystem exchange networks at two different levels could be aligned using a common scarce commodity in exchange across two levels have been presented. Important questions that present opportunities for further research have been put out.

This chapter presents early ideas that are intended to seed new multilevel research aimed at exploring the roots of our financial and socio-economic systems in the organization of living systems. It is believed that multilevel research and a multilevel view could not only enhance our understanding of natural systems, but could also provide new insights in how our economic systems could be synergized with life supporting ecosystems. It hoped that ideas presented here motivate domain level researchers to look beyond their research domains to collaboratively explore cross-disciplinary and multilevel research leading to a deeper understanding of living systems.

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