

Towards an Ecological Perspective on the Evolution of Online Communities of Practice

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Abstract

In the era of knowledge economy, more and more people view online communities of practice (CoPs) as wellspring of precious knowledge. Notably, many researchers support the notion that CoPs are not designed or made but grown. However, there is no systematic theory of online community development. Based on the properties of autotrophic and open system of online CoPs, there are several differences between traditional groups and online CoPs. Interestingly, there exists an ideal mapping between the properties of online CoPs and ecological ecosystems. We thus adopt Yin's analytic strategy of descriptive framework[46] and draw on Odum's model of ecosystem [25, 26, 27] to develop an online CoP ecosystem model, which serves as our dimensions of describing changes within an ecosystem over time.

1. Introduction

Communities of practice (CoPs) are groups of people who share a concern, a set of problems, or a passion about a topic, and who deepen their knowledge and expertise in this area by interacting on an ongoing basis [43, 44]. Guilds in the Middle Age are ancient form of CoPs, and their benefits and influence are amplified due to the pervasion of modern information technology. Recently the term CoP is widely used whether information technologies are involved or not. To make clear, we refer them as online CoPs when members of CoPs interacting primary through information technology rather by traditional form of face-to-face.

A teachers' professional virtual community, called SCTNet (<http://sctnet.edu.tw>), was established in March 2000 to provide a cyber space for teachers in elementary and junior-high schools to share professional expertise and to shape the norms and

values. On the SCTNet, teachers with a similar interest or domain may form an online CoP. Each online CoP enables practical knowledge and resource exchange by offering group communication mechanisms, such as discussion board, message board, e-mail, web recommendation, resource sharing, and member interaction statistics which exhibit interaction details of each members. However, from the statistics recorded on SCTNet that only 191 online CoPs remain active excluding 15 newly initiated by May 2005. 112 online CoPs were struggling to sustain, and 967 online CoPs had collapsed. We are curious about such high mortality and fluctuations of online CoPs on SCTNet, and eager to understand their development processes.

Interestingly, many researchers support the notion that CoPs must develop over time [23, 32, 35], they are not designed or made but grown [4, 19, 32, 33, 42, 44], however, there is no systematic theory of online community development [22]. In fact, when the changes over time are especially concerned, there are few field studies conducted to tackle with the longitudinal evolutionary process of online CoPs. Besides, numerous management and design principles for online CoPs are presented (e.g., [11, 19, 23, 30]). However, they seem mixed and bring little help to understand the complex of online CoPs' development. Flourishing CoPs are not developed over night, and we also observed some CoPs' development always endure fluctuation, while some CoPs are generally prosperous but suddenly failed. If we want to open the black box of evolutionary process, the question is, how to develop a systematic theory of online CoPs development concerning about the properties of online CoPs? In other words, how to model an online CoP so that we can thereby systematically describe the changes of online CoPs along the timeline?

Since online CoPs are formed by groups of people, existing group development models may provide us valuable frameworks to understand the driving forces

behind. Over the last five decades, researchers have postulated different models of how groups develop over time [10]. Nevertheless, drawn on the properties of online CoPs, there should be something different between traditional groups and online CoPs development models. We elaborate two points worthy of taking into account while they are fewer addressed in prior studies as follows.

First, *online CoPs are autotrophic systems*. The groups examined in all group development studies have limited life span; that is, groups have a fixed starting and ending point. In studies where time and deadline pressure are explicitly recognized, behavior changes in groups are evident with the passage of time, and will result in different models of development [9, 10, 34]. In contrast, since members of online CoPs can overcome space, time, and organizational boundaries by employing information technology, the life spans are lasting if intended. Besides, due to the limited life span of groups examined in prior studies, members may expect they will not work together in future. Expectancy theory indicates that future expectations can influence current behavior. Often such expectations lead to very different responses if the group has no future [15]. In an online CoP, however, the relationship of members lasts, and groups may form and reform continuously through information technology if desired.

Besides, all groups in prior group development studies are given specific tasks to complete [10]. Results indicated that the temporal pattern postulated in the punctuated equilibrium model reflects task pacing under a deadline, rather than the process of group development [34]. Chidambaram and Bostrom [10] pointed out that the examination of dissimilar tasks could contribute to the conflicting results. On the other hand, members in CoPs may pursue a common interest or goal within specific domain, by the way to exchange resources, practical knowledge, and advisory information, but not exactly perform certain tasks.

In ecological terms, online CoPs are autotrophic systems [31, 36]; namely, they are self-supporting system. The length of life of online CoP totally depends on members. If no members want to participate continuously in the online CoP, it collapsed. On the other hand, traditional groups in prior group development studies, or online groups such as online training/learning groups, virtual teams, are all heterotrophic systems. The fate of these groups hinges on outer forces rather group members themselves. They must undergo predefined length of lives, and what make major differences between them are group processes and final outcomes.

Second, *online CoPs are open systems*. Opposed to fixed membership in groups of development models, the membership is self-subscribed and member fluidity is relatively high in online CoPs. Membership might be open to anyone who is interested in the subject, and they can leave as intended. Therefore members may have to link and re-link their social networks, and define member roles repetitively. Similarly, because online CoPs open to the public, the size of membership can be very large. It may be impossible to know all of the members personally. The settings are quite different from those of prior group development studies. Furthermore, these differences may render the measurement of some research constructs such as trust or norm rather difficult, especially, when they are based on fixed membership or when the collection of perception data from all members is necessary. The problem of self-selection is also obvious because respondents of questionnaires are mostly active or core members.

Since traditional group development models are not ideally suitable for the settings of online CoPs, a novel perspective should be adopted. This study adopts the ecological perspective.

2. Why Ecological Perspective?

To answer the research question, this study decides to adopt the ecological perspective for several reasons articulated as follows.

First, the word evolution, is widely used for temporal change, that is, change with time [27]. This study concerns the evolutionary process, akin to the central theme of ecological theory. Therefore the evolutionary model of online CoPs can be suitably inferred from ecological perspective. Ecologists refer to the processes that population as a whole gradually changes composition as “phyletic gradualism,” namely, the gradual one-by-one selection of population members. Their focus is on how natural selection progressively transforms population over time [3]. Besides, the ecological perspective is more holistic and macroscopic, and the level of analysis is the whole ecosystem in this study, accordingly the problem of individual member fluidity can be easily tackled.

Second, many ecological concepts are mentioned in numerous CoPs-related literatures to describe CoPs, such as communities are organic [23, 44]; CoPs are much like living organisms [5]; CoPs can grow and evolve over time [5, 23, 32]; CoP’s organic growth [32]. Besides, being immersed in some CoPs for several years, the authors find that members usually use some ecological terms such as dead, alive, energy, sustainability or evolution to describe their

CoPs or other members. This phenomenon leads to the adoption of ecological perspective.

Third, several studies indicated that the ecological approach seems to provide a powerful framework for understanding complex human social issues (e.g., human development: [6, 7]; technology and literacy: [8]; cultural change: [20].) Moreover, an ecological model offers two main advantages [38]: a way of allowing for the inclusion of complexity and a new language and set of analytical and descriptive tools from the ecological sciences.

Thus, ecological perspective can structure the essential elements of group interaction in online CoPs, which may help to ensure that important elements of interaction are not ignored because they are too complex to integrate. This could potentially be helpful in accurately modeling the online CoPs and studying their development. We will further elaborate the concept of ecological perspective in the following section.

3. Ecosystem Ecology

The discipline of ecology is literally the study of households, and people live together as interdependent beings. Ecology is one kind of study of help for us to understand changes of populations in relation to time and space, such as (1) how many organisms, (2) how are they distributed, (3) how they changed, and (4) why they changed in that way [31, 36]. A fundamental concept in ecology that enables the holistic study of both parts and wholes is hierarchy. The basic, autonomous biotic unit is *organism*. A *population* is a group of the same organisms. *Species* is a similar concept to population, which signifies groups of organisms with specific characteristics. A *community* includes all of the populations or species living in a particular area. The community and the nonliving environment function together as an *ecosystem*. Groups of ecosystems along with human artifacts make up a *landscape*. *Biosphere* is the widely used term for all of the earth's ecosystems functioning together on a global scale. Among them, ecosystem is the lowest level in the ecological hierarchy that is complete with all the necessary components for function and survival over the long term. Since we view each online CoP as an ecosystem, we should pay special attentions on it.

The basic definition of the ecosystem was first proposed by Tansley [37]. He defined the ecosystem as a biotic community and its associated physical environment in a specific place. The main components of the concept are its biotic and abiotic (nonliving) features and the interactions between them. Ecosystems are open systems; that is, things

are constantly entering and leaving. As shown in Figure 1, an ecosystem can consist of a system, which represents the area we are interested in, and two large parts as input environment and output environment. Energy is a necessary input. The sun is the energy source for the biosphere, and directly supports ecosystems. Energy also flows out of the system in the form of heat and other transformed or processed forms such as pollutants. Moreover, organisms may enter (immigrate) or leave (emigrate) as well.

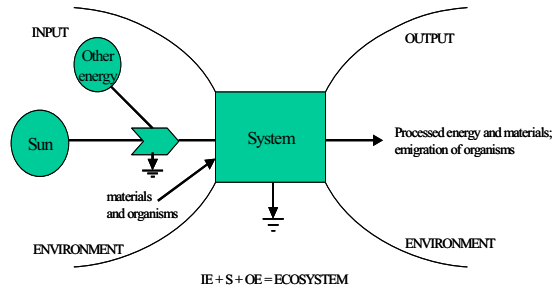


Figure 1. Ecosystem as an open system (Odum, 1993)

To further understand the components and functions of the ecosystem, we can refer to Odums' [25, 26, 27] ecosystem model, which is the most representative and has influenced a generation of ecologists [31]. As displayed in Figure 2, bullet-shaped units are autotrophs, hexagons are heterotrophs, tank-shaped boxes are storages, loop represents recycling materials, and arrows-into-ground are heat sinks (where heat is lost).

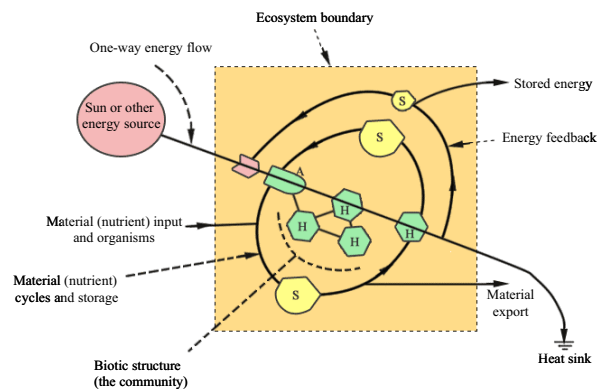


Figure 2. Odum's (1971, 1983, 1993) ecosystem model

An ecosystem has two major biotic components. First is an autotrophic component, able to fix light energy and manufacture food by the process of photosynthesis. The green plants constitute the

autotrophic component. These organisms may be viewed as producers. The second major biotic unit is the heterotrophic component, which utilizes, rearranges, and decomposes materials synthesized by autotrophs. Generally, fungi, animals, including human, constitute the heterotrophs. These organisms may be thought of as the consumers or decomposers. The autotrophic and heterotrophic components depicted in Figure 2 are linked together in a network based on their interaction relationship [24, 27].

Energy, materials, and pools are primary abiotic components. There are two abiotic functions that make the ecosystem operational, namely, energy flow and material cycles. Energy is defined as the capacity to do work. It is required to drive the cycling of chemical materials. Energy flow is one-way, although it may sometimes feedback through storage. It flows from the sun or another external source through the biotic community as the heat, and finally disappears. Therefore, an ecosystem demands continuous inflow of energy to sustain its lives. In contrast to energy, chemical materials, such as nitrogen or calcium, can be used repeatedly without losing utility. These materials are stored in pools. In a well-ordered ecosystem, many of these materials cycle back and forth between pools of abiotic and biotic components. These are called the biogeochemical cycles. A certain chemical materials are necessary for life. These are called nutrients and tend to be retained and recycled within living ecosystems [24, 27].

Besides, to establish an ecosystem model, there are several steps [29]: (a) identify the components of the model. (b) state the spatial and temporal scale of the model. (c) delineate the boundary of the ecosystem. (d) articulate the connections among the components. (e) identify the constraints on system behavior. The paper follows these steps and uses the concepts of ecosystem ecology to build an online CoP ecosystem model.

4. Online CoP Ecosystem Model

In science, metaphor plays a generative or creative role [28]. Metaphors are useful in viewing certain aspects of a complex system, but can greatly improve understanding of complex issues. We follow Yin's [46] analytic strategy of descriptive framework and thus use the metaphor of an ecosystem to integrate and organize sets of dimensions in relation to the evolutionary processes of online CoPs.

Mappings between ecological entities and online CoP entities are listed in Table 1. Among them, because ecosystem is the lowest level in the ecological hierarchy that is complete with all the

necessary components for function and survival, this study views every online CoP as an ecosystem, and its members are organisms who interact practical knowledge and exchange resources.

Table 1. The mapping of hierarchical ecological entities to online CoPs entities

Hierarchical Entities	Description	Mapping Entities	Explanation
Organism	The basic, autonomous biotic unit.	Individual member	Every member is a freewill, autonomous agent, they can choose to participate actively, dormant or leave.
Population	A group of the same organisms.	A group of members.	Two or more members formed a population.
Specie	A group of organisms with specific characteristics.	Members play the same ecological roles.	There can be various characteristics to judge members whether belong to the same species or not.
Community	Including all of the populations living in a particular area.	Members participate in the same online community of practice.	All members with various roles or domains in an online CoP formed the community.
Ecosystem	The community and the nonliving environment function together.	Online community of practice	The ecosystem is composed of biotic and abiotic components.
Landscape	Groups of ecosystems along with human artifacts.	System platform	The habitat of online CoPs.
Biosphere	The widely used term for all of the earth's ecosystems functioning together on a global scale.	The whole educational environment.	Referred to the universal and general surrounding of online CoPs, includes invisible culture and physical environment.

Steps proposed by Pickett and Cadenasso [29] are used to establish the ecosystem model illustrated in Figure 3.

4.1 Identify the components of the model

There are biotic and abiotic components in an ecosystem. Pools, nutrients and energy are all abiotic components. All interaction data between members are stored in the system; thus the system storage acts as pools for later access by members interested.

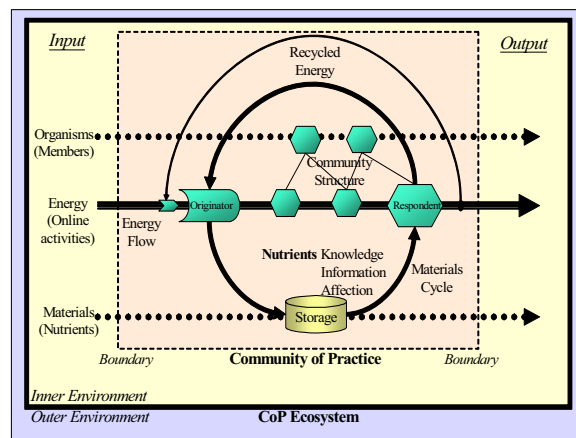


Figure 3. Components of an online CoP ecosystem

Nutrients are materials regarding members' survival cycling between pools of abiotic system and

biotic members within the online CoP. They can be used repeatedly without loss of utility. In an online CoP ecosystem, members participate to gain nutrients such as practical knowledge and information within their domain. Each online CoP has their explicit domain and corresponding domain knowledge. This study identified five categories of domain knowledge shared in online CoPs. As shown in Figure 4, there are content knowledge, manipulation knowledge, exercise knowledge, conviction knowledge, and context knowledge. Descriptions and examples of these categories of domain knowledge shared in online CoPs are further elaborated in Table 2. Knowledge once articulated and shared in online CoPs are nutrients, and can be used repeatedly without loss of utility because they are stored in the system.

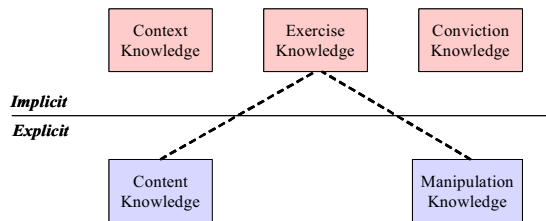


Figure 4. Categories of domain knowledge of online CoPs

Table 2. Descriptions for categories of domain knowledge of online CoPs

Classification	Categories	Descriptions	Examples (in the domain of education)
Explicit	Content knowledge	The codified body of knowledge for specific domain, including knowledge structures and contents.	The schemas and contents of environmental education.
	Manipulation knowledge	The knowledge of applying content knowledge.	How to teach environmental education?
Implicit	Exercise knowledge	When applying static knowledge in real world, there are some gaps and adjustments learnt.	How to represent and organize the teaching materials, so that my students can easily understand?
	Conviction knowledge	Personal beliefs or values toward the domain.	1. What is a good scientific teacher? 2. Are teachers professionals?
	Context knowledge	The knowledge of context around the domain.	1. The level of individual students. 2. The context of equipments and classrooms. 3. The newly educational policies.

Moreover, there is also a lot of information regarding the focal domain of online CoP exchanged. For instance, information about on-job training is welcome for most domain experts. Sometimes members may post news in relation to their domain. These information may attract members to join the online CoP. Furthermore, affection interflowing between members is another important type of

nutrient. Some members may share their practical situation and anticipate for emotional supports from others within the same domain. This kind of care is also an important inducement for members to participate in a CoP because they may share the same professions and own enough knowledge to understand key points. All nutrients may keep attracting members come back to online CoP. Without these nutrients, members may go dormant or even leave the online CoP. When some nutrients are deleted by leader or posters, they are discharged from the ecosystem.

This study analogizes the *energy* as all online activities performed by members. Because energy is the capacity to drive the nutrients cycle between organisms, and an ecosystem demands continuously inflow of energy to sustain its life. Energy is a necessary input that directly supports the life of an ecosystem. If there were no any online activities for certain periods within the online CoP ecosystem, members would judge the CoP was lifeless and never come back again. These online activities include the post or response to a topic discussion, the uploading or downloading of resources, logging into the online CoP, or any kinds of actions that can be perceived by others. Some online activities may carry nutrients and help the cycling of nutrients while some are irrelevant to nutrients. For instance, responding to a practical issue with personal experiences is good for the cycling of knowledge; whereas posting house keeping messages is a helpless effort.

Energy flow is one-way and finally degraded as heat then disappeared, that connotes the immediate utilities of every online activity once completed are degrading and disappeared. Popular issues may earn aggregated energy and accelerating the cycling of nutrients between members and system. Sometimes energy may recycle and feedback when stored online activities are brought up, such as old postings are re-mentioned by members. It happens occasionally because certain topics within a professional domain are rather important and may be taken repeatedly at some intervals. Sometimes members may have new experiences toward old discussions, or new members may dig out historical topics and infill their opinions as well. However, although past online activities may reappear, it is nutrients rather energy will recycle between members.

Besides, members whether playing important roles or not are all biotic components or *organisms* that form the community of the ecosystem. In an online CoP ecosystem, there can be two types of biotic components. People that initiate a topic for discussion or contribute related resources are originators, while those who respond to originators

are respondents. The former are akin to autotrophic component or producers, because they spend energy on bringing in or manufacturing nutrients. The latter are similar to heterotrophic component or decomposers since they may utilize and rearrange the nutrients brought in by the autotrophs. These two components trigger the cycling of nutrients. There is another type of heterotrophic component; that is consumer. Consumers consume nutrients only but irrelevant to the cycling of nutrients, just like some members gain valuable knowledge or information but contribute nothing. All members are autonomous agents because they can join or leave the online CoP ecosystem, and participate proactively or passively.

4.2 Steps b, c, and d

In step (b), we state the spatial and temporal scale of the model. Spatially, the ecosystem of online CoP resides in a system platform. Each online CoP is a distinct ecosystem. Temporally, the extent of the ecosystem can be unlimited if the online CoP is sustainable. We measure targeted online CoPs since their initiation for three years.

In step (c) we delineate the boundary of the ecosystem. Each online CoP has its innate and discrete boundary. That is, unless people self-subscribed and are granted permission to join the online CoP, they can't login the online CoP, let alone interact with members or access the resources of online CoP. A CoP ecosystem consists of a CoP, input and output environments. Members may join (immigrate) or quit (emigrate) the CoP. Nutrients can be brought into the CoP by members' online activities and excluded when deleted. Energy is imported when members perform certain online activities, but flowed out when the utilities of online activities disappeared. Besides, every online CoP has its own domain or goal of setting up, in ecological perspective, it is the ecological niche of the online CoP that distinct it from others and thus establish an invisible boundary.

In step (d), we articulate the connections among the components. Network analysis has been used to develop ecosystem theory [21]. In the last fifteen years, ecosystem ecologists have developed a theoretical approach and a set of computational methods called "ecological network analysis" [18, 39]. Mathematically and conceptually, ecological network analysis is similar to work in the domain of social network analysis [21]. Much like a food web, which is a representation of the various paths of energy flow through populations in the community [31], the originators and respondents are linked together in a social network based on their interaction relationship. As shown in Figure 5, linkages between nodes denote interaction between members. A dark

node symbolizes a dormant member (i.e., a member falls into inactive state that is motionless.), and a light one is a biomass (i.e., a member is active within specific time). Various shapes of nodes signify members joining at different time, and a large node denotes a core member of the last period.

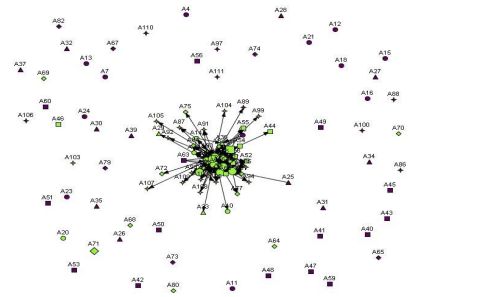


Figure 5. Example of network structure of an online CoP in specific time

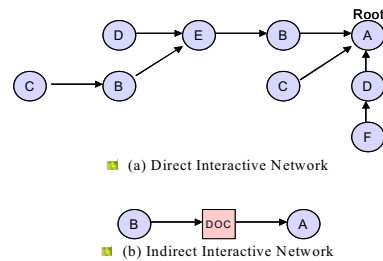


Figure 6. Two types of interactive networks

There can be various types of information technologies utilized to support the interaction between members of online CoPs. In our viewpoint, no matter which kind of interaction mechanisms is adopted, they only contribute to two types of networks: direct and indirect interactive networks. A direct interactive network is composed of an originator and several follow-up respondents; therefore their connections can be conceptualized as a tree structure [2]. Their connections are immediate, and they all have knowledge about who responds to whom. For example, in Figure 6(a), each node represents a respondent. Member A initiated a topic, and then member B, C, and D provided their knowledge or experiences answering him. Then, member E decomposed member B's response and contributed his opinions. We can derive their social networks by analyzing such responsive structures [2]. Discussion board and message board are primary information technologies leading to a direct interactive network.

Instead, resource exchange and site recommendation are functions leading to the formation of indirect interactive networks, because an originator uploaded documents but has no idea who downloaded them. They may have interactions but the relationships are indirect. As a consequence, the network is composed of one-to-one linkages without follow-up connections. As demonstrated in Figure 6(b), member A downloaded resources provided by member B, and there are no proceeded respondents. To construct such kind of networks, we can draw a directed linkage from member B to A. In practical situations, we observed some members seem voiceless but actually quite active in resource exchanging.

Besides, certain tight connections between members form core structures, and reveal some sort of ecological patterns. We can articulate the connections through sociograms of social network analysis and analyze the evolution of core structures, namely, keystone structures, as demonstrated in dotted box of Figure 7. Moreover, as Luczkovich and his colleagues [21] suggested, analyze the interaction relationship through structural equivalence or regular equivalence [12] of network analysis, we can identify ecological roles every member played and understand roles distribution in an ecosystem, as delineated in Figure 8, where nodes with the same color denote equivalent ecological roles.

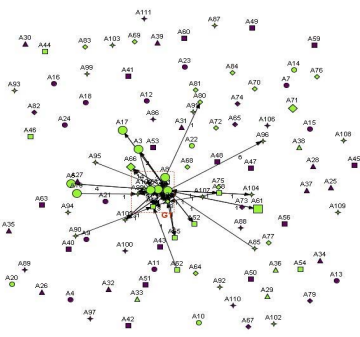


Figure 7. Example of keystone structure of an online CoP in specific time

4.3 Identify the constraints on system behavior

In step (e), we identify the constraints on system behavior. There are various factors may constrain the behavior of system components. For example, some constraints may limit the inflowing of energy and cycling of nutrients. Based on the CoP ecosystem model, we can systematically identify five categories of constraints on the source of outflows as shown in Figure 9.

The ecosystem concept has proven to be immensely flexible and productive [14, 17]. It

supports researches of individual processes [1], and studies of the reciprocal interactions between disparate organisms and their effects in particular sites [16]. Further, ecosystem can be an analytic or a synthetic concept [14], and can support an impressive variety of kinds of models [40]. It is also proved to be useful for understanding system change and institute policies of adaptive management [16, 45]. Moreover, the ecosystem metaphor integrates social capital through sociobiology [13]. Members perpetuate their genes by supporting members of their clan or share resources driven by reciprocal altruism. That is, members invest in each other because of their shared interests or because of their realization that they all need help some day.

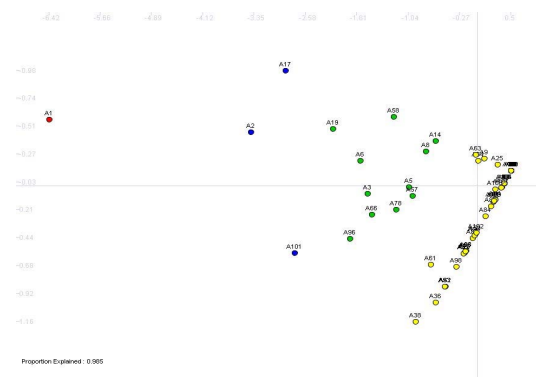


Figure 8. Example of ecological roles distribution of an online CoP in specific time

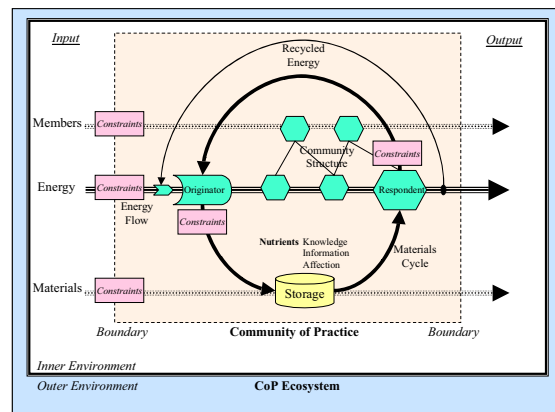


Figure 9. Constraints in an online CoP ecosystem

In this study, the online CoP ecosystem model serves as a conceptual framework for understanding the evolutionary processes of online CoPs. Draw on Odum’s ecosystem model, we propose our descriptive framework based on ecosystem ecology and network analysis. There are primarily three *components*: organisms, energy, and nutrients; and three types of

connections: network configuration, keystone structure, and ecological roles distribution. There are also five categories of *constraints* on the ecosystem functioning. They serve as our dimensions of describing changes within an online CoP ecosystem over time. The detailed tabular model of online CoP ecosystem evolution is listed in Appendix.

5. Conclusions

This study aims at modeling an online CoP in order to systematically analyze the changes within online CoPs over time. This study identifies an ideal mapping between online CoPs and ecological ecosystems, and develops an online CoP ecosystem model based on Odum's model of ecosystem to layout the dimensions of describing changes within an ecosystem over time.

In the near future, the authors plan to conduct a longitudinal exploratory study on online CoPs on the SCTNet tenure for a long period of time, for example, three years. Three years of longitudinal study may prevent the biases drawn from single snapshot and limited life span. We'll categorize online CoPs based on group member interaction statistics and select some representative cases. Every six months the aggregated data of targeted online CoPs are treated as the unit of analysis. The whole life span of an online CoP under study will be analyzed in order to avoid the problems of zero-history groups and drawn bias conclusion from observation of groups over different time periods. We attempt to detect and analyze the changes of community structures in the ecosystem using social network analysis tools. Moreover, since quantitative data may fail to capture some interaction modes, we'll employ content analysis and semi-structural interviews to gain insights from the evolutionary process.

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Appendix. The descriptive framework of ecosystem evolution

Categories	Attributes	Descriptions	Methodology and Measurements
Components			
Organisms	Immigration	The movement of individuals into an ecosystem. Number of new members approved to join the online CoP.	System logs analysis.
	Emigration	The movement of organisms out of an ecosystem. Number of approved members choose to leave the online CoP.	System logs analysis.
	Habitant	Organisms living in a particular area. Number of approved members remained in the online CoP.	System logs analysis. Habitants = Habitants (last periods) + Immigration – Emigration
	Biomass	The size of living weight or organisms. Number of approved members remain alive in the online CoP.	System logs analysis. Members come to this online CoP within certain time (i.e., six months).
	Dormancy	Organisms fall into inactive state that is not dead but motionless. Approved members but are not biomass, that is, they haven't login the online CoP for certain time.	System logs analysis. Members didn't come back to this online CoP within certain time (i.e., six months).. Dormancy = Habitant - Biomass
	Macrobiosis	Members keep coming to this online CoP since joined the online CoP.	System logs analysis.
Energy	Gross production	All kinds of online activities performed by members within the online CoP.	System logs analysis.
	Primary production	Production by autotrophs, which signifies the nature of some online activities are playing the role as initiators and having the potential to attract following energy concentrated. Such as topic initiated, and resource uploaded.	System logs analysis.
	Secondary production	Production by heterotrophs, which denotes the innate characteristics of certain online activities that cannot exist single-handed, but have to accompany with primary productions. Board reply and resource download are online activities fall in the category.	System logs analysis.
	Direct interactive production	Connections of direct interaction are immediate, and organisms have knowledge about who responses to whom.	System logs analysis.
	Indirect interactive production	They have interactions between organisms but the relationships are indirect. Resource exchange and site recommendation are online activities belong to this kind of interactive production.	System logs analysis.
Nutrients	Conservation	Number of nutrients retained in the online CoP. They can be categorized as domain knowledge, practical information, and supporting affection. Domain knowledge are classified as content knowledge, manipulation knowledge, exercise knowledge, conviction knowledge, and context knowledge.	Content analysis.
	Circulated organisms	Number of organisms involved in each thread of discussion.	Content analysis.
	Discontinuance of cycling	Frequencies of discontinuance of cycling identified. Proposed problems or requests remain unanswered, or targeted member didn't response.	Content analysis.
Connections			
Network configuration	Density	Density of the network is the proportion of possible lines that are actually present in the each group. It is the ratio of the number of lines present to the maximum possible.	Social network analysis. Identified through network properties analysis in network analysis tool: NetMiner (available at http://www.netminer.com).
	Inclusiveness	The number of connected points expressed as a proportion of the total number of points.	Social network analysis. Identified through network properties analysis in NetMiner.
	Reciprocity	The ratio of the maximum number of reciprocated ties to the total number of ties.	Social network analysis. Identified through network properties analysis in NetMiner.
	Hierarchy	This measure is to calculate how much network have hierarchical character.	Social network analysis. Identified through network properties analysis in NetMiner.
	Block density	To understand the interactions between immigrants of different times.	Social network analysis. Block Density Table in NetMiner
Keystone structure	Size	Number of organisms belong to the core structure.	Sociogram and social network analysis. Identified through K-core in NetMiner
	Density	Density of the core structure is the proportion of possible lines that are actually present in the each group. It is the ratio of the number of lines present to the maximum possible.	Social network analysis. Identified through K-core in NetMiner.
	# Cliques	Clique is a maximal complete subgraph of three or more nodes. It consists of a subset of nodes, all of which are adjacent to each other, and there are no other nodes in the network that are also adjacent to all of the members of the clique.	Social network analysis. Identified through clique analysis in NetMiner.
	Max CI size	Clique size with max cohesion index.	Social network analysis. Identified through clique analysis in NetMiner.
	Keystone organisms	Core organisms. We identified them and recorded their shift over time.	Sociogram and social network analysis.
Roles distribution	Network roles	Proposed by Wasserman and Faust [41]. They classified organisms as isolate, transmitter, receiver, carrier, and ordinary, based on their in-degree and out-degree behavior.	Social network analysis.
	Ecological roles	Ecological roles, such as producers, decomposers, or consumers.	System logs analysis and content analysis.
	Species equitability	The apportionment of organisms among the species.	Structural equivalence and Social network analysis.
Constraints			
Organisms	Constraints on the immigration of organisms.		Interviews and content analysis.
Energy	Constraints on the inflowing of energy.		Interviews and content analysis
Nutrients	Constraints on the inflowing of nutrients.		Interviews and content analysis
Originators	Direct network	Constraints on the organisms to play the role as originators.	Interviews and content analysis
	Indirect network		
Respondents	Direct network	Constraints on the organisms to play the role as respondents.	Interviews and content analysis
	Indirect network		