Emerging Autopoietic Communities – Scalability of Knowledge Transfer in Complex Systems

Susu Nousala, William P. Hall

***Abstract*—Knowledge-based communities are important but poorly understood systems for helping enterprises maintain their organizational integrity and address organizational imperatives. Based on an autopoietic theory of organization, we examine the emergence and development of knowledge-based communities at different scales up to large distributed enterprises and industry clusters. Knowledge-based communities are highly complex systems that evolve and mature through the phased emergence of new features and capabilities. Development and support of successfully sustainable communities needs to be based on a better understanding of how these features and capabilities emerge. To comprehend the impact of emergent behavior within and beyond organizational communities requires an understanding of the social or sociological aspects of a system in relation to the explicit formal/physical structures in the organization.**

***Index Terms*—Organization theory, autopoiesis, community of practice, knowledge management, complexity, emergence**

I. Introduction

ORGANIZATIONS of all sizes depend for their success and even survival on building and disseminating knowledge that addresses their organizational imperatives. The discipline of knowledge management attempts to facilitate knowledge-based activities in organizations, but often makes the mistake that knowledge management is all about information systems, or alternatively, about tacit knowledge in people. As we have learned in our respective practices, to be fully effective, knowledge management requires a foundational theory of organization and knowledge, and recognition that effective solutions must address people, processes and infrastructure.

The present paper provides an overview of an approach we are developing to better understand the knowledge building and dissemination needs of a range of organizations from small and medium enterprises (SMEs) working on a single site, to large distributed organizations (multi-national) and communities of organizations such as industry clusters and multi-organizational scientific and technical forums [1],[2],[3],[4],[5],[6],[7],[8],[9],[10],[11]. From this experience we have developed a theoretical framework [12],[13],[14],[15],[16],[17],[18] based on an autopoietic theory of organization [19],[20],[21],[22], as extended with insights from evolutionary epistemology [23] and metaphysical ontology of three worlds [24] and theory of hierarchically complex systems [25],[26],[27],[28],[30].

Here we provide a summary overview and introduction to our ideas specifically regarding the emergence, evolution and sustainment of knowledge sharing communities at various levels of organization. Our view is that human organizations are fractally complex systems where self-sustaining autopoietic structures may emerge at several levels of organization above human individuals. We describe how complex systems like knowledge-based communities emerge and may become self-sustaining organizations in their own rights via processes we think can be found at a variety of organizational scales. These "levels" of organization range from the emergence of small and medium enterprises; through organizational systems that form within larger organizations, such as project teams, Communities of Interest (CoI), Expert Communities of Interest (ECoI), Communities of Practice (CoP); to supersystems such as industry forums, industry clusters, urban districts and possibly even nation states.

II. Theoretical Background

A. Complex Systems and "Organizations"

Human organizations are complex systems. We consider systems to be complex when they are comprised of a number of components whose laws of interaction are imprecisely known or whose aggregate behavior cannot be predicted due to combinatorial explosion of possible interactions of components [28], [29]. Consequently, analysis of the behavior of the complex system cannot be reduced to an exact description based on the behavior of components at a lower level of organization. Human organizations display many features that are not predictable from our uncertain knowledge

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of the behaviors of the organizations' individual members. Basically, we need to look at such complex systems from a "biological" point of view [28], [29], [31], [32].

B. *Autopoiesis*

The term "autopoiesis" (~ self + production) was coined in the 1970's by the Chilean biologists Humberto Maturana and Francisco Varela as a set of criteria for recognizing when a complex system could be considered to be living [19], [20]. It was soon proposed that human economic/social organizations might be considered to be autopoietic [21], [22], [33], [34]. Others dispute this [35], [36]. We have argued that a broad-based analysis fully supports the autopoietic nature of many organizations [13], [14], [15].

As substantially paraphrased in realist terms from [19], [37], the six properties a system must exhibit to be considered living, and therefore autopoietic, are:

- *Bounded* (system components are self-identifiably demarcated by the system from its environment)
- *Complex* (there are separate and functionally different components within the boundary)
- *Mechanistic* (system dynamics driven by self-sustainably regulated fluxes or metabolic processes)
- *Self-differentiated* (system demarcation intrinsically produced)
- *Self-producing* (system intrinsically produces own components)
- *Autonomous* (self-produced components are necessary and sufficient to produce the system).

Our theoretical studies [13], [14], [15] based on Karl Popper's evolutionary epistemology have concluded that autopoiesis is a phenomenon driven by dissipative thermodynamics that can emerge wherever the world offers a sufficient variety of components and a persistent potential difference between sources of high potential energy and sinks for entropy.

C. *Epistemology and Ontology*

Based on Karl Popper's evolutionary epistemology [23], knowledge in the sense of solutions to problems of life is an integral and inescapable aspect of autopoietic systems. Autopoietic systems cannot emerge and become self-sustaining without producing knowledge and all knowledge has its origin in autopoietic systems [15], [37].

Popper [23] argued that all knowledge is constructed in living entities, and as such knowledge claims cannot be proven to be true. However, knowledge in knowing entities grows closer to a correspondence with reality via evolutionary processes involving the selective elimination of errors when knowledge is applied to the real world. Basically, by surviving, an autopoietic entity accumulates control information [38] in the structure of its cybernetic apparatus as needed for successful self-regulation and self-production in the face of perturbations from the real world.

Karl Popper also posited an ontology consisting of three metaphysical domains or "worlds" [24] that we have modified [15] [18], [37] as follows:

- *World 1 ["W1"]* – Physical reality, i.e., the real world, the totality of existence without interpretation.
- *World 2 ["W2"]* – Cybernetics of cognition and knowledge as control information incorporated in living structure, i.e., "living", "dispositional", subjective, or "tacit" knowledge.
- *World 3 ["W3"]* – Codified knowledge able to persist independently of living things. Includes knowledge encoded in DNA molecules, in writing on paper and as held in computer media.

In entities involving human consciousness, either at the personal level or as organizational processes, knowledge can be improved by the elimination of errors through critical rationalist approaches as well as by natural selection to eliminate errors [39], [40], [41], [42]. Criticism involves the recursive cycling of knowledge claims between tacit personal knowledge in W2 into W3 for sharing and criticism and back into W2 for further testing via action and testing [1], [3], [14], [16], [18]. Several loop processes for organizational learning based on cycles of action and testing have been proposed [41], [43], [44]. We prefer the depiction presented in Boyd's OODA Loop [12], [16], [45], [46], [47], [48], [49]. (See http://tinyurl.com/2twutf for additional graphics and animations of these concepts). This is a continuously iterated loop process involving Observation, Orientation, Decision, and Action where Observation begins again by observing the consequences of the previous Action.

D. *Hierarchical Complexity and Emergence of New Levels*

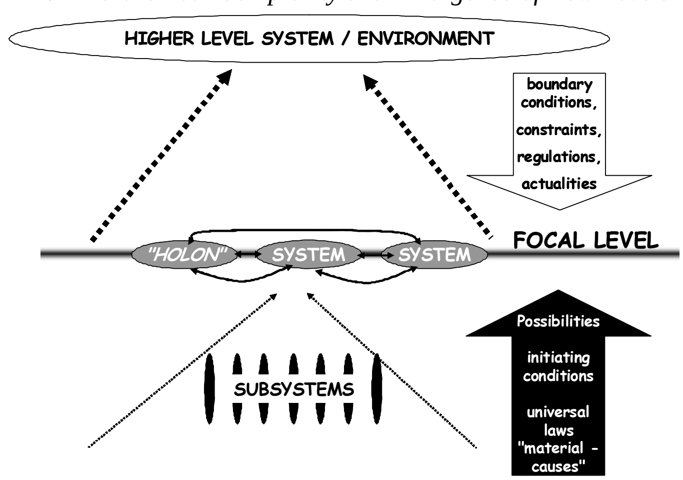

Fig. 1. Focal level systems in a complex systems hierarchy. Systems are comprised of subsystems, whose "laws" and past history of interactions define what it is possible for the system to do and provides a source of non-deterministic "upward causation" driving the focal system's evolution. In turn, the focal level system is a component in a higher level system providing an environment for the system's activities. This environment provides downward causation via the determination of boundary conditions, constraints and regularities that effectively prunes possibilities inherent in the subsystem's laws of interaction to realize a much smaller set of actualities. Koestler called such systems holons [50], [51], because they could not be considered apart from their hierarchies - the system must both look inward/downward and outward/upward for its causes.

The world is highly complex across a very large scale of size and frequency of interaction of components ranging from fundamental particles of physics, through biological systems, to solar systems and galaxies of astrophysics [25], [26], [27], [28], [29] that form a complex systems hierarchy. Many different levels of organization can be recognized within the hierarchy based on the preferential interactions of components or "subsystems" of similar size and reactivity to form a "system" at a particular "focal level" (Fig. 1) [28], [29]. In general elements below the subsystem level interact so fast that they represent a steady-state close to thermodynamic equilibrium from the point of view of systems at the focal level. Higher level systems basically form a slowly changing "environment" for focal level systems and may provide these systems with major potential disequilibria that can be exploited to fuel their activities. Salthe argues that dissipative systems defining new focal levels can emerge wherever lower level systems provide sufficient variety of interactions and higher level thermodynamic conditions provide potential differences that can be dissipated more readily than is possible at the higher level [30].

On one hand an observer can define a level of focus, point to any collection of interacting components and call it a system. On the other hand, autopoietic systems are self-defined, and recognition of an autopoietic system automatically defines a focal level where the autopoietic system exists in the complex hierarchy. We have argued [12], [13], [14], [15], [18], [37] that at least some human organizations such as commercial entities can emerge as autopoietic entities in the economic/social hierarchy within the overall social/economic system above individual humans. In the remainder of the present paper we will argue that there is a general process by which knowledge-based autopoietic entities can emerge at a number of different levels in the human economic/social hierarchy.

III. Case Material

The model for the emergence of knowledge-based autopoietic communities is based on many years practice working to build sustainable knowledge sharing communities in the organizational sphere. This ranges from our own involvement, not all of them documented, and related cases in the literature with small and medium enterprises, such as engineering [1], [2], [6] and software development companies; medium sized companies such as a bank, and service organizations [1], [17]; large, distributed organizations such as defense engineering project management and pharmaceutical organizations [1], [3], [4], [5], [8], [9], [13]; national and international science, technology and industry associations [1]; and industry clusters [10], [11].

IV. How Knowledge-Based Communities Emerge

Much of the writing about autopoiesis focuses on the concept of "closure": circular, semantic, semiotic, organizational, etc. [20], [52], [53], [54], [55], whereby the system continuously produces the system that produces itself. Many misunderstand this to mean that the autopoietic system is closed to outside influence. Popper's recursively iterated evolutionary process of knowledge generation (i.e., learning) [23], as illustrated with Boyd's OODA loop referred to previously illustrates. Although autopoietic systems recursively regenerate themselves, in each cycle survival knowledge held in the autopoietic system necessary for its perpetuation is exposed to the world where selection has the opportunity to selectively eliminate systems exposing errors to the real world. Thus, knowledge in the autopoietic system can change, as long as the change is not so great that the system is no longer able to survive perturbations from the world.

In autopoietic organizations, because self-conscious people are involved there may be a cycling between personal knowledge and various forms of explicit knowledge that are either held by individuals or that are more widely known and accepted in the organization.

Working to facilitate the formation of intra and inter-organizational communities for the sharing of knowledge and to establish the formation of industry clusters we believe we have seen the transformation of allopoietic communities (i.e., those formed or "produced" as a consequence of external intervention) to ones that become autopoietic (where the organization becomes autonomous and self constructing). We also believe we have seen similar transitions emerging from allopoietic to autopoietic at several different levels of organization (i.e., the process is self-similar - fractal? - at several levels in the scalar hierarchy of organizational structure). The types and roles of knowledge building and transfer seem to be similar at all levels of organization, and are anticipated to be ongoing in most organizations most of the time. This process of emergence is depicted in the following graphics.

Fig. 2 illustrates the dynamic structure of a generic autopoietic system. The boundary of the autopoietic system is denoted by the surrounding ellipse. Connected circles within the boundary represent component actors and subsystems whose interactions collectively serve to self-produce, self-maintain and self-regulate the organization as an autonomous system within the environment of a higher level supersystem. Actors and subsystems are individually dissipative processes whose rules of interaction and particular history of interactions with other actors and subsystems in the organization serve to maintain the organization's autonomy and boundaries. High potential inputs include energy, and income. Low potential inputs include untrained recruits, raw materials and the like. Outputs include entropy and waste, products, costs, and departing staff. Self-productive processes structurally couple dissipative flows from high potential energy and income to absorptive processes such as staff induction, production, environmental monitoring, and actions on the world. All of these processes can be considered to be subsystems that require knowledge in the form of appropriate structure and organizational routines [56] and possibly in terms of specific instructions in order to function properly in the autopoietic entity. Subsystems are comprised of people and possibly machines, where the people hold the living knowledge required for the subsystems to operate and where they may be able to call on other personal knowledge held in other areas of the organization and relevant explicit knowledge (if they know it exists) [1], [18].

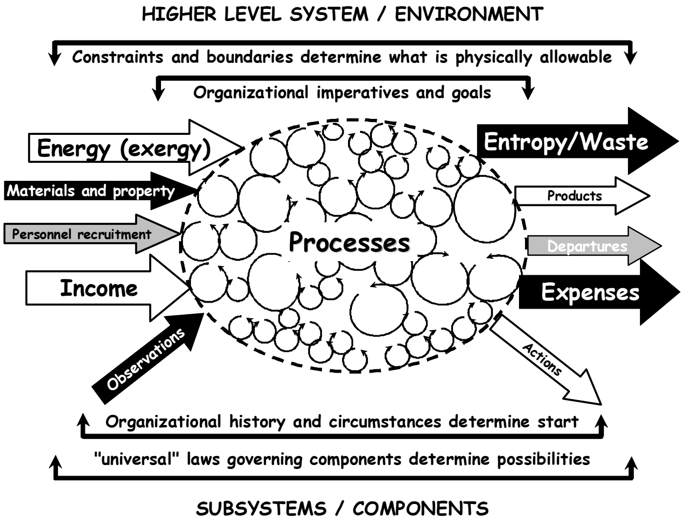

Fig. 2. Structure of an autopoietic organization. (after [13])

Fig. 3 illustrates some of the major functional subsystems that would be found in a medium sized autopoietic organization. Those around the periphery face outward and interact with the environment as well as with other systems in the autopoietic entity, the internal subsystems are necessary for managing the organization's survival knowledge.

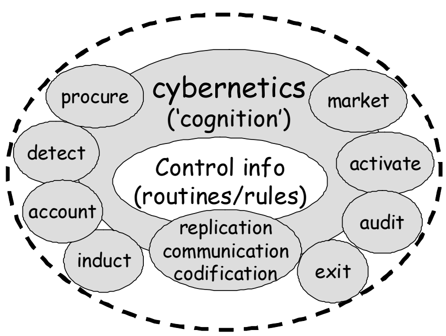

Fig. 3. Core sub systems in the autopoietic entity.

Nousala often works as a community facilitator, where she intervenes as a consultant with a brief to help establish some form of knowledge sharing community within or between organizations. These may be communities of interest (CoI - individuals that engage in an adhoc manner who share common interests within a loosely defined group, with the potential to develop into a community of practice), expert communities of interest (ECoI – individuals that engage in an adhoc manner who share specific interests through common expertise, with the potential to develop into a community of practice), or communities of practice (CoP – established group of individuals who over time have created sustainable knowledge sharing through trusting, working relationships) or various kinds of inter-organizational forms. Inevitably, any individual in an organization will have, at least tacitly, a network of knowledge sharing relationships with other people in the organization as required to successfully carry out organizational activities. Fig. 4 illustrates the first stages of an intervention, where organizational needs for knowledge sharing are assessed and key individuals who may assist are identified.

Stage 1 is the creation of a pilot framework for the preliminary analysis of personal and structural needs for living knowledge (W2). In stage 2 the results of the preliminary analysis are returned to key people for criticism and feedback (cycling between W3 and W2) to establish a 2^{nd} order framework. In stage 4 first attempts are made to invite appropriate people to join the community.

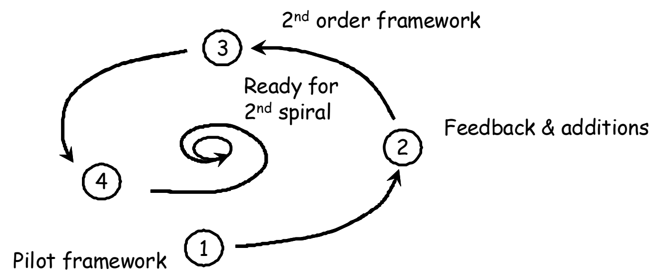

Fig. 4. Information, communities and knowledge – results of the first exchange of information among individuals/groups/beyond. This is a representation of an initial formation of "group states" such CoPs, CoI and ECoIs, beginning with interaction between layers of individuals and their knowledge networks. This focal point is operating between practice and process which is also occurring simultaneously with higher level systems. [1].

This should initiate a spiral process as shown in Fig. 5, enabled by organizational history and circumstances and oriented and constrained by the organizations imperatives and goals. As people with knowledge needs in common aggregate to form an initial community, various forms of tacit and explicit knowledge begin to be shared, oscillating between practice and process which also occur simultaneously with higher level systems. Communication is critical for effective interaction between process and practice. Good communication ensures effective access to critical information needed for building knowledge bases [1], [3], [4]. The facilitator attempt to shape the process so it becomes recursive, with opportunities to improve in effectiveness through related OODA activities and the elimination of ineffective knowledge and processes.

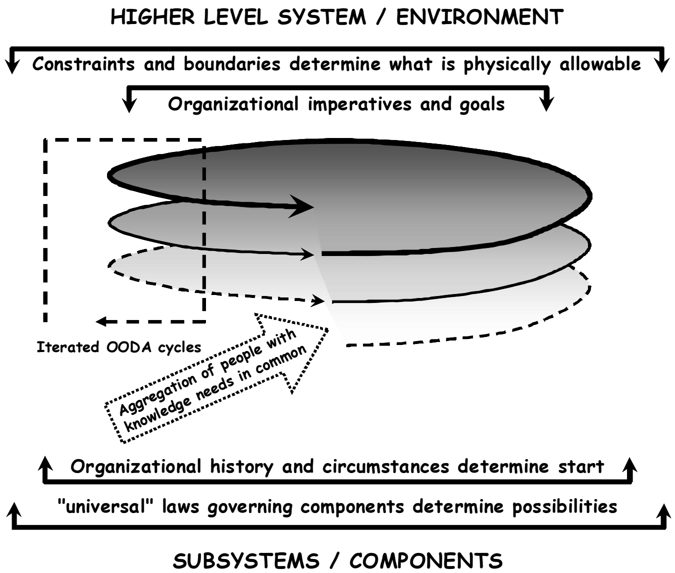

Fig. 5. The knowledge spiral process (from [1], [3]).

The next series of figures illustrates our understanding based on a number of similar cases of how the newly emerged/established community becomes autopoietic and robust enough to sustain itself against fluctuations in environmental resources and variable management. Fig. 6 depicts the situation within the larger organization where there is someone (the "human attractor) with a publically known interest in addressing a particular need or type of need. Formation of a community is positively and negatively constrained by higher level needs and enabled by the availability of appropriate components and resources based on organizational history and circumstances. Presumably, after inputs used and outputs produced are accounted for there will be a net benefit to the organization from addressing the higher level needs.

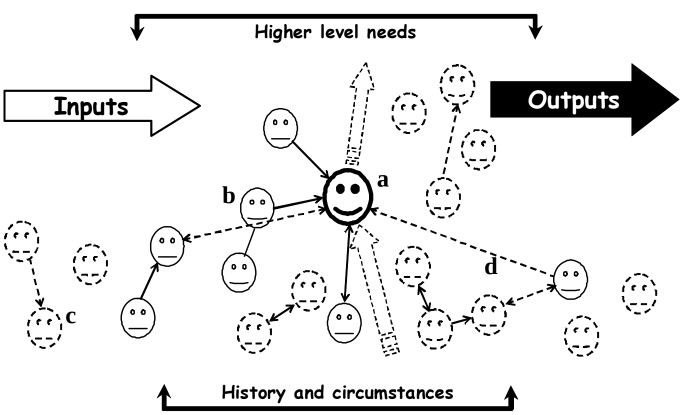

Fig. 6. A social network created by a "human attractor" [3] within the organization. "Faces" in these figures correspond to people/actors belonging to the organization at the level of subsystems/components (see Figs 2 & 3). **a**. A "human attractor" seeking knowledge to address a high-level organizational imperative or need. **b**. Other seekers socially transferring knowledge relating to what the "human attractor" seeks to know for the benefit of the organization. **c**. Other actors in the organization who are not connected to the seeker's current interest. **d.** A knowledge transfer between individual actors. Line weights indicate strength of the connection. The open vertical arrows indicate the possibility that the community may assemble and generate knowledge that will be valuable in addressing organizational needs.

If the human attractor has a public profile in the organization, other individuals in the organization with similar interests (i.e., other "seekers") will tend to join the attractors' personal network. If these seekers receive organizational/ social rewards for their involvement, a community of interest may coalesce around the attractor, as indicated in Fig. 7. Organizational management can intervene in a variety of ways to facilitate or retard the development of the community. If the problems are important to the organization, no intervention may be the best policy.

People joining the community receive rewards of personal and social satisfaction if they see that the community is identifying and solving real problems. In some cases rewards are ineffective because they turn a seeking for personal satisfaction into direct financial acquisitiveness. Alternatively, we have seen micromanagers concerned with time keeping stifle the formation of communities that would have been critical to organizational survival had they been allowed to form [57].

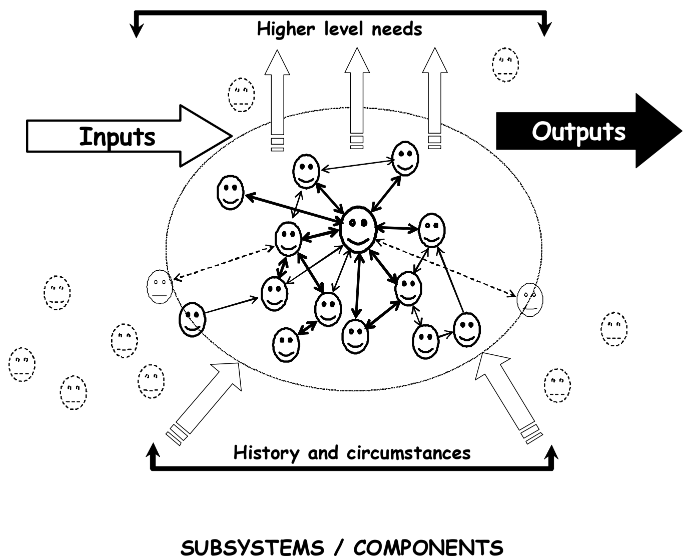

Fig. 7. The coalescence of a community of interest (CoI) around a "human attractor". The human attractor seeks knowledge to solve organizational needs addressing high level imperatives and goals. Bright smiley faces represent people/actors receiving organizational/social rewards for their involvement in addressing the organizational need. Such rewards reinforce the individuals' involvement in addressing the corporate need. Open vertical arrows indicate the value/importance of the assembled, ordered and directed knowledge in addressing higher level organizational requirements. The light dotted line surrounding the attractor's network indicates that participants and others begin to see the network as a specialized community addressing particular needs.

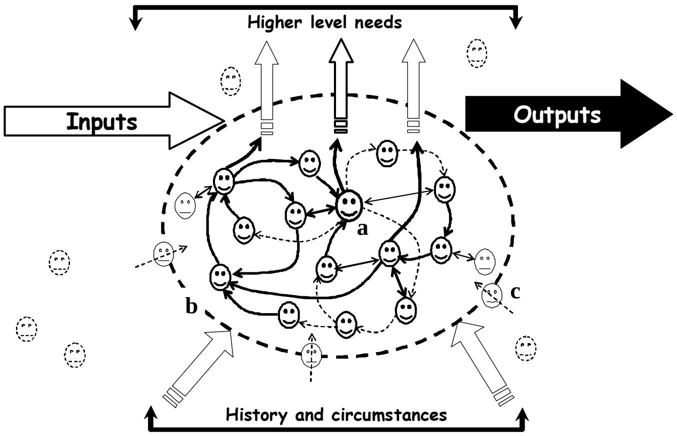

Fig. 8. Stabilization around a human attractor. Emergence of processes within a stabilized community of interest. Dashed arrows represent control processes. Solid arrows represent knowledge production processes. Knowledge about how to form and sustain the community is still emerging. **a**. Community facilitator. **b**. Emerging boundary between the system by those who identify themselves as participants in the community (for the purposes of the community only) and others in the community. **c.** Faces crossing the boundary are people in the process of being recruited and inducted into the community.

If the coalescence of the community is allowed to continue, the situation illustrated in Fig. 8 arises with the development specific tacit procedures and routines for community maintenance and sustainment within the community. These represent tacit structural knowledge *at the level of the community as an entity in its own right* [56]. It is at this point where the borderline of autopoiesis is reached. If individuals receive personal and social rewards they value as a consequence of belonging to the community they may take active roles in maintaining community goals and aspirations, This diminishes the need for a particular personal attractor to coordinate organizational survival and growth. Thus, the community becomes more autonomous.

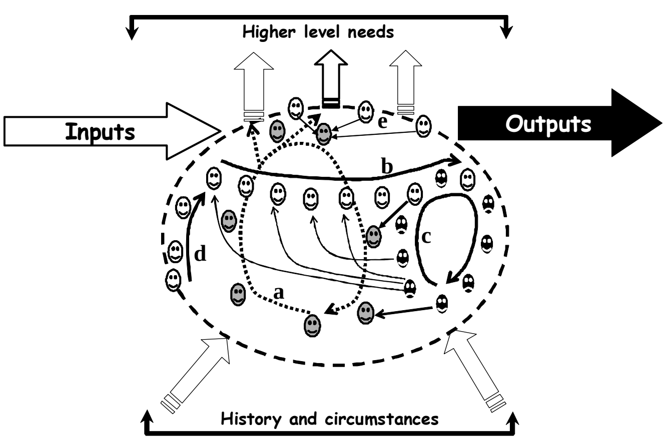

Fig. 9. Achievement of dispositional autopoiesis. Stage where discrete, self-supporting practices have evolved to produce particular (knowledge) products. **a.** grey faces - internal and external monitoring processes providing overall feedback control to maintain and sustain the community. **b.** white faces - a production process delivering a product to the broader organizational environment. **c.** product quality control cycle provides corrective feedback to the production process. **d**. induction process recruiting new individuals into the community to satisfy new needs and to replace attrition. **e**. environmental monitoring to feed observations into monitoring and control process. Note, this evolutionary stage still depends on tacit routines and tacit knowledge/acceptance by individual participants of their learned roles in the routines.

As the community evolves and becomes better at meeting its knowledge building and dissemination goals, internal routines become firmly established as distinct processes and are built into the "way we work" as organizational tacit or dispositional knowledge, as described in Fig. 9. These become organizational subsystems in their own rights. However, the community may be unstable if none of the routines are documented, If key people fail to transfer their tacit knowledge of how their parts of the community work, their loss to the community could cause the whole community structure to disintegrate.

Fig. 10 illustrates the most stable formation of an autopoietic community, which is the situation were its key activities are documented to the extent that a new recruit could without too much difficulty take over the roles of an existing member without significantly disrupting the organization's activities. This basically represents the situation of the generic autopoietic entity illustrated in Figs 2 and 3.

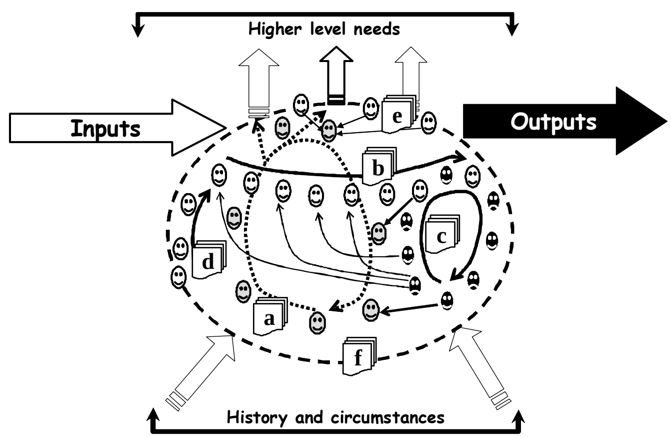

Fig. 10. Semiotic autopoiesis. State where the practices to form and maintain the community have been objectified and documented (as indicated by the records icons). Grey faces – those following codified knowledge (**a.**) about how to manage internal and external monitoring processes providing overall feedback control. White faces – those following codified knowledge (**b.**) about the production process. Black faces – those following codified knowledge (**c.**) about the product quality control cycle. **d.** codified knowledge about induction process recruiting new individuals into the community to satisfy new needs and to replace attrition. **e.** codified knowledge about environmental monitoring processes. **f.** codified knowledge about how to establish and sustain the community itself.

V. Conclusion

This series of developmental snapshots is what we have observed in several large organizations or in the establishment of inter company or organizational bodies and forums. The human attractor may be an outside facilitator or an existing charismatic staff member with a particular concern. Similarly, this corresponds to what we have observed happening in the formation of small and medium enterprises around a charismatic entrepreneur serving as the personal attractor. Where industry clusters are concerned, companies behave like individual people, and the attractor may be a particularly attractive company (e.g., a Nokia [58], [59]) or a research institute [10], [11], [60], illustrating the similarity of the process across several organizational levels.

Acknowledgment

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