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ARCHITECTING FLEXIBLE ORGANIZATIONS

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Introduction

The 21st century organization is faced with the apparent dilemma of being efficient and innovative, lean and flexible, and hierarchical and flat. The seemingly contradictory characteristics extend into every organizational system, from culture and strategy to process and technology. The flexible organization must embrace and cultivate opposites; indeed, the organization should recognize opposites as opportunities for inventiveness and synthesis and not a dilemma that requires a choice between opposites (Takeuchi et al. 2004). This is in contrast to a more traditional organization that either chooses one principle over its apparent opposite or adopts an engineering perspective that optimizes something between opposites. The knowledge organization, in contrast, synthesizes opposites into something unique and new.

At its source, apparent contradictions arise from the relative tacit and explicit knowledge content of organizational systems. Flexibility, then, arises from the capability of managers to manipulate the interaction and knowledge content within and among systems. For example, Toyota developed its Lexus product by embracing the seemingly contradictory product requirements of fast ride and fuel economy, noise reduction and light weight, warmth and function, and so on. By implementing both early and late knowledge construction (Morabito et al. 2000), product development followed, in sequence, an intended, emergent, and intended strategy. By understanding the knowledge creation process, Toyota was able to manipulate and combine their systems to produce a best selling luxury car (Osono 2004).

Classical approaches to design have typically leveraged context-specific knowledge to create a separate structure for each organizational dimension. This has led to a wide assortment of single-threaded architectures with specific purposes, but with little integration or synergy. By single-threaded, we mean that the architecture processes decisions or performs actions independently of other architectures. Other approaches attempt to integrate dimensions, but in effect create bulky structures that mirror management knowledge of context. As useful as this may appear to be locally, it operates sub-optimally at the organizational level. Moreover, each architecture or framework is not inventive within itself.

In the October 2006 issue of the Harvard Business Review, Stanford management guru James March discusses the importance of the elegance of ideas as opposed to their relevance. He does not mean that relevance is unimportant, only that the "beauty of ideas" (or "modeling as an art form") is the essence of scholarship. Management knowledge of context must be embedded within those elegant ideas. "It is the combination of academic and experiential knowledge, not the substitution of one for the other, that yields improvement" (March 2006).

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This paper discusses several "elegant ideas" in a broader "modeling as an art form" known as *organization modeling* (Morabito et al. 1999). We draw on the work of Herbert Simon and existing research on contracts to create a flexible approach to interrelate and specify the seemingly contradictory dimensions of an organization, using, for example, precise (fully explicit), relational (part explicit, part tacit) to psychological (fully tacit), to design the behavior of organizational dimensions.

Dimensions of Organizational Flexibility

Organizational flexibility is a concept that, at its core, refers to the capacity to rearrange or reconstitute a system configuration to adapt to an internal or external imperative. Flexibility extends to all areas of the organization, from its strategy to its technical systems. Moreover, at the organization level, flexibility must encompass all of an organization's systems simultaneously.

Flexibility has taken shape in various forms. For example, systems engineering, service-oriented or enterprise architectures, and adaptive strategies are ideas that, in principle, promote flexibility; otherwise, there is no reason for their being. In fact, every area of the organization, from its lowest level technical systems to its learning and cultural systems may be characterized by a corresponding framework or architecture that promotes design and flexibility.

Flexibility also extends to the knowledge characterization of the system itself. For example, a technical system is fully explicit while culture and learning are primarily tacit. This is significant since explicit and tacit systems are fundamentally different and hence must be characterized and designed differently – yet, they too must be embedded within all of an organization's systems.

Systems and Knowledge

In this paper, we take the view that the organization's systems may be characterized by a hierarchical relationship and their corresponding knowledge content in terms of explicit and tacit knowledge. Thus, the organization may be characterized by both levels of systems and by system knowledge characterization. This is illustrated in Figure 1.

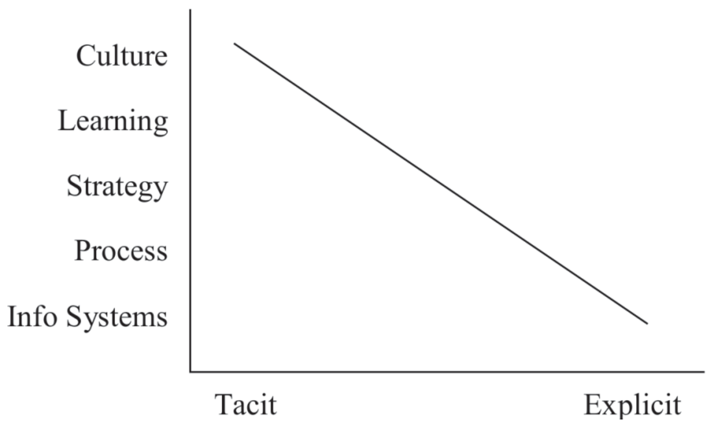

Figure 1: Organizational Systems and Knowledge Content

Figure 1 states that higher-level organizational systems have a comparatively larger tacit knowledge component than lower level systems. As we discuss below, higher-level systems have a lower frequency and respond more slowly than lower level systems (Simon 1973). Similarly, building tacit knowledge is a function of time and experience (Gill 2000); hence, we argue, that a comparatively high level system has a larger tacit knowledge component than a lower level system in the same organization.

Culture, for example, is a system where tacit knowledge is the dominant constituent. Edgar Schein has described culture as having three constituents: shared tacit assumptions that are the essence of culture, espoused values that expresses what tacit assumptions an organization would like to develop or be seen as representing, and overt behavior which indicates how it explicitly operationalizes the tacit assumptions; yet, it is shared tacit assumptions that shapes the other constituents (Schein 1992). To continue the argument illustrated in Figure 1, learning is largely determined by the organization's culture or sub-cultures; in fact, the learning associated with transformational change involves changing the basic assumptions of an organization – "basic assumptions about the culture lead to learning values and investments that produce a different learning style from a culture with another pattern of values and investments" (Nevis et al. 1995). Thus, culture and learning are intertwined through their tacit knowledge content; Schein, for example, claims that organizations have difficulty learning because occupational sub-cultures often have different and incompatible tacit assumptions that resist change and prevent the communication necessary for learning (Schein 1996). Finally, an information system shown at the bottom of Figure 1 is entirely explicit, as all non-human, machine-based systems must be.

Flexibility and Managerial Choice

Flexibility exists within and between systems, and may be configured based on the comparative tacit-explicit knowledge content of the systems. For example, where do we place *structure* in Figure 1? In the classical organization, structure is immediately above process; however, in the modern process enterprise, process is above structure (Rummler et al. 1995). That is to say, the 21st century organization chart (i.e., structure) is constrained by process requirements, and not the other way around. This is one example of flexibility and managerial choice: the process organization *chooses* to place process above structure.

Architecting Systems

What most existing architectures have in common is that they are single-threaded and represent experiential, management knowledge of an area such as strategy or process. There are no underlying concepts that span all disciplines or that can be said to represent modeling organizations as such.

Organization modeling is a level of abstraction that spans all the areas of an organization. Its ideas and principles are drawn from a variety of disciplines, including hierarchy theory, organization science, art, law, and software engineering, among others. Through the blending of a rich assortment of ideas, an elegant, inventive framework emerges that lends both rigor and discipline to design while promoting creative insights and design flexibility. Organization modeling, then, is our attempt at the "beauty of modeling" – a set of elegant, interlocking ideas with analytical discipline that encompasses and interrelates all the systems of an organization.

Properties of Organizational Systems

Discussed below are selected properties of systems that have a significant impact on organizational flexibility. We draw upon and extend the work of Herbert Simon on **hierarchy theory** to create a distinct perspective of organizational systems and then use elements of organization modeling such as **molecules** and **contracts** to account for these properties within the framework shown in Figure 1.

Thin and Thick Dimensions of Organizations

All social institutions have both visible and hidden characteristics. We borrow from the field of ethnography and describe these characteristics as *thin* and *thick*, respectively (Geertz 1973). Thin systems are characterized by visible, well-defined attributes and include information systems and routine process workflows. In contrast, thick systems are distinguished by their tacit belief content and include, for example, organizational culture and learning. The characteristics of thin systems come closest to explicit knowledge while that of thick systems to that of tacit knowledge.

The design of thin and thick systems is fundamentally different. The former requires the detailed structuring of content (lower right of Figure 1) (Drucker 1999) while the latter involves the design of the surrounding context (upper left of Figure 1) (Davenport 2005). Moreover, the systems must complement and reinforce each other. Successful organizations build and interrelate both their thin and thick systems.

As an example, Toyota characterizes itself in terms of explicit and tacit knowledge, known as the "Toyota DNA": one strand for thin and the other for thick. The visible thin strand includes elements of the Toyota Production System (TPS) such as just-in-time, leveled production, one-piece flow, and so on. The softer thick strand includes respect for people, change, and learning. Management practice and policies such as quality circles and continuous improvement represent the cross-links: they connect and build both strands *simultaneously*: improving thin TPS elements through the active participation of employees shapes the thick elements of respect for people and learning (Liker 2004). In contrast, many organizations adopt "lean production", but in fact are borrowing only the thin strand from the Toyota model. The thick dimension is either ignored or subsumed within the thin. It is no surprise, therefore, that no current "lean organization" even comes close to the "Toyota Way" (Liker 2004).

Hierarchy Theory and System Layering

We draw on hierarchy theory to elucidate the layering of systems illustrated in Figure 1. A **hierarchy** of systems is one where a system at any level corresponds to a *set* of lower level systems, known as a partial ordering or a tree. This is in contrast to a complete ordering where a system corresponds with only one other system below it. By way of illustration Herbert Simon uses the metaphor of Chinese boxes: opening one box reveals a *set* of smaller boxes; opening any of which reveals yet another set, and so on (Simon 1973).

System interaction is of two types. The first is symmetrical and characterizes tissues, such as crystalline or lattice structures as found, for example, in rocks. The second is asymmetrical, meaning the behavior across layers is different in each vertical direction. Partial ordering coupled with asymmetry characterizes a **molecule** (Simon 1973). Both biological and organizational systems may be configured as molecules. An example of a molecule in an organizational system is illustrated in Figure 2 – a process molecule (Morabito et al. 1999).

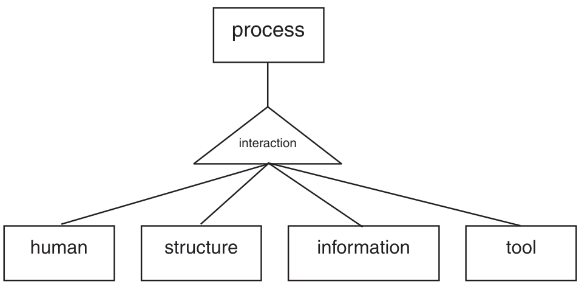

Figure 2: Generic Process Molecule

Observe in Figure 2 that the higher level {process} is a system whose constituents include {human}, {structure}, {information}, and {tool} at the next lower level. These lower level systems are sub-systems from the standpoint of process design: the sub-systems *implement* the higher-level process *specification*. The asymmetry is manifest in the molecule itself and is illustrated by the triangle identifying some type of interaction. Furthermore, the sub-systems communicate through messages; i.e., the pre- and post-conditions across the subsystems. The interacting subsystems implement and explain the structure and workings of the higher-level process. The systems within the molecule as a whole – the higher-level system specification and the set of lower level implementation sub-systems – are tightly bound. By tightly bound, we mean that the interaction of the defined implementation sub-systems delivers the functional requirements of the process specification; that is, tightly bound systems are those with the shortest functional distance (see below) for a specific design defined by the molecule itself.

Note that we do not mean "tightly coupled" systems, which are interdependent and reduce flexibility. Implementation constituents in a molecule are not necessarily interdependent; rather, the molecule sub-systems communicate independently of their internal structure and provide context to the specification they operationalize, and in fact, increase flexibility by interacting through the mechanism of loose horizontal coupling (discussed below). A given {process} specification may be implemented through any number of sub-system {human}, {structure}, {information}, and {tool} combinations, known as a refinement path (discussed below). For example, we have the option of automating a {process} specification by replacing the {human} with sufficiently robust {information} and {tool} constituents. In contrast, Toyota often chooses *not* to automate {process} specifications even when the appropriate implementation constituents are available. The reason is that the {human} constituent in the process molecule is the "most flexible" constituent and removing it would reduce overall process flexibility. Toyota only chooses to automate a {process} when that specification qualifies as both an industry best practice and a Toyota standard (Liker 2004).

Finally, for convenience we usually replace a picture of a molecule with its corresponding linear notation, as follows for process:

generic process: interaction (process {human, structure, information, tool})

Organization Levels and Molecules

The question that naturally arises concerns the relationship between system levels as illustrated in Figure 1 and the idea of molecules illustrated in Figure 2. This requires a more detailed discussion of hierarchy theory.

There are two types of hierarchies – **empirical** and **definitional**. Definitional entities are postulated before measurements are taken while empirical entities correspond to some observation and measurement and typically arise post-hoc to that observation. Definitional entities are indispensable to the development of research questions and their assumptions; they are scale and rate-independent and based on observer-generated criteria. Definitional entities guide the process of analysis; experience and observation may lead to the discovery of empirical entities or insights, which in turn yield a further refinement of definitional entities. In follows, then, that definitional entities are ordered into levels of organization while empirical entities are ordered into levels of observation (Ahl et al. 1996).

The sample hierarchy shown in Figure 1 is an empirical hierarchy arising from observation; i.e., the higher-level systems have an observerable lower frequency and longer response time than lower level systems. An organization molecule, in contrast, is a definitional hierarchy and is described according to the criteria of design, specifically context-specific specification and corresponding sub-system constituents that are tightly bound (close functional distance) during implementation.

When configuring a molecule for design purposes, we naturally define a context specification with a set of subsystems drawn from the entire pool of organizational materials (i.e., organizational systems). The generic process molecule, for example, was defined from our reading of organizational and management literature as well as management practice.

Let us extend our thinking into the context of strategy: a working model for configuring a strategy molecule (i.e., specification and implementation) may be as follows:

generic strategy: interaction (strategy {process, structure, information, culture})

In this case, we see that strategy leverages the values associated with culture during its implementation, even while culture constrains that implementation (Sushil 2007). Since culture is a high-level, low frequency system, it acts, in effect, as a *constant* during strategy formulation and implementation. Is this true? Toyota, for example, was able to synthesize both intended and emergent strategy because of its culture of learning, change and continuous improvement; that is, Toyota was able to implement a dynamic and changing communication pattern (i.e., univocal and multivocal dialogue) during its strategy making process (Osono 2004). Other organizations with a culture of conformity may have difficulty synthesizing the contradictory principles of intended and emergent; in fact, a bureaucratic culture would most likely restrict strategy implementation to intended (Mintzberg 1983). That is to say, the values and assumptions associated with culture are tightly bound to strategy design (at least in the case of Toyota's Lexus product strategy) and thus provide empirical evidence for including {culture} as a sub-system constituent of a strategy molecule.

Design flexibility arises from the definition of a molecule. Academic literature, practitioner experience, organizational context are factors that a designer may use to configure a given molecule. Thus, there is managerial choice in the design of a molecule, which, of course, may be subsequently refined after implementation in the real world.

Functional Distance

Systems at all levels communicate with each other on a *sliding scale of influence*: the further away a system is the less is its direct influence (Simon 1973). For example, a process molecule represents a tightly bound coupling of systems for a given process implementation; however, it is influenced by other systems "further away", including, in decreasing scale of influence, process funding, process support, strategy, culture, and so on. Furthermore, this sliding interaction occurs both vertically and horizontally as shown in Figure 1.

Loose Vertical and Horizontal Coupling

Systems interact within and between levels. Interaction among systems within a given level is known as loose horizontal coupling. Loose horizontal coupling means that the internal dynamics of participating systems are *hidden* and *isolated* from each other through clearly defined boundaries, and thus may be seen as black boxes with respect to each other. The systems, in turn, communicate through inputs and outputs (Simon 1973). As we will see in our discussion of contracts, we can extend horizontal interaction to include invariants that act as constraints on communication. Similarly, systems communicate vertically, and here too communication is constrained by the invariant underlying the layering logic.

Loose vertical coupling permits behavior *independence between levels*, and thus permits the assemblage of larger structures, provided subsystem equilibrium properties do not affect the system behavior at higher levels. Similarly, loose horizontal coupling also permits the creation of a larger structure, but here the key interaction considerations are the inputs and outputs between subsystems (Simon 1973). Both loose horizontal and vertical coupling share the properties of allowing system communications and independence, thus promoting flexibility during design.

Formally, a given association between entities in different levels is determined by the invariant governing the layering logic. An invariant is the background of procedures, rules, and relationships between entities that never change. The invariant, then, defines the association and the ordering logic. Note too that an invariant is not a state – a state is a function of time – while an invariant is not expected to change with time (Morabito et al. 1999). In contrast, the inputs and outputs of subsystems within the same layer associated with loose horizontal coupling may change the states of participating entities.

Level Ordering

A level is distinguished by a logical grouping of entities. There may, of course, be a set of subsystems at the same level that correspond to a given logical grouping. For example, {animal} at a high level may be associated with both {carnivore} and {herbivore} at the next lower level. Both {carnivore} and {herbivore} are of the same logical type – they share properties of animals and thus are at the same level – yet they differ by the criterion of diet and are therefore distinct subsystems (Ahl et al. 1996).

The ordering of levels is based on several criteria. As is illustrated in Figure 3, a high level entity has a slower frequency than a corresponding lower level entity, and in fact is one criterion that determines level ordering. We may also say that a higher-level entity has less bond strength and integrity, offers context to, constrains, or is a composite of a lower level entity. Finally, more than one association type often holds for a given hierarchy (Ahl et al. 1996). For example, the {process} in the process molecule specifies or describes a given process, and therefore contains, offers context, and constrains the set of lower-level subsystems, which in turn, implement and explain the function of the higher level {process}.

System Frequency (time-sensitive response)

It is a characteristic of system interaction that high-level systems respond slowly to inputs from systems at lower levels. This is a function of the comparatively different frequencies with which each vibrates and is illustrated in Figure 3.

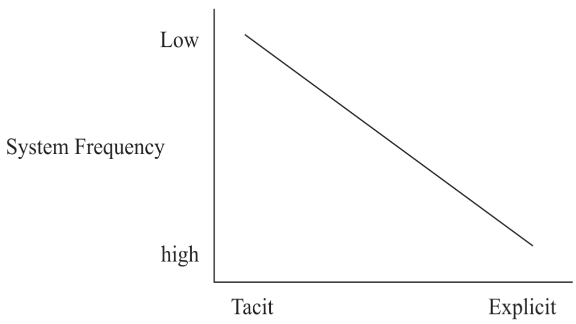

Figure 3: System Frequency & Knowledge Content

Those behaviors or motions of a system that depend on low frequency levels (high in the hierarchy of systems) are so slow that they will be difficult to observe and may be replaced by *constants*. In contrast, motions determined by high frequency modes within a subsystem (low in the hierarchy) will be, of course, isolated from that of other high frequency subsystems, and be so rapid that the corresponding subsystems will appear to be in equilibrium with no internal degrees of freedom. The result is that corresponding subsystems within the same low level will behave, with respect to each other, like *rigid bodies*. After eliminating the very high and low frequencies, then, it is the middle frequency layers that determine, to a good approximation, the observable dynamics of the major systems. Hence, the efficacy of a system model built on the interactions of middle frequency subsystems will be largely determined by the sharpness of the boundaries above and below the middle frequency layer (Simon 1973). At the end of this paper, we discuss this in more detail with an example of varying frequencies and organizational structure.

Near-Decomposability

The notion of asymmetry leads to the idea of near-decomposability. A system is nearly decomposable, meaning by virtue of its asymmetrical association, it cannot be completely decomposed (Simon 1973). Near-decomposability implies that a level, or a specific thing in a system known as an *entity*, is not merely a collection of the set of entities at the next lower level. For example, a single molecule of water (at a high level) is more than a collection of one oxygen and two hydrogen atoms at the next lower level; rather, combining entities at the lower level produces certain properties in the corresponding higher-level entity. These properties are *system-level* – they are displayed in the higher-level entity or level, but depend on the elements at the lower level, and therefore are functions of the entire system. The weight of a water molecule, for example, is a system-level property that, in this case, is a summation function corresponding to the weight of individual atoms at a lower level. In contrast, properties specific to an element, such as the specific weight of individual atoms of hydrogen and oxygen are said to be *deliberate*.

At this point we need to make a fine modeling distinction often overlooked in the literature. System-level properties (also known as *bulk* or *global* properties) are functions of the system itself – i.e., its multiple layers – and are of two types: The first are **resultant properties**, sometimes known as hereditary properties, and the second are **emergent properties** (Bunge 1977). Resultant properties are typically *functions* corresponding to lower-level properties and therefore exist in at least one lower-level subsystem. We believe Simon's reference to "weak emergence" as "the parts of a complex system have mutual relations that do not exist for the parts in isolation" (Simon 1996) comes closest to the terms resultant or hereditary property. Emergent properties do not exist in any of the lower-level subsystems and arise from the layering logic; that is, as a consequence of the *layering invariant*. Typically, emergent properties cannot be predicted on the basis of lower level properties, and thus are not mechanical but "creative" in character.

The Paradox of Tacit Knowledge and Flexibility

At first glance, it may seem that tacit-oriented, low frequency systems are resistant to change and hence inflexible. Actually, the reverse is true. If an organization's thick strand of DNA is constructed to embrace change, learning, and respect for people, then, in fact, people as individuals and in groups are an organization's *most* flexible system, not in spite of, but because of their tacit knowledge. As mentioned above, Toyota considers people its most flexible process constituent and hence resists automation even when technically possible. The result is "automation with a human touch" (also known as "autonomation"), where automation takes place only as part of a broader human system (Ohno 1978).

In fact, culture and learning systems can be changed, but the mode of change is different from that of explicit systems. Schein has defined the process of culture change as having three stages: unfreezing and creating the motivation to change, learning new concepts and new meanings for old concepts, and refreezing and internalizing new concepts and meanings. Change starts with *disconfirmation*, or some new force which upsets the stability of the high level systems. Disconfirmation may include, for example, economic threats (e.g., a pharmaceutical firm having a drug removed from the market for safety reasons), technological threats (e.g., the Internet), mergers and acquisitions, and so on. Eventually, it comes down to individuals who must learn and imbibe new concepts. Schein uses the term *cognitive redefinition* to describe this process of individual transformation where, in essence, the individual learns a new way of thinking that depends on several organizational factors, such as training, positive role models, consistent systems and organizational structures that support the new way of thinking and working, and so on (Schein 1999). Furthermore, the transformational learning and the ensuing *psychological contract* may be coercive or cooperative. For example, the authors' experience with a large corporate acquisition was that the disconfirmation was largely coercive, or to use Schein's words, the acquiring firm's culture simply "imposed itself on the other" (Schein 1999).

Finally, the knowledge organization is, by definition, flexible in that new threads of knowledge, and therefore organizational possibilities, are being created. Here too, knowledge creation originates with individuals and depends on the organizational context (known as "ba") that should be designed to cultivate tacit knowledge and its amplification throughout the organization (Nonaka et al. 1995). Several examples of the role of tacit knowledge in knowledge creation and organizational flexibility are described in the remainder of this paper.

In summary, we argue that tacit-oriented systems have the potential to be the organization's most flexible systems, right down to the individual. The real question is whether the tacit systems encourage creative and engaging flexibility or whether the effect will be restrictive and controlling. Below we discuss psychological contracts.

Modular Versus Integral Architectures

Modular architectures characterize thin or explicit systems; that is, systems with clearly defined boundary conditions that communicate through messages within the same level (i.e., loose horizontal coupling). In contrast, thick systems are characterized by unclear boundary conditions where many systems, context-specific subsystems as well as organization-wide systems (high level, such as culture) all interact. The combination of systems creates a context for thick behaviors such as research and development (R&D).

The source of flexibility is different for thin and thick systems. Designing thin systems involves rigorous analysis and design of content. For example, automating a given process requires a detailed functional specification of {process} if we are to replace the {human} with a {tool} constituent illustrated in Figure 2. Modularity, that is, entities with clearly defined boundaries in combination with both vertical and loose horizontal coupling represent the mechanism underlying thin system flexibility. Modularity makes possible reuse, recombination, and choice.

In contrast, designing thick systems relies on anthropological-like analysis and the design of context. Context design, in turn, involves the design and *interweaving* of both thick systems (e.g., culture and learning) and thin systems (e.g., supporting information and tools) – i.e., context is a consequence of systems interaction. For example, if we are to support "socialization" during a knowledge creation process (e.g., R&D) we would need to weave together the physical space to facilitate in-person interaction, organizational intention, respect for the individual, individual and group learning attributes (e.g., motivation), the willingness for people to share without judgment, among other system elements – we would not, in fact could not, design the creative process itself. Hence, flexibility arises from context, the design of which arises from the appropriate interaction of systems, the architecture of which is not modular but integral. With thick systems, flexibility ultimately extends to the tacit content of the individual or group.

As an example, a routine process may be specified independently from the corresponding implementation subsystems. This separation of concerns (e.g., abstraction) makes detailed specification possible, underlies Scientific Management, and therefore facilitates the design of complex industrial processes. In contrast, when designing knowledge work, the systems that comprise its context are intertwined and cannot be separated. In fact, detailed specification is not possible. The task cannot be separated from the {human} performing the task – the structure and workings of the task are inside the head of the knowledge worker (Drucker 1999).

Contracts

Loose vertical and horizontal coupling describe subsystems that are, at once, isolated and interacting. It follows, then, that a key design decision, in addition to the selection of the levels themselves, is the identification of boundary conditions and the energy or information transfer between them. This holds for both vertical conditions between levels and horizontal conditions between subsystems within a given level.

We propose to address both system specification and interaction, between and within levels, through **behavior** and the notion of a **contract**. The use of behavior as a specifying construct frees us from all implementation concerns, including “objects”, “agents”, “roles,” and so on. Furthermore, though systems are typically recognized by their states (i.e., attribute values), it is behavior that is responsible for state changes. This is true even in social systems such as organizations where behavior is not independent of internal state.

We specify behavior with a contract. A contract is a self-contained construct that specifies or describes a given behavior – each distinct behavior and its boundary conditions may be specified with a corresponding contract. Furthermore, complex behavior may be specified with a *hierarchy of contracts* (Morabito et al. 1993).

Where the behavior being specified is *mechanical* in nature (e.g., software), we say the contract is fully explicit and **precise**; however, as we move along the knowledge continuum shown in Figure 1 toward the tacit pole, a more *thoughtful* analysis arises and we necessarily accommodate people – observer and participant – and the contract becomes **relational** or even **psychological** in nature. Each of these ideas has been described in the literature, in everything from software engineering to economics and law. The legal system considers a contract continuum as having a transactional and relational pole (MacNeil et al. 2001). In organization modeling, we have extended this model in each direction – fully explicit at one end and fully tacit at the other – to accommodate organizational systems. This new contract continuum is illustrated in Figure 4 and represents a range of possible specifications based on explicit and tacit knowledge content.

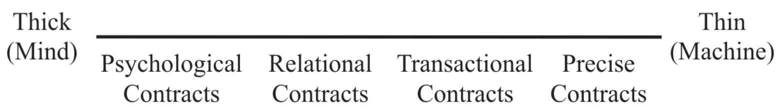

Figure 4: A New Contract Continuum

Industrial-era organizations are characterized by contracts that are, for the most part, mechanical-like descriptions of work. In fact, such specifications lead to the routinization of work. These contracts are *precise* or *transactional* and have a certain exactness and clarity that leads to engineering-like design.

In contrast, the knowledge-era has brought a new requirement: the specification of non-routine work and the application or creation of knowledge. In this case, mechanical descriptions are not sufficient; rather, values and expectations are often the primary parameters in the contract. Generally, as we move toward the thick pole in the new contract continuum, the contracts become more open and dynamic and subject to late knowledge construction (Morabito et al 1999).

In a modern organization, we must be able to specify both forms – everything from routine workflows to cultural processes – and thus accommodate both precise and rather implicit intentions.

The contract is distinguished by a certain intent, which may be communicated directly with explicit assertions, indirectly through a process of assimilation, or, of course, some combination. Thus, the concept of a contract embodies a range of communication modes, from explicit assertions such as “business rules” to implicit intentions in the form of strategic intent, cultural assumptions, or personal intentionality.

Contract Type-1. Precise Contracts for Specifying Behavior in Software and Other Fully Explicit Systems

The essential property of a precise contract is that it explicitly defines some behavior or operation in a system. The semantics of the behavior specified must be precisely and fully defined – there can be no room for ambiguity or interpretation. This requires the use of fully explicit *assertions* – logical statements or functions that define the parameters of the contract (Kilov et al. 1994). Precise contracts are ideal constructs for specifying the behavior of systems with clearly defined inputs and outputs, such as information systems, most workflows, and corresponding workflow management systems. The formal use of assertions and contracts, in fact, is increasingly common in the development of high quality, complex software (Meyer 1992).

There are four categories of assertions: *invariant*, *pre-condition*, *post-condition*, and *trigger* (Kilov 2002). An invariant is a logical assertion given in the form of rules that the behavior described in the contract may not violate. A pre-condition lists the inputs and system states that are required to exist before the contract can be satisfied. The third component of a contract is the post-condition that lists the outputs and system states that are expected after the contract is executed. The last component is a trigger, which lists the events and states that initiate execution of a contract. Triggers, pre-, and post-conditions are functions of time. In contrast, an invariant is the background of procedures, rules and relationships that never should change (and hence, an invariant is not a function of time). Collectively, these four constructs constitute a mechanism for the *precise specification of behavior* – and hence are most suitable for explicit contracts. Note too that we have enriched the concept of loose horizontal coupling to include triggers and invariants in addition to pre- and post-conditions.

The participants to a precise contract are the entities (i.e., software systems or objects within a system) participating in the contract. When describing the behavior of information systems (e.g., Human Resources (HR)), the contract describes the protocol of data exchange between them, where, for example, one system may be thought of as a producer and another, a consumer. When describing the behavior of objects within a system, the contract describes operations on its objects. For example, a *performance history* “depends on” a corresponding *employee*. The “depends on” is a dependency association; the invariant states that the existence of a dependent (*performance history*) implies the existence of a corresponding parent (*employee*). This means that a contract that deletes an *employee* instance from an HR database must also delete all corresponding *performance history* instances (Kilov et al. 1994).

Precise contracts typically exhibit an all-or-nothing pattern of operation: each and every assertion must be logically true if the behavior described by the entire contract is to exist. The all-or-nothing precise contract is typically the type that is used in software. A precise contract may also be used to describe behaviors with a parameterized range of possible pre- and post-conditions. Such *relativized* contracts may be used to describe decision making processes. The business rules of relativized contracts, stated with assertions, are sometimes called *decision rules*. Both all-or-nothing and relativized contracts are explicit in that the assertions may be described with clearly defined statements, algorithms, or functions. Furthermore, relativized contracts may be dynamic in that the assertion parameters may be dependent on a feedback loop, thus promoting a certain amount of learning with each instance or occurrence of the process. Both all-or-nothing and relativized contracts lend themselves to quantitative analysis.

The *signature* of a precise contract is typically a set of parameters that serve as input into the contract and another set of parameters that serve as the expected outcome. In both cases, the signature of the contract is defined by both its parameters and their specific sequence. The signature serves as the communication vehicle between objects; a user need not know the internal workings of a contract, only its signature (i.e., interface). This is an example of encapsulation or information hiding.[1] Both the specification of a contract and its signature collectively represent the design rules underlying the contract and are necessary to support modular design and architecture.

Contract Type-2. People and Exchange: Transactional and Relational Contracts

Outside of formal systems analysis, contracts, as are commonly used, involve people and some sort of an exchange, or an expectation of an exchange. Such contracts concern human behavior and are simultaneously individual and social in nature (MacNeil et al. 2001). Any discussion of contracts must include the individual, his or her social relationships, and context. Certainly, contracts can be studied in isolation, and for certain analyses this may be useful, but we must always recognize that most such analyses are necessarily incomplete (MacNeil et al. 2001). For example, in our discussion of relativized contracts and decision making above, the feedback loop by which most managers operate may be structured in a precise way, but the latitude and interpretation of the manager is largely a function of his or her context, organization, and relationships within that organization. *All contracts involving human beings, even transactional contracts, have a relational and even psychological component.* A key design issue, then, is to know when we can isolate a transactional contract from its relational context in order to solve some restricted analysis, or when we have to recognize that we must accommodate an array of contracts to specify our intention.

Both transactional and relational contracts concern exchange and coordination. In fact, there is a continuum of contracts where, at one end we have the transactional pole and at the other the relational pole. This represents a continuum from discrete exchanges to ongoing relations. Discrete exchanges are relatively short in duration and involve limited personal interaction with no entangling responsibilities beyond what is clearly and precisely specified. The parameters of these transactional contracts are fully defined, and in fact, are not very different from that of precise contracts. In contrast, relational contracts tend to be either long duration or ongoing, involve close "whole person" relations, and the objects of exchange typically include both easily measured quantities and not easily measured outcomes.

The participants to a transactional or relational contract may be individuals, groups, organizations, or any combination. For example, at the end of this paper we describe two types of relational contracts coordinating the behavior of organizations participating in inter-organizational knowledge creation.

An example of a contract that is toward the transactional pole is a labor contract where, by design, all relational components are removed from the contract. It is essentially an agreement between a union (on behalf of its members) and an organization where every anticipated contingency is explicit stated and accommodated. Hence, most labor contracts are quite lengthy with little or no flexibility. A labor contract is negotiated and covers a finite period time, after which, another agreement is required. Its sanctions are primarily legal. In contrast, an employment contract (e.g., an offer letter between an individual and an organization) is toward the relational pole and contains both explicit statements and tacit assumptions. Hence, it is fairly small, often no more than one or two pages, and quite flexible. Moreover, it is reinforced or undermined during execution of the contract – the primary means of control are the expectations and interests of the parties to the contract (Kay 1995).

Contract Type-3. Psychological Contracts

While transactional and relational contracts have some level of formalism, psychological contracts describe the relationship between an individual and an organization in entirely unstated expectations. These expectations, in turn, guide and characterize the behavior of both the individual and the organization (Handy 1993).

Schein has described three categories of psychological contracts representing increasing levels of involvement: coercive, calculative, and cooperative (Schein 1980). While each exists in an organization, one will predominate and thus characterize the organization's prevalent mindset. This comes closest to our notion of an essential architecture where the predominant level of involvement in an organization will govern the motivation, cooperation, and inventiveness of its employees, and ultimately, the organization itself. The essential or cognitive architecture of an organization – its set of psychological contracts – is simultaneously individual and organizational in nature.

Coercive, calculative, and cooperative contracts represent a range of attachments and commitments, from involuntary compliance to transactional behavior, to fully engaged dedication. In practice, calculative contracts are associated with the transactional pole of the contract continuum while cooperative contracts are associated with the relational. (The coercive contract does not appear on the legal continuum of Type-2 contracts since there is no "agreement" among participants in a coercive contract, such as a prisoner and a prison inmate.) While the calculative contract appears to predominate in most organizations, cooperative contracts are increasingly necessary if the organization is to flourish in the knowledge society.

The participants to a psychological contract are an individual and an organization. This is because, as defined by Schein, a psychological contract is a measure of engagement between an individual and an organization. This is particularly important to the knowledge organization and its knowledge workers where an individual's motivation and discretionary effort are critical to knowledge work. Furthermore, the factors that impact this level of engagement may be found in an organization's DNA – both in the strands and the cross-linkages – the specific elements of which constitute an organization's cultural and learning systems.

The Contract Continuum

In the contract continuum illustrated in Figure 4, contracts range in character from formal, and sometimes legal, specifications to partially formulated (and formed) relationships, to entirely tacit psychological mindsets. As requirements increase in richness, the contract shifts in character from thin to thick; from a "specification" in an engineered- to a "relationship" in a framed-context. In practice, this means that the assertions of an explicit contract – invariant, pre-condition, post-condition, trigger – become less precise. The explicit contract is an engineering or legal mechanism for specifying behavior and is not suitable for rich contexts. This is where both relational and psychological frameworks come into play. Specifying non-routine work, particularly knowledge work, requires developing and reinforcing expectations and the prospect of a long-term relationship. This cannot be done in a formal sense but depends on cultivating trust and social relationships.

The central motivation or requirement of thin design is to satisfy the corresponding (thin) contract specification by reducing organizational uncertainty. Thin contracts completely specify both discrete functions and their interfaces, and easily lend themselves to thin forms of abstractions (e.g., encapsulation). In contrast, the motivation underlying thick design is to arrive at an acceptable agreement among participants to the corresponding design contract. Thick design is ideal for ambiguous situations where a specification is satisfied through the attitudes and expectations that embody the human constituent of the design – thick contracts that focus on relationships, psychological orientations, and context of the design itself. The people or groups participating in thick contracts determine the design's structure, workings, and output.

Refinement Path

As discussed above, one source of design flexibility is the definition of a given molecule. A second source concerns the development of the molecule itself. For example, let us consider the process molecule and center our attention on the {tool} constituent. One of the design choices that needs to be made concerns the type of database. There are several possibilities, all existing at the same level immediately below {tool}: a relational database management system (RDBMS), an object-oriented DBMS, etc. After a given selection, say an {RDBMS}, there are several possible vendor products below {RDBMS}, such as IBM, Oracle, Sybase, etc. Moreover, the entire pathway down the hierarchy is almost always a function of the {process} specification itself – transaction vs. decision process processes, for example. Furthermore, the entire downward pathway, sometimes known as a *refinement path* is often *pre-selected* by an organization. This is particularly true with information technology tools, such as databases, networks, servers, desktop computers, etc. When a fully instantiated refinement path is pre-selected, organizations call the pathway a **standard** or **architecture**.

An Example from Organization Theory

As with any hierarchical system, organizational elements exist and interact within a wide range of frequency behavior. For example, the CEO, at the top of the hierarchy in the organization chart, is functionally a constant while the lowest level employees are rigid bodies with respect to each other. That leaves it to middle management to determine the dynamics of structure. In fact, it *is* middle management that largely determines structural behavior and has occupied the attention of organizational scientists. One perspective, for example, is that the *middle line* (i.e., the middle frequency layer in an organization's formal structure) is essentially an *information relay* in a firm operating as an information processing mechanism (Nonaka et al. 1995). This perspective is largely responsible for middle-level downsizing so apparent in American firms over the years. In contrast, a more modern perspective, one reflecting the emerging knowledge era, is that the firm is a knowledge creating entity and therefore the middle line consists of *knowledge engineers* (Nonaka et al. 1995). In either case, it is the middle line – the middle frequency layer – that rightly occupies so much academic and management attention.

The notion of high-middle-low frequency motion is critical in organization design and attention is not exclusively confined to the middle frequency layer. For example, *organizational culture* sits at the very top of the organization and hence its motion is so slow that it may be taken as a constant. This is one reason management is attracted to "culture change" initiatives – changing an organization-wide constant should have a dramatic effect on the organizational system as a whole. Similarly, *organizational learning* – another low frequency subsystem closely associated with culture, has attracted management effort in an attempt to create the "learning organization." Edgar Schein argues that such efforts often meet with failure: occupational subcultures (i.e., cultures based on education and work roles) – each with different and contradictory constants known as *tacit assumptions* – work against the communication necessary for learning (Schein 1996).

Attempts to change very low frequency subsystems – culture or learning for example – often meet with difficulty. As we have seen in hierarchy theory, the low, middle, and high frequency layers are isolated and therefore not easily affected by each other. Low frequency layers such as culture and learning are largely created through organizational evolution and are resistant to the effects of changes in high frequency subsystems. This is in contrast to changes in subsystems within the same layer – information technology subsystems within a given level, for example, are directly changed and integrated.

An Example of Inter-Organizational Knowledge Creation Networks

In this example we discuss two types of relational contracts, differing in the factors associated with the context each creates. Knowledge creating context is known as a *ba* or "place" where knowledge creation occurs. Organizations that want to build an inter-organizational knowledge network must find a way to build a *shared ba* in which all participating firms may participate (Ahmadjian 2004). The system elements associated with this shared ba include culture, language, and an atmosphere of trust and care. The factors that impact these elements include the number of participating firms, the ties (e.g., closeness, ownership stakes, trust) by which the firms are linked, and the temporal duration (i.e., short or long) of these relationships (Ahmadjian 2004). The first approach is known as the Toyota model and is characterized by an integral architecture. In contrast, the second approach is known as the Silicon Valley model and is modular in nature.

The Toyota model includes a primary organization (e.g., Toyota) with a set of comparatively few associated organizations with deep, long-term, and stable relationships. The participating organizations often share ownership ties. The ba is formed by the primary organization and spreads outward. The arrangement is one of a tightly linked set of firms that engage in activities that operationalize the SECI model of knowledge creation (Nonaka et al. 1995). For example, the participating organizations rotate employees and participate in activities (e.g., problem-solving groups, plant tours) that promote the creation of tacit knowledge and other activities (e.g., seminars, lectures, manuals) that subsequently promote externalization to make this knowledge explicit. One striking characteristic of this ba is the shared sense of identity between Toyota and its suppliers which has led to a strong, shared commitment to the Toyota Way (i.e., the Toyota DNA discussed above) (Ahmadjian, 2004). The Toyota model is common within the Japanese automobile manufacturing industry and within the Japanese economy generally. *Flexibility arises from the integral nature of tacit knowledge and a ba designed to maximize the sharing of experiences and ideas through inter-personal and group communication – i.e., socialization*.

The second approach is known as the Silicon Valley model. The ba is defined by an industry or geographic region (e.g., Silicon Valley) and includes dynamic links among many organizations (i.e., firms, universities, and research institutes). Inter-organizational relationships are many, thin, fluid, and depend on the need of any one firm. This type of ba is particularly effective at sharing and *recombining* existing, explicit knowledge. The Silicon Valley ba is appropriate where there exists a highly mobile workforce of knowledge workers. Learning occurs through recombination of existing knowledge across firms where only recombinations with market potential will be selected. A dynamic workforce maximizes the possible number of recombinations, thus providing a greater likelihood of market success than otherwise. *Flexibility arises from the modular nature of explicit knowledge and a ba designed to maximize the number of shared threads of explicit knowledge and possible recombinations*.

The Toyota model creates a ba that facilitates socialization (i.e., tacit knowledge) and focuses on process innovation. In contrast, the Silicon Valley model creates a ba that is effective at knowledge recombination (i.e., explicit knowledge) and focuses on product or technology innovation. Each model illustrates the importance of context in knowledge creation and how differing styles of relationships (i.e., relational contracts) may be used to create that context. This also illustrates the workings of architecture: the ba that each model creates shares characteristics (tacit vs explicit knowledge) with, and cannot be separated from the, wider context or ba (societal culture) within which each operates. This should not be surprising: Nonaka has stated that Japanese society is primarily tacit and the organizations that exist within that culture would create a ba that emphasizes *socialization*. In contrast, U.S. firms operate within an explicit societal culture and, hence, their respective inter-organizational ba emphasizes *combination* (Nonaka et al. 1995). The wider lesson, of course, illustrated by the SECI model, is that optimum knowledge creation should emphasize all phases of socialization, externalization, combination, and internalization.

An Example from Process Integration and Service-Oriented Architecture

Figure 2 is a representation of the process molecule – a process architecture that supports specification of {process} as well as its corresponding implementation subsystems {human}, {structure}, {information}, and {tool}. Figure 2 also shows the system and subsystem systems as separate and interacting entities. If the specifications of all participating systems are sufficiently rigorous – i.e., clear boundaries with system separation and communication (loose vertical and horizontal coupling), we would have a fully modular system. In such a case, flexibility arises from the options we have as designers: we may interconnect {process} task specifications (horizontally) in any appropriate configuration (i.e., a process map) to satisfy a particular business requirement (itself a high level contract specification); we may also select any number of implementation options (vertically downward). Furthermore, the precise contract shares properties with "object-oriented" objects that include, for instance, reuse, composition of contracts, contract sub-typing and dependencies, and so on. Thus, the approach we have been discussing in this paper is an abstract representation of the underlying logic of service-oriented architectures.

Concluding Remarks

In this paper we have presented a framework that extends Herbert Simon's work on hierarchy theory. Our framework associates levels of systems and their comparative knowledge content in terms of tacit and explicit knowledge. Systems are ordered based on several empirical criteria, such as frequency. A higher-level system typically has a lower frequency and therefore responds more slowly to input than a lower level system. Also, a higher-level system has a comparatively larger tacit knowledge content than a lower level system. This is a partial explanation of the behavior of systems – tacit systems are experiential and change more slowly than explicit systems.

We have also described an organization molecule as a special type of definitional hierarchy configured to specify and implement an organizational context, such as process or strategy. Both context and the sub-systems associated with its implementation are the "organizational materials" with which we design organizations.

We have also described contracts as a mechanism to specify both contexts and their corresponding sub-systems. Contracts exist in various forms, based on their knowledge content, from fully explicit, to some mix of explicit and tacit, to fully tacit. Thus, there is a "new contract continuum" that may be used to describe organizational systems in terms of their comparative tacit and knowledge composition.

An empirical hierarchy of organizational systems, definitional organization molecules for context design, and contracts for specification all intersect and produce a rich framework – organization modeling or "modeling as an art form" – that may be used to design, reconstitute, and align virtually every context in the organization. Flexibility largely depends on how we use these three pillars of organization modeling to reflect our design intention.

For example, we may manipulate system ordering to reshape our organization's work practices, from a traditional organization where process follows structure to a process enterprise where the reverse is true. Similarly, we may define an organization molecule to reflect a particular perspective where, for example, we may include culture as a sub-system in strategy design. To continue, we may also follow a particular refinement path during detailed design of a molecule to adopt, for example, a specific technology implementation; or, alternatively, we may pre-select a refinement path and thus establish an organization-wide standard. Finally, we may use contracts to precisely specify our technical systems and relational and psychological contracts to design an organization's "space" to cultivate its tacit knowledge systems.

Finally, we have seen that the 21st century organization must transcend the limitation of omitting or dealing separately with its mechanical and human systems. Rather, it has the option of designing its DNA molecule to define and interrelate virtually all the elements that constitute the organization itself. Thus, the organization may be designed as an organic configuration of systems and structures where "flexibility" is part of organizational life.

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