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Time-Based Frameworks for Valuing Knowledge: Maintaining Strategic Knowledge

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Time-Based Frameworks for Valuing Knowledge: Building Strategic Knowledge

Abstract

To survive and flourish in a changing and unpredictable world, organizations and people must maintain strategic power over necessary resources - often in the face of competition. Knowledge contributes to that strategic power. Without vigilance to maintain its currency and accuracy, the value of knowledge depreciates as circumstances change over time. Karl Popper's evolutionary epistemology and Maturana and Varela's concept of autopoiesis provide a paradigmatic framework for considering the roles and importance of time in constructing knowledge and using it to maintain strategic power. Following Popper, knowledge is constructed, used and evaluated via cyclically-iterated processes. We introduce nine time-based frames of reference based in this Popperian autopoietic paradigm to explore the relationships between time and a utility-based valuation of knowledge as it is constructed and applied. We believe this framework and associated paradigmatically consistent vocabulary provide useful tools for analyzing organizational knowledge management needs.

Keywords: Evolutionary Epistemology, Knowledge Management, Time, Organization Theory, Autopoiesis, OODA Loop, Strategic Knowlege

INTRODUCTION

Knowledge (in the sense of control information), power, value and time are important dimensions in the universe of human behavior and performance, whether in individuals or in business organizations or the domain of military command and control. Of these, time – and especially time's relation to the value of knowledge in realizing strategic power over markets, resources or landscapes, is probably the least understood (Das 1991, 1993; Ancona et al. 2001; Ancona et al. 2001a; Orlikowski & Yates 2002; Arrow et al 2004; Cunha 2004, 2004a; Bluedorn & Standifer 2006; Ericson 2006; Saunders & Kim 2007).

The discipline of organizational knowledge management confronts several paradigms of organization, e.g., (connectionist, cognitivist, autopoietic – von Krogh & Roos 1995; Magalhaes 1996, 1998) and the nature of knowledge itself (especially with regard to understanding the nature and relationships of what is conveyed by the terms "tacit", "implicit" and "explicit" – Polanyi 1958, 1966; Popper 1972; Nickols 2000; Stenmark 2002; Tsoukas 2005). These have led to conflicting theoretical approaches to knowledge management (Sveiby 1994, 1997; Nonaka 1991; Nonaka & Takeuchi 1995; Zeleny 2004; Choo 1995, 1998; Firestone and McElroy 2003; and others). This profusion of approaches has also led to considerable confusion due to incommensurable terminology (Kuhn 1962, 1982).

The paradigm of organizational epistemology followed (Hall 2003, 2005, 2006; Hall et al. 2005) treats enterprises and other self-sustaining economic organizations as complex adaptive (i.e., autopoietically "living") entities that maintain their identity and exist independently of any particular individual person or component belonging to an organization at any given time. Here we continue a series of articles on the changing quality and value of organizational knowledge over time as knowledge is involved in building and sustaining strategic power (Dalmaris et al. 2006; Martin et al. 2009; Philp & Martin 2008). Strategic power over the environment and other living things is achieved through superior knowledge of the world; but without vigilance, the utility value of that knowledge depreciates over time. In this paper we consider temporal aspects of organization and identify a number of time-related parameters affecting the depreciation of knowledge that human organizations should seek to monitor and improve.

The paper is organized as follows: We begin by summarizing our knowledge-based theory of autopoietic organization and concept of physical time. Next we explore the cyclic construction of knowledge in organizations and develop a vocabulary for time-related aspects of the construction, evaluation and depreciation of knowledge. We then consider how knowledge can be valued in relationship to time, and conclude by discussing relationships between causation, knowledge cycle times and strategic power.

AUTOPOIETIC SYSTEMS

Maturana and Varela's Autopoiesis

Maturana and Varela (Maturana 1970; Maturana and Varela 1980; Varela 1979; Varela et al. 1974) introduced the concept of autopoiesis as a necessary and sufficient definition of life at the cellular level. Autopoietic systems are those which have within their constitution the continuing cognitive processes and capacity to produce themselves. They are identified by the following criteria (after Varela et al. 1974, as abbreviated by Hall):

- *bounded* (distinguishably demarcated from the environment)
- *complex* (individually identifiable components within the boundary)
- *mechanistic* (system driven by cybernetically-regulated energy fluxes or metabolic processes)
- *self-referential* (system boundaries internally determined)
- *self-producing* (system intrinsically produces own components)
- *autonomous* (self-produced components are necessary and sufficient to produce the system)

Zeleny (1977), Luhmann (1986, 1995, etc.), Von Krogh & Roos (1995), Magalhaes (1996, 1998), Maula (1999, 2000, 2000a, 2005), and others suggested that organizations such as firms might be considered to be autopoietic and that autopoiesis might be involved in the generation of knowledge. Mingers (1992, 1994), Kay (2001), Biggiero (2001, 2007), Maturana (2002) and others take the opposite point of view: that the concept of autopoiesis developed for entities at the biomolecular level of organization is inappropriate for organizations. However, when autopoiesis is examined in a framework of evolutionary epistemology, it is seen that the evolution of adaptive knowledge is a fundamental property of autopoietic organization, such that autopoiesis cannot exist without knowledge, and that all knowledge is produced by autopoietic systems (Hall 2006; 2011). Hall (2003, 2005, 2006; Hall et al. 2005) argues that at least some human organizations are autopoietic and that these organizations represent a higher order of autopoiesis than people, where organizations have emergent properties and forms of knowledge that transcend the sum of their individual members. By surviving, autopoietic systems establish their own imperatives, ultimately to maintain their individual existences. For their autonomy to continue, such entities must maintain enough control (i.e., strategic power) over the world and its resources to maintain and produce their boundaries and components against entropic tendencies to disintegrate, blind changes in the environment, and competition with other living things for the resources of life. Initial survival is due to chance, but natural selection and conscious criticism favor the evolution of goal-directed (i.e., strategically-oriented) processes and behaviors to solve problems of survival (Campbell 1960; Popper 1972; Hall 2005, 2006, 2011).

Luhmann's Autopoietic Social Systems

Luhmann's Social Systems theory that provides a basis for European Postmodern organization studies is also supposedly based on autopoiesis (Luhmann 1986, 1990, 1992, 1994, 1995). However, although both we and Luhmann begin with autopoiesis, the paradigm we follow here has little resemblance to Luhmann's. In fact, for the following reasons, the two paradigm's are nearly incommensurable in Kuhn's (1962, 1982) terms.

Luhmann's theoretical framework reduces social systems to organizationally closed (i.e., "autopoietic") networks of self-producing "communications" (Luhmann 1989, 1995b), where networks are paradoxically their own boundaries, and people and their actions are formally external to and not part of the networks (Mingers, 1994, 2002; Moeller, 2006). Luhmann focuses on the supposed contradictions of self-reference, and uses Spencer Brown's (1972) Laws of Form to justify placing communication networks in an abstract or imaginary dimension (akin to the imaginary plane in mathematics) that is orthogonal to the material world (Luhmann 1991, 1995a). For us, Luhmann seriously misunderstands Maturana and Varela's biophysical definition of autopoiesis developed for materially physical "organizations" (e.g., Maturana, 1980; Varela, 1979; di Paolo 2005; Hall 2011; see also Mingers 1992, 2002, 2002a). Going beyond Maturana and Varela, we recognize the existence of autopoietic entities at different levels of hierarchical organization (Simon 1962, 1973) above the cellular. When these higher levels of organization are viewed from the focal level appropriate to the kinds of entities being considered (Salthe 1985, 1993, 2004), these are still materially physical (Hall 2005, 2006, Hall 2011; Hall et al. 2005). As will be discussed below, considering the role of time in the self-regulation and self-control of autopoietic systems and "strategic" controls such systems apply to the external environment does not create the paradoxes of self-reference that so concerned Luhmann in his development of theory. Where Luhmann considered the self-referential processes of autopoiesis to be paradoxically vicious circles, we see them as virtuously open learning spirals (Nousala 2006; Nousala 2010; Nousala and Hall 2008; Hall & Nousala 2010; Hall 2011).

AUTOPOIESIS AND EVOLUTIONARY EPISTEMOLOGY

Knowledge in Autopoietic Systems

Popper (1972, 1994) considered knowledge to be "solutions to problems (of life)". Compared to the common idea that knowledge is "justified true belief" (e.g. Polanyi 1958), Popper's epistemology is founded on lived experience in the real world. This use of Popper's concept of knowledge is defended in several works (e.g., Hall 2006, 2011; Hall et al. 2005; Hall & Nousala 2010; Dalmaris et al. 2006; Vines et al. 2007). At a fundamental level, Popper's "solutions to problems" can be compared to Bateson's (1972), Chalmers' (1996) and Luhmann's (1991, 1995) definition of information as "a difference that makes a difference":

> By information we mean an event that selects system states. This is only possible for structures that delimit and presort possibilities. Information presupposes structure, yet is not itself a structure, but rather an event that actualizes the use of structures. [Luhmann 1995: p 67]

Following Maturana and Varela we consider cognition in its broadest sense to be the cybernetic and material processes of self-regulation and self-production in the autopoietic system. These cybernetic processes embody in their structures solutions to problems that would otherwise disrupt autopoiesis, leading to disintegration of the autopoietic system. Corning (2001: 1278-1279) defines "control information" as something that "*causes* purposeful work to be done in or by cybernetic systems [our emphasis]" or the capacity to control the application of energy to do work that is always relational, specifically context dependent with no independent material existence independent of a specific cybernetic process. Corning also argues that "control information" is something quite different from Shannon's concept of information (Shannon 1948; Shannon & Weaver 1949; see also Hall 2011). Thus, control information is Popperian knowledge or the "difference that makes a difference" embodied in the structure of an autopoietic system that enables perturbations to be controlled in a way that prevents the system from being disrupted. How this "knowledge" becomes embodied as control information will be elaborated in context below.

Popper (1972, 1978, 1994) also divides the world into three ontological domains to discuss the creation and growth of knowledge that Hall (Hall 2005, 2006, 2011) interprets as follows:

- *World 1* (abbreviated here as 'W1') is uninterpreted physical reality.
- *World 2* ('W2') is the domain of the cybernetics of life or the dynamics of subjective experience, and thus, "dispositional", "subjective" or “living” knowledge—where "*cybernetics*" means the regulation, communication and application of control information, beginning at the biophysical level (Hall 2006). Here, I differ from Popper by placing speech in W2. At least in preliterate societies, speech exists only in the subjective responses of hearers (after Ong, 1982 as argued by Hall 2011).
- *World 3* ('W3') comprises the objective products of knowledge (e.g. the logical contents of DNA molecules, books and libraries, computer memories) as created, exchanged and acted on by living things.

Popper's "subjective" and "dispositional" knowledge in W2 resemble Polanyi's (1958, 1966) "tacit" knowledge. Popper argues that all claims to know are subjectively constructed and *can never be proven* to be "true" (i.e., to correspond exactly to reality). Unlike some knowledge management (KM) practitioners (e.g., Sveiby 1994, 1997; Biggiero 2007), who assert that knowledge can only be held in peoples' heads—mostly in tacit forms—Popper argues at length that knowledge claims (i.e., tentative solutions to problems) can be codified as persistent objects able to exist independently of the cognitive entity that created them; therefore, knowledge claims can be objects in W3 able to be cognitively transformed back into living knowledge by other cognitive entities and at other times and places.

Knowledge Cycles in Organizational Systems

Learning and knowledge creation for adaptive problem solving is a cyclic process of self-reference between embodied functions of the autopoietic entity and its dynamic interactions with the world. Maturana and Varela (Maturana 1970; Maturana & Varela 1980; Varela et al. 1974) equated “*cognition*” with the "semantically closed" (Pattee 1995) cybernetics of autopoietic self-regulation and self-maintenance/production, whereby the cognitive entity homeostatically maintains its continued existence through actions that respond to and compensate for perturbations (i.e., problems) that might otherwise cause it to lose control and eventually “disintegrate”.

Popper and the radical constructivists (von Glasersfeld, 1984, 1990, 2001; Reigler 2001a, 2006) argue that all knowledge of the world is cognitively constructed, such that it is forever separated from external reality and can never be proven to be true. However, Campbell (1960) and Popper (1972, 1994) argued that constructed knowledge can approach truth through an iterated "evolutionary" process where tentative solutions are made and tested against reality to eliminate errors (hence the name "evolutionary" applied to this form of epistemology). Popper (1972: pp 241-244) called this a "general theory of evolution", summarized as the "tetradic schema", where $\mathbf{P_n} \rightarrow \mathbf{TT/TS} \rightarrow \mathbf{EE} \rightarrow \mathbf{P_{n+1}}$. $\mathbf{P_n}$ is a problem, **TT/TS** are tentative theories or tentative solutions to that problem, **EE** is an error elimination process that removes those theories or attempted solutions that fail to solve the problem, and $\mathbf{P_{n+1}}$ is the remaining, somewhat changed, problem faced after solving $\mathbf{P_n}$. Hall (2006, 2011) argues that some form of inheritance is integral to self-production, and that all self-producing (i.e., autopoietic) entities must inevitably build knowledge this way.

Several similarly cyclical processes have been proposed to describe organizational learning/adaptation: SECI (Nonaka 1991; Nonaka & Takeuchi 1995 - where Zeleny 2004 specifically applies SECI to autopoietic entities); single and double loop learning (reviewed by Blackman et al., 2004); the knowledge life cycle (Firestone & McElroy 2003); and a variety of others (Choo, 1995; 1998; Day & Schoemaker 2004; Grant & Kooter 2004). Boyd's OODA loop (1996 - Figure 1) is a straight-forward depiction of the knowledge building/adaptation cycle by a master strategic thinker for both individuals and organizations and facilitates discussing how experiential knowledge for solving problems of life and achieving strategic power is constructed and maintained (Grant 2004; Osinga 2005; Hall 2003, 2005, 2006, 2011; Hall et al. 2005; Vines et al. 2007).

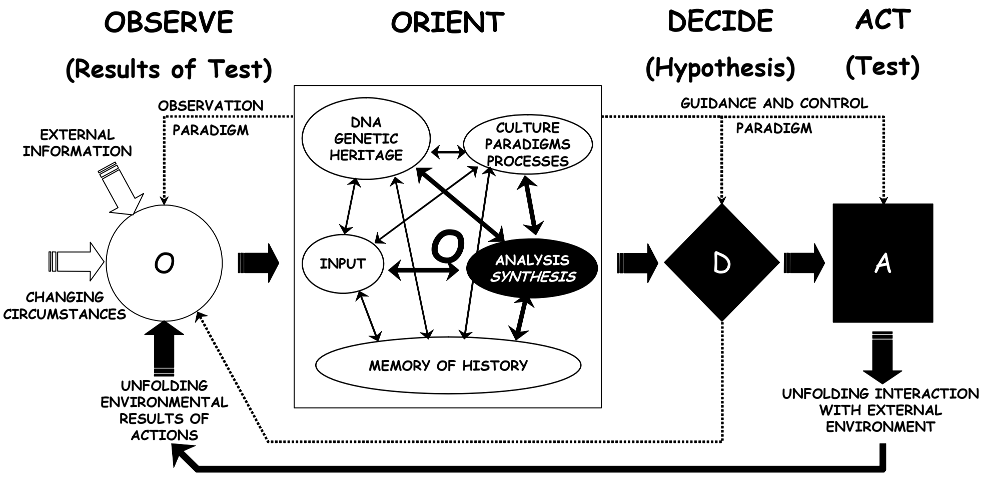

Figure 1. Boyd's OODA Loop

Boyd resolved the iterated OODA cycle into four major segments that may be further subdivided:

- *Observation*: perturbations or disturbances from the environment (or internal) are transduced into internally propagating cognitive disturbances (Luhmann 1989) or "*signals*" (i.e., *sense* "*data*"), as enabled by the entity's structure and organisation. This includes sense data about effects of the entity's prior actions on the world.
- *Orientation*: cognitive processing where signals are classified and evaluated against a "memory" of history (e.g. where the memory can be conscious, unconscious, genetically programmed) via processing paradigms as determined by learning and

inheritance to synthesize a picture of the world and possible actions (with associated, forecasted consequences). The analysis and synthesis functions specifically include making sense (i.e,. "*sensemaking*") of observations and planning actions and forecasting their results (Grant & Kooter 2004). Boyd also discussed this in terms of "destruction and creation", i.e., destroying the old world view and creating a new one based on the increment of new observations.

- *Decision*: process of selecting/or rejecting possible actions for execution (or deciding to do nothing) and "*planning*" how to effect these actions in the cycle.
- *Action*: process of implementing a decision.

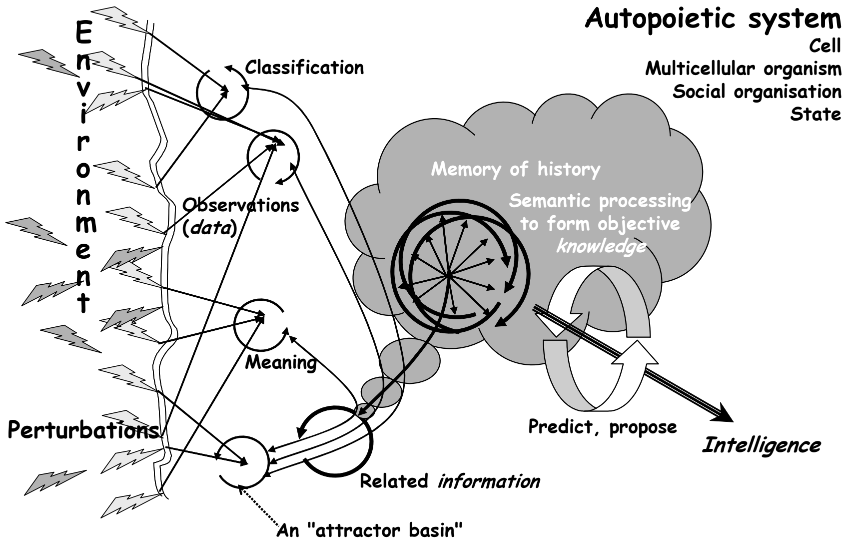

Figure 2. Graphical representation of observation and orientation in an autopoietic system (Hall et al. 2005). Definitions in this illustration: *Perturbation* – an extrinsically generated change that impacts the autopoietic system; *Observation* (datum) - initial changes induced within the autopoietic system by a perturbation; *Classification* - process by which perturbation induced changes result in the system settling into one of alternative attractor basins on a landscape of potential gradients (Rocha & Hordijk 2005); *Meaning* - the net result internally due to the initial propagation and classification of an observation.

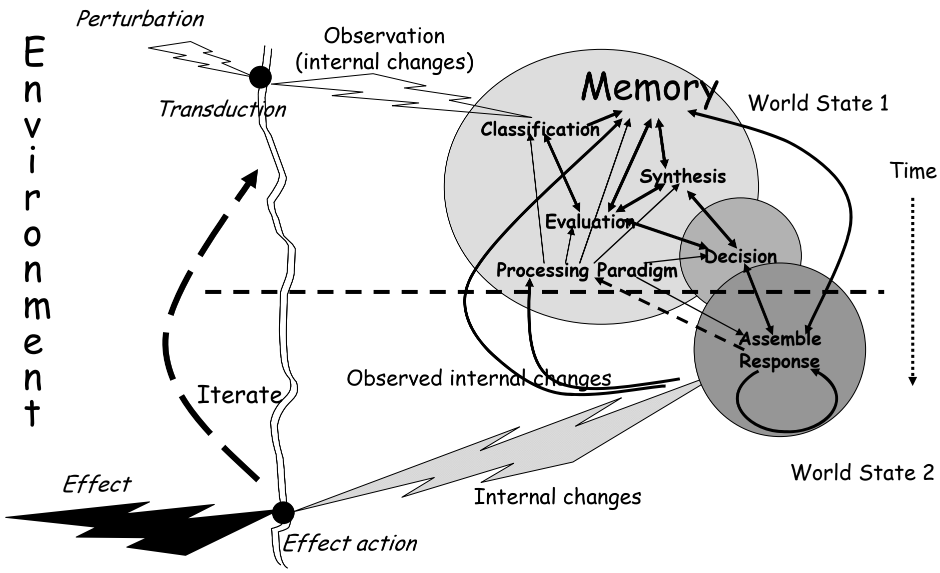

Figure 3. Graphical representation of an OODA cycle (Boyd 1996) in autopoietic cognition (from Hall et al. 2005). For an animation of this graphic see: http://tinyurl.com/3cxnw3, slides 11 & 12.

Figure 2 and Figure 3 (from Hall et al. 2005) show the relationships of time-based activities in a conscious entity contributing to the OODA process. In Figure 2 the environment perturbs the autopoietic boundary causing the propagation of internal changes that effectively transduce the perturbations into “sense data” propagating further into the cognitive system. This is sense-data classified semantically and compared to a memory of history in some form that detects environmental change. Depending how the changes are classified, further semantic processing and possible action may be triggered. Figure 3 depicts the full OODA cycle, emphasizing orientation, decision and action as disturbances triggered by the perturbations propagate further through the system. Where an entity’s OODA process fails to maintain viability by adequately anticipating and compensating for problems in the world, the entity dis-integrates (i.e., dies). In an organizational sense, this loss of viability is represented by bankruptcy or takeover; or defeat in military contexts. In a conscious entity, critical feedback loops in each cycle of the cognitive processes should improve the match between the world and the constructed understanding of it by detecting and deciding between more and less effective processes and actions. However, the cognition required to transform perturbations from external reality into a constructed model of the world is not effortless or instantaneous and the world is dynamic and continually changing, both as a consequence of blind, entropically-driven processes, and active interventions by other autonomous actors (Hall 2011).

Bounded Rationality and Limits to Human Organizations

Simon (1955, 1957, 1979) recognized that humans’ mental capacity to assimilate and process information to make decisions is limited both in terms of the volume that can be perceived and attended to and by the time required to reach a decision based on that information. It is impossible to take all the necessary time to make totally rational decisions based on all available information. Rationality is thus “bounded,” and people and organizations should “satisfice” decisions (i.e., do just enough work to make minimally satisfactory decisions and go on to the next thing). Arrow (1974) and Else (2004) extended Simon's ideas to organizations and identified factors causing organizational decisions to be even less rational.

Thus, time-based limits to bandwidth are major factors limiting both individual rationality and the rationality of group decisions at the organizational level.

TIME AND CAUSATION

Knowledge is about responding adaptively to a relentlessly unfolding dynamic world. For our purposes here, we accept the common belief that humans and other conscious entities, through volitional action, have the freedom to cause changes that affect the "future" world. Without this freedom and ability to cause change, the concept of "management" would be nonsensical. Time is central to all aspects of change, but even physicists and philosophers cannot agree among themselves on what time is (e.g., Deutsch 1997; Smolin 2004; Elitzur & Dolev 2005; Dieks 2006; Hájíček 2006, 2008; Christian 2007; Bertolami 2008; Lobo 2008).

The theory of relativity treats time as one of the four dimensions of space-time in a "block universe", such that the past, present and future represent different locations along the time axis in a static or "block" universe, such that our impression of the flow of time and our belief in our abilities to change things as acts of will are simply embedded in that which is now and for all time.

By contrast to the block universe of relativity, views of time emerging from quantum theory offer the possibility for free will, where some authors suggest that the future is undetermined and that the present state of the world progresses via a sequence of moments of becoming (e.g., Elitzur & Dolev 2005; Ellis 2006b; Ellis & Rothman 2010). There are several variants of this view (e.g., Deutsch's 1997 concept of multiverses, Penrose's 1989, 1994 concept of quantum mechanical entanglement and collapsing wave functions spread over microseconds to milliseconds; Smolin's 2004, 2008 loop quantum gravity; etc.). In the view we follow here (Elitzur & Dolev 2005; Ellis 2006b; Ellis & Rothman 2010), which is probably the most constrained of the quantum mechanical interpretations, the "past" is unchangeably fixed (if it exists at all), and the future exists only as possibilities we may anticipate until a particular possibility is realized in the present instant (Figure 4). The "*present*" or "*now*" is an instant of quantum mechanical interaction when one of many possible future worlds becomes real, closes off possibilities that existed previously but did not become, and establishes the possibilities for the next instant. Thus, the real world changes through an inexorable iteration of instants of becoming, where the becoming of each instance quantum mechanically determines the present and defines possibilities for the subsequent instance.

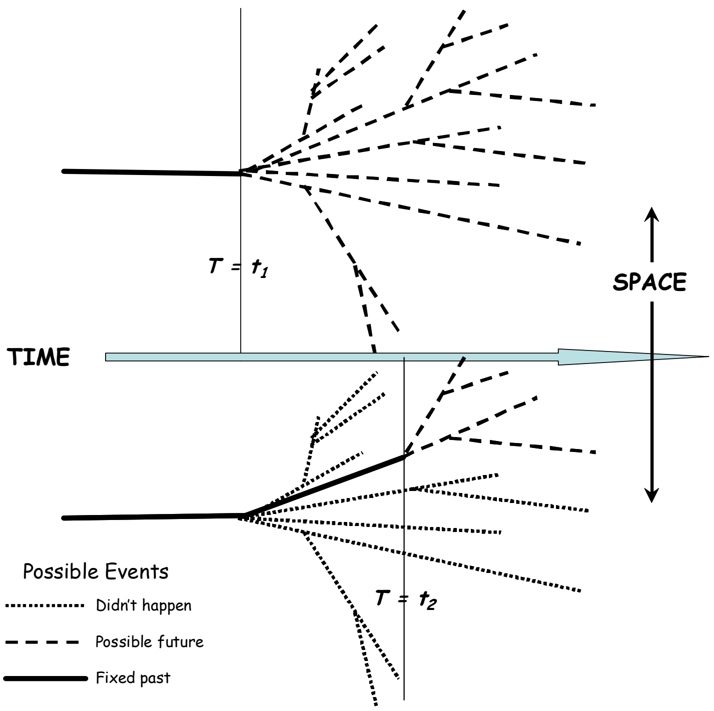

Figure 4. Motion of a particle through space and time where the motion is randomly perturbed. (After Ellis 2006). $\mathbf{t_1}$ and $\mathbf{t_2}$ represent different times of becoming or "nows".

Human perception and action through time also present quandaries. The quantum mechanical instant of realization of a possible world is something that would seem to happen over a time span somewhere on the order of a Planck unit (the smallest physically conceivable unit of time ~5 x 10^{-44} sec.); yet the neural processes involved in human physiology of human perceptions and decisions are measured in milliseconds (10^{-3} sec - Atmanspacher 2004; Glimcher 2005; Christian 2007; Hájíček 2006, 2008; Lobo 2008; Bertolami 2008). Perception and decision making processes in organizations will normally take hours or even days. How can such slow processes serve to "manage" or "cause" physical changes that seemingly must involve the selection of possibilities at the quantum level?

We don't claim to know what happens at the quantum level - one of the most fundamental questions of physics. However, there is some interesting work on "downward causation" that usefully frames the ontology of time and knowledge we present here (Emmeche et al. 2000; Pattee 2000; Hulswit 2005; Ellis 2006, 2006a, 2008; Auletta et al. 2008; Lobo 2008). Basically, the quantum mechanical laws relating to fundamental particles and their interactions determine the possible changes inherent in each particle existing in a moment (*upward causation*); while the specific spatial disposition and organization of the particles in that moment (as the result of historical positions and interactions in the previous instant) affect - at least stochastically - which possibilities can be realized (*downward causation*). Upward and downward causation in relation to time will be explored in relation to our overall view of the time value of knowledge, and we will argue later in this work that slow (in relation to Planck time) processes of downward causation mediated via cognitive processes can shape the becoming of the world even at the quantum level.

TIME AND ORGANIZATIONAL MANAGEMENT

There have been several treatments of time in relationship to organizational management (Stalk 1988; Vinton 1992; Ancona et al. 2001; Ancona et al. 2001a; Perlow et al. 2002; Sawyer and Southwick 2002; Ballard and Seibold 2003; Saunders et al. 2004; Saunders and Kim 2007; Bluedorn and Standifer 2006; Massey and Montoya-Weiss 2006). Few of these authors considered time in relationship to depreciation of the strategic value of the knowledge that must be used and applied in organizational management and operations.

Dalmaris et al. (2006) introduced the concepts of "*time-value of knowledge*" – to suggest the value of knowledge is some function of the duration between its acquisition and its use; and "*temporal convergence*" (Figure 5), which is how one can progress via a chain of willful causal actions from the “now” state (Figure 5) to shape an intended or desired end state (“*goal-state*”) in the future. Martin et al. (2009), and Philp and Martin (2009), respectively explored probabilistic and philosophical positions relating to temporal convergence, and highlighted different ways to consider the future.

A “*stochastic future*” (Figure 5) anticipates that after some interval of time from "now", the future state of the world resembles and is derived from the present and recent past. It encompasses all the different possible futures that could unfold from a “now”, as shown in Figure 4. However, as the duration between anticipation and realization increases, the actual realized future (a new now) will increasingly diverge from the reality that existed at the original “now”. The “stochastic” changes are a consequence of quantum level uncertainty, chaotic processes at the macro level and unanticipated actions of other actors. Some changes that happen as this future unfolds are to some degree predictable based on our understanding of physics and the psychology of other actors; some are imperceptibly slow (or at least nearly so) but may be highly significant; and some are unexpected and possibly even catastrophic.

An "*intentional future*" (Figure 5) is based on a belief that one has the ability and opportunity to influence the unfolding world to achieve a preconceived or desired but not yet achieved goal-state. There are also key differences in the way we think of time with respect to a stochastic future versus an intentional future:

(a) “*Calendar time*” (Figure 5), measures the inexorable progression into the future as events unfold from the past to present and as limited by our mental ability to process and understand the microcosm of cause and effect (our *event-horizon* - Figure 5). In this case, the progressively experienced “now” is referenced to clock or calendar time.

(b) "*Event-relative time*" addresses time as relative to a key future event in an envisaged future goal-state seen as a possible configuration of the future world. How might we act as time and events unfold to constrain the world to achieve that event? In this case, time is mostly considered relative to the unfixed time of a key event (e.g. lift-off minus 8 hours).

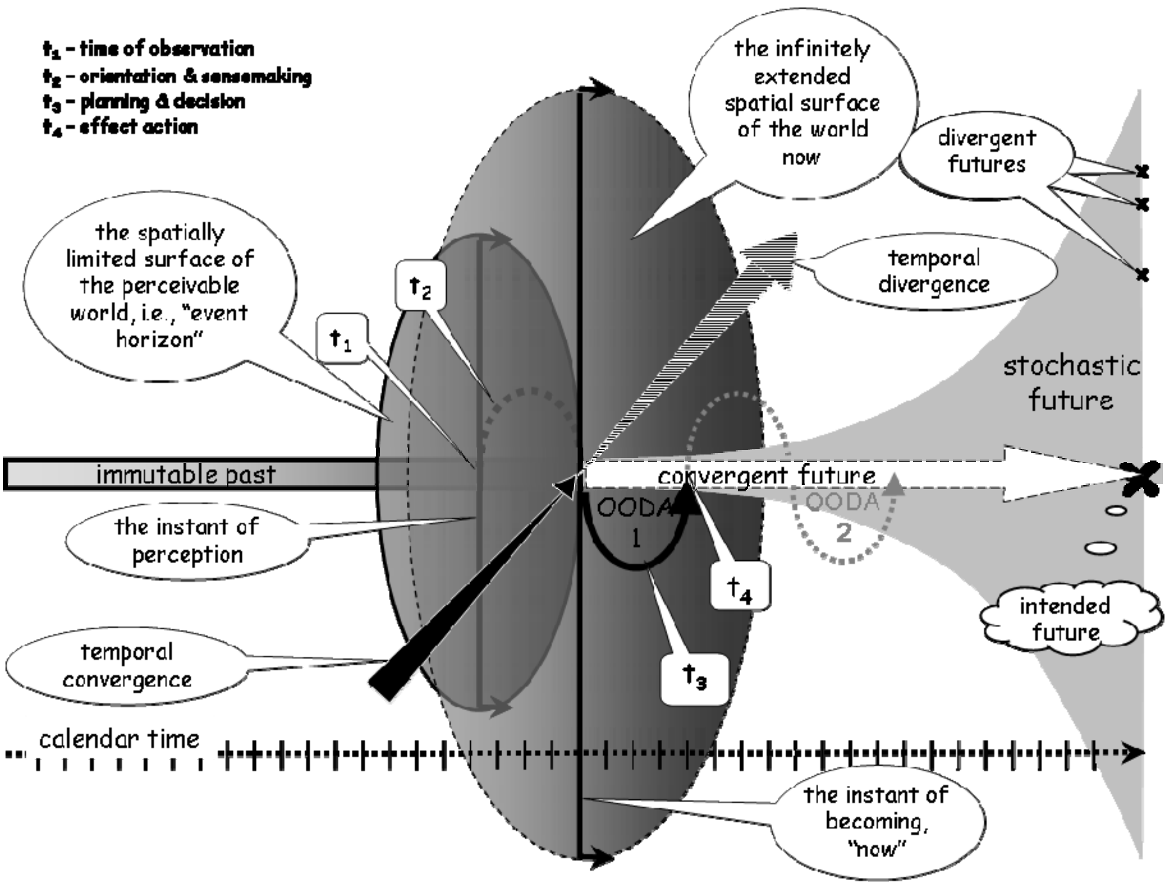

Figure 5. Boyd loops in time. In this figure, the OODA cycle is stretched out in time as a spiral. (See http://tinyurl.com/2twutf for an animation).

Temporal convergence is progressive and affirming. By contrast, temporal divergence is where we cannot see a path leading from where we are "now" to achieve the goal-state. Temporal divergence may result from insufficient capability/capacity to navigate with any confidence toward any goal. Also, one may not know if one is in a state of temporal divergence. Such a knowledge gap can be critical.

Boyd loops in time

Boyd loops (Figure 5) extend through time (i.e., feedback is not instantaneous) and are iterated to continuously update knowledge. In a relentlessly unfolding world of quantum time (**Figure 4**) a single Boyd loop is graphically represented as an open helix extended from the past towards the future along the time axis (Figure 5, Figure 6) rather than a nearly closed circular "loop". Four points in time can be defined for a single Boyd helix (heavy black spiral in Figure 5):

- "$\mathbf{t_1}$" - time of observation (the instant of "perturbation" - Figure 2). Associated with $\mathbf{t_1}$ is an "*event horizon*" (Figure 5) corresponding to the finite amount of space able to be perceived during the time slice when the observation is made. We think that sense-making involves integrating many instants of perturbation over milliseconds to seconds (e.g., as in the physical-chemical processes of exposing a photograph)

- "t_2" - completing the sensemaking and orientation processes using observations received at t_1 to update the model of the world. Note that sensemaking and orientation are based on a spatially limited sample of the world that could be perceived within the event horizon or “cognitive edge” at t_1.
- "t_3" – completing the planning and decision making processes based on the updated world model to decide go/no go action. Again, this is based on the perceptions of the world at t_1.
- "t_4" – the instant when action is affected on the world. The unfolding state of the world including results of action at t_4 is observed in the next OODA helix (in grey) at "t_{1+i}", where "**i**" is the overall duration or cycle time of the previous OODA helix process.

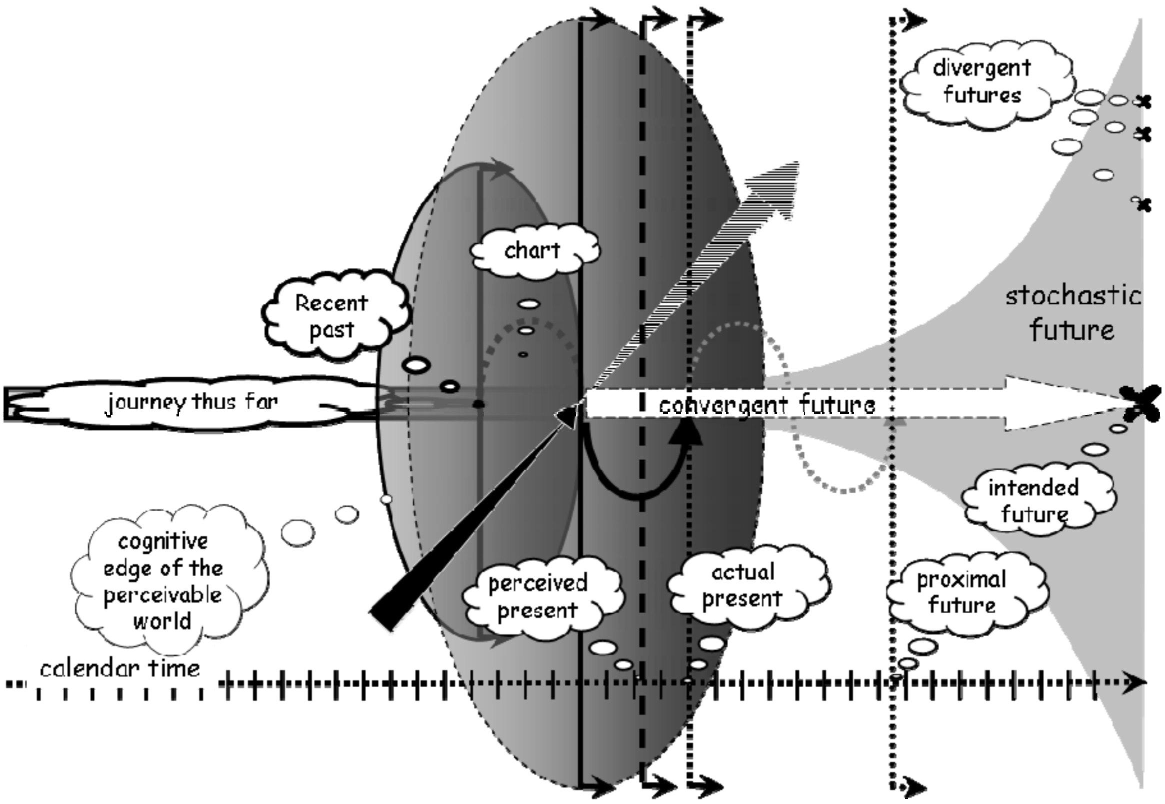

Figure 6. Time-based frames of reference relating to the Boyd loop.

Observations relate directly to the state of the world only at t_1, when external stimuli or perturbations are transduced into the internal 'sense data' of observations (Figure 2 and Figure 3). These sense data idiosyncratically and fallibly represent external reality (Ullman 2006, 2007). Cognitive processes subsumed in “observation” then filter, classify and evaluate sense data against memories of prior observations (i.e., to detect change) to construct a cognitive model at t_2 of what was observed. This takes more time. Further delays are introduced in deciding, planning and acting. To compensate, people consciously and unconsciously build dynamic world models in their minds for themselves and for their organizations that project regularities and trends through time, so as to anticipate or foresee what the world might be like at t_4, when an action is decided at t_3 (Collier 1999, 2006, 2008; Riegler 2001; Butz et al. 2003, 2003a; Leydesdorff 2005; Suddendorf & Corballis 2007).

In reality, even within a single individual, in any one instant there are probably several to many temporally overlapping OODA helices at various stages of progression. It is possible these may also interact to maintain current awareness.

Each activity in a single OODA helix has time-based frames of reference as shown in Figure 6. We define nine time-based frames of reference to facilitate discussing how cognising entities dynamically orient, act and navigate through time and space to achieve goals:

- *chart*: the part of the entity's received and constructed world view that remains extant and authoritative for the purposes of a single OODA cycle. The chart is constructed in W2 and W3 to map locations, events and chronology in the perceived world. One of the actions of an OODA cycle should be to amend the chart for the next OODA cycle. For human organizations, the “chart” can reference intersubjectively shared constructs or W3 knowledge objects.
- *perceivable world*: the part of the world that the entity can observe at $\mathbf{t_1}$ in relationship to the chart. This is the part of external reality (W1) the entity has the sensory capability and cognitive capacity to observe and understand in W2 (i.e., within its "*cognitive edge*" (Day & Schoemaker 2004)), compared to the journey thus far.
- *journey thus far*: the memory of history (who, why, what, where, when and how) as it exists at $\mathbf{t_1}$ as based on remembered changes in the perceivable world and progressively constructed and embodied in the entity's W2. Some aspects of memory can also be articulated and preserved as objects in W3 (see *chart*) to build understanding as observed prototypes for sense-making, from which the changing world can be extrapolated. Memories tend to focus on prospective and retrospective associations with events (*event-relative time*) and can also be chronological in nature (*calendar time*).
- *recent past*: recent sensory data in *calendar time* concerning the perceivable world at $\mathbf{t_1}$ (i.e., observations) the entity can project forward to anticipate a concept of the present situation (i.e., at $\mathbf{t_3}$), or some future situation. Recent past is constructed in W2 based on what existed in W1 immediately prior to $\mathbf{t_1}$.
- *present*: *calendar time* an action is executed.
  - *perceived present*: the entity's constructed understanding in W2 of its situation in the world at time $\mathbf{t_3}$;
  - *actual present*: the entity's instantaneous situation in W1 at time $\mathbf{t_4}$.
- *proximal future*: the entity's forecasted future situation in the world (W2) at $\mathbf{t_4}$ as a consequence of its actions at $\mathbf{t_{1+j}}$, where $\mathbf{j}$ is a time-step unit—typically the time to complete the next OODA cycle. This anticipation is based on observed recent past, perceived present and anticipating the future up to $\mathbf{t_4}$.
- *Intended future*: the intended goal or situation the entity is working to achieve in the world farther in the future (at $\mathbf{t_{gs}}$, where $\mathbf{gs}$ is a goal-state and $\mathbf{t_{gs}}$ is the moment when that goal is realized). Intentions are not necessarily time specific but are always associated with an event or goal-state (i.e., the arrival of a set point in calendar time can also be considered to be an event).
- *convergent future*: the entity’s mapping of the proximal future against an intended future in which $\mathbf{t_{gs}}$ can be specified. $\mathbf{t_1}$ and $\mathbf{t_{1+j}}$ can also be mapped to $\mathbf{t_{gs}}$ and then $\mathbf{t_{gs+1}}$ forecasted in the form of some subsequent goal.
- *divergent future*: a world state where the entity’s actions in the proximal future ($\mathbf{t_{1+j}}$) failed to achieve the world state of the intended future at $\mathbf{t_{gs}}$.

In organizations of people, those involved in the OODA loop risk getting "stuck" with no decision or action while trying to agree on what the observations mean (Ullman 2006 - i.e., "*analysis paralysis*" (Eisenhardt 1989), while competitors are continuing to progress. The choices are losing ground to competitors or making possibly bad decisions by "running out of time" or having them dictated by "fiat" from a superior (Ullman 2007). Individuals can also waste time dithering. However, time progresses relentlessly

Given the temporal, spatial and personal boundedness of cognition in the OODA cycle, increasing the length of the cycle can have positive or negative impacts. Extending the observation time captures more detail, to extend the cognitive edge (Day & Schoemaker 2004). More orientation time allows processing more detail for a larger, more accurate model of the perceivable world. Without other considerations, more accurate world models should enable more effective control information (Corning 2001) to support actions. However, striving too long to reduce uncertainty gives more time for random events and other actors to create a *stochastic future* diverging from the *intentional future*, leading to less relevant world views and less effective control information.

STRATEGIC POWER: ACTING ON THE PAST TO CHANGE THE FUTURE VIA DOWNWARD CAUSATION

Downward Causation to Quantum Level Change Via Spatial Control

The OODA analysis makes it very clear that the world we act on is never the same one we perceive. For individual humans, actions we have to think about (i.e., not reflexes) involve seconds to minutes between observing and acting on the observation. Even in the case of distributed cognition at the organizational level, where responses take place more-or-less as "routinized" organizational reflexes (Nelson & Winter 1982; Hutchins 1995, Amaravadi & Lee 2005), organizational responses will take many seconds to minutes. Where observing, orienting, deciding and acting require conscious social interactions, organizational responses are bound to take many minutes to hours or even days before the OODA loop can be completed with an action.

If time and change unfold on the basis of quantum mechanical interactions how can such slow processes achieve intended futures in a relentlessly unfolding world?

We argue that the key is to apply knowledge in ways that constrain and affect the spatial relations of fundamental physical particles (e.g, Ellis 2006, 2006a, 2008). The following argument is a worst-case sketch of how managerial decision can still be applied in/by autopoietic systems even if the choice between alternative futures can only be effected at the level of quantum interactions in single instants of Planck time.

A physical example clearly demonstrates how macro level spatial controls can directly affect quantum level interactions:

- Uranium-235 (U235) atoms have a half-life of ~700 million years against spontaneous decay to form Thorium 231 with the release of an alpha particle (helium nucleus) and energy.[1,2] Quantum mechanically, there is no way to tell if a given atom of U235 will decay in the next minute or in a billion years from now. However, if a fast neutron is absorbed by the nucleus of a U235 atom, the atom fissions within a femtosecond (10^{-15} sec) into two large fragments, 2-3 neutrons and

[1] http://www.eoearth.org/article/Uranium
[2] http://www.world-nuclear.org/education/phys.htm

a lot of heat energy (Halperin 1959). In nature today, free neutrons are rare and U235 atoms are so widely separated that the chance that one atom will absorb a neutron released by the spontaneous fission of another is essentially zero. However, humans have demonstrated the capacity to refine and physically concentrate U235, and quickly assemble enough atoms close together into what is called a "critical mass". If there are enough U235 nuclei within close range, when one nucleus fissions, other nuclei will absorb neutrons released by the fission event, and also immediately fission. This leads to a "chain reaction" that releases enough energy within microseconds to cause a nuclear explosion.

In general, the spatial distribution of particles is quantum mechanically determined by their spatial distributions and interactions in the previous instant, i.e., their present positions and possible futures are substantially constrained by their past histories. Thus the present configuration depends on the past that quantum mechanically determines what is possible and probable in the next instant.

Although not as dramatic as building an atomic bomb and pushing a button to cause it to explode, to remain viable even the simplest emerging autopoietic systems enforce downward causation on the underlying quantum and atomic level of organization from which they emerge. Autopoietic systems are organizationally (Maturana & Varela 1980) and semantically (Pattee 1995) "closed" systems that are self-determined by their structures (Hall 2006; Hall 2011). Systems are autopoietically integrated when their instantaneous organization is such that the positions and dynamics of their particles in phase space[3] perpetuates autopoiesis into the next instant, as elaborated by Urrestarazu (2004) and Hall (2006, 2011). Thus, the structural organization of the autopoietic system retains an historical trace of its past autopoiesis (the simplest form of self-reference). However, if this structure is perturbed in a way such that its structure and dynamics no longer maintains autopoiesis, the system dis-integrates and its thread of history is lost. As autopoietic lineages vary, natural selection leads to the evolution of compensatory control information (Pattee 1995, 1995a; 2000; Corning 2001) allowing the autopoietic entity to regulate its structure in ways that allow it to survive certain kinds of perturbations. Pattee (1995) expresses it this way,

> [S]elf-reference that has open-ended evolutionary potential is an autonomous closure between the dynamics (physical laws) of the material aspects and the constraints (syntactic rules) of the symbolic aspects of a physical organization only by virtue of the freely selected symbolic aspects of matter do the law-determined physical aspects of matter become functional (i.e., have survival value, goals, significance, meaning, self-awareness, etc.).

"Closure" refers to the fact that dynamic activities of the autopoietic system serve to maintain its autopoiesis, where autonomy is a key character of autopoiesis. By "symbolic aspects" Pattee is referring to control information (knowledge) encoded in the structure - as elaborated and clarified by Corning (2001) and Hoffmeyer and Emmeche (Hoffmeyer 2000, 2002, 2002a; Hoffmeyer & Emmeche 1991; Emmeche 1998, 2000, 2004). Collier (1999) says,

> A system is autonomous if it uses its own information to modify itself and its environment to enhance its survival, responding to both environmental and internal

[3] http://en.wikipedia.org/wiki/Phase_space

> stimuli to modify its basic functions to increase its viability.... an organism will not last long if its functioning does not contribute well to its autonomy; it will be selected against by natural selection [Collier 1999: p. 2 in linked document].

As noted, this "information" may be no more than historically determined structure that happens compensate for a perturbation that would otherwise disrupt the system. Where the self-maintaining structure is disrupted, the history is lost. Thus, selection operating on autonomous systems will lead to the growth of "dispositional" knowledge in the form of structural solutions to solve the problems of life (Popper 1972; Hall 2006, 2011). As new solutions are added to old ones, surviving lineages exhibit increasingly sophisticated and robust forms of compensation, including various forms of anticipatory responses. This is where the OODA loop processes begin to emerge.

In emerging autopoietic systems, dispositional knowledge (W2) is embodied in the instantaneous physical and dynamic structure (Urrestarazu 2004). In systems at the molecular/cellular level this embodied knowledge exists in the positions and properties of the systems' macromolecules and other components and contents. In human organizations, substantial knowledge is embodied in 'organizational routines', layout of plant and equipment, social and communications networks, etc. (Nelson & Winter 1982). In today's living organisms (including humans), natural selection has led to the evolution of a sophisticated genetic apparatus for the hereditary transmission, storage, replication (in DNA), transcription (into RNA) and translation (into polypeptide sequences) of large amounts of codified or "objective" knowledge (Popper 1972). The knowledge is built through natural selection (Popper 1972) rather than specific encoding processes (Hall 2006, 2011). For humans and human-based organizations, objective knowledge is consciously encoded, transmitted, stored, replicated and applied via writing and electronic means (Hall 2006a; Jablonka & Lamb 2006).

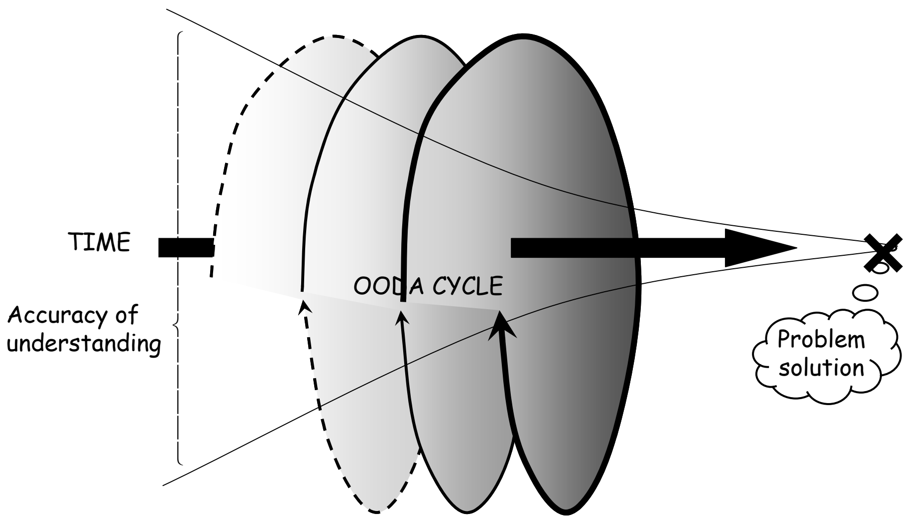

Figure 7. OODA spral working to converge on an intended future.

At the quantum mechanical level, impulses resulting in cognition are transmitted through the organized structure of an organism as "disturbances", propagating as the spatial and dynamic organization of particles (and photons) in one instant affect the organization of adjacent particles in the next instant. Spirally cyclic chains of such disturbances provide the opportunity to feed back results from applying control information, but *there is always delay as the disturbances propagate physically through a sequence of instants*, such that the cycle is an open spiral through time rather than a closed circle in an instant - Figure 7. The fact that impulses are coherently propagated and processed in cognitive processes that are adaptive for the organism is a consequence of billions of years of natural selection. In time this has led to the emergence of consciousness, self-awareness and an "executive" function (Donald 1997, 2001) able to recognize problems and generate, criticize, decide and apply tentative solutions to manage problems (Popper 1972), bearing in mind that "decisions" trace back to the "willful" application of constraints at the quantum level favoring one possible future over another, and that the constraints will be built up by the propagation of disturbances in the cognitive system over a succession of many instants (Ellis 2008).

In lower organisms with no consciousness, where the "decision" function is natural selection, the OODA spiral's cycle time is a generation. The evolution of a living memory of the past combined with the capacity for conscious self-reflection enables many cycles of criticism and decision making within a lifetime to conceive intended futures and to shape the world to reach them. Social coordination of many people within organizations provides even more tools for controlling the world to reach intended futures. The implementation of information systems and other cognitive tools, if used effectively, substantially increase the span and detail of the perceivable event horizon and thus, the bounds of rationality (Hall 2006a). The organizational OODA cycle is the product of many individual human OODA cycles as these are connected via organizational routines (i.e., organizational cognition) to form a larger order OODA cycle responding to organizational imperatives.

Valuing Knowledge

We do not seek to establish a subjective or monetary value for knowledge, as do most works on valuing knowledge, although our approach should help determine these kinds of value. Our focus values knowledge in terms of the utility of knowledge to control possible futures to address specific needs or problems, where utility is defined as the quality of being of practical use. The "*utility value of knowledge*" to its possessor equals the sum of its beneficial consequences minus the sum of its detrimental consequences from applying that knowledge. The principle of utility says whatever course of action (or solution) has the most utility—the best overall outcome—is the preferred (i.e., the most "valuable") choice. Cornejo (2003) gives two types of utility values for addressing personal needs:

- *Objective utility*: when the utility of a particular bit of knowledge can be directly compared with the utility benefits derived from other personal activities, e.g., when the knowledge objects help to improve the person's economic situation or job performance. Examples include methodologies, precedents, tools for professional growth, etc.
- *Subjective utility*: the knowledge isn't seen to have direct economic benefit, but is valuable because it satisfies personal curiosity or sustains a felt need for belonging or appreciation.

Similarly, Cornejo (2003) recognizes two kinds of utility values for organizations:

- *Direct utility*: leading to perceivable and measurable improvements to processes and operations, usually derived from personal knowledge.
- *Indirect utility*: when it is clear the organization benefits from acquired knowledge, but doesn't understand the mechanism so lacks a reliable measure for valuing it.

Therefore, in the case of the direct or indirect utility value of particular knowledge, value will be some function of (a) the claim's applicability to particular circumstances and (b) its accuracy in terms of the degree to which it reflects the true state of existence when applied (i.e., the degree that rational actions based on the knowledge produce predictable results). Pattee (1995) clearly adopts a utility valuation of knowledge: "Knowledge is potentially useful information about something. ... By useful information or knowledge I mean information in the evolutionary sense of information for construction and control, measured or selected information, or *information ultimately necessary for survival*" [our emphasis]. See also (Pattee 1995a).

Alberts and Hayes (2006: pp. 66 & 84) describe this in the stark terms of a military command and control environment. The utility value of current knowledge is measured by the "quality" and "effects" observed when that knowledge is enacted, as (1) a function of the action, (2) the time and conditions surrounding the action, (3) the quality of execution and (4) other related factors. The selection of the action and its timing is normally part of sensemaking, and is often a collective decision.

Command and control are particularly knowledge-intensive processes in military and commercial organizations for controlling various aspects of information processing and action to achieve convergence on an intended future. "Quality" measures the effectiveness (i.e., value to the entity) in maximizing positive results and minimizing negative ones to converge on the intended future. As noted by Boyd, Alberts and Hayes and others, the value of the knowledge involved in all of these processes is assessed by some measure of quality (i.e., utility value).

Surviving in a variable world depends on the ability to control the world's threatening aspects (i.e., to avoid detrimental futures), including threats to necessary resources. In conscious entities, this is the ability to achieve temporal convergence on goals relating to their imperatives. "*Strategic power*" is this ability to achieve temporal convergence through control. In a world where different entities compete, strategic power is relative—where the strategically more powerful entity can directly control other entities or resources needed by them, and thus maintain its own access to those requisites despite actions by its competitors. Control is based on knowledge of the world and is achieved by applying control information developed from that knowledge. The degree to which an entity's actions achieve their intended effects depends on the quality and currency (i.e., the utility value) of the knowledge on which they are based.

Cycle Times and the Achievement and Maintenance of Strategic Power

As identified by Dalmaris et al. (2006), a factor often overlooked in organization and KM studies is that the value of knowledge may depend strongly on the passage of time—the time when the knowledge was created, the time when it was last validated, and the time when it is actually applied in organizational actions.

Chen and Edgington (2005) consider two types of time-based knowledge depreciation, knowledge decay and knowledge obsolescence. "*Knowledge decay*" is a consequence of forgetting and other cognitive failures, and is not our primary concern here. "*Knowledge obsolescence*" is attributed to changing circumstances, but not well defined otherwise. Rosen (1975) defines knowledge obsolescence in economic terms as "negative changes in capital values that are solely a function of chronological time. Obsolescence occurs because stocks of knowledge available to society change from time to time".

The utility of any knowledge based on past learning—that is not routinely updated—will tend to depreciate as time increases between the circumstances of the learning and its application. In the case of temporal convergence, where the entity works towards an intentional future, convergence is achieved through periodically updating knowledge and controlling unfolding events to stay within the narrowing zone of convergence as the time of the present "now" approaches the intended future (Martin et al 2009). However, as the interval increases between observation and action in the OODA cycle, the world may diverge so much that executed actions at $\mathbf{t_4}$ no longer achieve intended effects, thus depreciating the value of knowledge generated during the cycle.

Where the world includes other entities directly competing for strategic power, as Boyd (1996) stresses many times, substantial strategic advantage accrues to an entity that can complete its OODA cycle and act to change the world before competitors can also act to make their changes. By changing the world before others complete their OODA processes, faster actors create worlds of stochastic futures and temporal divergence for slower competitors. In organizations, continued temporal divergence producing stochastic futures leads to irrationality and loss of morale. Even apparently rational forecasts of the proximal future deviate from charts of perceivable worlds. This has certainly been recognised in the area of military affairs, where a major driver for concepts of network centricity has been to minimize the interval between $\mathbf{t_1}$ and $\mathbf{t_4}$.

The importance of time has been less well-realized where non-military organizations are concerned. In reasonably symmetric competition or combat, the competitor with the fastest OODA cycle time has the opportunity to greatly depreciate the value of a competitor's knowledge, possibly leading to misinformed decisions, "*strategic paralysis*" (Eisenhardt 1989), with "stuck" OODA processes (Ullman 2007) and/or "magical thinking" (Boyd 1996). Entities with faster OODA processes have the strategic power to shape circumstances. Entities whose OODA cycles take too much time between observation and acting are increasingly at the mercy of the world.

We have shown here that current world-knowledge doesn't age well, but we also recognize that some kinds of knowledge can become more valuable with time. Some of the most valuable knowledge is in fact "old" knowledge that has survived testing (Popper 1972) in *many* OODA loops as cultural heritage or "formal knowledge" (Vines et al. 2007). Rapid decision also benefits from cultural paradigms (Boyd 1996) that don't have to be revisited often, whereas at the tactical level, one needs to deal aggressively with latency issues.

CONCLUSIONS

Whether in business or warfare, the longer decision and action are delayed without new observation and orientation, the more the knowledge on which they depend will depreciate. Such depreciation is reflected in increasing unpredictability of the results of actions based on the knowledge. Ullman (2007) observes, "Competitive advantage comes from quickness over the entire loop, and, as with each iteration the changes are smaller (as they are modifications to an understood situation) and can be more easily managed, therefore staying ahead of the competition." Fadok (1995, p. v) is even more explicit about how time depreciates knowledge in competition:

> [Boyd] speaks of folding an opponent back inside himself by operating inside his observation-orientation-decision-action (OODA) loop. This severs the adversary's external bonds with his environment and thereby forces an inward orientation upon him. This inward focus necessarily creates mismatches between the real world and his perceptions of that world. Under the menacing environment of war, the initial confusion and disorder degenerate into a state of internal dissolution which collapses his will to resist. [Fadok 1995, p. v].

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