A quantum approach to multi-agent systems (MAS), organizations, and control

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Abstract

In some rapidly approaching future, on a battlefield, deep-space or planetary mission, teams of agents will be confronted with a problem beyond their computational capability, putting missions at risk. This risk arises from a lack of social theory based on first principles for decision-making in the face of ill-defined problems (*idp*'s*)*. Also, no first principles exist to address the downside of cooperation (e.g., terrorist cells; corruption; and, regarding agents, reductions in computational power from communication costs when an increasing number of agents cooperates interactively). These problems make traditional social models impractical for a multiple-agent system to solve *idp*'s. In contrast to logical positivist models, such as command or consensus decision models, quantizing the pro-con positions in decision-making may produce a robust model that increases in computational power with *N*. Previously, optimum solutions of *idp*'s were found to occur when incommensurable beliefs interacting before neutral decision makers generated sufficient emotion to process information, *I*, but insufficient to impair the interaction, producing more trust compared to cooperation. This model has been extended to the first quantum information density functional theory of groups, especially mergers between organizations; we begin now to integrate our model with Markovian models.

Introduction

To address how systems of computational agents, working alone, in teams, or with humans, can cooperate autonomously to solve problems better than the current generation of remotely controlled unmanned systems (Darpa, 2002), it is increasingly clear that a revolution in computing foundations is necessary to achieve multi-agent autonomy. For example, a staff of 20 humans is now required to operate a single Predator drone, yet the crash rate is 100 Predators to one piloted USAF aircraft (e.g., Pfister, 2002). To reverse this relationship will require the rational control and optimization of group processes, beginning with the major unsolved problem in Social Psychology of how individuals become a group (Allport, 1962). The related problem in game theory (Luce & Raiffa, 1967) is the mathematical inability to distinguish between an organization such as IBM and the aggregation of individuals who comprise IBM. While being able to determine the optimum structure for decision-making or the formation of organizations may offer the greatest opportunity for advancements in computational agent technology, the "groupness" problem remains not only unsolved, but also virtually unstudied simply because social scientists have until now been unable to study groups except from the perspective of the individual (Levine & Moreland, 1998), a critique applicable to game theory for different reasons. As the first attempt to analyze social interdependence, game theory only produces static information, *I* (Von Neumann & Morgenstern, 1953, p. 45), including repeated or "evolutionary" games. Luce & Raiffa (1967) concluded that logic based on the individual perspective, such as game theory, was unable to solve the "groupness" problem.

The "groupness" problem arises by recognizing that once members have been surveyed with questionnaires or polls, summing individual data does not reconstitute the group (adapted from Zeilinger, 1999). Nash (1950) avoided this issue in bargaining situations by assigning zero social value to groups with dissent, assuring that game theory only addressed the more stable groups

where values might be summated. But even for stable, homogeneous, dissent-free groups, Lewin (1951) famously recognized that a group is different from the sum of its parts.

Disadvantages of the Traditional Approach

The idea that "cognitive systems might be best characterized as systems that know what they are doing" (Darpa, 2002) is a traditional rational vision of human behavior that sharply contrasts with vacillations between "rationality … [and] enormous irrational feelings" humans commonly experience as they anguish over difficult decisions (2002 interview of Fiona Shaw, the star of the acclaimed new interpretation of "Medea"; in www.washingtonpost.com). Besides not integrating emotion, there are three distinct disadvantages with traditional rational individual models of human behavior.

First, the knowledge, *K*, an organism holds about itself compared to observer *K* about the organism is replete with errors (Baumeister, 1995; e.g., alcoholic denial and hypochondria are common but opposite examples in the amount of extreme error possible with human self-*K*). Observer *K* is also error prone, such as eye-witness testimony (Loftus & Ketcham, 1992), captured in Umberto Eco's new novel by his character Bondolino: "The problem of my life is that I've always confused what I saw with what I wanted to see." Yet Simon (1992) speculated that an expert's *K* can predict the expert's behavior. Theoretically, however, if the *I* between an agent's actions and its perceptions of that action are conjugate (Lawless et al., 2000a), then the more perfect is either *I* or *I* flow the greater the divergence between them. Field evidence from a study with USAF combat fighter pilots of air combat maneuvering versus air combat *K*, and a replication of the combat pilot study in the laboratory with mathematics students of mathematics skills versus math skills perceptions, did not support Simon, but did support the conjugate or social quantum model (SQM) (Lawless et al., 2000b).

Second, the wide-spread and traditional belief, noted by Benardete (2002), that there always exists a single rational decision superior to the same decision made in a democracy (a democracy promotes autonomy and, from self-organizational processes, factional diversity among agents), remains the premise of game and decision theory (Luce & Raiffa, 1967), even though neither theory has been validated in the laboratory or field (Jones, 1998; Kelley, 1992; Klein, 1997). Interestingly, both theories use processes similar to convergence theory in the social sciences, eventually rejected by its founder Campbell (1996), and also in machine learning (e.g., genetic algorithms, neural nets, fuzzy logic, etc.), the premise being that an optimum solution exists at a global minimum in rational space (e.g., minimum cost functions), rejected early on by Bohr (1955; see also Von Neumann & Morgenstern, 1953, pp. 147-8) when *I* is interdependent and conjugate, as always occurs during social interaction. The convergence process in machine learning fails to capture the social interaction for two subtle, other reasons: Convergence governs social learning theory (i.e., classical and operant conditioning and modeling), whereas in groups governed by democratic decision-making, convergence is delayed by *I* processing, captured by SQM (Lawless & Castelao, 2001); and social learning theory is predicated on a lack of cognitive awareness (Skinner, 1978), but awareness is the *sine qua non* of democratic decision-making and self-roganization, also captured by SQM (Lawless & Schwartz, 2002).

SQM is congruent with dissonance learning theory. Surprisingly, dissonance learning theory offers a link between machine learning and cognitive awareness processes. Assuming that first

interactions before structure exists are approximately Markovian, then social (e.g., stable relationships, organizations, laws, cultures, business practices) and psychological structures (e.g., habits, stable beliefs, personal *K*) are social mechanisms that reduce randomness by increasing predictability (i.e., if $I = -\sum p(x) \log_2 p(x)$, and *I* flow *is* $\Delta I/\Delta t$, or *a, K* occurs as $\Delta I \rightarrow 0$). Management reduces to managing *I* to make rational decisions (e.g., Farber, 2002). According to Nicolis and Prigogine (1989, p. 255), by construing society as a dissipative system with chaotic attractors, predictability recovers along the direction of flow in contracting phase space (e.g., axes of *I* and *I* flow), while variety and choice generate along the expanding directions of flow. This leads us to postulate that outside of the range of social structure, randomness is more likely (e.g., the stock market as a random walk; in Malkiel, 2000). But with dissonance learning theory, randomness can be mindfully injected within structures. Examples are plans (e.g., in 2003, on the national stage the U.S. and N. Korea have lurched between plans for conciliation and confrontation; new recovery plans have recently been published by Ford, Gateway, United Airlines, and Fiat; new political plans have been announced for the 2004 Presidential race; and the Catholic Church struggles to plan past the issue of priest-child abuse); disagreements and arguments (e.g., Lawless & Schwartz, 2002); and a wide range of many others (war, art, entertainment, innovation, technology), including mergers (e.g., Lawless & Chandrasekara, 2002). Mergers occur in environments where uncertainty increases ($\Delta I \rightarrow \infty$), as when a sector loses pricing power (e.g., airlines in 2002), in an attempt to regain predictability by consolidation, just as slime molds and ants do (Nicolis & Prigogine, 1989, pp. 33 and 236, respectively). Randomness can be mindfully marginalized from structure (e.g., crime, dictatorship, consensus, bureaucracy), but by proportionately slowing its evolutionary rate. To generalize, increasing uncertainty among autonomous agents increases their emotional temperature (*T*, where $T = \partial E/\partial I$), producing more *I* and anxiety, thereby motivating efforts to reduce uncertainty by processing *I* to increase *K* (Lawless, 2001).

Returning to disadvantages, the third disadvantage is the belief that group decision-making is inferior (Darpa, 2002; see also Stroebe & Diehl, 1994, for lab support using toy problems). This overlooks the three greatest decision-making groups in the world today: the American stock markets (Insana, 2000), the U.S. Congress (Schlesinger, 1949), and the U.S. Courts (Freer & Perdue, 1996). In the Fall of 2002, The New York Times cited doubts by Hong Kong's Secretary of Security Regina Ip, a top aide to Tung Chee-Hwa, its Chief Executive, about the usefulness of democracy. But in contrast to command or consensus decision-making (CDM), we have found that democratic decision-making is significantly associated with scientific wealth, human health, economic freedom, increased trust, and reduced corruption (Lawless & Castelao, 2001). For example, unlike the experience of Soviet Russia, Communist China, or numerous countries in Africa during the 20th century, and despite a dogmatic belief in the value of communism and other command economies by Skinner (1978), the founder of operant conditioning, Sen (2000) concluded that no democracy has ever suffered from famine. Taken together, these findings illustrate the theory behind Western systems of justice, markets and science is that the same data can lead to multiple, incommensurable, or orthogonal interpretations that can be exploited with a social mechanism to power information processing in observers neutral to argument, evolving a social system (Lawless & Schwartz, 2002), crudely analogous to quantum computation (Lloyd, 2000).

Von Neumann (1961) admired that physicists signaled the limits of rational thought by conflict, they never avoided conflict, yet their resolution of conflict created the largest advances

in rational thinking. Encouraged by Von Neumann's insight, we combine Nash's (1950) criteria for the absence of conflict as a prerequisite for negotiation with the quantum *I* approach which allows us to combine two orthogonal states simultaneously, specifically cooperation and competition. If opinions are diametrical (180 deg out of phase; e.g., "Concept A is right"and "Concept A is wrong"), versus orthogonal ("Concept A is right" and "Concept B is right"), diametrical concepts represent conflict while orthogonal concepts represent *I* processing.

In sum, it has been found that the weakest decisions are made by individual rational logic, teams, or consensus seekers, the underlying rationale to CDM (e.g., authoritarian decisions, military failures such as the USS Vincennes incident, and bureaucracies; in Lawless & Schwartz, 2002). Even the previously consensus-minded European Council has rejected the consensus method as inefficient (WP, 2002). Thus, to build a computational system aware of its goals and internal states to determine where and why its *B* strayed from the desired, while laudable, is a traditional approach unlikely to solve *idp*'s, to save scarce resources, or to be computationally efficient, making it unwise to assemble these agents into teams or systems that would be able to coordinate in unprecedented ways.

As an alternative, because social reality is bistable (action *I* and observation *I* are conjugate), to eliminate redundancies and gaps in large complex systems and reduce their overall cost, a system of agents with multiple factions of complementary beliefs and actions, producing something akin to a virtual *K* characterized by increasing belief strength associated with decreasing observational accuracy about agent actions (Lawless et al., 2000a), *strangely*, will increase information processing power as the number of decision-makers increase (Lawless, 2001), precisely the opposite of what happens as traditional computational power increases: As systems get larger and more complex, there is evidence that utility and productivity are increasingly falling off the curve that tracks pure processor size and speed leading to the conclusion that no amount of pure computational power will afford us the kind of intelligent computations that we need to address new problems, thus investing in more of the same will not get us where we need to go (Darpa, 2002). Traditional models cannot easily account for information processing among agents, trust, the value of emotion between agents, or what it is about groups that make them superior or inferior decision makers, natural derivatives of conjugate or quantum models (Lawless, 2001). Nor can traditional models explain the power of a plan that succeeds, like the U.S. Constitution—an imperfect plan written by imperfect men that has allowed imperfect leaders and imperfect power centers to excel—with its system to maximize autonomy among multiple deciders and to minimize autonomy with checks and balances, yielding a system to reduce corruption, increase trust (from Montesquieu), and balance cooperation and competition with tension (Berken, 2002), but the quantum model can (e.g., Lawless & Castelao, 2001). The value of SQM is that it helps us to see that in contrast to the "efficiency" of CDM, and with it Plato's model of the "ideal leader", the social tumult associated with oppositional decision making in democracies and decision centers allows for continuous tuning of a decision with feedback that converts argument into a source of bifurcations and uncertainty (near zero or incommensurable social forces; i.e., $\sum F = 0 = Force(argument\ 1) - Force(argument\ 2)$), whereas a single leader or bureaucracy slows the rate of evolution by promoting consensus or homogeneity (Lawless & Schwartz, 2002).

To computationally simplify cognitive models, Simon believed that rationality was bounded, but that is insufficient to characterize conjugate *I*. The chief characteristic of an optimum decision-making system is one that can exploit the conjugate *I* that exists in every social

interaction, yet at the same time accepts that conjugate *I* precludes participants from accurately articulating their own decision processes (Lawless et al., 2000a; also, see Zeilinger, 1999), e.g., legal decisions sometimes become highly valued as precedents even as the best rational justifications for them decline in social value (Polanyi, 1974); similarly in physics, Planck spent years attempting to rationalize his own accidental discovery of discrete energy packets that ended the traditional view of causality so important to his own mechanical view of reality, *R*.

Mathematical approach

The question of "groupness" has puzzled Aeschylus, Plato, Descartes, James, and Bergson, but it was finally solved by Heisenberg with his uncertainty principle for atomic objects, then extended to human systems as an interdependent interaction between action and observation by Bohr (1955; see also Von Neumann & Morgenstern, 1953, pp. 147-8). While considerable research into quantum effects has already addressed signal detection theory (i.e., the Békésy-Stevens model; see Luce, 1963, 1997, who considers it to be a satisfactory alternative), little research has added to Bohr's initial insights for social systems, leaving open many key issues. However, Bohr's approach has several advantages that have begun to pay off with SQM. Given conjugate action *I* uncertainty (Δa) and observational *I* uncertainty (ΔI), the relationship becomes:

$$\Delta a \Delta I \geq c \qquad (1)$$

Since *c* is unknown, boundary conditions are necessary to solve (1). The first case, already discussed with the USAF study (as $\Delta I \rightarrow 0$, $\Delta a \rightarrow \infty$), found that expert versus non-expert *K* was conjugate, supporting the interdependence of training and learning (Lawless et al., 2000b).

The second case (as $\Delta I \rightarrow \infty$, $\Delta a \rightarrow 0$) establishes the value of argument (Lalwess & Schwartz, 2002), leading to the finding that the rational logic of an optimal individual (e.g., command and consensus decisions) is significantly inferior to group decisions that exploit randomness (e.g., decision centers and democracy), leading to the discovery of techniques that prevent decision stalemates (van Eeten, 2002) by engaging both sides ($\sum F = 0 = F_1 - F_2$) and those neutral to an argument, increasing *I* processing and creativity to solve *idp*'s, producing optimum decisions. It has also helped us to recognize similarities between signal detection theory and decision-making ("detecting" solutions to *idp*'s; Lawless & Schwartz, 2002).

Revising (1) with *j* as inertial reactance, with time, Δt, and energy uncertainty, ΔE (Lawless et al., 2000), $\Delta a \Delta I = \Delta\,(\Delta I/\Delta t) \bullet \Delta t/\Delta t \bullet \Delta I = j \bullet \Delta\,(\Delta I/\Delta t)^2 \bullet \Delta t$ becomes

$$\Delta t \Delta E \geq c \qquad (2)$$

Equation (2) predicts that as time uncertainty goes to zero, *E* becomes unbounded (e.g., big courtroom cases, science, or urban renewal projects); inversely, when ΔE goes to zero, time becomes unbounded (e.g., at the low *E* expenditures around resonance, voice boxes operate for a lifetime). Equation (2) allows the interaction to be quantized, producing *E* wells localized around ideas or beliefs as set points, accounting for the stable reactance to social change we defined as information inertia, *j*. As increasing *E* levels approach set points, emotions increase, forcing a return to stability (e.g., in set point theory, an "insult" provokes an agent's response as its set points are engaged, or a group when its "laws" are broken; for a review, see Lawless, 2001).

Countering the current belief that prediction with agent systems is not possible (e.g., Bankes, 2002), mathematical formulations of a group (Lawless & Chandrasekara, 2002), including heterogeneous couplings (e.g., terrorist sleeper cells), can be determined *ab initio* with vocal cross-sections by construing the group as a series of interdependent interactions between individuals represented approximately as vocal harmonic *I* resonators. Then the growth rate of an organization fits a pattern, with different processes, *P*, like diffusing or adsorbing recruits, given by:

$$\Gamma_P = n_A n_B \, a \, \sigma_{AB} \, exp \, (-\Delta A/k_B T). \quad (3)$$

where n_A and n_B are the numbers of recruits and leaders interacting; $a = \Delta I/\Delta t$; σ_{AB} is the cross-section (the probability an interaction produces usable *E*, ΔA, is an area determined by the vocal frequency of indoctrinators, ω, and recruits, ω_0, increasing rapidly as language "matches" increase or differences decrease; i.e., $f(\omega^4/(\omega^2-\omega_0^2)^2)$); $exp(\bullet)$ is the probability of sufficient free *E*, ΔA, for the activity to go forward; k_B is Boltzman's constant; and *T* is emotion temperature (Lawless, 2001). Equation (3) indicates that the more ΔA required for an activity, the less likely it occurs; that friendship is optimal for those who listen to synchronize with each other, similar to a state of resonance between harmonic oscillators; and that terrorists cooperate to manipulate their cross-section to preclude warning observers about their hidden intent.

Information Density Functional Theory-IDFT

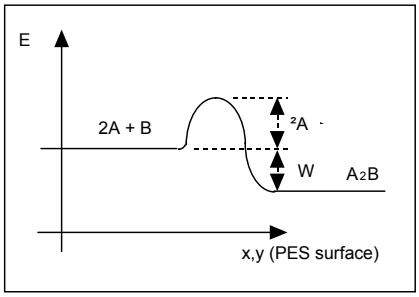
IDFT approximates the function of *I* density and discrete *E* effects in an organization of adding or removing members. A group forms or reforms by entangling *I* from an aggregation of individuals to solve an *idp* (Ambrose, 2001), like designing a complex weapon. The chief characteristic of an *idp* is that *K* concepts do not correspond to objects or actions in *R*. Once solved, however, an *idp* becomes a well-defined problem, *wdp*, characterized by a correspondence between *K*, skills and *R* (Sallach, 2002) (cooperation implies low *I* density, maximum *K*, and *E* ground state). In the solution of *wdp*'s, individuals function in roles bonded into a stable network oriented by a shared emotional potential *E* field (set point theory).

The potential *E* surface (E^{PES}) represents the function, hierarchy and geo-cultural differences across a group, organization, or society (Sallach, 2002). A recruit moves across the *E* surface of an organization, R_{org}, where E^{TOT} is the ground state and PES the minimum total *E* along the *z* coordinate of the organizational configuration, including its hierarchy, until reaching a minima (stability).

$$E^{PES}(x,y) = min_{z,R\text{-}org} \, E^{TOT}(x,y,z,R_{org}) \quad (4)$$

A bond forms between two members, A and B, proportionately as its joint ground *E* state becomes less than the aggregate ground state of its members, the difference being the binding *E*, *W*. The *E* required to reverse the process and break apart the group becomes $\Delta A + W$ (Figure 1). *W* is calculated from the configuration of barriers and nearest and next-nearest neighbors.

Figure 1. The binding *E* to form a group or break it up. Shown here, two followers (2A) bind together with each other and then to one leader (B) to form a group (A_2B).



Assuming that two recruits (A) bind to one another and to one leader (B), the Hamiltonian consists of a site contribution, H_0, and an interaction term, H_{int}, giving:

$$H_0 = E_b^A \sum_k n_k + E_b^B \sum_k m_k + V^{A\text{-}B} \sum_k n_k m_k \quad (5)$$

where k as a role site, n_k, is either 0 or 1 if k is empty or filled, m_k is the same for leader sites, V is an interaction parameter, and

$$H_{int} = 1/2V_{1n}^A \sum_{k,a} n_k n_{k+a} + 1/2V_{2n}^B \sum_{k,b} n_k n_{k+b} + 1/2V_{1n}^B \sum_{k,a} m_k m_{k+a} + 1/2V_{2n}^B \sum_{k,b} m_k m_{k+b} + 1/3\ V_{trio}^B \sum_{k,a,a'} m_k m_{k+a} m_{k+a'} + \ldots \quad (6)$$

Here $k + a$ and $k + b$ denote nearest and next nearest sites.

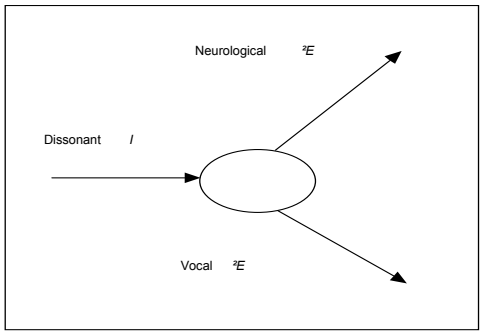
The processes above (Equations 3-6) can be used to model a heterogeneous group. Stresses resulting from a mismatch between an organization and new members can also model the merger between two organizations (e.g., HP and Compaq). As a heterogeneous island nucleates on the surface of a consolidator, the tension on it to be absorbed relaxes the larger the island grows, creating a distance between the consolidator and the island's leaders, the release of E acting as a driving force in the island to choose a hierarchy of leaders less like those in the consolidator, motivating the need to integrate both cultures (e.g., the inability to integrate is the putative cause of the failure in 2003 of AOL and Time Warner).

In sum, joining a group promotes the survival of individuals by reducing E expenditures in exchange for membership: social loafing (Latane, 1981); audience effects enhance skills (Zajonc, 1998); greater interaction density promotes health (House et al., 1988); and protecting belief systems (Rosenblatt et al., 1990). In exchange, a group exploits the E and skills it collects (Ambrose, 2001), forming a structure around a network of interactions between roles bonded to each other (Sallach, 2002). Generally at the lowest E state, interaction exchanges —voice, visuals, products, and money— between agents cycle I back and forth in interactions coordinated by common K (Wendt, 1999). Among the groups that gain more E than it costs to survive (Coase, 1937), some gain sufficient free energy, ΔA, to grow in size, experience and wealth, deepening E wells to process more I, while others merge to offset competitive weaknesses (e.g., HP merged to offset its weakness in computer servers, Compaq's strength).

Most interactions within a stable organization serve to fulfill a mission, defend a worldview, or acculturate members, but interactions to solve *idp*'s are different. Modeled by Equations 1-2, these interactions temporarily shift members from roles to bring into play factions (underdetermined R), neutrals and decision making, where Δt is the time for the system to evolve to an orthogonal state to reach a decision (Aharonov & Bohm, 1961). For optimal decisions,

dissonance (argumentation) between polar opposite views processes *I* uncertainty into *K* (e.g., political, legal, and scientific dissonance usually precede optimal decisions; in Lawless & Castelao, 2001). Identifying the optimum solution of an *idp* is analogous to signal detection, the time (Δt) to detect and adopt a solution lasting until the solution signal is separated from social noise; e.g., air-to-air combat, environmental cleanup, environmental disaster recovery, or weather prediction (Lawless & Castelao, 2001). However, given the unreliability of self-reports (measurement collapses the interaction into individual histories that cannot recreate it), a new approach must be initiated to measure physiological *E* states, such as vocal energy changes, to contrast normal and dissonant states (see Figure 2).

Figure 2: Picard's liquid model of emotion suggests that social perturbations caused by dissonant *I* produce a spectrum of emotional responses. Significant vocal *E* changes from normal to angry speech have been confirmed (Lawless, 2001).



In earlier work, we associated quantum-like square *E* wells with emotion and decision-making (e.g., Lawless, 2001). After finding that interaction cross-sections are related to vocal frequencies (Lawless, 2002), we speculated that it also applies to brain waves: if gamma waves (≈ 40 Hz) mediate the binding of sensory features into objects (Engel et al., 1999) and concepts (Lawless & Chandrasekara, 2002), transitions between opposing views in an argument act as concept reversals that reflect the time required to sufficiently grasp and apply difficult concepts to solve *idp*'s, linking solution "detection" to signal detection. It may be this time is necessary for decision-makers to determine whether an argument can be defended "against all contestations" (McBurney & Parsons, 2001, p. 76).

Conclusion

The primary advantage of using SQM is that it is an analytical model that simulates the conjugate aspects of decision making and organizational growth (IDFT). SQM explains why traditional models based on the individual perspective of rationality fail, or why ABM's cannot be validated; IDFT accounts for differences between an aggregation and a group constituted of the same individuals; and, more importantly, both suggest new approaches to study the interaction. If language is the assignment of meaning to physical vibrations between human oscillators (speech from vocal sounds), and if the primary tool of social science is the self-report, then SQM and IDFT suggest many opportunities for interdisciplinary collaborations that could

lead to new tests of falsification by contrasting single versus social *E* states with neuro-physiological-psychological data (self-reports, voice, qEEG's, fMRI's, EMG's, Lie Detectors, etc.) to determine whether as predicted during decision-making for *idp*'s and *wdp*'s that ground and excited states can be distinguished, whether competition produces *I* and, and whether cooperation enhances deception. Finally, by recognizing how uncertainty is injected into decision-making via argument, the potential compatibility of SQM and Markovian models opens a new avenue of research.

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A quantum approach to multi-agent systems (MAS), organizations and control

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8th ICCRTS, Jun 17, 2003, NDU-DC

Reasons for this Research

- Reducing errors by human/computational organizations (e.g., DOE/MAS) => regulation, control, and dynamics ə mergers
- The game theory-rational theory failure to resolve an organization and its disaggregated members (GT: Luce & Raiffa, 1967; Kelley, 1979, 1992; attitudes v. behavior: Eagly, 1993; Tversky, 1993)
- Can *E* transitions in argument be modeled?

Agent Based Models (e.g., Robotics)

- Currently:
  - **One Predator per 20 human operators** (Pfister, 2002, Annie-02)
    - Single agents (MDP, GA, ANN)
    - Rational individual
    - Limit: *wdp*'s w/few *N*
  - Global Hawk, Predator w/Hellfire, Helios, & X-36
- Future:
  - **One operator per 20 Predators**
    - Social agents
    - Rational group perspective
    - *idp*'s w/unlimited *N*
    - *Swarms?*
- However, Bankes (2002) concluded that many ABM's
  - aren't as complex as the social
  - predictions cannot be validated

NASA Dryden Flight Research Center Photo Collection
http://www.dfrc.nasa.gov/gallery/photo/index.html
NASA Photo: ED01-0230-3 Date: August 13, 2001 Photo by: Carla Thomas
The Helios Prototype aircraft in a northerly climb over Nihau Island, Hawaii, at about 8,000 feet above sea level.

NASA Dryden Flight Research Center Photo Collection
http://www.dfrc.nasa.gov/gallery/photo/index.html
NASA Photo: EC97-44165-149 Date: July 16, 1997 Photo by: Tony Landis

1997 Research Aircraft Fleet on Ramp - X-31, F-15 ACTIVE, SR-71, F-106, F-16XL Ship #2, X-38, an

Table 1: Some strengths and weaknesses of game theory after 60 years of research	
Strengths	**Weaknesses**
Rational model of the interaction (event trees, conditional probabilities)	Emotion is not integral to the model
Mathematical logic of interdependence	Uncertainty is modeled sequentially, not interdependently (i.e., observation uncertainty is independent of action uncertainty; Von Neumann & Morgenstern, 1953, pp. 147-8)
Mixed motives of conflict and cooperation	Argumentation, incommensurability, and diversity have zero social value (contrast Nash, 1950 with Von Neumann, 1961)
Mathematical equilibria (e.g., Axelrod, 1984)	Static configurations (Von Neumann & Morgenstern, 1953, p. 45) and equilibria imply information processing (dI/dt) occurs "extra-rationally" (i.e., contingent on others) without regard to social forces, producing descriptive data and increasing observational uncertainty
Quantitative utility of expected outcomes	Arbitrary utilities for cooperation and competition lead to explanation versus prediction, overstating the value of cooperation (e.g., Axelrod, 1984; Shearer & Gould, 1999)
Learning is predicated on rewards and punishments (traditional Social Learning Theory -- SLT)	SLT occurs outside of awareness, devaluing rational problem solving skills (Skinner, 1978)
Models lead to clear predictions	No lab (Kelley, 1992) or field validation (Jones, 1998); further, ABM prediction not possible (Bankes, 2002)
First model of group behavior	Shifts between individual to group or ingroup to outgroup utilities cannot be studied;
Simple model of groups	Model complexity insufficient to model social organizations (Bankes, 2002)
Generalizable	Conclusions are normative (Gmytrasiewicz, 2002); e.g., "fairness"

When Cooperation works

- The evolution of cooperation improves civilization (Axelrod, 1984)
- Cooperation is more moral (rejects compromise) and reduces bloodshed (Worchel, 1999)
- For well-defined problems (*wdp*'s) (Lawless et al., 2000b)
- Mathematically, less diversity => + stability (May, 2001, p. 174)

When Cooperation does not Work

- Cooperation does not work with:
  - Social loafing (Latane, 1981)
  - Asymmetric *I* (**terrorism, corruption, blackmail**)
  - Computational blowup as *N* cooperating agents exceed 100 (Darpa, 2002)
  - For ill-defined problems (*idp*'s)(Lawless et al., 2000a)
- Government by Consensus
  - Japan: Unable to reform
  - Germany: More Corrupt (from 14th in 1999 to 20th in 2000, TI, 2002); Tietmeyer (2002), ex-president Bundesbank, "… what we need are majority decisions ... [not] consensus."
  - EC: **"The requirement for consensus in the European Council often holds policy-making hostage to national interests in areas which Council should decide by a qualified majority."** (WP, 2001, p. 29)

Alternatives to Game Theory

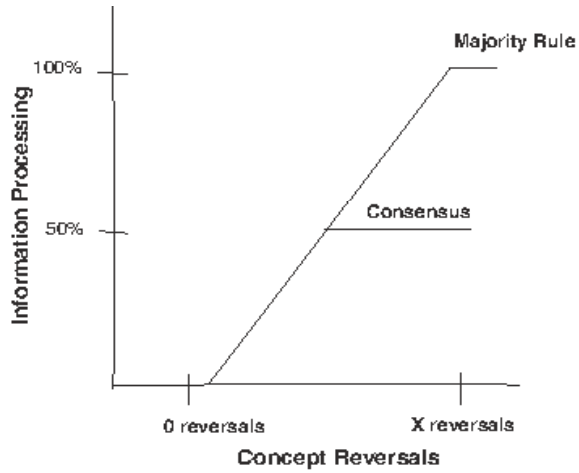
- Quantum Game Theory (Eisert et al., 1999, PRL)
  - Entanglement, Superposition
  - No field support
- Social Quantum Perturbation Theory => Bistable *R* *(Lawless et al., 2000)*
  - Entanglement, superposition -> maps (Zlot et al., 2001)
  - Democratic d.m. (DDM) -> science, politics, courtroom law (Lawless & Schwartz, 2002)
  - Difficult to rationalize b/c meaning arises from convergence into **bistable** beliefs

History of Quantum and Social Theory

- Traditional Signal Detection Theory = continuous ROC curves (Signal-y, S-n) (Swets, 1964)
- Quanta
  - Bèkèsy-Stevens discrete linear model v. ogives
  - Linear 2:1 relationship w/frequency, *E* effects (=> *E* levels)
  - Luce (1963, 1997) HMψ, JMψ
  - Eye as quantum *I* processor (French & Taylor, 1978)

History, continued

- Bistability (Bohr, 1955)
  - Multiple cultures
  - Differences between observation and action
- DDM => *I* processing -> # of concept reversals -> a solution ≈ SDT (Lawless & Castelao, 2001)
- Shifting between *E* levels (cooperation = ground state; competition = excited first state)



Bistability Fundamentals

- Organism exists superimposed simultaneously as
  - Observer and actor
  - Individual organism and member of a group
  - Member of a group A and group B
  - Superposition represented as $\alpha|\uparrow> + \beta|\downarrow>$, where prob($\uparrow$) = α^2 given that $|\alpha|^2 + |\beta|^2 = 1$
- Measurement -> bistable shift to observer (static *I*) or actor (action $I = \Delta I/\Delta t$) (Gibson, 1986)
- Measurement -> individual Event Histories = $K_{EH} = K_{\chi} \neq$ reconstruct interaction (Zeilinger, 1999; Carley, 2003

Models of Bistable (quantum) *R*

- Given Bankes (2002) concerns:
  - Models must be at least as complex as the social
  - However, ABM predictions cannot be validated
- Feynman (1985) found similarly:
  - Traditional computers model quantum *R* w/difficulty
  - Quantum computers easily model *QR*
- Maybe Quantum ABM's could easily model *SR*
- ABM's based on *QR* => parallelization + QIP -> + increased power

Bistable *R* (e.g., Faces-Vase Illusion) **=> Multiple Frames**

1. Object acquisition based on + *E* -> convergence (γ waves => + *E*)
2. **(**K&T, 1981**)**: "Framing" => Convergence of beliefs reduces dissonance; e.g., "culture" (Bohr, 1955)
3. Participants can perceive "frame" A or B, but not both simultaneously (Cacioppo et al., 1996)
4. Convergence marginalizes divergent groups (Campbell, 1996)
5. Opposite K&T frames -> tension, disagreement, or conflict (Janis, 1982)
6. Managing opposed frames = argument -> *I* processing, optimal d.m. (compromise) (Schlesinger, 1949)

Interdependent (Social) Uncertainty Relations

- We are actors or spectators (Bohr, 1955)
- Convergence of ingroup worldview increases outgroup uncertainty (Tajfel, 1970)
- Let $\Delta a = \Delta I/\Delta t$ = action uncertainty;
- Let ΔI = information uncertainty;

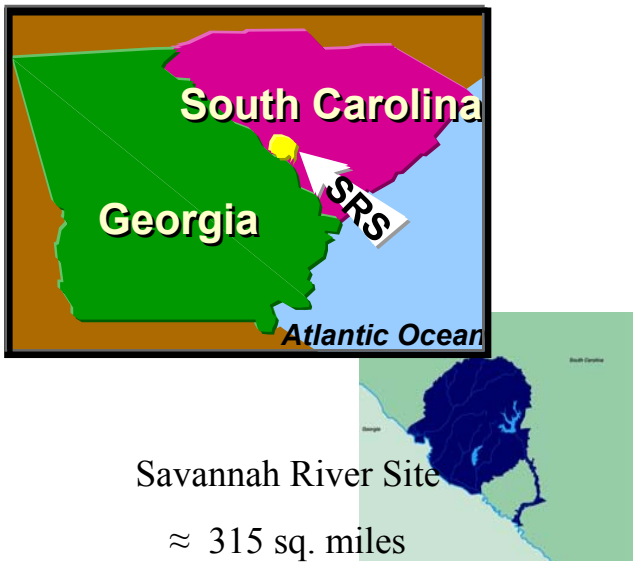
$$\Delta a \Delta I \geq c \qquad (1)$$

Solving $\Delta a \Delta I \approx c$

- Case i: $\Delta I \rightarrow 0$, $\Delta a \rightarrow \infty$
- Results:
  - 125 USAF combat pilots in eight 3-min ACM encounters against machines and humans. Book *K* of air combat = multiple-choice exam. Experience = flight-time histories + training.
  - Multiple regressions => experience predicted wins-losses (R=.34, p<.03), total aircraft relative E availability (R=.37, p<.01), and expert rating of performance (R=.47, p<.0001).
  - **Book *K* did not predict wins-losses, *E* availability, or expert ratings** (R=0.0, p n.s.). (Lawless et al., 2000, SMC)

Case ii: $\Delta a \rightarrow 0$, $\Delta I \rightarrow \infty$ [Nuclear Waste Cleanups]

- Theory => adversarial decision-making (e.g., courts, science)
- **Contrast SAB (competition) v. HAB (consensus)**



Savannah River Site

≈ 315 sq. miles

t-tests: SAB (competition) versu HAB (consensus)		
1. Demographics	More Minority members	2.9 **
2. Member perceptions of Site	Site needs advice	4.7 **
	Concurs with Site	5.3 **
	Site progressing	1.6
	Trusts Site	1.6
3. Member perceptions of members	Internal conflict	-2.1 **
	Likes consensuses	-3.3 **
	Trusts other members	0.6
	Members share ideas	3.2 **

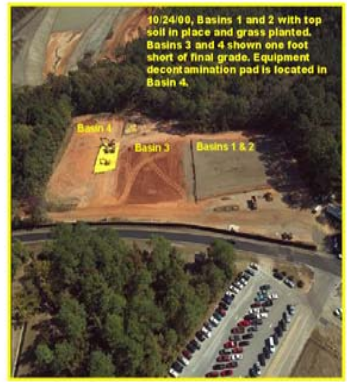
Conclusion: "competition of ideas" improved nuclear waste cleanup + trust (Wendt, 1999); neutral participants decide outcome

SAB Success Examples

- 2 HLW tanks closed
- 1200 vitrified HLW cans
- Plug-in-Rods (borrowed from Hanford)
- Old burial ground closed
- 2500 tru drums v 551 drums

Contaminated

Remediated



SRL basins before-after: SAB saved 2 years on cleanup -> plug-in-rods (i.e., *idp*'s -> *wdp*'s)

DWPF/GWSB

F&H and LLW-BG

(Lawless et al., 2000, SMC)

Case ii: $\Delta a \rightarrow 0, \Delta I \rightarrow \infty$ [Inter-Nation Competitiveness]

	1	2	3	4	5	6	7
1. SW	1.0						
2. H	-.72**	1.0					
3. E	.73**	-.66**	1.0				
4. pc's	.93**	-.70**	.78**	1.0			
5. web	.61*	-.37	.74**	.71**	1.0		
6. EF	.88**	-.79**	.70**	.84**	.48	1.0	
7. CPI	.81**	-.72**	.73**	.89**	.60*	.82**	1.0

- **Summary: Increased SW, H, E, EF, reduced corruption** (versus Skinner, 1978, Worchel, 1999)
- Trust in Congress > EU (W.E. Forum, 2003)
- Notes **(**Lawless & Castelao, 2001, IEEE**):**

SW Scientific Wealth (May, 1997, Science)
H Poor Health (infant mortality per 1000 births; World Bank)
E Energy consumption in Energy kg OE per capita, World Bank
pc's personal computers per 1,000 capita, World Bank
web Internet web hosts per 10,000 capita, World Bank
EF Economic Freedom, Cato Institute w/Milton Friedman
CPI Corruption Perceptions Index, Transparency International

Case ii: $\Delta a \rightarrow 0, \Delta I \rightarrow \infty$ [U.S. Airspace System]

QuickTime™ and a
GIF decompressor
are needed to see this picture.

Convection Weather = Single most disruptive force within NAS

NCWF: Computational Forecasts (**$\Delta I \rightarrow 0$**)

Sep 3, 2001: 19Z

QuickTime™ and a
GIF decompressor
are needed to see this picture.

21Z

QuickTime™ and a
GIF decompressor
are needed to see this picture.

QuickTime™ and a
GIF decompressor
are needed to see this picture.

Collaboration Forecasts: CCFP (**$\Delta a \rightarrow 0$**)

FAA's Validation Results (FSL RTVS)

Product	Issued (UTC)	Forecast Length	Human/ Automated	Ave area Forecast covered	Average PODy	FAR	Bias
CCFP	1500, 1900	1,3,5 and 3,5,7 h	H	5.2%	.28	.84	1.9
Convective SIGMET	Hourly	1,2 and 0-2 h	H	2.3%	.28	.70	1.0
SIGMET Outlook	Hourly	2-6 h and 6 h	H	14.9%	.04	.92	6.1
NCWF	5 min	1 and 2 h	A	0.5%	.09	.41	.10

Table 1. In this table, better forecasts have a lower convective area covered by the forecast, a greater PODy, a lower FAR, and a Bias closer to one (bias greater than one over-predicts convection; less than one under-predicts). [SIGMET is significant meteorological information; NCWF is the automated computer generated numerical prediction; POD-y is the probability of a forecast being observed = Y(forecast)Y(observed)/(YY+NY); FAR is the false alarm ratio = YN/(YY+YN); and Bias is the tendency to over or under predict convection = (YY+YN)/(YY+NY).]

Forecast Conclusions:

- **Experts Best; CCFP a close 2nd; NCWF worst**
- **However, no conflict w/ CCFP versus SAB**

(Lawless, 2002)

Decision-Making: Conclusions

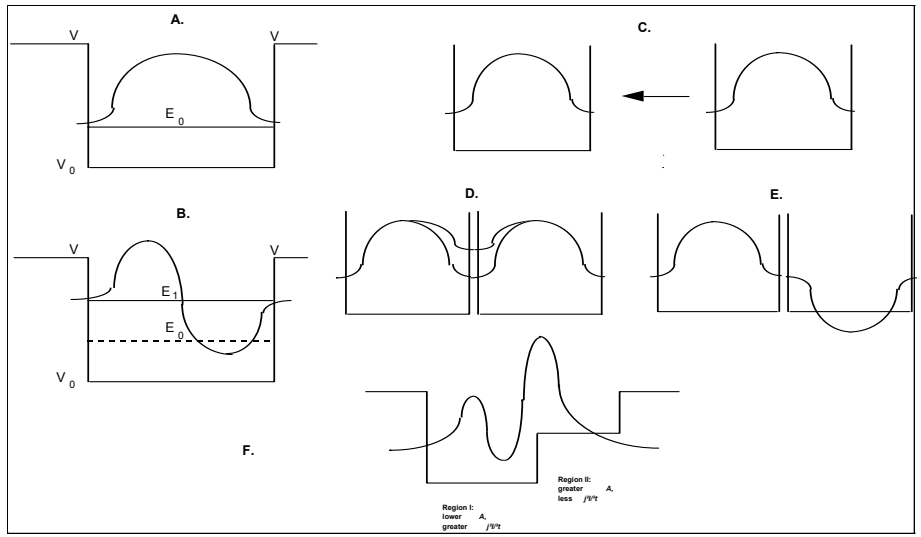
- Bistable *R* => orthogonal operators (competition of ideas) => dissonance arousal + neutral judges => superposition -> + *E* and *I* processing => optimal d.m.
- Resonance tunnels thru social barriers (compromise)
- Converts *idp*'s to *wdp*'s
- Solution ≈ best fit (from increasing number of participants => more Fourier components)

Revising Equation (1)

- Given reactance, j, $\Delta a \Delta I = \Delta\ (\Delta I/\Delta t)\ \ \Delta t/\Delta t\ \ \Delta I = j\ \Delta\ (\Delta I/\Delta t)^2\ \ \Delta t$, giving
- $$\Delta \boldsymbol{a} \Delta \boldsymbol{I} = \Delta \boldsymbol{t} \Delta \boldsymbol{E} \geq \boldsymbol{c} \qquad (2)$$
- Case iii: $\Delta t \rightarrow 0$, $\Delta E \rightarrow \infty$ (e.g., big court cases & science)
- Case iv: $\Delta E \rightarrow 0$, $\Delta t \rightarrow \infty$ (e.g., vocal resonance)
- Human cognition
  - 40 Hz Gamma waves => object acquisition ≈ 75-150 ms
  - 16 mm movie film ≈ 62.5 ms
  - $\Delta t \Delta E \geq c = \Delta t \Delta hw = h$
  - $\Delta t = 1/\Delta w = 1/(40\ \text{Hz}) = .025\ \text{s} = 25\ \text{ms}$ (Roger Penrose)

Community Set-Point Theory (C-SPT): Square wells of *E* form emotion = set points => SPT (e.g., food, lotto; Diener & Oishi, 2000). Baseline E_0 associated with emotion potential energy, *V*. As excitation *E* attempts to redefine meaning, *V* keeps beliefs stable. C, D, E: Groups. **C-D illustrates E_0, D-E shows first excited state, E_1**. F. **Experts at I, Novices at II**

(Landers & Pirozzolo, 1990; Lawless & Chandrasekara, 2002)



Conclusions:

- 1st model of a group ≠ Σ disaggregated individuals
- Models experts versus novices
- Models *ΔE* levels for groups

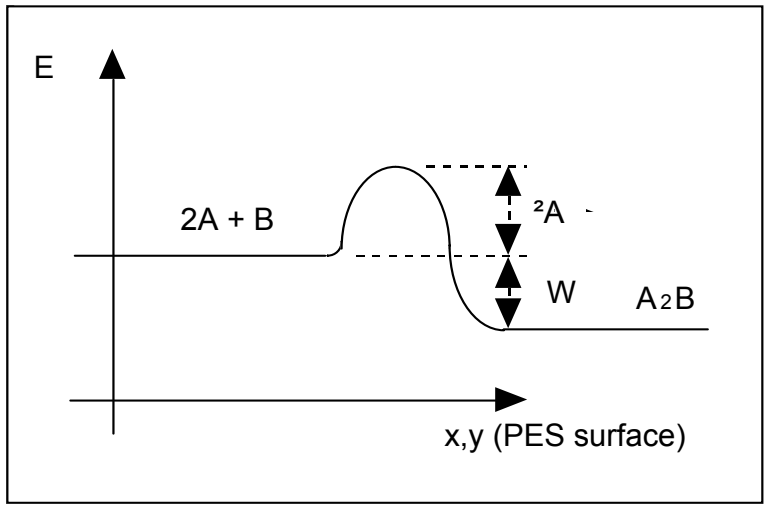
IDFT (organization, mergers, and *K*)

- $E^{PES}(x,y) = min_{z,Rorg}\, E^{TOT}(x,y,z,R_{org})$ (3)
  - Function, hierarchy, organization (Sallach, 2002) => **Hamiltonian** (Lyapounov)
- $H = H_0 + H_{int}$ (4)
  - $H_0 = E_b^A \sum_k n_k + E_b^B \sum_k m_k + V^{A\text{-}B} \sum_k n_k m_k$ (0 if empty, 1 if occupied)
  - $H_{int} = 1/2 V_{1n}^A \sum_{k,a} n_k n_{k+a} + 1/2 V_{2n}^B \sum_{k,b} n_k n_{k+b} + 1/2 V_{1n}^B \sum_{k,a} m_k m_{k+a} + 1/2 V_{2n}^B \sum_{k,b} m_k m_{k+b} + 1/3 V_{trio}^B \sum_{k,a,a'} m_k m_{k+a} m_{k+a'} + \ldots$

Conclusions:

- W/growth heterogenous island stresses reduce from Hi to Low (**terrorism**)
- Replaces Utility theory: $\Gamma_P = n_A n_B\, a\, \sigma_{AB}\, exp\,(-\Delta A/k_B T)$ (5)
- **Interaction cross-section $\sigma_{AB} = \alpha_\chi(\omega^4/(\omega^2-\omega_0^2)^2)$** (6)
  - Friends ≈ vocal harmonic oscillators => **resonance** = HXS
  - terrorists cooperate to preclude warning observers = LXS

$E^{PES}(x,y) = min_{z,R\text{-}org}\, E^{TOT}(x,y,z,R_{org})$; explains in g.t. why $\sum x_i \neq$ organization



(Lawless & Chandrasekara, 2002)

1. E_{min}:

- Social Loafing (Latane, 1981)
- Audience Skills enhancement (Zajonc, 1998)
- Terror Mgt (Rosenblatt et al., 1990)
- Health (House et al., 1988)

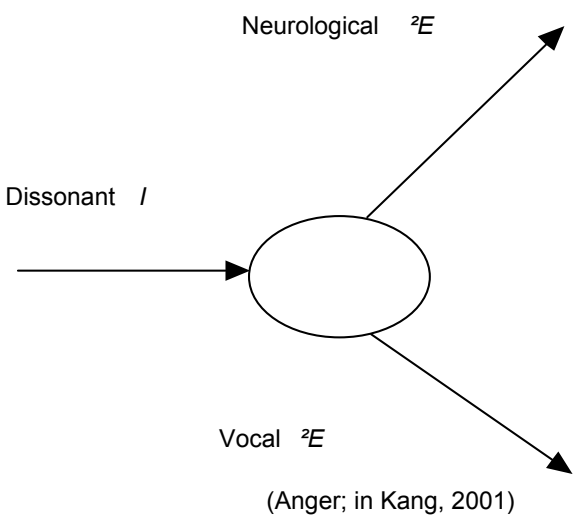
2. E_{min} => Perturbation Theory (Lewin, 1951)

- Attacks (cyber, business pricing, war)
- **Only way to M(K_{EH})**

Future Research

Perturbations Theory (Picard's Liquid model of Emotion -> Spectrum)

$\Delta E \approx h * \Delta v$ (Penrose: 40 Hz, gamma)



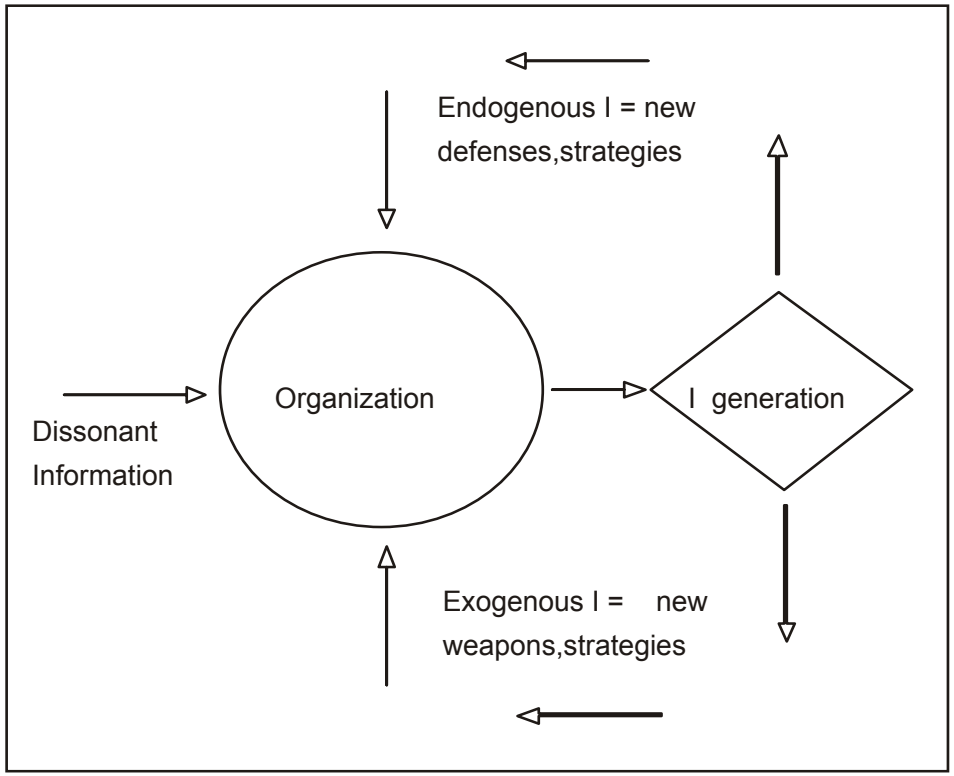
$\Delta E \approx h * \Delta v$

(Kang: Anger ≈ + 100 Hz)

Individual versus group Measures

1. Neurophysio-psych (SR's, qEEG's, fMRI's, EMG's, Lie Detectors, etc.)
2. Ground States (Single, Joint)
3. Anger (S, J)
4. Relationships (U-AZ, Foster)
5. D.M. (S, J)
6. Entanglement ***(interaction F's stronger than context F's => EPR test: entangled subjects separated: M(1) => State(2))***

Quantum Perturbation Theory

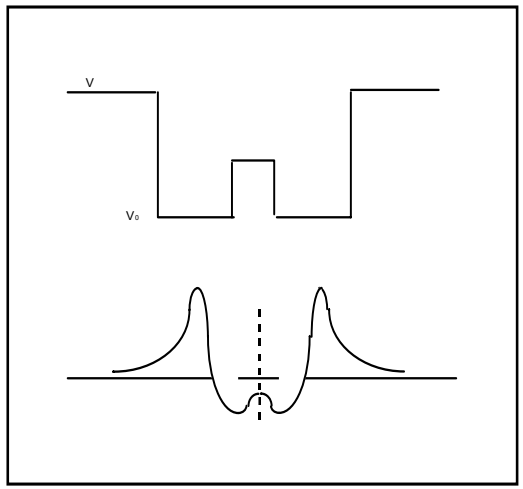


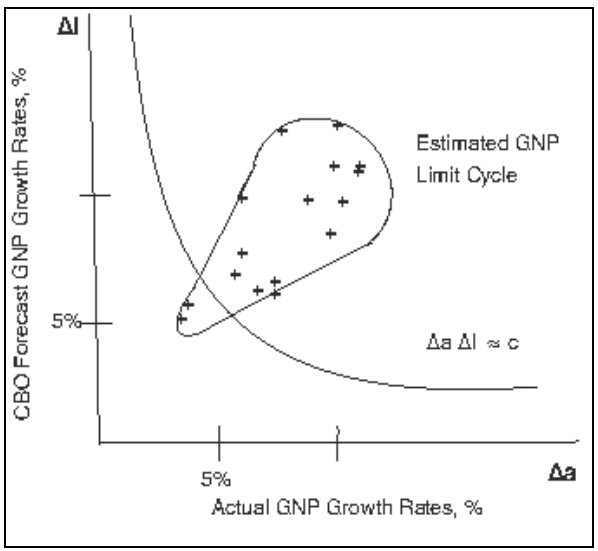
After perturbations, an organization uses endogenous feedback to defend itself. A competitor uses exogenous feedback to defeat the organization. In general, the quicker one wins; e.g., in 2003 in the war with Iraq, coalition decision-making and implementation of those decisions occurred faster than Iraq's Defense Forces, causing the latter to panic.

Current Research (links to Markovian Processes)

1. Predicted-Actual CBO two-year average growth rates for GNP (USA), 1976 to 1992 (CBO, 1999; in 1992, CBO switched to GDP). The estimated limit cycle is for GNP data; it contracts towards origin (increasing predictability), and expands away (increasing choice). (We have not calculated the dimensions of this phase space or attractor to see if chaotic, but in a contrast with a CDM economy, we expect a market economy to have a higher dimension; e.g., Nicolis & Prigogine, p. 281.)

2. For curve $\Delta a \Delta I \approx c$, the value for c is arbitrary, but predicated on no feedback.





1. Bifurcations: The double square well model represents E barrier between opponents and neutral middle, overcome in democracy by compromise or persuasion (e.g., even for BMW or GM to succeed, a company must appeal to neutral middle). Feedback $(\Delta I \rightarrow \infty) \approx$ fluctuations -> bifurcations when $\sum \boldsymbol{F \approx 0}$, giving $\tau = exp(N\Delta V) \Rightarrow$ $\tau_{\text{majority rule}} << \tau_{\text{consensus}}$ -> regulation [$\mathbf{M(K_{EH})}$]

2. *dI/dt* and *dX/dt* are Kolmogorov coupled nonlinear equations + $F_E(t)$ as forcing function is predicted stronger for CDM (dampening) than democracy (stochastic resonance) => $\boldsymbol{K_{EH}}$)

3. Regulatory Control (Lyapunov exponents => divergence from feedback) = f(environmental stability, **productivity,** $\boldsymbol{K_{EH}}$)

4. λ = wave length ≈ organizational distances (no threat -> + cooperation w/less I dense, + K_{EH}; competition + I density, -K_{EH})

Conclusions

- Observation interacts with *R* (Pauli), collapsing State function (*K* of *R)* -> new *K* (Laurikainen, 1997)
- But K_{EH} cannot reconstruct *R* (Zeilinger)
- Org's under attack + *E* -> -λ => tighter, closer groups
- C-SPT: If level of fluctuations are constant, given a stable env: => + diversity but w/- dyn stability (evolution wins); given an unstable env: - diversity but w/+ dyn stability (dynamics wins; e.g., survival mergers)
- Thus, while prediction may not be possible (deterministic chaos from density dependent signals), regulatory control or management of MAS is possible (i.e., limit cycles)

Additional Reading

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