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BISTABILITY, NASH EQUILIBRIA, RELATIVELY DARK COLLECTIVES, AND SOCIAL PHYSICS: MODELING THE SOCIAL BEHAVIOR OF TEAMS

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□ *To reduce costs and increase effectiveness, a new theory is being sought to transform teams, enterprises, and systems with computational approaches of complex social behavior that create "smart" systems. A new theory is necessary because, unlike the physical sciences, the economic, organizational, and, in general, social sciences have no overarching theory of fundamental principles that build from individuals to collectives. Instead, social science is mostly a-theoretical, derived primarily from ad hoc studies of individuals. Many of the "rational" results emerging from methodological individualism models at the collective level are misleading, such as collaboration, supposedly associated with increased trust and social well-being; instead, we have found that the more collaboration is isolated from competition, the more knowledge generation is reduced, illusions increased, and social welfare made dysfunctional. With our theory, still crude at this stage of development, using bi-stability, a simplified form of interdependence, we have constructed a theory of the dynamics of collectives that naturally arise from illusions along with natural measures for the metrics of organizational performance based on relative (entropy) darkness. However, at the unit level, unlike building a bridge or robot, while predictions about social behavior are possible, our theory of interdependent uncertainty indicates that traditional explanations of social behavior are both unavoidable and irreducibly incomplete. We discuss the implications for enterprise transformation. Our theory will be applied in a future companion article.*

Keywords measurement uncertainty; interdependence (bistability); modeling; metrics

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INTRODUCTION

This article provides a progress report on the development of our theory of social interdependence. We review the failure of traditional social science of groups to justify the new theory of interdependence that we are developing. In our theory, we borrow as needed from other fields, including quantum mechanics, biology, and engineering. After proposing our theory, we review our future program of research in the following topics:

1. The unsolved problem of social aggregation of individuals into a collective;
2. How unit beliefs at the individual level rotate into and out of alignment with unit behavior at the team, organization, and system levels;
3. How our proposal for emotion is incorporated into collective decision-making;
4. How we hope to construct "smart" bistable agents as part of hybrid teams (by hybrid teams, we mean teams in arbitrary combinations of humans, machines, and robots) that can act interchangeably with human teams; and
5. We speculate on how to visualize an enterprise as an engine that replaces game theory with the physics of energy and uncertainty.

To set the stage, we review the traditional approaches to the research of teams, enterprises, and systems; in general, we agree that much of conventional social science theory is subjective. For example, in what has come to be known as "critical systems thinking," Ulrich (2002) constructed a social process for researchers to seek consensus on what constitutes a social fact without regard to physical reality; however, physical network science flatly rejects subjectivity (Barabási, 2012). Instead of providing a path forward, we and others have concluded that both of these traditional approaches to teamwork are flawed (Bell, Kozlowski, and Blawath, 2012; Lawless, Angjellari-Dajci, Sofge, Grayson, Sousa, and Rychly, 2011). In contrast, we combine subjective and objective elements in our model of social reality (e.g., a simple thought experiment illustrates the value of including both subjective and objective aspects of social reality: two or more passengers arguing to decide when and where a car should depart an expressway via an exit ramp). While the theory of the group has been elusive, without a new and improved theory based on engineering principles, the metrics to transform a group into a team or enterprise, whether hybrid or not, is more than likely to be no better than ad hoc and suboptimal.

In our future companion article, we apply what we have learned in this article to evaluate one of two projects or both: the U.S. Department of Defense's (DoD's) electronic Institutional Review Board (eIRB), one of the largest in the world, and cybersecurity for firms, industry, and DoD (for an earlier version, see Lawless, Moskowitz, Mittu, and Sofge, 2015).

THE PROBLEM: THE COMING AGE OF SMART SYSTEMS

Literature Review

Organizational communities are searching for innovative theory as part of a new approach to the computational, mathematical, and engineering of complex social behavior (e.g., Schweitzer, Fagiolo, Sornette, Vega-Redondo, Vespignani, and White, 2009). Such a theory could help with the design of humanly "smart" systems. But unlike mathematics and the physical sciences, the social sciences have no overarching theory of fundamental principles to scale from individuals to teams and to collectives (Clarke and Primo, 2012). Rejecting calls by Ulrich (2002) to seek consensus on what constitutes a social fact, to move into a future governed by the fundamental interactions between humans and smart systems, we propose a new model of human teams based on the mathematics of interdependence to determine whether the "smartness" in collective systems is effective and efficient (e.g., autonomous sensor systems already utilize adaptable machine intelligence with internal standardized operational criteria built in to reduce errors and to measure performance; IEEE Spectrum, 2010).

Most of social science is atheoretical, derived from ad hoc studies of individuals known as methodological individualism (MI). We believe that MI needs to be replaced with engineering principles. However, we need to address why MI is pervasive in mainstream social sciences. We believe that MI is pervasive because it is the way that humans think logically (Ahdieh, 2009), it is intuitive (e.g., common sense), and the confirmation bias of individual thinkers makes it difficult to reject (Darley and Gross, 2000), the combination of which leads to a convergence of rational conclusions that are common to consensus seeking (Lawless et al., 2010).

The primary studies that use MI are economics (e.g., game theory) and social sciences (Ahdieh, 2009). As the focus here is on teams and enterprises, from game theory, the folk theorem assumes that a group is equal to the sum of its parts (Tirole, 1988), contradicted famously by Lewin (1951, p. 192): "The whole is greater than the sum of its parts." Both game and social theory promote cooperation, but we have found that many of the "rational" results at the collective level can be misleading, such as collaboration, which, preferably isolated away from competition, is supposedly associated with increased trust and social well-being. Axelrod (1984, pp. 7–8) believed that competition reduced social welfare: "the pursuit of self-interest by each [participant] leads to a poor outcome for all" and can be avoided, he argued, when sufficient punishment exists to discourage competition. But Darwin (1871/1973) stressed the opposite, that cooperation in a competitive environment is important to those in collectives who were "ready to warn each other of danger, to aid and defend each other" to survive. In agreement with Darwin, Bowles (2012, p. 877) concluded that "Whatever the balance of cultural and genetic factors in the evolution of human cooperativeness, between-group conflict almost certainly played a pivotal role." And Hackman (2011) found that in-group competition made groups more creative.

Generalizing from Ridley's (2011) idea about collaboration in a group isolated from competition, when cooperation is enforced, the information available to an isolated group is reduced, the illusions among its members are increased, and the more dysfunctional its social well-being becomes, as in North Korea and China; e.g., China is one of the most polluted countries on the planet (fully 90% of its shallow groundwater is contaminated (Qui, 2011), and China

> still doesn't have a grip on food safety. Not even close: Recent safety scares have included chickens injected with hormones and antibiotics, the recycling of used cooking oil at restaurants, and the discovery of plasticizers in a Chinese alcohol drink. (Sternberg, 2013)

As a striking contrast between traditional theory and practice, although game theory predicts that while cooperation between two competitors leads to higher payoffs for them, Western society defines cooperation between two businesses as collusion (e.g., Apple and e-Books versus Amazon; NPR, 2012); further contradicting game theory, the competition between two businesses can lead to extraordinary improvements in social welfare. For example, consider the competition between Apple and Microsoft (MS): In 2000, Bloomberg valued MS at over $500 B and number one in its market, with Apple at $16 B; their positions were reversed by 2013. Then Bloomberg estimated the value of MS at $218 B, and "Apple is in rare company. It is the sixth U.S. corporation to reach the $500 billion milestone, and the only one to be worth that much at current prices" (Culpan, 2011; Svensson, 2012).

In addition to the theoretical limitations unique to game theory, there are other severe problems with MI. The following list makes little sense in MI:

- mergers to prevent organizational collapse (e.g., the collapse of Blackberry [Gallagher, 2013] and Genzyme's collapse in its market valuation following news of contamination among its rare-disease treatments combined with Sanofi's inability to innovate in its drug pipeline motivated a hostile merger offer by Sanofi [Nicholson, 2011]);
- maintaining the borders of an opponent ("Israeli security officials point to an erosion of Egyptian sovereignty and authority in the vast, sandy

expanses of the Sinai desert, particularly in the year since the Egyptian revolution" [Kershner and Kirkpatrick (2012), n.p.]);

- determining how an organization or system reacts to unexpected perturbations (e.g., the patent counter-lawsuits by Apple and Samsung [Sayer, 2012]);
- thefts of proprietary information;
- senseless murders; and
- how organizational darkness from the relative reduction of entropy increases with organizational success (Lawless et al., 2011; compare the images[1] of relative darkness at night in satellite photos of North Korea to reflect its stalled social evolution arising from enforced cooperation under its autocracy versus South Korea and neighboring China).

Theoretically, MI cannot properly explain the following:

- the function of mergers;
- their role in organizing human society, for examples, MS's

> deal with Nokia is an apparent acknowledgment that MS needs a stronger hand to play in the mobile-phone business, where it is playing catch-up to Apple and Google Inc.... For Nokia, the onetime leader of the mobile-phone business, the deal is a capitulation to the harsh realities of its deteriorating position—a sign that management concluded it is unable to take on rivals like Apple and Samsung on its own (Ovide, 2013);

- what went wrong when mergers do not function well (open questions exist about the value of mergers; Webber et al., 2010);
- why peer review improves the practices of scientists (Stern and Walker [1992] recommended scientific peer review in post-Soviet states to save its resources, improve its policy analyses, and motivate a competition of scientific ideas; initially, their recommendations worked but are threatened today; from the National Research Council [NRC, 2006]: All reports undergo a rigorous, independent peer review to assure that [scientific] conclusions are adequately supported [NRC, 1997; paraphrase];[2]
- why conflicts of interests devalue scientific practices ("conflicts of interest [may occur when] an independent observer might reasonably question whether the individual's professional actions or decisions are determined by considerations of personal gain, financial or otherwise" [Stanford University, n.d., n.p.]); or
- the function of emotion in social dynamics (Lawless, 2016).

In general, traditional organizational science has failed (Pfeffer and Fong, 2005). Yet, complex and smart systems to control interdependence are being built (e.g., the rapidly approaching future of driverless cars; Crovitz,

[2012]), but they remain difficult to control, with much of the mathematics unknown (Jamshidi, 2009), explaining why Barabási (2009) called for a new model of human behavior to study complexity. Similarly, Helbing (2013), while recognizing the danger caused by global interdependencies, called for "a paradigm shift towards a new economic thinking ... [since] our current financial and economic problems cannot be solved within the current economic mainstream paradigm(s)" (n.p.) If such a new theory of "smartness" is successful, in addition to control, smart systems can be used to measure the performance of teams, whether in submarines, eIRB systems, or hybrid teams of humans, robots, and machines (Lawless et al., 2010). New theory is necessary because current theories of team performance are "fraught with confusion" (Bell et al., 2012). Yet, as resources decrease, approaches that rely on teamwork and multitasking become more important. With our new theory, we aim to provide the missing tools that can produce the metrics to measure and transform teams and enterprises.

INTRODUCING THE NEW RESEARCH PARADIGM OF SOCIAL PHYSICS: BISTABLE ILLUSIONS

One of our first findings with social physics was the discovery of a tradeoff between competition under majority rules versus the cooperation under consensus rules for citizen advisory boards advising on the cleanup of nuclear wastes across the United States (Lawless et al., 2010). Majority rules produced faster and more concrete recommendations, but they also generated more conflict; e.g., we attributed the U.S. Department of Energy's (DOE's) mismanagement of its military nuclear wastes to a lack of competition in its decision making (Lawless, Akiyoshib, Angjellari-Dajcic, and Whitton, 2014). To accelerate the DOE's cleanup of Savannah River Site (SRS), Aiken, SC, since 1992, we encouraged the DOE to adopt majority rules for its citizen advisors at SRS, resulting in significant reductions of risk from transuranic wastes and high-level reprocessing wastes at SRS. In contrast, earlier research by the NRC (1994) promoted consensus-seeking; today, the DOE's Hanford citizen advisory board relies on consensus, but it has been unable to accelerate the cleanup of Hanford, WA (Lawless et al., 2014). With our crude but novel mathematical model, we have accounted for bistability and uncertainty, modeling orthogonal tradeoffs, social-psychological (cognitive) rotations of neutrals, Nash equilibria (NE), knowledge generation, and the value of perturbations among enterprises as a source of information. These findings are described next.

Bistability and Uncertainty

Lewin (1951, p. 3) founded social psychology and social dynamics with the goal of producing a social physics of human behavior. He was the first to claim that interdependence in a social whole makes a group greater than the sum of its parts. Bistability is a simplified form of interdependence. Interdependence is mutual dependence between two or more parties, i.e., not only inside of a firm among its workers (Smith and Tushman, 2005) but also a firm and its suppliers and distributors.

With first principles on the dynamics of collectives, we have found that a relative darkness emerges with the reduction of structural entropy below the baseline emitted by the sum of the individuals participating in a collective (viz., per Wickens [1992], individuals multitask poorly; in contrast, multitasking is the function of teams; Ambrose [2001]). To create social dynamics mathematically, borrowed from engineering and population dynamics (Lawless et al., 2011), we built our theory of social physics around the bistable illusions that abound in daily life (Figure 1). Contradicting the repeated, but static, games model of Axelrod (1984), and driven by centers

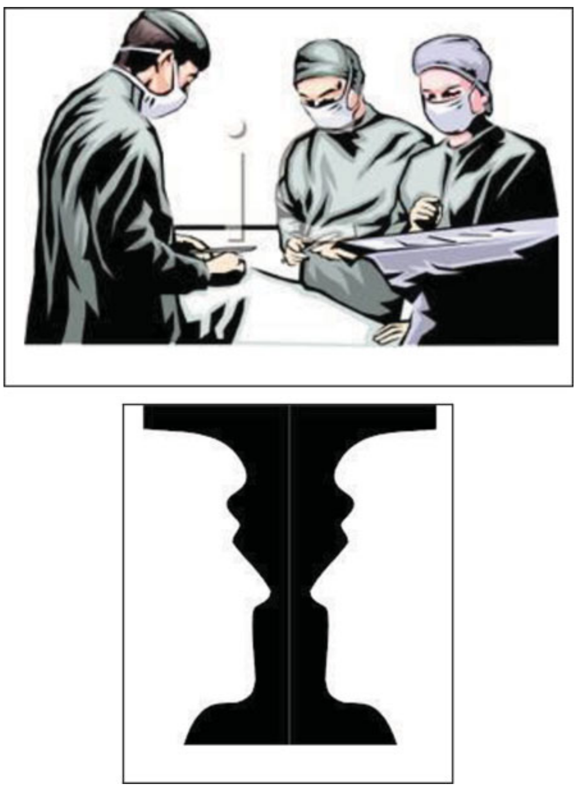


FIGURE 1 On the left, an image of a medical team performing surgery generates a stable interpretation (e.g., http://www.picturesof.net/pages/100616-172686-253048.html). Independently of culture, those who view the team should reach the same interpretation. On the right, is a bistable illusion that leads to an interpretation of either two faces or a vase. For bistable illusions, observers cannot "see" both interpretations at the same time derived from what amounts to a single data set (Cacioppo, Berntson, and Crites, 1996).

of conflict that we have renamed NE, competitive environments generate information by dampening illusions with public challenges, increasing social well-being (e.g., the lawsuits involving Goldman Sachs and Morgan Stanley that produced information about hidden conflicts of interests; Guerra [2012]).

For example, those states in the United States with more freedom spend significantly less of their money on playing lotto ($r = -0.29$, $p < 0.05$).[3] We also found that as the international competitiveness of a country increased, its favorability ratings increased ($r = -0.87$, $p < 0.05$),[4] its 10-year sovereign bond interest rate significantly decreased ($r = -0.85$, $p < 0.01$), and its association with freedom significantly increased ($r = 0.58$, $p < 0.05$). Further, we found that a higher United Nations human development index (HDI) was significantly associated with indices of more freedom ($r = 0.74$, $p < 0.05$), less inequality ($r = 0.60$, $p < 0.05$; i.e., Gini), and a cleaner environment ($r = 0.72$, $p < 0.01$).

Illusions and Social Dynamics

Illusions, we argue, drive social dynamics. As one group incorporates illusions in its attempt to attract clients (e.g., that its software product is superior, that its cars are better equipped for emergencies, that its policy for the treatment of poor in a society is superior, etc.), the other group challenges the claims whenever they believe an illusion exists (e.g., with direct contradictions, alternative interpretations, etc.). These back-and-forth competitive interactions produce social dynamics, modeled by the non-linear predator–prey equations from biology for limit cycles, but also with the linear algebra of quantum mechanics, thereby returning to Fourier pairs in signal detection theory (SDT; e.g., Cohen, 1995).

In our theory of the tradeoffs that occur daily with the decisions to compete or cooperate, illusions can be modeled with the mathematics of complex numbers, where i is imaginary (e.g., see Eq. (3)), information generation can be captured with entropy at the collective level, and the production of knowledge (e.g., algorithms) and its association with relative darkness can be captured at the group level by the increase in the skills of multitasking (Lawless et al., 2011). Despite the crudeness of our mathematical sketch, the implications are surprising.

Uncertainty

Unlike traditional theory, but as hoped by Kohli and Hoadley (2006), we expect performance metrics of systems to follow from our new theory. However, at the unit level, unlike building a bridge or robot, while metrics for and predictions about social behavior are possible, our mathematical model indicates that traditional explanations of behavior in the form of stories are the best explanations possible but are forever incomplete, an essential result that emerges from the interdependent uncertainty between action and observation (Lawless et al., 2010). In a state of interdependence, as in a discussion between two spouses, politicians, or scientists, it is common to find two mutually exclusive interpretations (stories) of a topic, event, or data under discussion; subsequently interviewing participants after a state of interdependence produces information that cannot be used to reconstruct the original state of interdependence, generating a gap in the stories that makes the information incomplete. This gap leads to long-running arguments (e.g., Palestine arguments over settlements in Israel versus the recognition of Israel as a legitimate government; Rudoren [2014]). Despite claims of truth with claims based on the logic of MI (e.g., those claimed by atheists; see, for example, Harris [2010]), the incompleteness arising from interdependence makes the scientific search for the understanding of social affairs, such as politics or the law or unsettled science, largely "meaningless," a blow to such rational theories as bounded rationality, game theory, and social learning theory (SLT).

MODELING SOCIAL DYNAMICS

Addressing behavior and observation, the quantum physicist Bohr (see Pais, 1992) adopted the principle of complementarity from the psychologist James (1890) to account for the dualism he had found to exist in the interdependent states of action and observation at the human level. James (1890, p. 206) concluded that "consciousness may be split into parts which coexist but mutually ignore each other ... [I call] complementary." Building on the conclusion by James (1890), Bohr (in Pais, 1992, p. 440) concluded that complementary properties "exclude each other" so that "different human cultures are complementary to each other" (p. 445) and that humans "are spectators as well as actors" (p. 439). Later, however, James (1912) rejected consciousness and dualism along with it, inadvertently helping the rise of behaviorism. But Robinson (2012), noting Godel's argument that human forms of mathematical thought could not be captured by formal (mechanical) systems, added, "Although dualism has been out of fashion since the advent of behaviorism ... and in philosophy ... [since James and others], the argument is by no means over" (n.p.).

Indeed, in split-brain research, Gazzaniga (2005) discovered not only that our internal observer/speaker reacts differently depending on which side of a split-brain new information is captured, but also that the internal observer is easily induced to confabulate (we create illusions). Gazzaniga further noted that the rational view of reality is an illusion—the brain integrates different sensory signals with different signal transmission rates into a unified perception of reality for the internal observer. Our internal observer also reacts to the interdependent presence of others (groups), which cannot be explained with behaviorism (Lovejoy, 1930, p. 17). Finally, Chalmers (1996) concluded that "naturalistic dualism" is necessary because mental states are not reducible to physical systems. For our purposes, we argue that interdependence between the two independent brain systems of action and observation (Rees, Frackowiak, and Frith, 1997) does not map directly from one to the other but allows illusions and misconceptions to operate, which, when challenged by the individual or others, produce social dynamics (Lawless et al., 2013).

MODELING ORTHOGONAL TRADEOFFS

Quantum Models

Our mathematical model of social dynamics employs linear algebra, essential to quantum mechanics, at the micro-level and SDT at the macro-level. Let a state of interdependence be represented abstractly by $|\psi>$. Social interdependence implies, for example, the reduction of structural entropy between two agents, two firms, or two systems with actions that are correlated. We hypothesize that entropy is reduced by the reduction in the degrees of freedom among the members of a team (Lawless et al., 2015). By definition, agents within a firm exist in a state of interdependence (Smith and Tushman, 2005). Two mutually exclusive states held in a state of interdependence, say with the orthogonal factors of action and observation, can be represented by

$$|\psi >= a|action > +b|observation >, \tag{1}$$

where a and b are state probability measures that sum to 1, assuring orthogonality. Equation (1) can represent other orthogonal but interdependent states of interest, say those between two political parties ($|\psi> = a|$*republican perspective* $> + b|$*democratic perspective*$>$), two attorneys in court ($\psi> = a|$*prosecutor's perspective* $> + b|$*defense attorney's perspective*$>$), or a firm under transformation ($\psi> = a|$*transformed firm*$> + b|$*untransformed firm*$>$).

In Eq. (1), $|\psi>$ is an arbitrary state vector. A complete set of eigenfunctions forms a basis to span Hilbert space, where measurement collapses $|\psi>$ into an eigenvector $|n>$ with probability $|a_n|^2$. If $<m|n> = \delta_{ij}$ {1, $m = n$; or 0, $m \neq n$}, and if the community operator matrix is A, then $A|\psi> = a_n|n>$. Let A and B represent the operators of two different communities. Then

$$[A, B] = AB - BA = C. \tag{2}$$

When commutator C disappears, i.e., when $[A, B] = AB\text{-}BA = C = 0$, then C represents the commutative situations where rational decision making is promoted, command decision making occurs (organizations, military), or dictators suppress NE. But in an open society, it also reflects the agreement that represents a settled conflict (e.g., the agreement between two traditional competitors in the media about the medical science of vaccines).[5]

Modeling Subjectivity

When commutator C does not disappear, arguments remain unsettled (Mercier and Spulber, 2011), $[A, B] = AB\text{-}BA \neq [B,A]$ (i.e., non-commutative), representing the disagreement we have modeled with NE producing rotations in the minds of neutral observers who act as social-psychological harmonic oscillators (SPHOs; the continuing oscillations of SPHOs result from a long-term polarization, e.g., the extended reaction to President Obama's Administration's rules under the new healthcare law).[6] Then

$$[A, B] = iC, \tag{3}$$

where ι represents an imaginary belief, an illusion or a subjective belief disconnected from reality that can be challenged by others, causing social dynamics; C is unknown (but see Eq. (5)).

Fourier Pairs, SDT, and Social Psychology

Bistability from individuals to collectives produces dynamic tradeoffs, modeled by Fourier pairs. We revise Eq. (3) to this result: $[\delta A, \delta B] = [(A\text{-}{<}A{>}),\delta B] = {<}\delta A^2{>}^{1/2}\ {<}\delta B^2{>}^{1/2}$,

$$\Delta A \Delta B \geq 1/2 < C >, \tag{4}$$

producing at the atomic level the Heisenberg uncertainty principle to reflect quantum orthogonality. At the social level, we argue that this result reproduces many social-psychological effects, especially the fundamental ingroup–outgroup effect (Tajfel, 1970; e.g., the racism and conflict between groups [e.g., Culotta, 2013]). To see this at the social level, Cohen (1995; also, Rieffel, 2007) converted Eq. (4) into the following equation at the macro level for SDT; thus, $\Delta A \Delta B \geq 1/2\ {<}C{>}$ becomes

$$\sigma_A \sigma_B > 1/2. \tag{5}$$

We adopt Eq. (5) from SDT for the social tradeoffs between orthogonal factors with this logic: Adelson (2000) found in his study of light–darkness illusions that the eye is inferior to a light photometer (i.e., SDT) because of individual and collective human experiences that shape interpretations (see

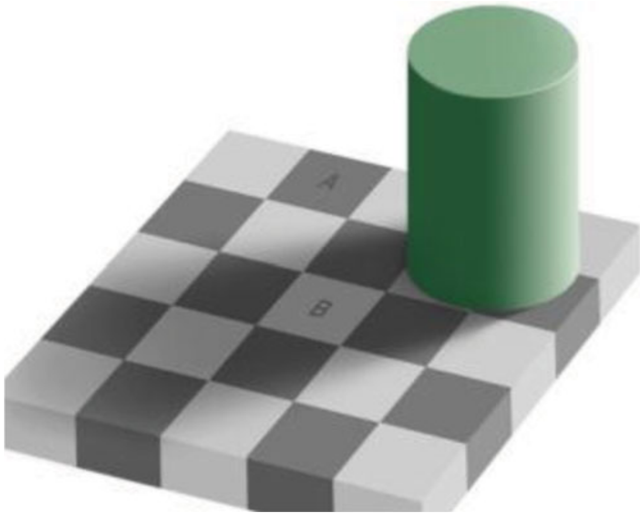


FIGURE 2 The checkerboard illusion (Adelson, 2000). The brain construes the shadowed area in checker square lettered "B" to be lighter than the darkened square lettered "A", but both are equally dark. © Massachusetts Institute of Technology. Reproduced by permission of MIT Press. Permission to reuse must be obtained from the rightsholder.

Figure 2). Based on Figure 2 and Eq. (5), we have concluded that SDT provides a floor effect for the uncertainty associated with human performance (Lawless et al., 2010).

Let Fourier pairs establish a floor for the social orthogonality as an NE or center of conflict. Accepting Eq. (5) as correct, then an interdependent state for an individual neutral's actions-observations or bistable beliefs can be represented orthogonally as $|\psi_{neutral}> = a|0> + b|1>$; but for a dyad (or larger), this becomes non-factorable equations, such as $|\psi_{dyad}> = 1/\sqrt{2}(a|00> + b|11>$. In either case, orthogonality at the individual level or non-factorability at the group level creates a measurement problem (e.g., Lawless et al., 2011); that is, measuring the state of interdependent beliefs among neutrals always produces incomplete information.

As an example of bistability in the tradeoffs in support of Eq. (5), we confirmed with multiple regressions that the size-volatility tradeoff in business is represented by Fourier pairs of Gaussian distributions based on business signals (Lawless et al., 2010). With σ as a standard deviation and $\sigma_{firm\ size}\sigma_{volatility} > \frac{1}{2}$, SDT implies that as $\sigma_{firm\ size}$ increases, $\sigma_{volatility}$ decreases, a motivation for mergers. In agreement with Andrade and Stafford (1999), SDT mathematically accounts for the motivation of mergers between organizations struggling to survive (mergers for survival occur even between disparate organizations, such as that between Georgia Health Sciences University with Augusta State University to "reduce administrative costs at the institutions and help the University System recover some of the $1 billion in state funding cuts that have been made in the past four years"; Crawford, 2012, n.p.).

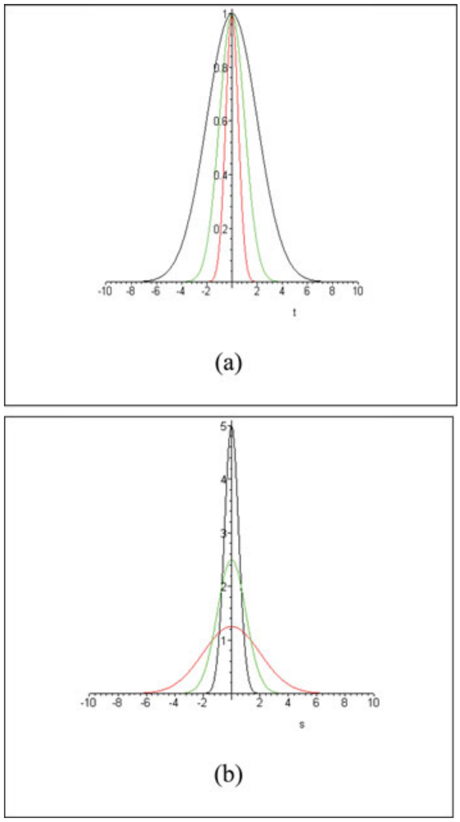


FIGURE 3 Notional Gaussian distribution diagrams and table: (a) as the standard deviation σ_f increases and (b) as the standard deviation of its Fourier transform σ_F decreases.

In Figure 3, we use Gaussians and their transformations to represent the bistable uncertainty tradeoffs between the Fourier pairs in Eq. (5):

> it is not necessary to look up the transform of a Gaussian distribution, just invert the variance. Thus, the product of the variance of a Gaussian and the variance of its Fourier transform will be a constant, the origin of many classical and quantum uncertainty relationships. (Gershenfeld, 2000, p. 20)

It can be noticed in Table 1 that even with notional data, the Fourier pairs (far right column) are roughly constant.

TABLE 1 Standard Deviations of Functions and Fourier Transforms

Color	Function	σ_f	Fourier transform	σ_F	$\sigma_f\sigma_F$
Red	$f_1(t) = e^{-2t^2}$	0.33	$F_1(s) = \frac{\sqrt{2\pi}}{2} e^{-\frac{s^2}{8}}$	5.01	1.67
Green	$f_2(t) = e^{-\frac{1}{2}t^2}$	0.94	$F_2(s) = \sqrt{2\pi}\, e^{-\frac{s^2}{2}}$	2.51	2.36
Black	$f_3(t) = e^{-\frac{t^2}{8}}$	2.66	$F_3(s) = 2\sqrt{2\pi}\, e^{-2s^2}$	1.25	3.33

Figure 3 exemplifies an orthogonal representation of a phenomenon over time (e.g., time series data and their transformation). We argue that this bistability drives dynamic tradeoffs between subjective states. For example, if we (Fourier) pair self-esteem with action by focusing greater attention on self-esteem, then variability should increase for action, exactly what Baumeister, Campbell, Krueger, and Vohs found (2005).

Modeling Social-Psychological Tradeoffs by Neutrals

Building on the concept of bistability, in agreement with others, we have concluded that opposed beliefs (orthogonality) in a free society are essential, for example, to find justice (Freer and Perdue, 1996), for the best practices of science (Stern and Walker, 1992), to resolve moral dilemmas in philosophy (McConnell, 2010), to entertain (the bistability between what a director wants to grasp for an audience versus what an audience interprets is known as "mise-en-scéne" [Sarris, 1968/1996]), to best educate about political choices (Coleman, 2003), and for the stability of government (Madison's Federalist Paper No. 10 [Hamilton, Madison, and Jay, 1945]; however, reflecting a difference as scale increases, in the United States, the rules governing politics tend to be locally unstable and globally stable [Lawless et al., 2011]). When opposed beliefs in entertainment, politics or sciences are interesting, they attract and engage what are known as audiences for extended periods of time. These audiences are usually neutral to the opposed beliefs. Even stock market pickers are more neutral to their choices than to whether they can make money (Lawless et al., 2010). Conflict produces bistability; in free societies, it drives rotations (i.e., social psychological harmonic "oscillations"), but rotations occur primarily in neutrals (e.g., neutrals often determine the outcome of political elections [e.g., Rutenberg and Thee-Branan, 2010]), less often in ideologues or true believers (Lawless et al., 2015). In addition, rotations promote learning (Dietz, Ostrom, and Stern, 2003), political judgment, and social evolution (Lawless et al., 2011).

NE, Subjectivity, SPHO Rotations, and Knowledge Generation

The problem with linear algebra is that to use Hilbert spaces, it must be possible to fully characterize the states of agents, but self-reports are subjective, making that option problematic. Alternatively, we looked at impacts that the SPHO rotations should have caused from bistable behaviors across a system (e.g., audiences rotate into a "synchronized" state while watching a movie together [Hasson, Nir, Levy, Fuhrmann, and Malach, 2004]). We use rotations to describe the shift from a belief to its opposite belief. Bistability should aggregate individuals who are believers (ideologues) and non-believers into ingroup–outgroup collectives (Tajfel, 1970). Across a social system, neutrals should float back and forth between these collectives as they are attracted by information generated from ingroups–outgroups in response to common, daily perturbations that regularly occur over time. The ingroups–outgroups also rotate their beliefs, especially after a set of beliefs becomes associated with failure (e.g., today's Democrat Party strongly defends minority rights; in 1864; however, just as strongly, the Democrat Party opposed ratification of the 13th Amendment to the U.S. Constitution banning slavery [Zelikow (2012)]). A similar effect occurs with technology, e.g., with Apple's new iPad:

> In pioneering a new category, it has in some ways been even more significant than the iPod and even iPhone because it has disrupted so many different device manufacturers, creating a market opportunity for other smartphone makers, a challenge to other PC makers and even potentially influencing how we may watch television in the future in a multi-screen scenario. (Choney, 2013)

ORGANIZATIONAL PERTURBATIONS

Non-Linear Limit Cycles

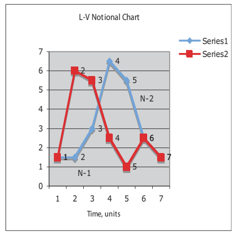
Where x represents the change in a collective due to a small perturbation, $N(t)$ for the number of members in a collective becomes

$$N(t) = N_0 + x(t). \tag{6}$$

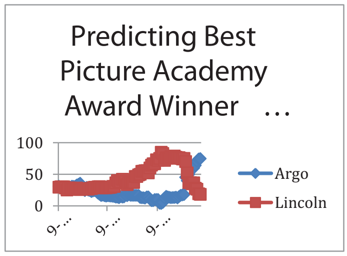
Then $dN/dt = dx/dt = F(N(t))$, where $dx/dt = ax(t)$ from a Taylor expansion indicating that for only the first term $a = dF/dN_0$, a solution for $x(t)$ is

$$x(t) = x_0 e^{at}, \tag{7}$$

and perturbations die exponentially when $a < 0$. For a multi-group community collective, the community matrix A becomes $a_{ij} = (\partial F_i/\partial N_j)$. Evaluated near equilibrium, eigenvalues $\lambda = b + ic$, in complex form for the community matrix A, are found when det $|A - \lambda I| = 0$; i.e., the community is stable iff the eigenvalues have negative real parts. The result is a bistable limit cycle (Eq. (8)). In Figure 4a, competitor organizations attract "neutrals" to their competing versions of reality; however, neither the neutrals nor the true believers can fully grasp social reality (Lawless et al, 2010). Further, the winner's model of reality eventually fails in some aspect, contributing to another limit cycle (e.g., the growth and collapse in 2012 of protests in Moscow).[7] We illustrate mathematically the limit cycle with coupled equations (Figure 4a), where x_1 represents community A, x_2 represents community B, $r_{1,1}$ represents the growth of A, $r_{1,2}$ represents the rate that at which A loses support



(a)



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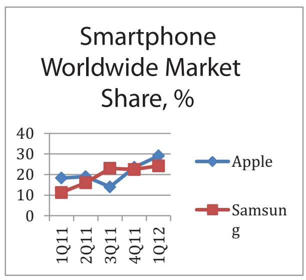
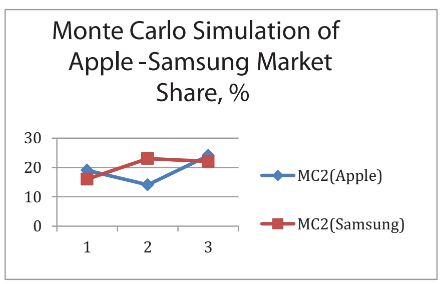


(c)



(d)

FIGURE 4 (a) Bistable data (from a simple coupled equation) generate a limit cycle N_1 versus N_2 (May 1973) are displayed over time t. Notional parameters produce "frictionless" oscillations. We interpret N_1 and N_2 to reflect competition at time 1 (and $t = 3.5$, 6, and 7; from Lawless et al. [2011, p. 296]). (b) Despite the notional data in (a), in 2013, the graph of the competition between the films *Lincoln* and *Argo* to win the Academy Award for the Best Picture of 2012 closely models the limit cycle on the left (it has 400 data points), a finding that we have since found to occur regularly in other areas governed by competition, such as political contests (e.g., the primary contest in January 2008 between Obama and Clinton vying to become the Democrat nominee for president [Lawless et al., 2010]). (c) Smartphone market share estimates by IDC (using single end-of-year data points [IDC, n.d]). (d) We replicated the limit cycle in (c) with simulated data from Monte Carlo simulations of the smartphone market share of Apple and Samsung from 2Q11 to 4Q11, averaged over 2,400 runs.

to B, $r_{2,2}$ represents the influence of B, and $r_{2,1}$ represents the rate at which B gains by defeating A:

$$\frac{dx_1}{dt} = r_{1,1}x_1 - r_{1,2}x_1x_2, \tag{8a}$$

$$\frac{dx_2}{dt} = -r_{2,2}x_2 + r_{2,1}x_1x_2. \tag{8b}$$

In our model, non-linear limit cycles reflect the public's indecisiveness caused by competition. After the public has made a decision, the limit cycle has ended (e.g., the decision on *Argo*; see Figure 4b).

Numerous other limit cycles could have been chosen (e.g., the three limit cycles obtained by averaging the polling data from October 2013 through January 2014 indicating that the American voters have not yet decided to end the Democrats' control of the U.S. Senate).[8] The non-linearity of limit cycles makes predictions impossible (to paraphrase Bohr, from Paris, predictions are difficult, especially about the future), but once a society has moved beyond a limit cycle, prediction is much easier (e.g., based on data in 2013, it was likely that Apple's iPad would have been a market leader during 2014 and that President Obama would remain unpopular during 2014; the latter data are also from Real Clear Politics).

There are several limitations to our research (for a discussion of limits, see Lawless et al. [2010]). First, MI and Gaussian distributions imply a lack of interdependence. How does interdependence affect Fourier pairs of Gaussian distributions? Second, interdependence and bistability are not equivalent—more than two sides exist for stories, more than two cultural interpretations, more than two religious explanations, and so forth. And third, interdependence may transform Gaussians into power law distributions (e.g., White, 2007, pp. 20–21). But the rate equation in Figure 5 provides an example of a power law distribution that fits our model of tradeoffs.

To model the parameters with Monte Carlo estimates (Lawless et al., 2010), we use an interaction rate equation separately for each leg of a bifurcation:

$$\Gamma = N_{1,2}{*}N_{\eta}{*}f_{1,2:\eta}{*}v_{1,2:\eta}\exp(-\Delta \mathrm{A}/ < \mathrm{A} > \approx \Delta x/\Delta t. \tag{9}$$

In Eq. (9), η is for neutrals, f measures the frequency of belief or behavior matching, v measures information exchange rate, exp (•) measures the probability that an interaction will occur, ΔA denotes the resources or skills required for an interaction, and $<A>$ is the average resources or skills available to conduct the interaction. Applied to a team, f reflects resonance from the agreement between a team's capabilities and its market opportunities (Spulber, 2009, p. 231); $v_{1,2}$ is the velocity of information exchanged

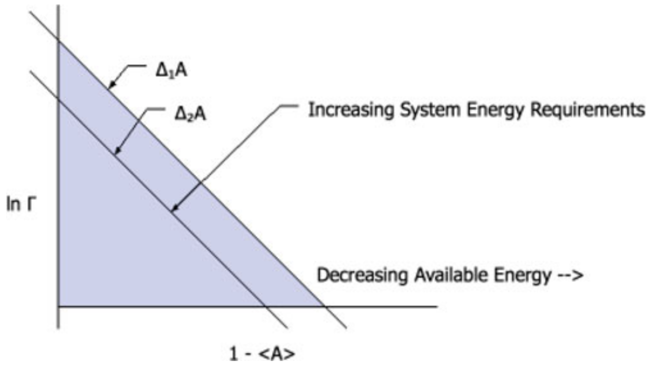


FIGURE 5 To determine whether an interaction will proceed, with notional data, considering only the exponential aspect, exp $(-\Delta A/<A>)$, from our rate equation for interactions, Γ, where ΔA is the uncertainty in the resources required for, say, a team to interact, $<A>$ denotes the average resources available in a team from its organization or system, if the resources required for an interaction increase, Γ decreases; in contrast, if the resources and time available for an interaction increase, Γ increases. Note that by keeping the available energy constant by following a vertical line downward, ln Γ. decreases; conversely, by keeping system resource requirements constant while increasing the available energy, ln Γ increases.

between the team, its clients, and its competitors; and exp(•) is the probability of an interaction based on the barriers placed against as requirements for the interaction to occur $(-\Delta A)$.

To illustrate, higher barriers to market entry from competition lead to fewer entrants into the market by competitive teams) and the average wealth (insurance, Medicare) of the users available to consume the products or services obtained from a target organization $(<A>)$. Thus, the better the average level of wealth of the users is in the pool of potential consumers available to a team, the greater the likelihood is of a team's success.

Evidence of the Effects of Interdependence

As an alternative that restructured the rational model to address the human's limited cognitive assets, with his idea of bounded rationality, Simon (1992) assumed that a full rational assessment of the knowledge held by an expert would completely determine the behavior of that expert. Contradicting Simon's expectation that "knowing" what an expert "knows" will explain the expert's behavior, indicating an orthogonality between action and observation, self-esteem for both academics and work correlate poorly (Baumeister et al., 2005), managers poorly judge their firm's performance (Bloom, Dorgan, Dowdy, and Van Reenen, 2007), book knowledge of air combat does not correlate with the results of air-to-air combat (Lawless et al., 2010), and experts and novices alike are poor at justifying their behavior (Tversky, in Shafir and LeBoeuf, 2002; Kahneman, 2011). Loftus (1980) raised significant questions about the validity of direct eyewitness accounts of crimes. Blanton, Jaccard, Klick, Mellers, Mitchell, and Tetlock (2009) found that the implicit association test (IAT), a test designed to measure racism, unexpectedly measures anti-racism. And Axsom and Lawless (1992) found that phobia experts observing subjects approaching a phobic object were unable to take the perspective of the subjects.

FUTURE RESEARCH ON ENTERPRISE TRANSFORMATION

To replace traditional game theory and SLT, our new theory has challenges ahead of it, making it high-risk research. We discuss these challenges next.

First, there are social physics of uncertainty that no one yet knows how to solve, including the aggregation of individual data into collectives (e.g., Giles, 2011), which we have estimated using Eq. (9) (we have made an advance here by realizing that when a team operates as a single unit, the degrees of freedom of its members have been reduced [Lawless et al., 2015]). Second, how to rotate beliefs into and out of alignment with behavior is unknown. Third the way to incorporate emotion into collective decision making is also unknown (further discussed later). Fourth, although the building and controlling of "smart" bistable agents to act like humans is already working well for individual agents (autonomous vehicles), it is not yet so for teams (but see our AAAI Symposium in 2016).[9] Finally, researchers must learn how to build organizational (collective) engines. With the physics of uncertainty, our approach is designed to address and provide mathematical solutions for these unknowns. We review each of these challenges in what follows.

Aggregating Individuals into a Collective[10]

Centers of conflict (NE) temporarily aggregate neutrals (Obama versus Clinton in January 2008 [Lawless et al., 2010]). NE reflect an orthogonal decision process (Benincà, Jöhnk, Heerkloss, and Huisman, 2012), linking the orthogonality modeled in Eq. (1) with the orthogonality found in population dynamics in Eq. (8). We aim to populate a mathematical model of a society with computational agents of three types (the left and right ideologues who entrain neutrals). With it, we aim to establish that a human collective, as do bees with quorum sensing (Seeley, Visscher, Schlegel, Hogan, Franks, and Marshall, 2012), inhibit or amplify their options until a threshold is reached, as the choice is selected with the highest survival value (increased social welfare). When mistakes occur, social welfare decreases (e.g., the R&D costs for pharma have doubled over the last two decades while productivity has declined, "essentially a disaster for the industry" [Service, 2012, p. 1289]). The structural differences of open versus repressed systems have a large impact on the choices that are made (Acemoglu and Robinson, 2012). Based on the research of teams in the field, Hackman (2011) agreed; he concluded that a team's structure had a greater impact (60%) than both leadership (10%) and talent (30%), increasing the likelihood that enterprise transformations can succeed by making the right transformations. For human collective systems, the best choice is more likely to be found by a society that permits an open competition among its available choices (e.g., quoting Justice Ginsburg, "as with other questions of national or international policy, informed assessment of competing interests is required" [Barnes, 2011]), indicating the value of local instability and suggesting maximum entropy production (Lawless et al., 2015). For example, societies that have more freedom are less corrupt (Lawless et al., 2010).

Defining information I and knowledge K as $\partial I^2/\partial t^2 = \partial K/\partial t \rightarrow 0$ (Conant, 1976), then $|\psi>$ can be used to search for the maximum free energy available, $A_{available}$. For example, when technology advances occur outside of an organization, leaving it vulnerable, the firm can seek to merge with another to offset a vulnerability (e.g., Boston Scientific, struggling with sales, sought to merge with Cameron Health, innovator of the world's first implanted cardioverter defibrillator system, pending FDA approval [Benoit, 2012]). But mergers often occur between the opposed cultures of former competitors, suggesting the value of (energy) barriers and boundaries to organizations (e.g., mergers are occurring rapidly in the health care industry [Kendall, 2012]). We plan to study mergers to address such questions as "Do different cultures across a collective reflect internal barriers?" and "Can barriers to communication between firm elements be found and measured?"

Rotate Unit Beliefs into and out of Alignment with Unit Behavior

Often, subjective reports disagree with action, e.g., self-esteem and academics (Baumeister et al., 2005), management and firm performance (Bloom et al., 2007), or book knowledge and air-to-air combat (Lawless et al., 2010). We propose that context and responses to queries can be parallel or orthogonal, for example, knowing that at a given time t, conservatives (A) and liberals (B) agree when viewing the same data implies that community states $[A, B]$ are commutative (i.e., parallel, where $\cos 0^\circ = 1$; e.g., opposing media sometimes agree, as over the inappropriate behavior of a prosecution);[11] otherwise, they are not commutative (i.e., orthogonal, where $\cos 90^\circ = 0$; e.g., when running debate in the *Wall Street Journal* over climate change, see its Op-Ed followed by the first reply in its Letters).[12] We suspect that agreement is possible when the mutually exclusive self-interests of opposed groups align or if there is a cash or universal value that justifies one position over another, as in scientific proof, jury decision making, or business mergers that succeed (e.g., to date, Oracle has been far more successful with its mergers than has HP [Winkler, 2012]).

Alone, self-reports cannot be relied upon (Lawless et al., 2011). The reasons are many, e.g., confirmation biases affect processing new information (Darley and Gross, 1983). As we have argued, it is possible that self-reports of behaviors and actual behaviors are mutually exclusive (orthogonal). And it is possible that reducing the state of orthogonality has survival value for tribes, e.g., normative beliefs to increase intra-tribal cooperation. We suspect that self-reports of trust and autonomy interact,[13] such that for well-defined problems, trust and cooperation are directly related, but that for ill-defined problems (e.g., science, courtrooms, politics), trust and competition are directly related. These issues with self-reports are seldom addressed; a good example of this was the killing of 16 Afghan civilians on March 10, 2012, which illustrated the uncertainties with self-reports, questionnaires, and interviews. U.S. Army Staff Sgt. Robert Bales allegedly killed the civilians in cold blood. Not speaking directly about Sgt. Bales, Gen. Peter Chiarelli, former Vice Chief of Staff for the U.S. Army, said in NPR (2012) that the Army lacks reliable diagnostic tools to screen for mental health:

> I can guarantee you that he was screened, and before he was allowed to redeploy, doctors indicated that he was fit for deployment.... Unless the investigation shows something different, this is not uncommon for a force that has been fighting in two separate theaters for over 10 years. (n.p.)

He said what the incident "proves more than anything ... is just how much we don't know" (n.p.). As Vice Chief, Chiarelli said he was frustrated by not having reliable diagnostic tools to screen for behavioral health issues. "This was a huge problem for us, and continues to be a problem today," he said (n.p.). When it comes to screenings, some are done by a healthcare provider when a soldier returns home. There are also written surveys. "I don't trust those as much because soldiers know how to answer those in order to be able to go home to their loved ones and not be caught up in future evaluations," Chiarelli said. "It's also possible," he said, that "soldiers know how to game the system in order to be redeployed" (n.p.).

But there are also problems in the mathematics of fusion and semantics. From the traditional assumption that the information produced from the social interaction is stable (we define information as Shannon information; we define knowledge as analogous to an algorithm that generates zero information; from Conant [1976]), collecting information from individuals to study organizations with social network analysis (SNA) or other analytics appears straightforward. Thus, for relatively "dark" social networks comprised of illicit drug gangs or terrorists (Carley, 2006), uncovering information to compute an SNA is significantly more difficult. However, even when the information is readily available from well-established organizations and networks, the analyses for SNAs (NRC, 2009) or data mining (NRC, 2008) have not produced satisfactory results. Barabási (2012) even stated that to practice in his mathematical discipline of network science, theorists must avoid subjective network data. In contrast to the purely subjective or objective aspects of reality, our model includes both objective measures of behavior and subjective observations of social reality along with the tools to account for both. But as a consequence, our theory raises questions about the value of meaning.

In his search for meaning, Frankl (1946/1997) concluded that finding meaning gives purpose to life. But instead of finding truth (e.g., in religion, politics, science, philosophy), per Glüer and Wikforss (2010), "meaning" is reductive to the prevailing normative beliefs that guide social understanding. Kahneman (2011), however, believed that "understanding is an illusion" (p. 199) that can be exploited by deception, even self-deception (e.g., alcoholic denial). Especially at the quantum level, conclusively, meaning derived from subjective experience has no value (Gershenfeld, 2000). Similarly, the search for truth in interdependent contexts (politics, collective decision making) may have greater value than its discovery, which is elusive in interdependent situations (Lawless et al, 2010). For example, compared to competitive approaches to reach consensus (i.e., majority rule), consensus-seeking produces fewer challenges to illusions and with less concrete results.

Incorporate Emotion into Collective Decision Making

If emotion is observable, Landers and Pirozzolo (1990) found that military novices compared to experts exhibited more turmoil, a finding extended to the emotional states of novices versus experts in (team) multitasking studies (Bell et al., 2012). To account for these effects, we aim to craft a bistable mathematics of emotion that functions like set-point theory (Brickman and Campbell, 1971; Diener, 2000; Kahneman, 2011); the benefit of this approach is that, mathematically, compared to expert teams, novice teams will have a shallower and narrower step function due to less training, making them easier to spot (Lawless et al., 2010). As a common example, warming up audiences with lesser-known acts prior to the main show implies a step function.

Emotional responding is also implicated in learning processes. Assuming there are the two broad types of SLT (association, rewards–punishments, and modeling) and cognitive dissonance (CD; the struggle associated with replacing one central belief with another, e.g., shifting from an addict to non-addict), SLT is reserved for simple learning and CD for learning difficult concepts. CD better fits our model, where bistable fields around neutrals produce an SPHO oscillation from the conflict between two central beliefs until the emotion aroused by conflict is resolved as when a new belief is adopted (e.g., see the limit cycles in President Obama's job approval in 2013, reflecting his unpopularity in early 2014).[14]

For a team, emotion may offer a more fruitful model. Assume that a perfect team is at its lowest point for structural entropy requirements. As a baseline, this least entropy state should coincide with a ground state for team emotion (Lawless, 2016). Then an emotional state would exist at a higher energy level; e.g., internal team conflict that paralyzes a team would act like in a divorcing couple.

Construct and Control "Smart" Bistable Agents to Act Like Humans

Human brain systems act and observe independently (Rees et al., 1997), producing bistable effects when these systems are linked interdependently (Lawless et al., 2010). But present agent-based systems are "god-like" in their ability to act and observe simultaneously, a problem with which real robot teams must contend. Along with others (e.g., Wilensky, 2011), our plan in the future for computational environments is to craft and control bistable agents to act more like humans by modeling "smart agents" able to self-report in agreement with their beliefs but at odds with their actions, just like humans.

We must also resolve why Fourier pairs of Gaussian distributions appear to be correct for our theory at a time when power laws seem more realistic (Barabási, 2009). We speculate that random walks with multitasking teams in an interdependent state produce Gaussian distributions when interrupted (i.e., where by breaking interdependence, an interruption increases independence), but when allowed to proceed to completion, they produce power law distributions (Figure 5). Eventually, we plan to test whether collective engines are random walks by firms in interdependent (multitasking) states.

Building an Organizational (Collective) Engine with Control Theory

Great interest is occurring for using mathematical principles of entropy to model enterprises. The emerging field of enterprise engineering (EE) provides a "promising outlook" (Huysmans and Verelst, 2013). Verelst and Mannaert (n.d.) proposed "to include entropy in the foundations of EE [to gain] A prescriptive theory.... An integrating theory.... [and] A dynamic perspective" (n.p.). We, too, have begun to use entropy to measure the perfect fit of a member into a team, producing the least entropy production for the structure of a perfect team and maximum entropy production for the output of a perfect team performing its mission flawlessly (Lawless et al., 2015).

For now, we begin to develop organizational boundary maintenance and control theory. Energy inputs produce structures with boundaries, structures require energy to offset entropy generation, and all structures eventually collapse (Nicolis and Prigogine, 1989; e.g., RIM, the Canadian cell phone company, was once very profitable and number one in its home market in Canada until 2012, but early in 2012, it faced collapse and has since begun a turnaround).[15] From energy inputs versus product and entropy outputs, organizations and other collective engines emerge, making control theory plausible, indicating that complex feedback systems promote trade-offs between robustness and efficiency (Chandra, Buzi, and Doyle, 2011). But boundary maintenance is problematic once firms become very successful; e.g., the bureaucracy in a firm making too much profit may begin to misallocate its funds. We speculate this effect is similar to obesity, a disease when humans consume too many "energy dense foods with low nutritional value" (Obesity Society [OS], 2010, n.p.), thereby increasing "the risk of many morbidities … and reduc[ing] … functional capacity … and lifespan" (Allison et al., 2008). Applied to enterprises, often the top firm in a market today will not remain at the top in the out-years (e.g., past market leaders: HP, Yahoo MS, Enron, etc.). The implication is that firms get to a leadership position in a market partly by random exploration, which becomes a barrier when striving for a follow-on success, where success is characterized by stochastic resonance (Nicolis and Prigogine, 1989; as an example of stochastic resonance, after what has been estimated to be 100 failures, Google "discovered" success with its social networking platform, Google+ [Stone, 2011]).

For an enterprise involved in multitasking, at a fundamental level, we assume that it is represented by a lattice (Figure 6). Firms form (lattice) boundaries around their internal transaction processes to create stable information channels (Conant, 1976). External transactions by a firm's group of multitaskers are less in costs than the same activities made by independent contractors (Coase, 1937), forming an entropic baseline. Indirectly supporting Coase (1937), individuals cooperating in a multitasking exercise consume less energy (money) than when competing against each other; for example, when enterprises merge with other firms in their struggle to survive, one of the reasons often given is to reduce costs and competition (Andrade & Stafford 1999). Consider the following examples.

- *Beer:* brewers are all competing in the larger market of alcoholic beverages. Beer has been losing market share on this wider playing field for a decade or more. Fruity vodkas and tequilas have lately been creating new consumers for hard liquor.… Do antitrust lawyers drink beer, or for that matter grocery shop? Those questions come to mind after watching the U.S. Justice Department trot out its traditional pseudo-science to block a brewery merger (R&O, 2013).
- *Stock exchanges:* intercontinental exchange (ICE) offers to buy the New York Stock Exchange (NYSE). Reasons for the merger by ICE include a reduction in its costs, reduced competition in its market, and a reduction

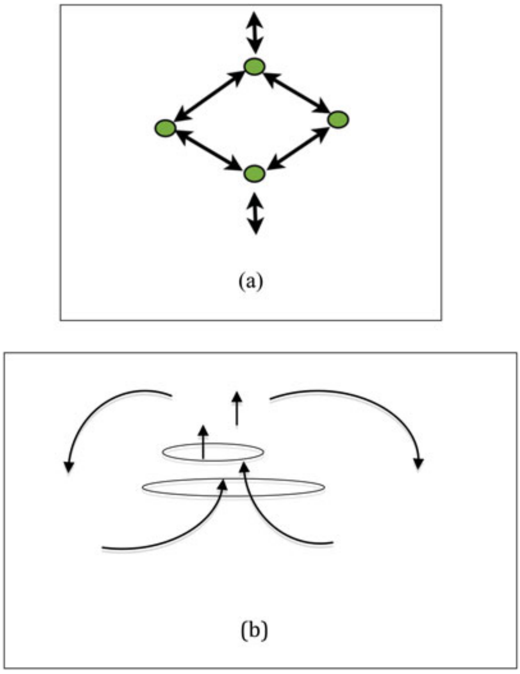


FIGURE 6 (a) Bistable information flows in from the bottom and out of the top of the group structure. The information is distributed in channels among the four agents who create a state of multitasking across the team; however, skills uncertainty and observational uncertainty are interdependent, making them inversely related, consequently forming Fourier pairs (e.g., estimations by managers of their firm's business performance is unrelated to its actual performance [Bloom et al., 2007]). (b) An abstract visualization of an enterprise as an engine.

in the need to innovate to stay ahead of the NYSE, combined with the loss of commissions on stock trades by the NYSE made NYSE vulnerable to a takeover. ICE's increased size will help it to compete against other exchanges. But its real target was NYSE's Liffe, the U.K. exchanged owned by the NYSE that is a leader in income futures (Strasburg and Das, 2012).

- *Office products:* the perceived vulnerability to Staples, compounded by store traffic declines with consumers switching to online purchases, led to the merger.
- The two companies are competitors to Staples, the world's largest supplier of office goods who dominates the space. The deal appears to be an attempt by both Office Max and Office Depot to become more competitive with Staples, even as they confront declining market share and consumers that move to buy online (Terlep and Solsman, 2013).

But, and contradicting Lewin's (1951) dictum that a group is greater than the sum of its parts, when the parts exceed the value of a firm, market pressure pushes the enterprise to spin off its parts (Cox and Cryan, 2012). Figure 7 ties these ideas together.

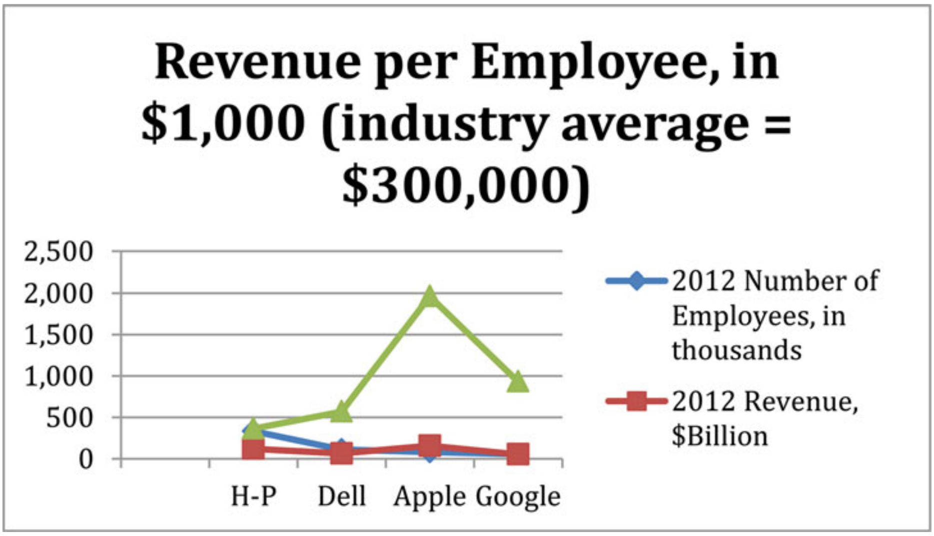


FIGURE 7 In 2007, the average revenue per employee in the computer industry (in million $/employee) is about 0.3 (data from Fortune 500; money.cnn.com). Based on this average, H-P and Dell are slightly about and below average, respectively, compared to the much farther above average results for enterprises Google at about 0.93 and Apple at about 2.0.

The goal of an enterprise is to bring into the firm more negentropy (free energy) than the entropy it generates, or than the energy it consumes. Let $-\Delta A$ be positive negentropy, ΔE be the energy consumed by an enterprise, and $T\Delta S$ be the entropy generated by the enterprise. With free energy as the greatest amount of work that can be performed, then

$$-\Delta A = \Delta E - T\Delta S. \tag{10}$$

Further, let ε be an enterprise's efficiency; then $\Delta W = E_{Into\ a\ firm} - E_{A\ Firm's\ Products} - E_{Other}$, where other is profit, overhead and waste, giving,

$$\varepsilon = \Delta W / (-\Delta A_{\text{In a Firm}}). \tag{11}$$

When work is negative, the enterprise is being transformed; when positive, the firm is productive.

The enterprise as an engine is powered by the inflow of money (energy) into the firm compared to baseline conditions (independent contractors). We visualize the inflow as a virtual spiral inward producing a virtual rotation about the axis of the firm and the flow velocity inward increasing until the flow enters the firm's boundaries, where the flow turns abruptly upward (Figure 7), converting the maximum negentropy into entropy as the flow climbs the hierarchy of an enterprise's lattices. That is, negentropy is converted into an enterprise's work products, overhead, profit, and wastage (its overhead includes the costs of communication, interference among the parts of enterprise engaged in multitasking, overcoming employee and management illusions, and outright mistakes; for example, "Since 1992, the FDA has received nearly 30,000 [voluntary] reports of medication errors" (n.p.), indicating that new technology may reduce the confusion among drug names and labeling errors, while monitoring expected patient responses to medication[16]).

In Shannon, the entropy of the parts of an enterprise equals the sum of its parts (e.g., Conant, 1976). However, interdependence in the form of multitasking effectively reduces a firm's structural entropy; also, a structure that improves multitasking further reduces its structural entropy (Lawless et al., 2015). Compared to self-reports by managers about a firm's performance (e.g., Bloom et al., 2007), the key metric of organizational performance, or an enterprise before and after transformation, becomes the degree of a firm's interdependence, measured indirectly by Figure 7.

FUTURE RESEARCH: AN eIRB[17]

Our original goal was to develop metrics for organizational performance; we are not there yet. Toward that end, we have been evaluating the DoD's primary Institutional Review Board (IRB) since 2006 with that goal in mind (initially reviewed in Lawless et al. [2010]); we have also been studying cybersecurity (Lawless et al., 2015). If the rational transformation of enterprises is important, then valid measures and metrics of performance are central to knowing where an enterprise is today and when it has been satisfactorily transformed (Rifkin, 2011). In our companion article, we plan to apply our theory to one or both of two possibilities: the DoD's medical research and cybersecurity. For the first, in 2006, we began to help the DoD's medical and physician scientists develop an eIRB system; in 2008, we first analyzed it; in 2013, we began a new evaluation of it.[18] In a companion article, we plan to review what we have found with a focus on the factors covered by our theory, including but not limited to cultural noise defined by the number of complaints made at an eIRB user's site as a byproduct of the lack of standards applied across its system of sites by DoD, the productivity of a site's researchers, the value of an eIRB to training, and the value of an eIRB to the development of meaning at each site. Other applications may arise with the use of artificial intelligence to seek peace (e.g., Chaudron, Erceau, Duchon-Doris, and Fighiera, 2015) and to prevent human-caused accidents (e.g., Lawless, 2016).

CONCLUSIONS AND IMPLICATIONS FOR INDUSTRIAL PRACTICE

We have reviewed the research literature and our findings on teams, firms, and systems of firms. We find that most of traditional social science of organizations is lacking, primarily due to its reliance on either subjective or objective information alone. We reviewed the progress on the development of our new theory on the physics of interdependent uncertainty and the mathematics representing the new theory that combines subjective and objective information as orthogonal factors. We also reviewed our future plans. We conclude by recognizing the value of studying the energy and entropy flows into and out of teams, enterprises, and systems of firms. Grounding our theory in energy flows offers promise—not only for human teams but also for hybrid teams. Moreover, it produces metrics for organizational performance and enterprise transformation that can also be applied to hybrid teams, firms, and systems of firms.

Implications for Industrial Practice

One of the major problems with the theory of enterprises is the lack of metrics based on first principles (Kohli and Hoadley, 2006). We believe that once our theory has been developed and validated, the principles of metrics will more easily be crafted. In our companion study, we begin to explore and apply this thesis.

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NOTES

1. Images are available at http://www.google.com/imgres?imgurl=http://blogs.scientificamerican.com/plugged-in/files/2011/12/NKlights.jpg&imgrefurl=http://blogs.scientificamerican.com/plugged-in/2011/12/19/north-korea-by-night-photograph/&h=700&w=548&sz=63&tbnid=vAaKo6KGi2keSM:&tbnh=92&tbnw=72&zoom=1&usg=__mvh-E-uoyaSpsfbE0BjPeL3oTPM=&docid=SqnbXjyHld05rM&sa=X&ei=sXhAUvGAFYi88ATUxICIBQ&ved=0CDAQ9QEwAA&dur=515
2. Compare Allakhverdov and Lawler (1997) and Englund (2011).
3. Data sources are Bloomberg (http://www.bloomberg.com/news/2012-03-14/georgia-lottery-players-suckers-spending-most-for-least.html) and George Mason University (http://mercatus.org/freedom-50-states-2011).
4. Favorability ratings (of China, the United States, Iran, and Russia) are from the Pew Global Attitudes Project (July 13, 2011); competitiveness ratings are from the World Economic Forum (December 2011; www3.weforum.org).
5. Compare Hobson (2011), Andrew Wakefield's MMR vaccine fraud, and Dominus (2011).
6. Compare Radnofsky (2012) and Preston (2012).
7. Compare Schwirtz (2012) and Rosenberg (2012).
8. Data are from October 31, 2013, to January 6, 2014, for the "generic congressional vote" and were obtained by averaging poll numbers collected and published by Real Clear Politics (http://www.realclearpolitics.com/epolls/other/generic_congressional_vote-2170.html).
9. More information regarding our contribution to the 2016 AAAI Symposium can be found at https://www.aaai.org/Symposia/Spring/sss16symposia.php#ss01.

10. Lawless and Sofge co-organized the AAAI Spring Symposium at Stanford on aggregation in 2012 (www.aaai.org/Symposia/Spring/sss12symposia.php#ss01).
11. Compare Emshwiller and Fields (2012) and Savage (2011).
12. Compare Allegra et al. (2012) and the first reply in its "Letters" (Wilson, 2012).
13. In 2013, D. A. Sofge, G. K. Kruijff, and W. F. Lawless co-organized the AAAI Spring Symposium at Stanford on "Trust and autonomy" (http://www.aaai.org/Symposia/Spring/sss13symposia.php#ss07).
14. These data are available from a plethora of sources but were gathered for this study from www.realclearpolitics.com/epolls/other/president_obama_job_approval-1044.html.
15. Compare Connors et al. (2012) and Lynley (2013).
16. These conclusions were drawn in the FDA's 2011 "Strategies to reduce medication errors: Working to improve medication safety" (www.fda.gov/Drugs).
17. We participated in a team that was instrumental in getting an eIRB adopted by DoD for the review of human and animal research protocols (Lawless et al., 2010).
18. The DoD grant was funded to evaluate its eIRB system as a comprehensive web-based solution for research management, compliance, and oversight needs. We plan to evaluate its current business process metrics and its leadership management decisions; see also the "Acknowledgments" section.

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