Lecture Notes in Computer Science: Incompleteness, uncertainty and autonomy: Intelligent systems

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Abstract. We are producing an innovative theory to make a group of autonomous systems as intelligent as possible to serve as surrogate human decision makers in a hybrid group of humans and machines for a variety of purposes to include countering human interpretive and decision-making deficiencies. This theory could help design systems for UxVs and computational alternatives to prevent or mitigate military incidents. Unfortunately, unlike the physical sciences, the social sciences have no overarching theory of fundamental principles to build from individuals to collectives. To move into a future governed effectively and efficiently by humans interacting with smart systems, we propose a scalable model of human behavior based on the mathematical physics of interdependent uncertainty. Unlike building a bridge or robot, while predictions about social behavior remain possible, our interdependent model of uncertainty for collectives finds traditional explanations of decisions unavoidably incomplete that makes the search for understanding largely "meaningless", a blow to traditional theories (bounded rationality, game and social learning theory). We address whether incompleteness can be exploited to provide a computational alternative perspective to make better decisions under uncertainty.

1.0 Introduction

After the introduction, we critique traditional models and provide a series of case studies of group decision-making under uncertainty; the mathematics of taking Gaussian states into Gaussian states; computational alternatives to reduce uncertainty; and a summary.

An innovative theory based on computational, mathematical, and engineering approaches could help in the control of complex "smart" systems. Unfortunately, unlike the physical sciences, the social sciences have no fundamental principles to scale from individuals to collectives, pejoratively known to some social scientists as "physics envy".[1] But, to move into a future governed effectively and efficiently by humans interacting with intelligent systems, a new model of behavior based on interdependence is required.

With hybrids of robots, machines and humans, we characterize the principles of a new direction for mathematical models of interdependence to operationalize autonomy for

[1] Clarke, K.A. & Primo, D.E. (2012, 3/30), "Overcoming 'Physics Envy'", *New York Times*.

hybrid collectives multitasking as teams, organizations and systems. We have rejected traditional social science, and, instead, borrowed from biology (May, 1973), linear quantum information (Busemeyer & Bruza, 2012) and linear algebra (Gershenfeld, 2000).

To advance the science of multi-agent systems (robots), a new theory of social behavior was called for in a special issue of *Science* (Jasny et al., 2009). Unlike the normative nature of game theory, to instantiate Bohr's [1955] model of human action and observation, a new theory should include dynamic and static states of interdependence, analogous to the mathematics of quantum interaction, which Von Neumann and Morgenstern (1953, p, 148) thought was "inconceivable". It should be foundational. And it should address actual, not normative, behavior by combining cooperation and competition.

Most of social science is atheoretical, cobbled from ad hoc studies of individuals, known as methodological individualism (MI), the primary approaches being game and social learning theory (Ahdieh, 2009). MI arbitrarily treats a collective as the sum of the contributions of its participants, where a collective is an arbitrary line drawn around a random group of individuals. Game theory first introduced interdependence, but it was static (Von Neumann & Morgenstern, 1953), whereas multi-tasking in groups are interdependently dynamic (Smith & Tushman, 2005).

1.1 The Importance of Competition

From this perspective, Axelrod (1984, pp. 7-8) concluded that competition reduced social welfare: "the pursuit of self-interest by each [participant] leads to a poor outcome for all". This outcome can be avoided, he argued, when sufficient punishment exists to discourage competition. The cooperation needed to establish the "fairness" in the distribution of resources has become construed as one of the "cornerstones of human society" (Van Segbroeck et al., 2012) responsible for the unprecedented success of the human species (Smith & Szathmary, 1995) and its social complexity (Nowak, 2006). But in the field, game theory is an unsatisfactory model of social behavior (Schweitzer et al., 2009). It predicts an increasing computational complexity when scaling from pairwise to collective interactions that makes quantitative estimates of social effects problematic (Van Segbroeck et al., 2012). And for all of its value as a "cornerstone", the traditional model of cooperation is not a foundation that has served well to solve ill-defined problems or even to justify theoretically well-established social practices, like the modern scientific method.

Both game and social theory famously promote cooperation, preferably isolated from competition. But we have found that many of the "rational" results at the collective level follow normative traditions (viz., religion), like those that advocate the value of cooperation over competition (e.g., Simon, 1990; Nowak, 2012). But Darwin (1973) stressed that cooperation in a competitive environment is important to the members of collectives "ready to warn each other of danger, to aid and defend each other" to survive.[2]

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[2] Inadvertently exemplifying the importance of cooperation inside of organizations, Abigail Thernstrom became famous for saying that American universities are "islands of repressions in a sea of freedom." (Magee, 2002, p. 255)

Even today, organizations composed of members who fail to cooperate with each other struggle in competitive environments.[3] Ridley (2012) observed that groups isolated from competition fail to evolve; for isolated cooperative groups [Lawless et al., 2011], information is reduced, illusions unchallenged, and, like North Korea and China, social well-being becomes abnormal.[4] Moreover, although game theory predicts that while cooperation between two competitors leads to higher payoffs for both, society defines this behavior as collusion;[5] and, unpredicted by game theory, competition between two businesses can lead to extraordinary improvements in social welfare.[6]

Supporting competition, the success of the scientific method is its openness to challenges against established scientific theories;[7] similarly, competition in the marketplace of ideas is not only the modern approach to the freedom of speech (Holmes, 1919), but also the essence of good public policy[8] and the best path to justice (Freer & Purdue, 1995).[9] Social conflict engages in entertainment by producing "mise-en-scéne" (Sarris, 1968).

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[3] *MarketWatch* (2012, 5/29), "TNK-BP Stalemate Hurts Both": "The two sides have been unable to agree on a new independent board member, preventing [the CEO] from making important operational decisions. … BP's problem is that TNK-BP also gives it significant cash flow. The $3.7 billion it received last year was almost equivalent to BP's own $4 billion dividend payout. In all, TNK-BP has returned $19 billion to BP after its initial $8 billion investment in 2003. Without a board quorum, those dividend payments will dry up, leaving TNK-BP's owners in a stalemate damaging to both sides."

[4] China is one of the most polluted countries on the planet (fully 90% of its shallow groundwater is contaminated, in *Science* (2011, 11/11), "China to Spend Billions Cleaning Up Groundwater").

[5] *npr* (2012, 3/9), "Justice Dept. Warns Apple, Publishers Over E-Books Price Collusion", www.npr.org .

[6] In 2000, *Bloomberg* valued Microsoft at #1 and over $500 B, with Apple at $16 B; their positions were reversed in 2011 (*Bloomberg*, 2011, 5/8), "Apple Brand Value at $153 Billion Overtakes Google for Top Spot" (www.bloomberg.com). In 2012, Bloomberg estimates the value of MS at $218 B. Now, "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." (*Wall Street Journal*, 2012, 2/29, "Apple market value hits $500B, where few have gone", www.wsj.com).

[7] Stern & Lee (1992) recommend peer review in post-Soviet states as a way to save essential human and data resources; improve policy analyses; employ practices that have been demonstrated internationally in a variety of settings; reduce bureaucracy in decision-making; evaluate alternative interpretations of data; encourage critical thinking; and motivate a competition of ideas with open access to information. Initially, the recommendations worked ("Peer review lands safely in Russia", 1997, *Science*, 275(5299): 469), but no longer (*Washington Post*, 2011, 12/21, "In Russia, the lost generation of science"). In the US, justifications for peer review are based on practices advocated in National Academy of Sciences publications; e.g., NRC (2006): "All reports undergo a rigorous, independent peer review to assure that the statement of task has been addressed, that conclusions are adequately supported, and that all important issues raised by the reviewers are addressed."

[8] Justice Ginsburg: ""… as with other questions of national or international policy, informed assessment of competing interests is required," she wrote." *W. Post* (2011, 6/20), "High court throws out states' climate lawsuit".

Why is competition valuable? From Shannon information, compared to perfect cooperation (e.g., a team yoked to its leader), the skills to compete generate information about a group's potential value, including religious groups (Abrams et al., 2011), the motivation to reduce this information into actionable knowledge (Conant, 1976). For example, the more competitive is a nation, the lower is its interest rates.[10] Contradicting Axelrod, this means that stable centers of competition by individuals and groups pursuing self-interests, like a prosecutor and defense attorney or opposing politicians or judicial checks and balances or two scientists like Bohr and Einstein, are valuable social assets (e.g., the Bohr-Einstein debates in 1927 became entertainment in 1998 in the play *Copenhagen* by Frayn). Because we propose that society cannot produce a better rational strategy to solve its problems, we re-define stable centers of competition as social Nash (1951) equilibria (SNE);[11]e.g., Apple and Google actively compete against by pursuing their self-interests to innovate new products and services to attract undecided customers (Korolev & Nelson, 2012). If SNE are stable, they are Pareto Optimal (Arrow, 1968).

What makes our approach interesting is that social-psychological reality is always in a state of interdependence, socially from awareness of another's presence, or psychologically from the interdependence between action and observation (Bohr, 1955). Thus, Shannon entropy is replaced with Von Neumann entropy (the trace of a density matrix); e.g., the lower the Gaussian variance in the multi-tasking skills that build an organization, the greater the variance in its conjugate observation, increasing uncertainty.

1.2 Intelligent Behavior

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[9] Inadvertently exemplifying the importance of cooperation inside of organizations, Abigail Thernstrom became famous for saying that American universities are "islands of repressions in a sea of freedom." (Magee, 2002, p. 255)

[10] On May 31, 2012, the data for national competitiveness was from The *Global Competitiveness Index 2011-2012* rankings (http://www3.weforum.org/docs/WEF_GCR_CompetitivenessIndexRanking_2011-12.pdf). Data for the 12 National bonds was from "Global Government Bonds" listed in the *Wall Street Journal* (http://online.wsj.com/mdc/public/page/2_3022-govtbonds.html?mod=mdc_bnd_gvtbnd). Greece's data was obtained from the *Financial Times* (http://markets.ft.com/RESEARCH/Markets/Government-Bond-Spreads). For the 12 nations with 10-year bond rates reported in the *Journal*, the correlation with competitiveness rankings was inversely and significantly related ($r = -.85$, $p < .01$). Thus, the more competitive was a nation6, the lower was its 10-year bond rate.

[11] We reinterpret an NE as a set of opposed positions motivated by self--‐interests. Those who occupy an NE drive their relatively stable views into stable oppositions with the ultimate goal of obtaining social, financial, or political support for their self--‐interests. From our perspective (Lawless et al., 2010), with reality being not easy to access or capture, an NE plus feedback provides sufficient information and knowledge for a system to solve computationally difficult, intractable, or otherwise ill--‐posed problems.

How are intelligent behavior and interdependence related? First, individual intelligence is insufficient for multitasking (Wickens, 1992), whereas the purpose of groups is multitasking (Ambrose, 2001). Second, what exactly is intelligent multitasking? From a group perspective, a problem with the social control of hybrid systems is interdependence (Jamshidi, 2009). One approach to addressing interdependence is to establish a series of swarm or pattern formations of cars,[12] airplanes, cities,[13] and robots (Goodwine & Antsaklis, 2011). Information from deviations is negative feedback to control a formation to solve well-defined problems under certainty. In contrast, to solve ill-defined problems under uncertainty, like the stock market in its attempt to identify innovative or successful firms and business trends, made difficult today by the uncertainty by the Federal Reserve's low interest rate policy;[14] or like a jury in its attempt to solve a complex criminal case; or like a society in its attempt to choose a political leader in difficult times; or like scientists in their attempt to build a quantum computer; or like the control of multiple UxVs (Cummings et al., 2011); then, as Becker, the nobel laureate, noted, interdependence makes systems difficult to understand.[15]

We derive intelligent agent behavior from our theory of darkness (Lawless et al., 2011). The Turing test was the first to define intelligence for a computer (Turing, 1950). But, intelligence for a human may be more difficult to establish and less useful than for a group of agents (Kurzweil[16] has predicted that a machine will pass the Turing test in 2029). In contrast to Turing, Fitzgerald's (1936) definition agrees with our theory: "The test of a first-rate intelligence is the ability to hold two opposed ideas in the mind at the same time, and still retain the ability to function." Festinger (1957) was the first scientist to establish this phenomenon with his experiment on cognitive dissonance. Today, cognitive dissonance is avoided with confirmation bias (Darley & Gross, 2000), the belief that humans seek evidence to support their beliefs while rejecting disconfirmatory evidence. But, we propose, as uncertainty rises in social systems, the hallmark of intelligent agents is the spontaneous existence of debate centers (SNE) to resolve uncertainty. Based on our prior research (Lawless et al., 2011), we conclude that a team, organization or system using checks and balances to constrain power should produce less entropy than collectives managed by command decisions (e.g., Cuba and Russia).

2.0 Case Studies

We provide case studies to exemplify the types of decisions that can be improved. We hypothesize that a computational process that builds and presents orthogonal viewpoints during decision-making not only improves decisions, but also prevents an over-reliance on

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[12] *Wall Street Journal* (2012, 3/5), "The Car of the Future Will Drive You".
[13] *New York Times* (2012, 3/3), "Mission control, built for cities".
[14] *Wall Street Journal* (2012, 6/21), "Bernanke Is Fighting the Last War, 'Everything works much better when wrong decisions are punished'", Weekend Interview, Anna Schwartz, coauthor with M. Friedman, "A Monetary History of the United States" (1963).
[15] *Wall Street Journal* (2009, 3/21), "Now Is No Time to Give Up on Markets".
[16] http://longbets.org/bets/

automation by reducing group convergence processes (e.g., groupthink; in Janis, 1972); reversing the inverse relationship between situational awareness and increases in automation (Cring & Lenfestey, 2009); and improving the partnership between human users and automation as the "workplace … [becomes] increasingly complex, unstable, and uncertain" (Lee & See, 2004, p. 52).

Air France. In the crash of flight Air France 447, problems ensued when its sensors failed. From the *Washington Post* (2012, 7/5)[17], "... Ice crystals blocked speed sensors on the underbelly of the plane known as pitot tubes ... The erroneous speed readings prompted the autopilot to disengage. Alarms started sounding in the cockpit. The pilot at the controls couldn't tell if the plane was stalling or going too fast, the report said. One of the alarms was saying "Stall! Stall!" But the report says another alarm, ringing for 34 seconds straight, "saturated the aural environment within the cockpit" and confused the pilots. Meanwhile, the plane's flight director system gave faulty, conflicting information. The flight director shows the pilot what movements of the controls he needs to make to keep the plane on a set course and altitude — but the flight director relies on information from the pitots and other sensors. Investigators said the crew should have turned off the flight director at that point. Instead, the pilot in control nosed the plane upward, thinking he was going too fast and the plane was in a dive, the report says. In fact, the plane was in an aerodynamic stall. BEA chief Jean-Paul Troadec ... said the pilots should have turned off automatic signal systems and flown entirely manually as soon as they realized the pitots were blocked."

US Submarines. Alternative viewpoints are often invoked as needed to prevent or mitigate convergence processes such as the confirmation biases that often precede or are associated with accidents (Smallman, 2012). As examples, emotional convergence caused the USS Vincennes in 1988 to fire on an Iranian commercial airliner; command convergence suppressed warnings by the crew to its Commander against a rapid ascent, causing the USS Greenville tragedy in 2001; and relaxation convergence after a long deployment led some of the crew to fall sleep at duty stations and the Commander and navigator to be absent from the Bridge, causing the USS Hartford accident in 2009.

Bullet train disaster in China. China's high-speed rail network was built with imported signaling-system components designed to prevent train collisions but that its engineers did not fully understand.[18] During a lightning storm, two of China's bullet trains collided in the eastern city of Wenzhou, killing 40 people and injuring nearly 200 in one of the world's worst high-speed passenger-rail accidents. China's government initially blamed flawed signaling and human error. In the US, the "crash of a multimillion UAV usually generates intense pressure to isolate and correct the cause" (Cring & Lenfestey, 2009). But

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[17] *Washington Post* (2012, 7/5), "Faulty data, pilot error, lack of training caused 2009 Brazil-France crash in Atlantic".

[18] *Wall Street Journal* (2011, 10/3), "China Bullet Trains Trip on Technology"

China postponed the public release of its crash findings. The precise cause of the disaster remained uncertain. "An examination of China's use of foreign technology in its bullet-train signal systems highlights deep international distrust over China's industrial model, including weak intellectual-property protections .... ."

"We aim at the world's top-notch technologies," then-Railways Minister Liu Zhijun declared four years ago. A few months before the July crash, Mr. Liu was fired after China's Communist Party accused him and other top officials of unspecified corruption."

China completed a study of its train disaster,[19] even though a lot of the evidence had already been buried or lost.

The U.S. Department of Energy (DOE). To understand DOE's mismanagement of U.S. military nuclear wastes generated during the production of nuclear weapons, Lilienthal (1963), the first chair of the U.S. Atomic Energy Commission (AEC), succeeded now by DOE, recognized that AEC's policy of self-regulation, isolated from competitive challenges, compromised the practices of its scientists.

Until 1983, hidden behind claims of national security, DOE maintained to the U.S. Congress that it was protecting the air, water and soil (ERDA, 1977, p. I-1). However, after extraordinary environmental contamination across the entire DOE complex was exposed (Lawless et al., 2010), the public and Congress forced DOE to comply with US Environmental Protection Agency (EPA) and State regulations. The estimate today is about $200 billion just to cleanup Hanford, WA and Savannah River Site (SRS), SC, the two sites in DOE with the largest budgets.

The DOE cleanup after 1983 has become more competitive and successful. Today, DOE faces competitive threats to its interpretations and its oversight from multiple sources. The National Academy of Sciences, the Defense National Facilities Safety Board, and DOE's Citizen Advisory Boards (CABs) have joined with EPA and State regulators, and sometimes with the Nuclear Regulatory Commission, to challenge DOE's decisions. In this new environment, DOE has made significant strides in cleaning up its complex, especially at SRS (Lawless et al., 2010).

A **UAV Strike**.[20] The Pentagon reported that in 2011, Marine commanders in Afghanistan and the USAF crew controlling a Predator in Nevada were unaware analysts watching a firefight via live video in Indiana had doubts about a targets' identity. A Marine and Navy medic were killed by the airstrike when Marines in Afghanistan mistook them for Taliban fighters. The USAF Coordinator was a trainee supervised by a trainer.

The friendly fire deaths occurred in Helmand province after the Americans came under enemy fire. The platoon split up while trying to clear a road near the crossroads town of Sangin, an area where Marines often engaged in combat with insurgents. Unknown to the Predator crew, the two killed had separated from the others and taken cover behind a

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[19] YANG Mu & CAO Shenshen (2012, 5/18), "HAS THE WENZHOU TRAIN CRASH DERAILED CHINA'S HIGH-SPEED "RAILWAY PLAN? *EAI Background Brief No. 723*.

[20] *Los Angeles Times* (2011, 10/14), "U.S. deaths in drone strike due to miscommunication".

hedgerow, while firing on insurgents in a cluster of nearby buildings. Infrared cameras on the Predator overhead had picked up heat signatures of three men and detected muzzle flashes as they fired weapons at insurgents.

Air Force analysts who were watching the live video in Indiana noted that the gunfire appeared aimed away from other Marines behind the three. But the Predator pilot in Nevada and the Marine commanders on the ground "were never made aware" of their assessment. The analysts, who communicated with the Predator pilot via a written chat system, described the pair as "friendlies," but withdrew that characterization a few seconds later. They later wrote, "Unable to discern who personnel were."

"The chain of events … was initiated by the on-scene ground force commander's lack of overall situational awareness and inability to accurately communicate his friendly force disposition in relation to the enemy," the report said.

Summarizing the Case Studies, to make better decisions in the field and to prevent an inappropriate level of reliance on automation (Lee & See, 2004), we propose a decision-making system that promotes intelligent decision-making for hybrid systems.

3.0 Mathematics Model

To develop interdependence theory, we adapted Cohen's (1995) interpretation of the classical uncertainty principle for signal processing. With Rieffel (2007), we linked quantum entanglement and social interdependence theory. Next, we initially assumed that interdependence could be simplified with bistable models. For an example, see Figure 1.

Figure 1. Examples of stable and bistable images. Fig. 1A. On the left is an image of an Abrams M1A1 Main Battle Tank that generates a stable interpretation (e.g., www.army-technology.com/projects/abrams). All who view the tank reach the same interpretation. Fig. 1B. On the right is a bistable illusion of two-women that creates a bistable interpretation (an older woman looking downward and to the observer's left; or a younger women looking away over her right shoulder). For bistable illusions, observers cannot "see" both interpretations of its single data set at the same time (Cacioppo et al., 1996).

Conservation of Information (COI). The key to building abstract representations necessary to construct an SPHO is to locate a neutral audience between opposing clusters in Hilbert space. A Hilbert space is an abstract space defined so that vector positions and angles permit distance, reflection, rotation and geospatial measurements, or subspaces with local convergences where measurements can occur.

We specify the state of bistable system with a state column vector $|\psi>$. If an operator $\boldsymbol{A_n}$ maps another state vector n onto itself plus a coefficient x_n,

$$\boldsymbol{A_n}\ |n> = x_n\ |n>, \tag{1}$$

then $|n>$ is an eigenvector, its coefficient x_n is its eigenvalue, and n is the index number of the bistable state of a two-state social system (e.g., guilty-not guilty). When it exists, a complete set of eigenfunctions forms a basis for $|\psi> = \sum_n a_n\ |n>$, where $|a_n|^2$ is the probability that a measurement of $\boldsymbol{A_n}$ collapses it into $|n>$ with observable x unless $|\psi>$ is already one (e.g., in Figure 1, a classical image of a military tank transforms into a tank, but the interpretation of states oscillating between $|\psi>$ and $|\square>$ for a bistable state--e.g., a bistable illusion--is transformed into the other interpretation as attention shifts; in Lawless et al., 2010). a_n is the coefficient of an orthonormal basis, normalizing $|a_n|^2$.

Operators map state vectors into eigenfunctions; the outer product from two eigenvalues, $|n><n|$, is a projector, $\boldsymbol{P_n}$. It maps a vector $|\psi>$ into an observable,

$$\boldsymbol{P_n}\ |\psi> = |n><n||\psi> = a_n\ |n>, \tag{2}$$

where the expectation value of a projector is the likelihood that a measurement produced that state,

$$<\psi|\ \boldsymbol{P_n}\ |\psi> = |a_n|^2, \tag{3}$$

and where projectors for an operator form a spectral representation of its eigenvectors,

$$\boldsymbol{A_n} = \sum_n x_n\ |n><n|. \tag{4}$$

We represent a function of an operator as

$$f(\boldsymbol{A_n}) = \sum_n f(x_n)\ |n><n|. \tag{5}$$

The commutator of two operators $\boldsymbol{A}$ and $\boldsymbol{B}$ is:

$$[\boldsymbol{A},\boldsymbol{B}] = \boldsymbol{AB} - \boldsymbol{BA}. \tag{6}$$

When the eigenvalues of the two operators are equal (Equation 6), as it should be in rational discourse under command authorities and in dictatorships which enforce conformity, the commutator vanishes, i.e., $[\boldsymbol{A},\boldsymbol{B}] = 0$. However, when the commutator exists, then $[\boldsymbol{A},\boldsymbol{B}] = \boldsymbol{AB} - \boldsymbol{BA} = i\boldsymbol{C} \neq [\boldsymbol{B},\boldsymbol{A}]$. In that case, the two eigenfunctions for community operators ***A*** and ***B*** are different, producing an "oscillator" when they form an orthonormal couple with commutator ***C*** before an intelligent audience of neutrals (SPHO).

The oscillation defines a social-psychological decision space embedded within an organization or system. It is called an "oscillator" because decision-making occurs during rapid-fire turn-taking sessions that "rotate" attention for the topic under discussion in the minds of listeners or deciders first in one valence direction (e.g., "endorsing" a proposition) followed by the opposite (e.g., "rejecting" a proposition) to produce a "rocking" or back and forth process for an SPHO, like the merger and acquisition (M&A) negotiations between a hostile predator organization and its prey target, as commonly witnessed by investors.[21] But oscillations likely do not occur in the minds of the agents who drive them (Lawless et al., 2010); e.g., the Commander aboard the USS Greenville; the team aboard the USS Vincennes; or the copilots aboard Air France AF 447.

Equation 6 is the Heisenberg uncertainty principle the atomic level, $\Delta A \Delta B \geq 1/2 \langle \boldsymbol{C} \rangle$ (Gershenfeld, 2000, p. 256). It models the variance around the expectation value of two operators along with the expectation value of their commutator. And at the social level?

We believe that with his checkerboard illusion, Adelson [2] established a floor effect (see Figure 2). Adelson found that a photometer, but not a human, could distinguish that the two cells A and B in the illusion below were of the same darkness. Humans are biased by grouping processes and experiences, such as confirmation bias, to misjudge the illusion.

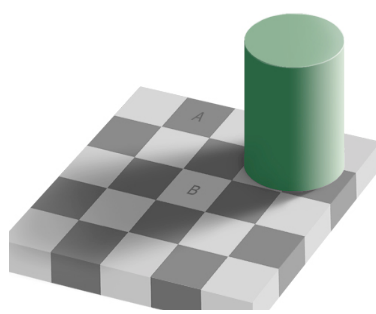

Fig. 2. The Checkerboard illusion (Adelson, 2000). The brain construes the shadowed area in checker square B to be lighter than the darkened square in A, but both are equally dark.

With signal detection theory (SDT; see Cohen, 1995), the uncertainty principle in Equation [6] becomes a Fourier pair consisting of standard deviations that models tradeoffs for individuals, organizations and systems:

$$\sigma_A \sigma_B \geq \tfrac{1}{2} \; . \qquad (7)$$

[21] Daines, R.M., Nair, V.B., & Drabkin, D. (2006), *Oracle's Hostile Takeover of PeopleSoft*. Harvard Business Review.

From Equation (7), as variance in factor *A* broadens, variance in factor *B* narrows. At the social level, to model social welfare across a system or between two organizations, Lotka-Volterra type equations with limit cycles capture the effects of SNE (May, 1973). By letting Equation 6 represent an inner or simple dot product, where *cos* 90 deg = 0, because a limit cycle produces 90 deg rotations (Benincà et al., 2009), the orthogonal beliefs of an SNE and a limit cycle become synonymous, linking linear algebra to social macro effects.

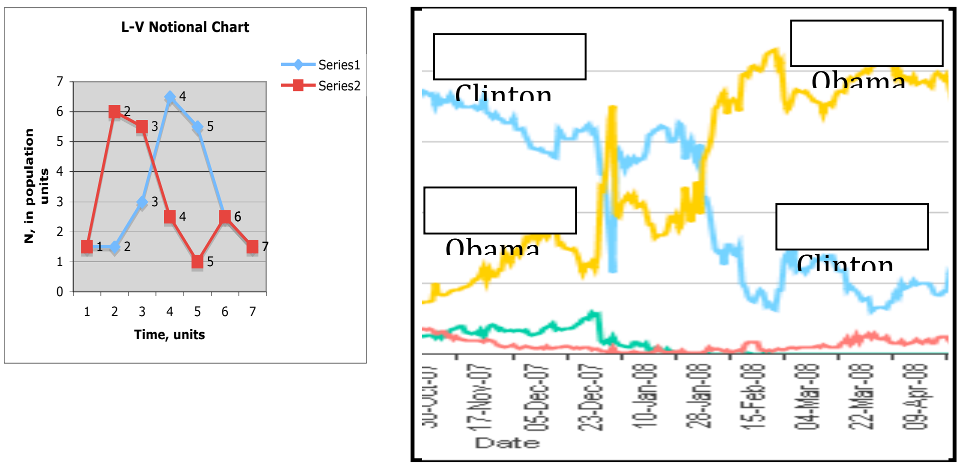

Fig. 3. Instead of as a limit cycle (N_1 versus N_2; in May, 1973), the data are displayed with *N* over time, *t*. *Left*: Arbitrary parameters produce "frictionless" oscillations. We interpret N_1 and N_2 to be in competition at time 1 (and t = 3.5, 6 and 7). The public acts at time 2 (and t = 3, 4 and 5) to produce social stability. *Right*. Despite the arbitrary nature of the data on the left, in the campaign to become the Presidential nominee for the Democratic Party, it models the public bets made on the Iowa Electronic Market (www.biz.uiowa.edu) in support of Clinton and Obama during a brief period of intense competition (January 2008), followed by the IEM public's decision for Obama (February 2008).

Self-Reported Observations ($\sigma_{Observation}$) and Action (σ_{Action}). 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., 2000). Even experts misjudge the causes of their behavior (Tversky, in Shafir & LeBoeuf, 2003). We propose that context and responses to queries can be parallel or orthogonal; e.g., knowing that at a given time, *t*, conservatives (***A***) and liberals (***B***) viewing the same data agree implies that community states [***A***,***B***] are commutative (i.e., parallel, where *cos* 0 deg = 1),[22] but often they are orthogonal (i.e., where *cos* 90 deg = 0).[23] With $\psi_{neutral}$ as the state of an individual neutral, and say |0> representing a neutral's view of reality and |1> reflecting its behavior or a different belief, then for orthogonal action-observations or for the orthogonal beliefs held simultaneously by a neutral individual, a superposition is formed: $\psi_{neutral}$>= a|0> + b|1>.

This problem with incompleteness can be exploited. We hypothesize that whenever uncertainty is present, conflicting interpretations (NE) spontaneously arise. Commanders can enforce their viewpoint, but that sometimes results in an inferior decision (e.g., USS Greenville). Being able to always know that an alternative viewpoint exists, despite the prevailing viewpoint, may provide what is needed to improve decisions or to increase trust in automation. What we foresee is the following: Shifting from Shannon information to Von Neumann entropy, the trace over the density matrix (Gershenfeld, 2000), two orthogonal states exist simultaneously, a |0> and a |1> (e.g., the bistable interpretations of the illusion in Figure 1, right). This is expressed below in Figure 4.

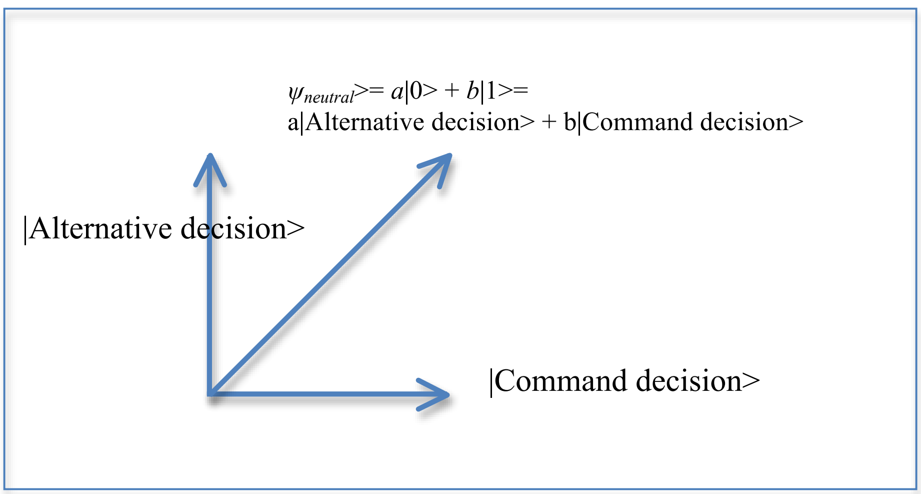

Figure 4. Notional diagram of Command decision and its orthogonal alternative as an example of incompleteness.

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[22] For an example of social agreement between the *Journal* and *Times*, see: Emshwiller, J.R. & Fields, G. (2012, 3/27), "Prosecutors Are Rarely Punished Over Disclosure" *The Wall Street Journal*; and Savage, C. (2011, 11/21), "Court-Appointed Investigator Offers Scathing Report on Prosecution of Senator Stevens", *The New York Times*.

[23] For an example of disagreement in the *Wall Street Journal* alone over climate change, see the Op-Ed ""No Need to Panic About Global Warming" (2012, 1/ 27), followed by the first reply in Letters: The Anthropogenic Climate-Change Debate Continues (2012, 2/7).

In the figure, θ is the angle from the x-axis (i.e., |*Command decision*>) to the current state of the observers (i.e., |ψ>); with the vector dot product (or inner product), *cos* θ measures agreement (i.e., *cos* 0 deg = 1) or disagreement (i.e., *cos* 90 deg = 0).

4.0 Summary and Future Research:

At times, a collective under a command authority can act autonomously. For teams engaged in multi-tasking (controlling multiple UxVs, teams of soldiers in combat, or the bridge in a submarine), when approaching or in an autonomous state, it is often stated that alternative viewpoints (NE) may improve decision-making or even prevent the occurrence of an accident (Smallman, 2012). While it is not yet possible to provide oral alternative viewpoints with automation, as an application, to increase trust in automation, we propose to explore as a first step the possibility that a machine (computer) providing levels of automation or overseeing it as a supervisor can interpret the actions of its automation users sufficiently well enough to warn the supervisor of the operators of a team of robots, or a field Commander of the risks in continuing an action that increases the risk to the mission or a danger to the command, thereby increasing trust for users of an autonomous system, and provide a metric for operational performance. Ultimately, in the future, this may one day lead to a control theory of hybrids; from this control theory, one day, we expect to derive operational metrics for hybrid teams and for command and control more general (e.g., Chandra et al., 2011).

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ODD (Updated)

Purpose: A mathematical model of interdependent uncertainty is proposed.

Entities, state variables and scale: Action and observation are the primary interdependent (conjugate) Gaussian state variables. As the variance in one state variable reduces, its conjugate's variance increases.

Process overview and scheduling: Replication with an agent-based system is not yet possible.

Design Concepts: Not relevant.

Initialization: Not applicable.

Input data: Not available yet.

Sub-models: Not relevant.

Conclusion: None at this time.