

Interdependent human-machine teams: A theory of teams, but not groups, advances Artificial Intelligence (AI)

W.F. Lawless, Paine College/ Naval Research Lab summer faculty researcher

Abstract:

In this work-in-progress, to advance theory, we begin to sketch a new mathematics of interdependence for human-machine teams and entropy, the latter from forces modeled on the subjunctive mood ("as if"). We begin with a brief review of reasons for new theory on interdependence; past findings supporting the new theory; and a brief excursion into the new theory for our work-in-progress, followed by examples of decision-making from the field. New theory is needed for the advent of human-machine teams, yet social science almost exclusively is predicated on methodological individualism, a statistical and purely qualitative science which does not generalize to teams nor provide guidance for the engineering of human-machine teams. Interdependence has long been known to not only transmit social effects, but, as we have theorized and the literature and our research has supported, compared to independent individuals, maximum interdependence in human teams is associated with the performance of the best teams, including science teams; our theory of interdependence predicts and we have confirmed for the top oil firms and the top militaries in the world that impaired interdependence is associated with less freedom, increased corruption and poorer team performance from an unnecessary excess of workers (redundancy; free loaders). We have further found maximum interdependence in teams requires intelligence to overcome obstacles on a team's path to fulfill its mission, where intelligence was represented by our surrogate variable of education. New theory is next introduced to account for one of our earliest reported findings on the oscillations driven by two federal agencies as a quasi-Nash equilibrium that generates information from checks and balances to suggest how social systems in free societies self-organize to improve social decisions (e.g., political, economic, military). We close with a table of common examples drawn from the field.

Introduction:

The advent of human-machine teams has elevated the need to determine context computationally, yet social science has offered little guidance for their design or operation or to prevent accidents (see the Uber self-driving car accident next that killed a pedestrian in 2018), let alone the means to construct a computational context (Lawless et al., 2019). Recognizing their plight, social scientists argue, and we agree, that their science is a repository of an extraordinary amount of statistical and qualitative experience in determining and evaluating contexts for humans and human teams (NAS, 2019). Nonetheless, this situation leaves engineers to seek a quantitative path on their own. Instead, as part of a work-in-progress, we offer an integrated path forward as the better course.

To illustrate the importance of this topic, as an example of a human-machine team system involved in an accident, the National Transportation Safety Board (NTSB, 2018) investigated the death of a pedestrian in 2018, finding that the Uber self-driving car saw the pedestrian 6s early, applied the brakes 1.3 s early, but the brakes had been disconnected by Uber engineers to improve the car's ride. The human operator saw the pedestrian 1s early but hit the brakes 1s after impact. However, the Uber car did not update the context for its human operator when it could have; its lack of interdependence with its operator made it a poor team player (Lawless et al., 2019).

Introduced by Lewin (1951), the founder of social psychology, interdependence has made a mixed contribution to social theory, more of an impact after it was introduced (e.g., game theory, exchange theory), virtually none in recent decades primarily from the failure to advance predictive theory. While Jones (1998), an eminent social psychologist, agreed that interactions were highly interdependent, he concluded that the complexity it caused in the lab was "bewildering," his conclusion more or less ending interdependence as a theoretical focus of study. Worse, social psychologists (Kenny et al., 1998) recommended the removal of interdependence to make data *iid* (independent and identically distributed), recommended also by engineers (Fromm, 2005) and information theorists (Conant, 1976). We have argued that this deletion of interdependence as a focus of study amplified the value of methodological individualism, impeded the study of teams, and is likely associated with the struggles in social science research that cannot be replicated (Nosek, 2015) and the inability to build new, valid theory.

In the social sciences, validity is a wide-ranging problem, whether it is in forensic science (Edwards & Gatsonis, 2006; for an update, see Segura & Smith, 2019); gender dysphoria (Davy & Toze, 2018); suicidal ideation (Murray, 2016) and the Diagnostic and Statistical Manual's "major weakness is its lack of validity" (Insel, 2013).

There is little that can be generalized from the social sciences to human-machine teams from research on humans. Human teams in sociology focus on individual differences (surveys, observations, patterns of communication), cognitive processes (e.g., mental models, psychological safety), training (with mental models) and diversity (for a review, see Cooke & Hilton, 2015). Of these factors, only team goals seem generalizable to human-machine teams (e.g., McDaniel & Salas, 2018); one factor, diversity, appears to be counter-indicative; e.g., Cummings (2015) found that the least productive teams were interdisciplinary teams, contradicting the literature on the goal of diversity (e.g., see McDaniel's assertion in support of diversity in Weir, 2018). But we find some studies of teams at work to be helpful (e.g., Sundstrom et al., 2000).

Unexpectedly, making interdependence a respected subject of study again, the National Academy of Sciences (NAS; see Cooke & Hilton, 2015) concluded that interdependence is critical to helping teams to perform superior to the same collection of individuals performing when independent of each other, the best teams being the most interdependent (Cummings, 2015). But what is interdependence was left open by the Academy's review, as was the optimum size of teams.

Interdependence:

Interdependence is, first, the bistable information associated with the construction of context shared by two or more agents (e.g., two-sided stories, such as "he said, she said;" or two-different world views such as religious versus atheist, conservative versus liberal political views, fiction versus non-fiction books; the difference between an observer and a performer), but few of us humans like to engage in two-sided (contradictory) views, motivating a segregation into tribes and hierarchies (e.g., opposing political parties each with organizational hierarchies). Second, a measurement problem of social objects commonly invalidates self-reported questionnaires or surveys (e.g., self-esteem in Baumeister et al., 2005; implicit racial bias in Blanton et al., 2009; the views of managers of their own organization's performance; in Bloom et al., 2007); the measurement problem is avoided by censoring one world view in favor of another's, causing individuals, teams, organizations or the tribes that perform single-minded acts to be more likely associated with error (e.g., authoritarians dampen innovation; single-minded views promote accidents or errors, e.g., the Boeing 737 Max). Third, the final aspect of interdependence is non-factorability (e.g., verbal speech versus the non-factorable aspects of non-verbal language; the intractability of assigning blame in complex legal cases; the difficulty of giving attribution for a heroic act on the field of battle). In summary, we attribute these three aspects to interdependence: bistable information; the measurement problem; and non-factorability. All three aspects enter into each and every social interaction, making the processing of interdependent information and its outcomes uncertain, unlike for Shannon information (except for noise).

To set the stage for new research on autonomous human-machine teams, we briefly review the literature. Following the literature, we review some of the previous findings in this report of our work-in-progress.

1.1 Our previous findings on interdependence

We have theorized that interdependence is characterized by bistability, the means to the construction of a shared context critical to the performance of teams (e.g., for science teams, see Cooke & Hilton, 2015, and especially Cummings, 2015); a measurement problem; and non-factorability. If true, our assumptions would explain theoretically why book knowledge is less efficacious to improve a physical skill than the physical training of that skill, which we address in our first finding; it would also explain why the best size of teams is the minimum number of personnel to complete the mission of a team, addressed in the second and third findings; and, in our fourth finding, it would indicate that book knowledge and action-skill knowledge are orthogonal, a guide to an uncertainty principle for the future research on the tradeoffs faced by the members of a team when the team is confronted by an obstacle to the completion of its mission.

1. In a study of USAF single-seat jet aircraft fighter pilots for USAF educators, we found that a test of air-to-air combat knowledge learned from their classroom studies based on the results of an examination of that knowledge led to no association with air-to-air combat win-loss outcomes determined with multiple regressions; at the same time, however, the amounts of training received by these fighter pilots led to significant differences in predicting which pilots would win or lose in air-to-air combat due strictly to the amount of highly-specialized air combat maneuver training that the winning pilots had received compared to the losing pilots (reviewed in Lawless, 2017a). The USAF educators who paid for this study did not like the

results and they replicated the study with questions loaded in favor of education; this was the data we analyzed for these USAF educators to find no support for their hypothesis.

2. In our first direct study of interdependence, considering interdependence to work somewhat like the communication among quantum entangled particles extrapolated to a similar effect occurring between two or more social objects, producing a state of total communication from all of the verbal-nonverbal sources of interference possible in a team (compared to Shannon's two-way communication across a channel), we predicted and found that the more interdependent were the members of a team, the better that those teams performed, in agreement with findings reported by the National Academy of Sciences on teams (see Cooke & Hilton, 2015; also, Cummings, 2015). We tested and confirmed this theory in a study of the top oil-firms in the world. We considered that the more redundancy existing in a team, the lower would be a team's level of interdependence and thereby adversely affecting a team's performance, especially a team's efficiency, which we attributed to destructive interference (Lawless, 2017a). Specifically, we found that the more freedom associated with a firm's home country of record, the less redundancy in one of its businesses such as an oil-firm; e.g., Exxon and Sinopec produce about the same amount of oil, but Exxon has about 1/8th the number of employees.
3. In a replication of our first study on interdependence, by collecting the data from the world's top militaries, we replicated and extended the oil-firm study. Again, we assumed that the more redundant were the members of a team, the poorer that team would perform. Results were significantly in agreement with our first study, reaffirming its findings (Lawless, 2017b): that is, we found that the more freedom in a nation, the smaller the size of its military measured by its number of military personnel. In addition, we extended our research by predicting and finding that redundancy was significantly associated with the levels of corruption in a country, and that the interdependence in a nation's teams was significantly associated with the individual freedom and the free market scores of a nation. In our interpretation, as interdependence in a team was reduced, team performance suffered. This reduction was easy to calculate based on the size of a team; that is to say, the larger a team that it took to complete the mission of a team, holding the mission of the differently sized teams constant, the poorer was the performance of a team; the latter finding contradicts the Academy which had argued that "more hands make light work" (Ch. 1, p. 13, in Cooke & Hilton, 2015). Significantly, redundancy was associated with the perceived levels of corruption in a country, implying to us that the redundancy existing in a team could be attributed as a payoff, reducing the constructive interference of interdependence.
4. In the last study that we have published, a study of MENA countries (Middle Eastern and North African countries, plus Israel), we have found that the average academic levels of schooling in a country, as a substitute for the intelligence existing in a team, were significantly related to the patents produced by a country (Lawless, 2019; also see Lawless et al., 2019). We took academic levels to indicate that the more intelligent were the students in a country about the fields of endeavor that they had engaged in, the better prepared were they to contribute to that field by knowing or suspecting what was missing in the technology indicated by the existing patents pertinent to a field or discipline. We reconfirmed the adverse impact that corruption in a country had on performance; that is, the more corrupt that a country was perceived to be, the lower was that country's patent productivity (we have not repeated a study of redundancy at this time, but we are still analyzing the data with the plan to report more fully on that aspect of our study in the future). Of great interest to us, this fourth study seemingly contradicts the results from our first study, which found that the training of physical skills, but not educating their associated cognitive skills, improved those physical skills, results that we have interpreted to be orthogonal (i.e., representing information vectors, the results of a dot product for Vector *A* and Vector *B* are equal to the magnitude of *A* times the magnitude of *B* times the cosine of the angle between the two vectors; when the two vectors are aligned, representing agreement, meaning that the angle between these two information vectors is zero degrees, the cosine of the angle between them is 1; e.g., two members of the same business who are in agreement; in contrast, however, when the angle is 90 degrees, or orthogonal, the value of the cosine for the angle between the two vectors is zero, representing disagreement; e.g., a member of the team at CBS and another from Viacom recently when the two sides underwent a hostile merger attempt; see Flint & Hagey, 2018). This result suggests that an application of a social uncertainty principle is in play.

Interdependence

Returning to interdependence, as we asserted, three effects characterize interdependence (Lawless, 2017): bistability (two sides to every story; the source of inspiration and innovation; checks and balances; social reactivity); measurement (produces one-sided stories; consensus-seeking or minority control; increased uncertainty and errors); and non-factorability (court cases; proprietary or patent claims; he said, she said). Measurement, for example, produces an uncertainty relationship that promotes the emergence of trade-offs; e.g., from signal detection theory, Cohen (1995) concluded that a

narrow waveform yields a wide spectrum, and a wide waveform yields a narrow spectrum and that both the time waveform and frequency spectrum cannot be made arbitrarily small simultaneously.

Emergence

Emergence, like surprise, can become the weapon that Clausewitz (1873) claimed caused “confusion and broken courage in the enemy's ranks ...” In competition against an adversary, the goal of a team should be to avoid internal surprise by being sufficiently well-trained to manage it, by navigating as a team around obstacles, and by exploiting it when seeking (e.g., emotional) vulnerabilities in an adversary's defenses to cause surprise in an adversary. Teams can emerge as a unit; unlike the Uber car, human-machine teammates can anticipate each other's vulnerabilities to construct contexts in real time to help their team to operate effectively and efficiently in a context shared by a team that they come to trust when their team navigates safely around obstacles (Lawless et al., 2019).

Multi-tasking

Individuals multi-task poorly (Wickens, 1992); e.g., using a cell-phone while driving a car. In contrast, multitasking is the reason that teams exist (Lawless, 2017a,b), giving them a comparative advantage over a non-team collection of the very same agents (Cooke & Hilton, 2015). To form and operate a team requires multiple forms of communications (verbal, non-verbal) that include the constructive and destructive interference transmitted by interdependence, making teamwork into an emergent property unequal to the sum of a team's individual contributors. Communications among humans include angry debate even among the best teams (Hackman, 2011); they also include explanations for the behaviors to be or not to be chosen in a particular, or even dynamic context, for which AI systems, especially machine learning, have so far been unable to manage (Pearl, 2002; Pearl & Mackenzie, 2018), a problem that has to be solved for the metrics that must be able to determine effective and efficient human-machine teams performing in real time, the subject of our Special Issue in AI Magazine (Lawless et al., 2019).

Correlations: Associations present three problems:

Before we briefly advance our new theory with simple mathematics for teams, we offer a conjecture to explain the current failure to advance a theory of interdependence. The original theory of close relationships, based on interdependence theory (Thibaut & Kelley, 1959; Kelley & Thibaut, 1978), while well-theorized, failed, leading to a new theory of "Close relationships" (Kelley, 1983) that also failed. Summing up these failures of interdependence theory, Kelley (1991) tried but could not explain why. We speculate that at the heart of this problem is the phenomenon of complementarity, where a couple or larger team forms an orthogonal relationship or a series of relationships that are at least pairwise orthogonal. Kelly's failure is that supportive correlations could not be found for at least orthogonal pair relationships. The reason is simple.

First, orthogonal implies independence; a zero correlation implies independence.

Second, for a relationship, a correlation means an association, mutual relationship, state of interdependence or connection between two or more elements. In social groups, social psychologists call that complementarity, for which the evidence does not support (e.g., Erber & Erber, 2016), a conundrum. We have often heard that a correlation does not mean causality; how can we account for causality with interdependence but without a correlation?

Third, the absence of a correlation in close relationships has been taken to mean the absence of an interdependent relation between orthogonal social objects. If two social objects are interdependent, however, they are causally connected. Interdependence means an ordering effect between two or more variables has occurred. If a pair is in an interdependent relationship occupying orthogonal roles (e.g., husband-wife; pitcher-catcher; prosecutor-defense attorney), however, the information they collect and self-report, coming from orthogonal roles, *must* have zero

correlation by definition. Confused? A waitress-cook pair working together are interdependently connected, yet each self-reports that each sees the world differently.

As an example of orthogonality and the lack of a correlation from a severed team, interestingly, via the carpus collosum, the two independent halves of a brain work together seamlessly like a team, but once surgically separated into two parts, each half of the brain now sees and self-reports the world differently (Gazzaniga, 2011). Thus, instead of assuming independent elements, the same statistical effect occurs if the roles of a team form orthogonal relationships (ship's captain, ship's engineer, etc.). Then the entropy gradient for a well-functioning team's structure reduces as its degrees of freedom (*dof*) reduce, producing a reduction in structural entropy similar to when the last element completes a molecule; when such a team emerges as a unit, it can direct maximum entropy production (MEP) to the task at hand (Martyushev, 2013). In sum, orthogonal roles in a team are interdependent; but orthogonal roles produce independent information; reduced *dof* explains bewilderment; and entropy links engineering and social science.

Future research for human-machine teamwork:

We suggest that a team operates as a network of intelligent agents from a catalaxy of exchanges (Hayek, 1976) to exploit and maintain sufficient free energy and negentropy, A , for it to order, organize and manage itself; to survive; and to solve a problem or other work that it has designated for itself, or, if part of an organization's hierarchy, that it has been ordered to act upon. Guided by Wissner-Gross & Freer (2013), based on the value of intelligence that we have found in our fourth study (Lawless, 2019), assume that a limited mental energy landscape exists, an idea modified that we borrow from the theory of ego depletion by Baumeister et al. (1998), one of the most famous experimental phenomena in social psychology, but one that has failed to be replicated (for a recent review, see Dang, 2018). We further assume that the mind's view of its potential negentropy landscape is at least three-fold: To solve the problems encumbered upon it; to find vulnerabilities in its opponents; and to maximize its exploitation of A . In this paper, we focus on the latter.

At each time step in a team's work performance, proportional amounts of A under its management or control is converted to entropy; maximum performance occurs at with maximum convergence of A into MEP (Martyushev, 2013).

Available energy and negentropy, A , are required for any action including the size, building or mergers of teams, with V being the potential intensity of its collective intelligence across the field applied per unit of A , and with J , the flow of available free energy-negentropy per unit of time, giving power normalized over distance for a team, P_x , as:¹

$$P_x = V * J = \frac{dS}{dA} \frac{dA}{dt} \quad (1)$$

We assume that teams are free to choose their own members, but that freedom, especially for successful teams, can motivate constructive and destructive interference (entropy). Competition is an example of constructive interference serving to obtain and drive the best teammates (e.g., Cummings, 2015) and for the best team performance (Lawless, 2017a,b). For destructive interference, gangs, authoritarian rulers, and the decision criteria for consensus-seeking, also known as minority control (Lawless et al., 2014), interfere destructively with a team's performance.

To operate a team to perform work requires A . Two teams competing against each other at a quasi-Nash equilibrium consume the most A to produce MEP (Martyushev, 2013). This quasi-Nash equilibrium could reflect a courtroom trial between an equally competent prosecutor and defense attorney (Freer & Perdue, 1996), between two businesses competing to merge with a third (e.g., the merger duel for Anadarko won by Occidental Petroleum Co. against Chevron; in Olson, 2019), or the recommendation by citizens advising the Department of Energy (DOE) on the cleanup of DOE's radioactive waste mismanagement at one of its sites, the target problem is fully described below.

¹ At this point for our work-in-progress, we use S for entropy; dS/dt as information processing, giving for knowledge $dS/dt=0$; from Wissner-Gross & Freer (2013), we use for force $F(x) = TVS(x)|_{x_0}$; and we shift to P_x for power to normalize distance in mental space, where $Work = F \times \cos\theta = P_x t$.

The quasi-Nash equilibrium. As a model of V , two teams serve to enter into a competition as long as they have sufficient A to perform, the performance of the two teams being similar to a harmonic oscillator described below. We assume that equation (1) is similar to a network or circuit for electricity. Assume a series-like circuit where a Nash-like equilibrium (Lawless, 2017a) acts like a unit capacitor to represent a polarized pair of teams expressing their intelligence to describe V as dual skirmish lines set against each other in the hopes of persuading an audience of voters to adopt its proposed solution to a target problem, the audience acting like a unit inductor, induced to consider one set of beliefs fleshed out in an argument countered by an opposing set of beliefs (orthogonal), the back and forth a tool that induces sufficient familiarity among the members of an audience with both sets of beliefs well-enough for them to determine strengths and weaknesses of the arguments to enable them to vote on the program they support. Let $z(t) = x(t) + iy(t)$, with x representing real resistance or social reactance along the abscissa, y on the ordinate representing beliefs by the imaginary parts of a solution (see Figure 1 below). Then,

$$\frac{d^2z}{dt^2} + \frac{dz}{dt} + z = e^{i\omega t} = \text{Re}[e^{i\omega t}] + \text{Im}[e^{i\omega t}] = \cos(\omega t) + i\sin(\omega t) \quad (2)$$

We sketch the real solutions from equation (2) on the x axis and imaginary ones on the y axis.

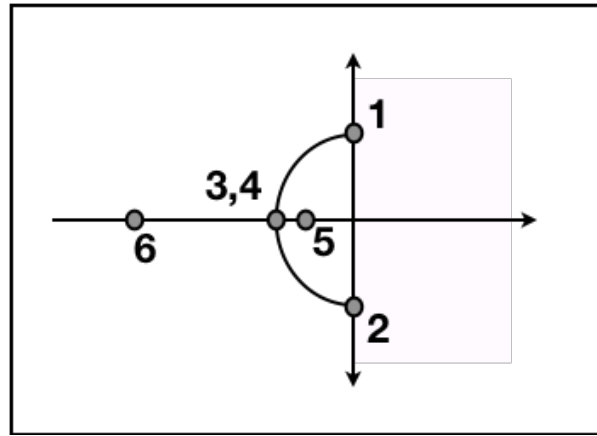


Figure 1. For Equation (2), in cases when no resistance exists (no audience feedback; two equal sides of an issue talking past each other), solutions fall only on the y axis, producing harmonic oscillations (points 1 and 2). When two equal competitors in a debate fully engage with each other with equal resistance to each other, a compromise provides a solution where the y curve meets at the x axis (e.g., points 3,4). When there is little debate when one side dominates the other, solutions fall entirely on the x axis without oscillations on the curve (solution 6 represented stronger resistance than solution 5).

Harmonic oscillator example. In 2005, a law was passed that required the Nuclear Regulatory Commission (NRC) to review all high-level radioactive waste (HLW) tank closure plans across the Department of Energy (DOE). The extra review provided by NRC, the competitor of DOE, illustrates interdependence in the field. "Turf battles" arise between nearly equal centers of power, displayed as undamped behavioral oscillations similar to predator-prey oscillations in biology or similar to a harmonic oscillator in social affairs. When humans witness a debate, the two power centers (P_{x1} and P_{x2}) become drivers of information to the neutral witnesses as they process the information (dS/dt) until they are able to decide an issue (Lawless, 2017a). Just such a turf battle between NRC and DOE was exposed after five years during a public meeting held in 2011 when the State of South Carolina complained in public that DOE was unlikely to close its two HLW tanks by 2012 as had been legally agreed, the slipping milestone caused by NRC's repeated and unrelenting challenges to DOE, with DOE being pushed by the State of South Carolina. However, after hearing both sides of the argument in public (bistability), and after the citizens realized that this "turf battle" was causing a key milestone to slip, the majority-ruled SRS CAB recommended closing the tanks immediately, a decision subsequently adopted by NRC and DOE (points 6 and 5). The tanks were closed in what one DOE official described as ". . . the fastest action I have witnessed by DOE-HQ in my many years of service with DOE" (Lawless et al., 2014).

Since then, even with the increased oversight by NRC, motivated by its Citizen Advisory Board (CAB), DOE's Savannah River Site in South Carolina has closed an additional seven tanks.

We close with a table below from current events to provide examples of the common occurrence of quasi-Nash equilibria to reflect its generality as a phenomenon.

Table 1. Examples of quasi-Nash equilibria drawn from common examples.

| Example | Description | Reference |
|---------|---|-------------------------|
| | A courtroom trial between an equally competent prosecutor and defense attorney provides the best outcome for society. | Freer & Perdue, 1996 |
| | The merger duel for Anadarko won by Occidental Petroleum Co. against Chevron. | Olson, 2019 |
| | Recommendations by citizens advising the Department of Energy (DOE) on the cleanup of its radioactive waste mismanagement at one of its sites. Majority rules produce superior results compared to consensus-seeking rules (the EU White Paper reached the same conclusion; WP, 2001). | Lawless et al., 2014; |
| | The trade fight between China and the USA. | Zumbrun, 2019; EB, 2019 |
| | The fight between the U.S. House of Representatives, Senate and White House over the disaster aid bill for Puerto Rico. | Duehren, 2019 |
| | In response to the appearance of growing threats from Iran in the Persian Gulf area, US Naval forces are being built up. | Youssef, 2019 |
| | The coming political battle in the State of Virginia in 2020 between Republicans and Democrats after Virginia was at the epicenter of one of the most embarrassing and horrifying political scandals in recent memory with its Governor and Lt. Governor. | Hemingway, 2019 |
| | Unable to persuade its European antitrust authorities to let it split into two companies, in an about face, Thyssenkrupp plans to restructure itself and to sell outright its elevator unit. | Bender, 2019a |
| | In preparation for potential space war, a series of war games “did not go well ...” Some satellites are already being strengthened with new defenses (shields against directed energy weapons and greater maneuverability to let them steer clear of space weapons). | Sciutto, 2019 |
| | Bayer is appealing the verdicts and argues that hundreds of studies and regulatory bodies around the world including the U.S. Environmental Protection Agency have concluded that Roundup and its active ingredient, glyphosate, are safe. More cases need to go to trial and more appeals heard before the direction of the legal fight becomes clear, Bayer and some investors say. Others, though, say only a win in court right now would help them regain confidence in the company. | Bender, 2019b |

Conclusions:

The new book on *Superforecasters* (Tetlock & Gardiner, 2015) is considered to be one of the best traditional models of decision making. In this model, the best predictors of social outcomes are trained to be even better. On its website, however, the authors posted their first two predictions: Brexit would not occur; and Trump would not be elected President of the United States.² As our work-in-progress, we propose a better model is the harmonic oscillator that we proposed in this manuscript. In addition to what we have predicted and found, we expect that the best decisions arise from the interdependence established by a quasi-Nash equilibria, as in the two-party system offered by the USA; or the competition for merger targets provided by free markets; or the reduction in corruption provided by checks and balances in a republic like the USA.

² <http://goodjudgment.com/superforecasting/index.php/2016/11/03/is-donald-trump-mr-brexit/>

References:

- Baumeister, R.F., Bratslavsky, E., Muraven, M. & Tice, D.M. (1998). "Ego depletion: Is the active self a limited resource?" *Journal of Personality and Social Psychology*, 74 (5): 1252–1265.
- Baumeister, R. F., Campbell, J.D., Krueger, J.I., & Vohs, K.D. (2005, January). Exploding the self-esteem myth. *Scientific American*, 292(1): 84-91; from <https://www.uvm.edu/~wgibson/PDF/Self-Esteem%20Myth.pdf>
- Bender, R. (2019a, 5/10), "Thyssenkrupp Abandons Planned Split, Pursues Elevator-Unit IPO. German company also expects planned European steel joint venture with India's Tata to be blocked; shares jump," Wall Street Journal, from <https://www.wsj.com/articles/thyssenkrupp-abandons-planned-split-pursues-ipo-11557486499>
- Bender, R. (2019b, /19), "Bayer's Roundup Problem Slashes Its Market Value. Investors and analysts say even radical change is unlikely to help the German company," Wall Street Journal, from <https://www.wsj.com/articles/bayers-roundup-woes-send-investors-fleeing-11558266059>
- Blanton, Hart, Klick, J., Mitchell, G., Jaccard, J., Mellers, B. & Tetlock, P.E. (2009), Strong Claims and Weak Evidence: Reassessing the Predictive Validity of the IAT, *Journal of Applied Psychology*, 94(3): 567–582.
- Bloom, N., Dorgan, S., Dowdy, J., & Van Reenen, J. (2007). "Management practice and productivity." *Quarterly Journal of Economics* 122(4): 1351-1408.
- Bohr, N. (1955). Science and the unity of knowledge. In L. Leary (Ed.), *The unity of knowledge*, Doubleday, pp. 44-62.
- Cohen, L. (1995). Time-frequency analysis: theory and applications, Prentice Hall Signal Processing Series.
- Clausewitz, C. Von (1873), *On war. J.J. Graham translation of Clausewitz's Vom Kriege (1832) published in London in 1873.*
- Cooke, N.J. & Hilton, M.L. (Eds.) (2015), *Enhancing the Effectiveness of Team Science*. Authors: Committee on the Science of Team Science; Board on Behavioral, Cognitive, and Sensory Sciences; Division of Behavioral and Social Sciences and Education; National Research Council. Washington (DC): National Academies Press.
- Conant, R.C. (1976), "Laws of information which govern systems," *IEEE Trans. Syst. Man Cybern.*, 4: 240–255.
- Dang, J. (2018), An updated meta-analysis of the ego depletion effect, *Psychological Research*, 82(4): 645–651; doi: [10.1007/s00426-017-0862-x](https://doi.org/10.1007/s00426-017-0862-x)
- Davy, Z. & Toze, M. (2018), What Is Gender Dysphoria? A Critical Systematic Narrative Review, *Transgender Health*, 3.1, DOI: 10.1089/trgh.2018.0014
- Duehren, A. (2019, 5/10), "Disaster-Aid Bill's Passage in House Kicks Off Next Phase of Negotiations. Democrats push through package of more than \$19 billion; talks continue in Senate over funding for Puerto Rico," Wall Street Journal, from <https://www.wsj.com/articles/house-prepares-to-vote-on-disaster-aid-package-11557503354>
- EB (2019, 5/10), "Editorial Board: The China Trade Impasse. The tariff damage rises as Beijing backtracks on its earlier concessions," Wall Street Journal, from <https://www.wsj.com/articles/the-china-trade-impasse-11557528495>
- Edwards, H.T. & Gatsonis, C. (2006, August), *Strengthening Forensic Science in the United States: A Path Forward*. Committee on Identifying the Needs of the Forensic Sciences Community, National Research Council. Report 228091, from <https://www.ncjrs.gov/pdffiles1/nij/grants/228091.pdf>
- Erber, R., & Erber, M. W. (2016). *Intimate relationships: Issues, theories, and research*. 2nd Edition. Hove, UK: Psychology Press.
- Flint, J. & Hagey, K. (2018, 5/14), "CBS Ups Stakes in Feud With Redstones. The media company turns to 'nuclear option' to eliminate Redstones' voting control and block a Viacom merger," Wall Street Journal, from https://www.wsj.com/articles/cbs-goes-on-attack-against-redstones-suing-controlling-shareholder-for-breaching-fiduciary-duty-1526308237?mod=article_inline
- Freer, R. D. & Perdue, W.C. (1996), Civil procedure, Cincinnati: Anderson.
- Fromm, J. (2005) "Types and forms of emergence," *ArXiv Prepr. Nlin0506028*.
- Gazzaniga, M.S., (2011), *Who's in charge? Free will and the science of the brain*. New York; Ecco.
- Gryta, T. (2019, 2/13), "GE Power has a \$92 billion backlog. For new boss, that's a problem. CEO Larry Culp says turbine-making division is weighed down by low-margin orders that came from chasing market share," Wall Street Journal, from <https://www.wsj.com/articles/ge-power-has-a-92-billion-backlog-for-new-boss-thats-a-problem-11550068479>
- Hayek, F.A. (1976), *Law, legislation and liberty*, 2: 108-09.
- Hemingway, M. (2019, 5/10), "*How Virginia's Top Democrats Survived a Storm of Scandal*. The media lost interest in the Northam blackface brouhaha when it realized the GOP could benefit," Wall Street Journal, from <https://www.wsj.com/articles/how-virginias-top-democrats-survived-a-storm-of-scandal-11557529444>

- Insel, T. (2013, 4/29), "Post by Former NIMH Director Thomas Insel: Transforming Diagnosis," NIMH, from <https://www.nimh.nih.gov/about/directors/thomas-insel/blog/2013/transforming-diagnosis.shtml>
- Jones, E.E. (1998), Major developments in five decades of social psychology, In Gilbert, D.T., Fiske, S.T., & Lindzey, G., *The Handbook of Social Psychology*, Vol. I, pp. 3-57. Boston: McGraw-Hill.
- Kelley, H.H. & Thibaut, J.W., (1978). *Interpersonal relations: A theory of interdependence*. New York: Wiley-Interscience."
- Kelley, H.H. (Ed.). (1983). *Close relationships*. New York: W.H. Freeman and Company.
- Kelley, H.H. (1991), Lewin, situations, and interdependence, *Journal of Social Issues* 47: 211-233.
- Kenny, D. A., Kashy, D.A., & Bolger, N. (1998). Data analyses in social psychology. *Handbook of Social Psychology*. D. T. Gilbert, Fiske, S.T. & Lindzey, G. . Boston, MA, McGraw-Hill. 4th Ed., Vol. 1: pp. 233-65.
- Lawless, W. Akiyoshi, M., Angjellari-Dajcic, F. & Whitton, J. (2014), Public consent for the geologic disposal of highly radioactive wastes and spent nuclear fuel. *International Journal of Environmental Studies*, 71(1):41{62, 2014.
- Lawless, W.F. (2017a), The entangled nature of interdependence. Bistability, irreproducibility and uncertainty, *Journal of Mathematical Psychology*, 78: 51-64.
- Lawless, W.F. (2017b), The physics of teams: Interdependence, measurable entropy and computational emotion. *Frontiers of Physics*, 5:30. Doi: 10/3389/fphy.2017.00030
- Lawless, W.F. (2019, under review). Interdependence, shared context and uncertainty for human-machine teams. Towards the mathematics of explainable AI. *Frontiers of Science*.
- Lawless, W.F., Mittu, R., Sofge, D.A. & Hiatt, L. (2019), "Artificial intelligence (AI), autonomy and human-machine teams: Interdependence, context and explainable AI," Introduction to the Special Issue, *AI Magazine*.
- Lewin, K. (1951), *Field theory of social science. Selected theoretical papers*. Darwin Cartwright (Ed.). New York: Harper & Brothers.
- Hackman, J. R. (2011). "Six common misperceptions about teamwork." *Harvard Business Review* <https://hbr.org/2011/06/six-common-misperceptions-about>
- Martyushev, L.M. (2013), "Entropy and Entropy Production: Old Misconceptions and New Breakthroughs," *Entropy*, 15(4): 1152–1170.
- McDaniel, S.H. & Salas, E. (2018), The science of teamwork: Introduction to the special issue, *American Psychologist*, 73(4): 305-7; <http://dx.doi.org/10.1037/amp0000337>
- Murray, Declan (2016-02-18). "Is it time to abandon suicide risk assessment?" *British Journal of Psychiatry Open*. 2 (1): e1–e2. doi:10.1192/bjpo.bp.115.002071.
- NAS (2019), *A Decadal Survey of the Social and Behavioral Sciences: A Research Agenda for Advancing Intelligence Analysis*, National Academies of Sciences.
- Nosek, B., corresponding author from OCS (2015), Open Collaboration of Science: Estimating the reproducibility of psychological science, *Science*, 349 (6251): 943; supplementary: 4716-1 to 4716-9. (National Academies of Sciences, Engineering, and Medicine. 2019. *Reproducibility and Replicability in Science*. Washington, DC: The National Academies Press. <https://doi.org/10.17226/25303>.)
- NTSB (2018, 5/24), "Preliminary Report Released for Crash Involving Pedestrian, Uber Technologies, Inc., Test Vehicle," National Transportation Safety Board, from <https://www.nts.gov/news/press-releases/Pages/NR20180524.aspx>
- Olson, B. (2019, 5/10), "Occidental Chief Defends Anadarko Deal to Shareholders, In sign of dissent, Occidental board sees lowest vote totals in years," *Wall Street Journal*, from <https://www.wsj.com/articles/occidental-chief-defends-anadarko-deal-to-shareholders-11557513040>
- Pearl, J. (2002), "Reasoning with Cause and Effect", *AI Magazine*, 23(1): 95-111; from <https://aaai.org/ojs/index.php/aimagazine/article/download/1612/1511>
- Pearl, J. & Mackenzie, D. (2018, 5/18), "AI Can't Reason Why. The current data-crunching approach to machine learning misses an essential element of human intelligence", *Wall Street Journal*, from <https://www.wsj.com/articles/ai-cant-reason-why-1526657442>
- Sciutto, J. (2019, 5/10), "A Vulnerable U.S. Really Does Need a Space Force. China and Russia are developing new weapons that can attack crucial American satellites, and the U.S. has been slow to respond to the danger," *Wall Street Journal*, from <https://www.wsj.com/articles/a-vulnerable-u-s-really-does-need-a-space-force-11557480601>
- Segura, L. & Smith, J. (2019, 5/6), "Bad evidence. Ten years after a landmark study blew the whistle on junk science, the fight over forensics rages on," *The Intercept*, from <https://theintercept.com/2019/05/05/forensic-evidence-aafs-junk-science/>

- Sundstrom, E., McIntyre, M., Halfhill, T., & Richards, H. (2000). Work groups: From the Hawthorne studies to work teams of the 1990s and beyond. *Group Dynamics: Theory, Research, and Practice*, 4(1), 44-67; from <http://dx.doi.org/10.1037/1089-2699.4.1.44>
- Tetlock, P.E. & Gardner, D. (2015), *Superforecasting: The Art and Science of Prediction*, Crown.
- Thibaut, J.W., & Kelley, H.H., (1959). *The social psychology of groups*. New York: Wiley.
- Weir, K. (2018), What makes teams work? Psychologists are pinpointing the factors that make teams gel—research that has far-reaching implications for health care, education, research, industry and more, *Monitor on Psychology*, 49(8): 46; from <https://www.apa.org/monitor/2018/09/cover-teams>
- Wickens, C. D. (1992). *Engineering psychology and human performance* (second edition). Columbus, OH, Merrill.
- Wingfield, N. (2017, 9/10), "As Amazon pushes forward with robots, workers find new roles," *New York Times*, from <https://www.nytimes.com/2017/09/10/technology/amazon-robots-workers.html>
- Wissner-Gross, A. D., and C. E. Freer (2013), Causal Entropic Forces, *Physical Review Letters*: 110(168702): 1-5.
- WP (2001). White Paper. European governance (COM (2001) 428 final; Brussels, 25.7.2001). Brussels, Commission of the European Community.
- Youssef, N.A. (2019, 5/10), "U.S. Bolsters Its Gulf Defenses to Counter Iran. Pentagon to deploy Patriot antimissile system, assault ship as officials say Tehran shows no signs of changing posture," *Wall Street Journal*, from <https://www.wsj.com/articles/u-s-to-send-antimissile-battery-to-gulf-to-counter-iran-11557520326>
- Zumbrun, J. (2019, 5/10), "With Trade Deal in Jeopardy, Trump Pledges Aid to Farmers. Administration signals it is ready for a prolonged standoff as new tariffs on China take hold," *Wall Street Journal*, from <https://www.wsj.com/articles/with-trade-deal-in-jeopardy-trump-pledges-aid-to-farmers-11557503755>