(Computational) Context: Why It's Important, What It Means, Can It Be Computed?

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Abstract
Reputedly, context explains how the environment influences human perception, cognition and action. Context can be clear, uncertain or an illusion. **Clear contexts:** A chaplain giving last rites; a doctor’s visit; a traffic policeman asking for registration and insurance. It is the word sequence in a sentence that allows humans to learn an unknown word. Context-specific dependencies have been applied in cancer and biomedical research. An organization’s context is its management, culture and systems. **Uncertain contexts:** The fog of war; a jury’s reaction to counter-arguments; a shout to “Abandon ship!” **Context as an illusion?** Individuals are affected by illusions; e.g., humans are prey to Adelson’s checkerboard illusion, while a photometer is not. Rovelli, a physicist, wrote “reality is not as it appears”. In 1944, supporting Einstein’s theory of relativity, a New York Times editorial declared that the physical world was “largely illusory”. After reviewing numerous behavioral and social data (e.g., polls) in the search for context, Dzhafarov et al. concluded that “none of these data provides any evidence for contextuality”. Their conclusion indirectly supports Bekenstein who suggested that the holographic principle may place the struggle to interpret quantum mechanics into a more rational or intuitive context. However, even outside of awareness, individuals act differently whether alone or in a team. Can computational context with AI adapt to clear and uncertain contexts, to change over time, and to individuals, machines and robots in teams? But whether AI “knows” the context is clear, uncertain or illusory. This idea agrees with the Department of Defense’s need for “having a common perception of the surrounding world and able to place it into context”. We believe that integrating systems to work together for the members of a (hybrid) team will present a computational challenge, but that it will also offer an opportunity to advance the science of context in teams, one of our research interests.

Introduction

**Clear contexts.** Context reputedly explains everything in the environment that influences our perceptions, cognitions and actions (Sobell, 2009). When is context clear? Examples of clear context might be a chaplain’s blessing; a regularly scheduled visit at a dentist’s office; an official letter from the IRS; a traffic policeman writing out a ticket for speeding; a boss’ reprimand. Context is the word sequence in a sentence that allows the brain to learn a new, previously unknown word, handwriting or grammar (McClelland & Rumelhart, 1988). Using Bayesian inference, Marwhah and colleagues (2012) discovered context-specific dependencies in ontologies with application to cancer and biomedical research. An organization’s context is its management, culture and systems (Doolen et al., 2003), symbolized by its resistance to change (Lawless, 2017).

**Uncertain contexts.** Can applications of context be customized with AI to adapt to an uncertain context as well as to those that change over time? When is context difficult to apprehend? Examples of uncertain context abound: The fog of war; a jury’s reaction to counter-arguments; he said, she said; PTSD complaints; a pilot in an emergency replying to a tower; a shout to “Abandon ship!”

**Contexts as illusions.** Even more difficult to apprehend, is context an illusion? In 1944, based on mostly empty space at the atomic level written about by Eddington, the British scientist who led the expedition that garnered convincing support for Einstein’s theory of relativity, an editorial in the New York Times declared that the physical world was “largely illusory”. Rovelli (2016), a physicist, wrote “reality is not as it appears”. Experience is an individual’s life-long context that makes an individual vulnerable to an illusion; e.g., humans are prey to Adelson’s (2000) checkerboard illusion, while a photometer is not. Outside of awareness, individuals act differently whether alone or as a member of a team (Lawless, 2016b; 2016c). Unbeknownst to experimental subjects as well as to scientists, illusions may also be at play in social science. After reviewing numerous behavioral and social data sets (e.g., polls) in the search for context, Dzhafarov et al. (2015) concluded that:
none of these data provides any evidence for contextuality. Our working hypothesis is that … behavioral and social systems are non-contextual … [in that] all “contextual effects” in them result from the ubiquitous dependence of response distributions on the elements of contexts other than the ones to which the response is presumably or normatively directed.

Whether an AI program automatically “knows” the context and yet still improves performance, it may not matter whether context is real, uncertain or illusory. This idea agrees with the Department of Defense's need for a hybrid team automatically “having a common perception of the surrounding world and able to place it into context” (RCTA, 2016). We think that integrating systems to work together for the members of a hybrid team will present a computational challenge, but that it will also offer an opportunity to advance the science of teams, especially as it may apply to hybrid teams, one of our research interests (Lawless, 2016c).

A computational approach to context

We recognize that context may be clear, difficult to apprehend or governed by illusions. At present, we leave the topic open-ended. But we ultimately envision a computational approach to the construction of context with recommender systems using predictive analytics; e.g., recommender systems are used to sentence criminals (Palazzolo, 2016); to estimate the risks for suicide (Peterson, 2016); and to create music (McFarland, 2016):

Google's Project Magenta … aims to push the state of the art in machine intelligence … to generate music and art. … the neural network soon begins to realize which note should come next in a sequence. … Amper Music is a start-up that uses artificial intelligence to create original songs that match the emotions a video producer wants to convey … music doesn’t … come from great individuals … it comes from communities … over many years … As machines have become more a part of our lives, we can count on them to share a hand in the artistic process.

Context can be manipulated; e.g., from the Presidential election in 2016, the Wall Street Journal reported (Nicas & Andrews, 2016),

Alphabet Inc.’s Google battled accusations that it manipulates its predicted-searches function to favor Hillary Clinton, the latest dust-up over the influence large tech companies exert in modern life.

Mergers are being pursued in the hopes of strengthening teams in the race for the technology that can develop predictive systems with machine learning and big data (Greene, 2016):

Microsoft, Apple Inc. and Alphabet Inc. are moving deeper into using machine learning, in which computers rapidly examine existing information in search of patterns that their products can use to understand new information as it arrives.

Getting data management correct is important; e.g., (Anderson & Wladawsky-Berger, 2016),

Inventing effective organizations for the digital economy is the grand challenge for our time, and the companies that are already adapting are leading the way.

Context is being used with predictive analytics

Predictive analytics constructs individual and team mission contexts to improve individual and team performance. Predictive analytics adds value for users and contexts. By addressing the needs of users, better predictive analytics in recommender systems improves the interpretations of situational awareness and business decisions; e.g., from an advertisement by an Uber data-science manager (Mehrotra, 2016),

I'm always looking for people with background in building statistical models, econometrics, time series analysis, some experience with machine learning. We are working on making Uber smarter about operating in a city by leveraging the power of data.

In healthcare, predictive tools are being used to predict the probability that a patient has a suspected ailment, resulting in fewer antibiotic prescriptions than a control group of physicians not using the tools (Lagnado, 2016):

using [this] technology to help diagnose and treat patients can reduce the large number of unnecessary tests doctors order and antibiotics they prescribe by ruling out certain diseases.

Context helps to measure errors. Our AAAI Symposium in 2016 considered how to reduce the error that humans, and possibly intelligent robots in the future, are prone to make (Mittu et al., 2016). We have found that error reduction and protecting humans from making errors are key to the optimal performance of teams (Lawless, 2016), including goal attainment, trust, intelligence and resilience.

The context associated with an excited team state

A perfect team structure consumes the minimum of available energy (Lawless, 2017). Perfect team performance implies a ground state (a low emotional state; e.g., Zajonc, 1998). In contrast, an excited state can consume all of the

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1 A hybrid team is used to refer to those teams arbitrarily composed of humans, machines and robots.
2 Amper music: Artificial Intelligence Music Composer; see https://www.ampermusic.com
3 We have a book forthcoming from Springer that goes well beyond but also includes some of the presenters at our 2015 (autonomy) and 2016 (error mitigation) AAAI Symposia.
available energy, leaving none for a hybrid team to accomplish its mission.

If the boundary of a hybrid team includes its human operators, for a well-trained hybrid team, if a human or robot operator threatens the hybrid team or human life, the AI team can take over its system and place it into a safe mode (Mittu et al., 2016). For example, Gill Pratt, Toyota’s top research executive, said that Toyota is pursuing a semi-autonomous track that would rescue the human driver when the human user becomes distracted or inebriated. Per Pratt the system (Bigelow, 2016) would amount to an:

autonomous "guardian angel" … that would allow humans to maintain control of their vehicles in almost all cases except when it can help them avoid poor decisions or imminent dangers.

A concern may be that poorer decisions arise when a system, for example a “recommender system”, provides positive feedback that pushes information to a user that strengthens the user’s confirmation bias (Darley & Gross, 2000), increasing disagreement between the two sides of an issue, potentially leading to polarization (Sibley, 2016). The result may be an excited state (Lawless, 2016) arising from the disagreement between two central attitudes, beliefs or when an action compromises a central belief (Cooper, 2007, p. 182).

The breakdown of context from redundancy

By breaking down interdependence (Lawless, 2016), redundancy increases uncertainty in determining context. Generalizing from the Uber model, Hyden (2016) wants to optimize management assets for warriors in the field by replacing, to the extent practicable, the redundancy arising from centrally managed logistics with local or distributed controls (e.g., satellite image production and dissemination). First, as an example of the misallocations that weaken central control to produce redundancy (Denyer, 2016),

“You’ve had massive credit growth and investment in projects that don’t generate an economic return ... said Rodney Jones, founder of Wigram Capital Advisors in Beijing. ... Gansu [in China] is making basic economic missteps, investing in heavy industry at a time of global overcapacity and building infrastructure when it should be reducing its debt. ... The central government talks of reducing industrial overcapacity, cutting debt and transitioning to a new, innovation-driven economy, but provincial leaders, under pressure to meet economic targets, seem unable ...”

Second, providing indirect support for Hyden's (2016) model, as an example of the efficiencies that interdependence transmits across a market by increasing competition, a business merger between two equals reduces redundancy in a transformed enterprise (Andrade & Stafford, 1999). As an example of team formation in a consolidating market, consider the proposed merger by Computer Science Corporation and HP Enterprise. First, consider HP’s situation (Clark & Stynes, 2016),

HP Enterprise faces increasing competition from cloud-computing vendors including Amazon.com Inc. and Microsoft Corp. that sell metered access to raw computing power over the Internet. Customers must decide whether to opt for cloud services, maintain conventional data centers, or build their own private cloud-like facilities—a business especially targeted by HP Enterprise.

Second, consider what physically happens during the formation of the new team by Computer Science Corporation and HP Enterprise (Bogage, 2016),

The companies ... expect reduced costs in the combined entity to the tune of $1 billion, largely by consolidating real estate, data centers and procurement activities.

Context and the Second Law of Thermodynamics

When two groups merge, they “cut costs” by reducing redundancy (e.g., Herman, 2015); similarly, when a crystal forms, it gives off energy. When groups are poorly run, or when a new merger fails, spinoffs into an independent state occur (e.g., Mattioli et al., 2016), increasing entropy and energy. This similarity between mergers and crystals in the way that teams form and break apart appears to follow the second law of thermodynamics.

We speculate that the type of merger noted earlier by HP and CSC also simulates the second law of thermodynamics. Namely, the formation of team’s structure requires excess energy (e.g., choosing the right leader; rejecting those who do not “fit” a position or a role as a member of a human or hybrid team; reducing redundant personnel; and reducing unnecessary or duplicate back-office operations); in contrast, the dissipation of team’s structure absorbs energy, converting a team’s members into independent individuals.

We also suspect that emotions may serve to confirm our hunch about the second law of thermodynamics in the formation and dissolution of teams. By applying set-point theory to a team (Brickman et al., 1978), the better the team performs, the more stable becomes the team, but, and as a consequence, the harder it is to understand why (i.e., the subadditivity of its Von Neumann information); this accounts for the finding by Zajonc (1998, p. 619) that expertise is otherwise non-obvious to a team’s members and to observers beyond the physical display of skills, explaining the need for coaches with trial-and-error approaches to improve a team’s performance (Lawless, 2017); e.g., despite having lost in the championship game, Saban’s meticulous preparations at the University of Alabama help to explain his success in building a football program that is often in the playoffs at the end of recent football seasons (Uthman, 2016). Just the opposite is true for the Shannon
information generated by a divorce; e.g., regarding Britain’s vote to exit from the European Union (Erlanger & Bilefsky, 2016):

The sense of shock was … acute in London … which reacted … with anger, disappointment and even tears.

Failure, too, can often trigger an emotional response (Zanjonc, 1998); e.g., the recall by Samsung of its new flagship phone, its Galaxy Note 7, led to the open display of emotions (Sang-Hun, 2016):

A former South Korean teacher, Kim Jeong-min was at Narita Airport in Japan this month when he watched a television news report that Samsung Electronics’s Galaxy Note 7 smartphone was banned on airplanes because it was prone to catching fire. Mr. Kim, 58, said he had felt humiliated, as if the non-Koreans in the airport lounge were looking at him. Though he does not own a Galaxy Note 7, his reaction was typical of the intense feelings South Koreans hold toward Samsung, the most dramatic corporate success story to emerge from the country’s transformation from a war-torn agrarian nation to a global economic powerhouse.

What about AI and emotions? Can computers use AI to model the emotions of a team? Some scientists feel that the answer is no; e.g., from Gelernter (2016),

Thinking-about can be simulated on a computer. But no computer will ever feel anything. Feeling is uncomputable. Feeling and consciousness can only happen (so far as we know) to organic, Earth-type animals—and can’t ever be produced, no matter what, by mere software on a computer.

Picard (1997), however, disagrees. According to her, if we want computers to be genuinely intelligent and to interact naturally with humans, we must give computers the ability to recognize, understand, even to have and express emotions.

From a computational perspective, we agree with Picard. For future research on teams and the second law of thermodynamics, we hypothesize that the least redundancy existing among the members of a team that achieves and maintains a full state of interdependence among all of the members of a team maximizes the team’s performance (i.e., the team generates maximum entropy production or MEP; in Lawless, 2017). Regarding context, whether its context is obvious and apparent to a team’s members, its external observers or not (Dzhafarov et al., 2015), we believe that redundancy in hybrid teams can be mathematically established and measured (Lawless, 2017); e.g., when the proper team fit is achieved, a team’s entropy is reduced; for a “perfect” team, entropy reaches a minimum; and a team’s minimum entropy state can be designated as its ground state. As a team becomes excited say from failing, being attacked or having a non-performing teammate, its entropy is increased above its predetermined ground state. In this example, it is not necessary for context to be obvious to a team’s members (whether, say, a team’s members are openly crying or not after a divorce or a team’s failure); regardless, based on our model, the context of a team can still be computationally determined.

Conclusion: A non-linear model of decision-making

From a convergence perspective (e.g., the superforecasting model built by Tetlock & Gardner, 2015), if one side of a debate was the clear winner, superforecasting might have been the end of the matter. Superforecasters have made numerous and widely publicized major forecasts based on their team of top-notch forecasters; however, none of these predictions have been correct (e.g., from Lawless, 2017, Brexit; the Senate won by the US Republicans in 2016; and Hillary Clinton lost the race for the electoral college that determines the US President in 2017). Their thesis is that politics and human affairs are not inscrutable, but a bit like weather forecasting, where short-term predictions are possible and reasonably accurate forecasting ... is a skill that can be cultivated. (p. 4)

We disagree; the evidence supports us. Instead, one-sided convergence processes mislead decision-makers; increase the opportunity for errors; and preclude advances in computational models for decisions. Smallman (2012) argued for the value of showing both sides of an argument or interpretation, weighting the stronger argument. For our purposes, however, the result should be a non-linear limit cycle where meaning loses value the stronger becomes a limit cycle; limit cycles arise when two sides are relatively equal, or elites decide that one side of a debate is socially inappropriate (e.g., by the editorial boards of leading newspapers; academics; professionals); in 2016, that would be those who voted for Brexit, Republicans, and Trump.

We propose that limit cycles are created by the interdependence between the relatively balanced or relatively equal two sides of a debate as they entangle observers (e.g., juries in courtrooms; independents in politics; the undecideds in science; in Lawless, 2017); we identify the source of these limit cycles as those decisions driven by Nash equilibria, arising from a people free to move and capital free to invest. Further, when one of those two sides are shortchanged or suppressed, as often happens under autocratic regimes, errors increase because checks on decisions are overridden by authoritarian leaders (e.g., Cuba; China; Russia; experts). In conclusion, while limit cycles are modeled by the simple bistable equations used to model predator-prey relationships, the loss of meaning in social systems is profound, leading to endless debates, but better decisions that vastly improve social welfare (e.g., poorer decisions were made by the Department of Energy when the public had no idea that the consequences of DOE’s
waste management practices at its Savannah River Site plant in South Carolina lead to disastrous radioactive releases into the air; surface waters and ground waters; and across and under the land; however, nowadays, every decision made at SRS is fought in public between the affected States, National Academy of Scientists, DOE managers and scientists, and local citizens, leading to decisions that have vastly improved the environment at and around SRS; in Lawless et al., 2014).

![Graph](image)

**Fig. 1:** The last part of the extended limit cycle taken from the Los Angeles Times as the Presidential election ended in 2016 (http://www.latimes.com/nation/politics/trailguide/la-na-election-day-2016-a-last-look-at-the-polls-clinton-lead-1478618744-htmlstory.html).

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