# Artificial Intelligence for the Internet of Everything

**W. F. Lawless,[1] Ranjeev Mittu,[2] Donald Sofge[2]**
[1] Paine College, Augusta, GA 30901; [2] Naval Research Laboratory, Washington, DC 20375
[1] w.lawless@icloud.com; [2] {ranjeev.mittu, donald.sofge} @nrl.navy.mil

**Abstract**

For the Internet of Everything (IoE), from an AI perspective, we discuss the meaning, value and effect that the internet of things (IoT) is expected to have on ordinary life, in industry (IIoT), on the battlefield (IoBT), in the medical field (IoMT) and with intelligent-agent feedback in the form of constructive and destructive interference (IoIT). We consider the topic open-ended but with an AI perspective that addresses how the IoE affects sensing, perception, cognition and behavior, or causal relations whether the context is clear or uncertain for mundane decisions, complex decisions on the battlefield, life and death decisions in the medical arena, or decisions affected by intelligent agents and machines. We pay attention to theoretical perspectives for how these "things" may affect individuals, teams and society; and in turn how they may affect these "things". We are most interested in what may happen when these "things" begin to think. Our ultimate goal is to use AI to advance autonomy and autonomous characteristics to improve the performance of individual agents and hybrid teams of humans, machines, and robots for the betterment of society.

## IoE: IoT, IoBT, and IoIT--Background and overview

The Internet of Everything (IoE) [1] generalizes machine-to-machine (M2M) communications for the Internet of Things (IoT) to a more complex system that also encompasses people, robots and machines. From Chambers (2014), IoE connects

> *people, data, process and things. It is revolutionizing the way we do business, transforming communication, job creation, education and healthcare across the globe. ... by 2020, more than 5 billion people will be connected, not to mention 50 billion things. ... [With IoE] [p]eople get better access to education, healthcare and other opportunities to improve their lives and have better experiences. Governments can improve how they serve their citizens and businesses can use the information they get from all these new connections to make better decisions, be more productive and innovate faster.*

This IoT is expected to become big business with a large impact on day-to-day life. From Marr (2015),

> *By 2020, a quarter of a billion vehicles will be connected to the Internet ... new possibilities for in-vehicle services and automated driving. In fact, we already have cars that can drive on their own – Google's self-driving cars currently average about 10,000 autonomous miles per week. ... Machine-to-machine (M2M) connections will grow ... to 27 billion by 2024, with China taking a 21% share and the U.S. 20%. ... the IoT will have a total economic impact of up to $11 trillion by 2025*

The industrial internet of things (IIoT)[2] is impacting industry by forcing alliances to keep pace with innovation; e.g., (Ramachandran et al., 2017):

> *Amazon could help finance a network Dish is building focused on the "Internet of Things"—the idea that everything from bikes to Amazon's drones can have web connectivity everywhere.*

The internet of things (IoT) is "all about connecting objects to the network and enabling them to collect and share data" (Munro, 2017). But a big question is (Alessi, 2017):

> *who will create and dominate a realm of technology ... to become the backbone of industrial automation and provide mountains of data about everything from parts inventories to how products are wearing long after their purchase.*



[1] http://ioeassessment.cisco.com

[2] http://www3.weforum.org/docs/WEFUSA_IndustrialInternet_Report2015.pdf

With the approach of IoT in everyday life (Gasior & Yang, 2013), in industry (IIoT),[3] on battlefields (IoBT),[4] in the medical arena (IoMT),[5] distributed with sensory networks and cyber-physical systems, and even with device-level intelligence (IoIT),[6] some of the known issues identified by Moskowitz (2017) are the explosion of data (e.g., cross-compatible systems; storage locations); security challenges (e.g. adversarial resilience,[7] data exfiltration, covert channels; enterprise protection; privacy); self-* [8] and autonomic behaviors, and the competitive risks to users, teams, enterprises and institutions. Still, despite the pace of rapid advance, "Humans will often be the integral parts of the IoT system" (Stankovic, 2014, p. 4).

For the Internet of Everything, IoT, IoBT, IoMT, IoIT and on will manifest as heterogeneous and potentially self-organizing complex-systems that define human processes, requiring interoperability, just-in-time (JIT) human interactions, and the orchestration of local-adaptation functionalities to achieve human objectives and goals (Suri et. al, 2016).

For military matters, IoBT is about the relation of persons-to-machines; e.g., (Cartwright, 2015):

> *how many men it takes to run a machine to how many machines a man can control.*

There are practical considerations: Whatever the systems used for the benefits afforded, each must be robust to interruptions, to failure, and resilient to every possible perturbation from wear and tear in daily use. For system-wide failures, a system must have manual control backups; user-friendly methods for joining and leaving networks; autonomous updates and backups; and autonomous hardware updates (e.g., similar to re-ordering inventory or goods automatically by a large retailer like Amazon or Wal-Mart). A system must also provide forensic evidence in the event of a mishap, not only with an onboard backup, but also with an automatic backup to the cloud.

IoT is causing creative disruption to commerce, militaries, medicine and life in general (Hymowitz, 2017):

> *Combined with faster processors, better sensors, and larger data sets, machine capabilities are growing exponentially. The data we now collect from everything from traffic sensors to Facebook visits to the Internet of things are essentially robot protein; more data, more powerful robots ... [implying] machines are becoming self-driving ...*

To be able to address disruption for coming and future systems, we want to see these questions addressed:

> *Will systems communicate with each other or be independent actors? Will humans always need to be in the loop? Will systems communicate only with human users, or also with robot and machine users? How will intelligent systems communicate?*

But there are few practical methods to address these questions for IoE systems. One proposal is to study IoT with agent-based models (ABMs). ABMs offer opportunities to pursue solutions to problems like IoT that happen to be too complex to solve by traditional methods, but ABMs are not yet ready (Houston et al., 2017):

> *Based on insights from this work, it is clear that this integration possesses great capacity for capturing the complexity of the modern world when compared to other forms of simulation and analysis. However, ... [ABMs are not yet capable of] answering practical business questions.*

## When "things begin to think"

For the near future, we are becoming interested in what may happen when these "things begin to think". Foreseeing something like the arrival of the IoE, Gershenfeld (1999, p. 8, 10), the Director of MIT's Center for Bits and Atoms,[9] predicted that when a digital system

> *has an identity, knowing something about our environment, and being able to communicate ... components ... [must] work together ... so that the digital world merges with the physical world.*

Gershenfeld helps us to link this symposium with our past symposia in 2016 for using AI to reduce human errors[10] and another symposium in 2017 for using AI to determine "computational context", especially under uncertainty.[11] Gershenfeld leads us directly to intelligence.

Intelligence is a critical factor in overcoming barriers to direct maximum entropy production to solve difficult problems (Wissner-Gross & Freer, 2013; Martyushev, 2013). In battle systems, intelligence is necessary to

[3] WEC, 2015
[4] Kott et al., 2016
[5] Haghi et al, 2017
[6] Dibrov, 2017
[7] e.g., password authentication, back proofing, etc.
[8] To self-manage autonomy, human operators define the policies and rules to guide self-managed systems, identified by IBM as a self-* or self-star autonomous property (e.g., IBM, 2005).

[9] http://cba.mit.edu
[10] e.g., in 2016, AI and the mitigation of human error; see https://www.aaai.org/Symposia/Spring/sss16symposia.php#ss01
[11] e.g., our symposium on Computational context in 2017: https://aaai.org/Symposia/Spring/sss17symposia.php#ss03

complete missions by overcoming barriers, such as satisfying military "rules of engagement" (Mehta, 2017):

> *U.S. forces are no longer bound by requirements to be in contact with enemy forces in Afghanistan before opening fire, thanks to a change in rules of engagement orchestrated by Secretary of Defense Jim Mattis. Mattis ... told a pair of congressional hearings that the White House gave him a free hand to reconsider the rules of engagement and alter them to speed the battle against the Taliban if need be.*

But intelligence may also help to save humans lives. For example, a fighter plane can already take control and safe itself if its fighter pilot loses consciousness during a high-g maneuver.[12] We had proposed in 2016 that with existing technology, the passengers aboard Germanwings Flight 9525 might have been saved if the airliner had secured itself by isolating the copilot who purposively crashed his airliner to murder passengers and crew as he committed suicide (Lawless, 2016). Similarly, the Amtrak train that derailed in 2015 from the loss of awareness by its head engineer could have been spared the loss of life had the train slowed itself until it or its central authority had control of the train,[13] a remedy that might have prevented another train accident by an engineer in the State of Washington (Park & Yan, 2017):

> *Amtrak's president says the company is "profoundly sorry" after a train derailed this week in Washington state and hurtled off an overpass onto a freeway, killing three people. ... It's unclear why the train was traveling 80 mph in a 30-mph zone*

Gershenfeld's evolution may arrive when intelligent "things" and humans team together as part of a "collective intelligence" to solve problems and to save lives (Goldberg, 2017). A new theory on intelligence indicates that machine learning simulates compression and renormalization, both related to a lack of redundancy (Lawless, 2017). As reviewed by Wolchover (2017a),

> *Using [Shannon's] information theory ... Imagine X is a complex data set, like the pixels of a dog photo, and Y is a simpler variable represented by those data, like the word "dog." You can capture all the "relevant" information in X about Y by compressing X as much as you can without losing the ability to predict Y ... a deep-learning algorithm ... works ... as if by squeezing the information ... retaining only the features most relevant to general concepts ... like renormalization, a technique used in physics to zoom out on a physical system by coarse-graining over its details and calculating its overall state ...*

Relevant information is key when intelligent things replicate (Tegmark, 2017):

> *What's replicated isn't matter (made of atoms) but information (made of bits) specifying how the atoms are arranged. When a bacterium makes a copy of its DNA, no new atoms are created, but a new set of atoms are arranged in the same pattern as the original, thereby copying the information. ... [Similarly, human] synapses store all your knowledge and skills as roughly 100 terabytes' worth of information, while your DNA stores merely about a gigabyte, barely enough for a single movie download. ... even though the information in our human DNA hasn't evolved dramatically over the past 50 thousand years, the information collectively stored in our brains, books and computers has exploded.*

To better understand intelligence, England (2013) uses thermodynamic "fluctuation theorems" to quantify how humans select and shape certain physical processes happen than the reverse; e.g., from Wolchover (2017b),

> *by harvesting the maximum energy possible from the environment. Living creatures ... are superconsumers who burn through enormous amounts of chemical energy, degrading it and increasing the entropy of the universe ... groups of atoms that are driven by external energy sources ... tend to start tapping into those energy sources, aligning and rearranging so as to better absorb the energy and dissipate it as heat. ... Jeremy is showing ... that as long as you can harvest energy from your environment, order will spontaneously arise and self-tune*

**Limitations**

A possible limitation is that IoT "things" can be used to easily spy on users. James Clapper, the former US director of national intelligence, told the US Senate in public testimony (Thielman, 2016),

> *In the future, intelligence services might use the [IoT] for identification, surveillance, monitoring, location tracking, and targeting for recruitment, or to gain access to networks or user credentials,*

Privacy issues aside, the success of IoT depends on taming large quantities of data: 85% of all IoT devices are not yet connected and 4/5$^{th}$ of the data available is not yet structured for IoT; still, by 2020, machine data is expected to grow by 15 times; and stored data is expected to grow 50 times (Wind, 2015); e.g. (Fruehe, 2015),

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[12] http://aviationweek.com/air-combat-safety/auto-gcas-saves-unconscious-f-16-pilot-declassified-usaf-footage

[13] https://www.nytimes.com/interactive/2016/05/17/us/amtrak-train-crash-derailment-philadelphia.html?_r=0

*Companies today are grappling with the Internet of Things (IoT) ... encompassing devices, industrial equipment, sensors, and extended products. For some manufacturers everything they build could feed into IoT, from cars to buildings or even consumer products. ... Instead of focusing on the how of IoT, customers need to be focused on the what of IoT—namely the data. All of the strategy and shiny objects in the world won't help if the data isn't accurate, secure, and actionable. The data should always drive the strategy; the implementation tail should not be wagging the data dog.*

Yet, explaining the decisions made with machine intelligence is also a serious limitation; e.g., from Kuang (2017),

*artificial intelligences often excel by developing whole new ways of seeing, or even thinking, that are inscrutable to us. It's a more profound version of what's often called the "black box" problem — the inability to discern exactly what machines are doing when they're teaching themselves novel skills — and it has become a central concern in artificial-intelligence research. ... [But] In 2018, the European Union will begin enforcing a law requiring that any decision made by a machine be readily explainable, on penalty of fines ...*

Further limiting machines are machine illusions; e.g., machine intelligence can be easily fooled (Somers (2017):

*A deep neural net that recognizes images can be totally stymied when you change a single pixel, or add visual noise that's imperceptible to a human. Indeed, almost as often as we're finding new ways to apply deep learning, we're finding more of its limits. Self-driving cars can fail to navigate conditions they've never seen before. Machines have trouble parsing sentences that demand common-sense understanding ...*

More machine intelligence limitations were elaborated in an interview by Rodney Brooks, the famed roboticist at MIT (Miller, 2017; also, Garling, 2014) who stated that:

*many of these detractors don't actually work in AI, and [he] suggested they don't understand just how difficult it is to solve each problem. "There are quite a few people out there who say that AI is an existential threat — Stephen Hawking, [Martin Rees], the Astronomer Royal of Great Britain ... they share a common thread in that they don't work in AI themselves ... For those of us who do work in AI, we understand how hard it is to get anything to actually work through [the] product level."*

## Conclusion

For the Internet of Everything (IoE), in the future, we want to not only advance the present state of these "things" and to overcome its limitations, but also we want to manage how these "things" think so that the science of "collective intelligence" contributes to the welfare of society.

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