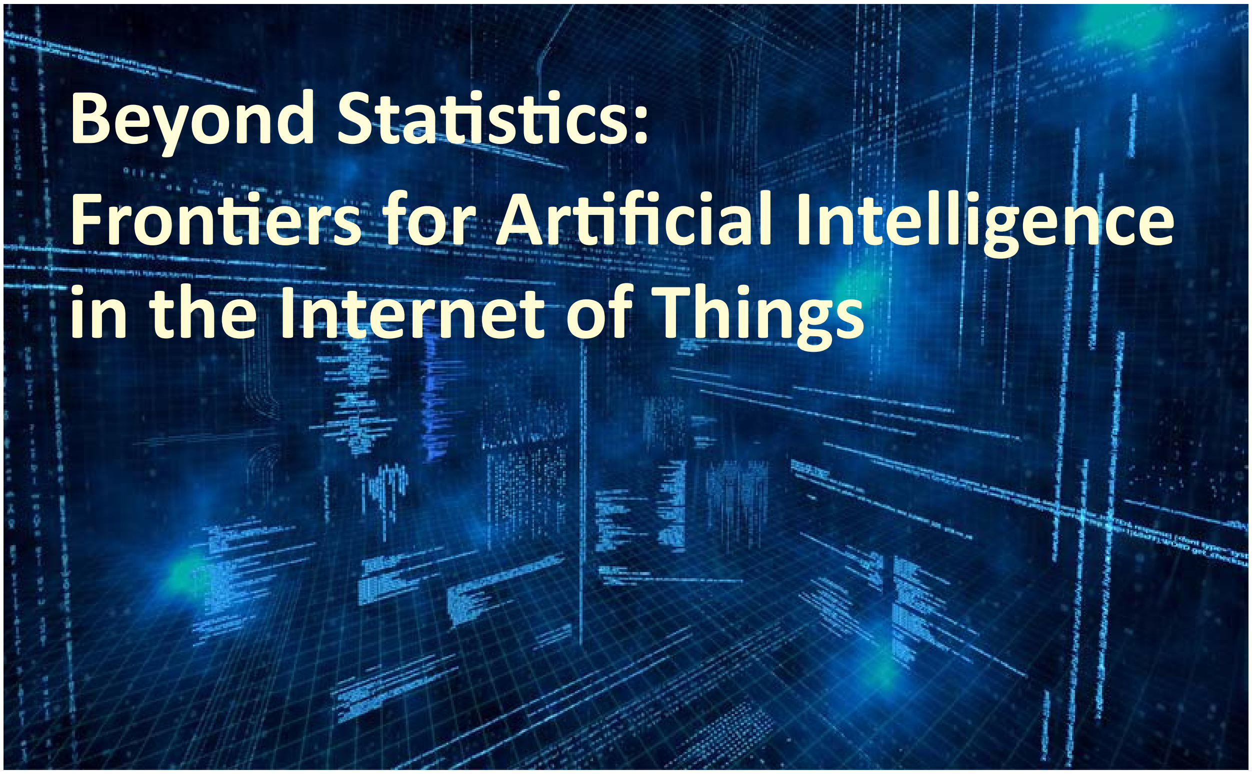

Beyond Statistics: Frontiers for Artificial Intelligence in the Internet of Things

Special Report

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Introduction: The 4D Cycle

Driverless cars, which are examples of Artificial Intelligence (AI) and the Internet of Things (IoT), are attracting a lot of attention.

The car needs sensors to know and process the changing and dynamic environment, as well as intelligence to make driving decisions in real time. It's analogous to the human body, which senses the environment, uses intelligence to process sensory experience, has an autonomous capability to decide what to do, and actuators to carry out the decisions. If we go over the 4D cycle of autonomous systems—detect, derive, decide, do—we note that both IoT and AI play a role in such systems.

The **detect** phase is the act of bringing into the system's sphere of understanding the occurrence of an event. IoT becomes the major source for detection, where sensors, cameras, and other devices provide an increasing portion of the event reporting, while the portion of event reporting by humans is decreasing. AI plays an increasing role in the event detection process. While in traditional systems events are directly reported as raw data, in the IoT world the "making sense in what is sensed" is an important phase. This is done using text understanding, voice understanding, and vision understanding techniques.

The **derive** phase is the act of becoming aware of events that are not directly detectable by bringing together events with other events, data, and patterns, and publishing the observation as a derived event. The event-processing area provides the building blocks for these derivations, however the derivation rules themselves are now in many cases inferred rather than authored manually. Regarding the derive phase we'll discuss later the notion of "causality" vs. the notion of "correlation."

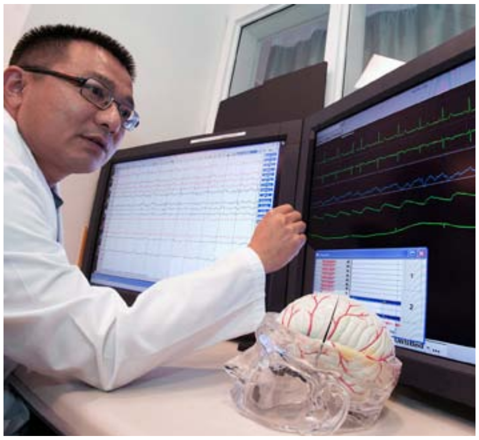
The **decide** phase is the act of determining the course of action to take in response to the situation. In autonomous systems, many decisions need to be made under time constraints. This may require an intelligent decision-making process using heuristic methods.

The **do** phase is the act of performing the course of action that was decided upon. Intelligent actuators such as robots are used to carry out the decisions.

Use Cases of IoT: Health Care

Before going deeper into the intelligent techniques that are required to support all these phases, let's consider examples of intelligent IoT systems in the field of health care.

- Rehabilitation and assistive robots can enhance the motor-control and cognitive skills of patients and enable independent living of the elderly or disabled. In these cases, robots need to make autonomous decisions that may be based on instructions from the patient, as well as on situations that the robot detects through sensors. In terms of cognitive assistance, an intelligent system can infer that a person has not eaten today, or has not taken a shower. Robots could also help people with disabilities sit down or stand up. This is again an application that requires visual sensing of the patient, and decision-making capabilities to cope with dynamic situations.



- Autonomous moving of drugs and medical equipment and even patients within a hospital. This requires robots to safely navigate inside a hospital and to detect drugs labels, barcodes, or RFID tags.

- Robots may support medical staff in various activities, including surgeries that require delicate handling. In these cases the robot is typically fully operated by physicians; however, it requires a sensing ability for constant monitoring of the surgery.

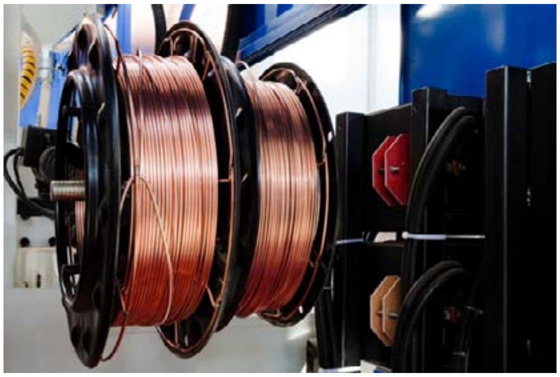
- Real-time planning of surgeries. The sensors track the progress of a surgery relative to the surgical plan. An intelligent system estimates the expected delay, and reschedules the use of resources (surgery rooms, staff, and equipment).

- Assisting people in panic and dangerous situations. Here robots have multiple sensing abilities--such as sensing of danger and an individual's level of stress. The actions can include alerts, assisting with stress situations, or saving a life. In the case of the elderly, for example, sensors can detect stress in the voice, the status of objects (such as whether a door is locked), or can detect and in some cases prevent falling events.

- Many people do not comply with their medication schedule. One way to enforce a medication schedule is to implant sensors in the body's digestive system.

- Monitoring chronic patients at large. This lets chronic patients live a relatively normal life under which they are monitored by an intelligent system that can take actions such as calling physician, or giving alerts and advice.

Use Cases: Manufacturing



In manufacturing, the traditional use of robots involves production, machinery control, and product design. Industrial robots also exhibit IoT and AI capabilities:

- Autonomic management and coordination of production activities among multiple robots requires communication among robots, and sensing of the environment to oversee production activities.

- Autonomous management of equipment and instruments. Sensing capabilities are required to locate equipment and to detect faults in equipment. The intelligence can often inform when to pull a piece of equipment from service for maintenance.

- Immediate reaction to critical situations such as: high temperature or harmful chemicals in the air. Here the robots serve as monitors and disaster controllers.

Defense Applications

The defense industry has a variety of cases where AI meets IoT. Robots are used for unmanned equipment (ground and air), intelligence, threat detection, and combat. This kind of robot requires sophisticated capabilities in all of the 4-D phases, and capabilities of real-time decision making. Examples include:

- Autonomous and smart detection of harmful chemicals and biological weapons. This again requires sophisticated sensing capabilities and real-time decision making.

- Autonomic control of land vehicles and aircraft. While the "driverless car" is for civilian use, the technology has it roots in the famous DARPA grand challenge, which sought to drive supplies into combat areas while minimizing jeopardy to human drivers.

- Identification and access control, such as for preventing suspicious people from entering sensitive places. This capability requires face recognition and sensing of other biological indicators blended with intelligent processing of data.

- Robotic rescue of trapped people such as from earthquakes or other natural disasters, including in areas that are not easily accessible by humans.

AI Techniques

Several AI techniques are used along with IoT applications in the 4D cycle:

Vision understanding is an area that has been investigated for decades and has matured in the industry. It is vital in the detect phase to have the ability to analyze pictures as well as video streams. Vision understanding is used for many applications, including navigation of autonomic vehicles and tracking of suspects.

Speech recognition is also a relatively old area that consists of acoustic analysis and linguistic interpretation and is used both in communicating with people and in detecting various types of situations based on voice data.

Causality determination is a crucial area for inferring situations out of raw data. There are three types of causalities among events:

- Type I: predetermined causality. Event E2 always (or conditionally) occurs as a result the occurrence of E1, thus we don't need to have any sensor to detect event E2--we may assume it happened if E1 happened (and the condition is satisfied). A time offset or interval may be attached to this causality. Note that in this case E1 and E2 are both raw events.

- Type II: The event E1 is an input to a processing element PE and event E2 is an output of PE. In this case E2 is a derived (virtual) event. The specification of PE is part of the system, thus the context and conditions are known.

- Type III: The event E1 is sent from a computerized system to a consumer C. The consumer, C, applies (conditionally) some action AC, where the specification of AC is not known to us, but we observe that it emits the event E2. This is another type of causality; however, E2 may or may not have functional dependency with respect to E1.

The ways to identify causalities and define them for specific applications are: expert knowledge, statistical reasoning, and reasoning through semantic or association nets.

Getting Beyond Correlation

In the current trend of analytics, there is a bias towards using statistical correlations as indicators for causality. However, there are some dangers in doing that. A correlation between A and B may be interpreted as:

- A causes B
- B causes A
- Exists C that causes both A and B.
- The statistical correlation may not indicate any causality.

Here are a few examples of correlation and causality logical fallacies:

- Faster windmills are observed to rotate more with wind. Therefore wind is caused by the rotation of windmill--this is an interpretation that reverses the causality.
- Sleeping with one's shoes on is strongly correlated with waking up with a headache. Therefore, sleeping with one's shoes on is a cause for headache. (Correct answer: drinking too much causes both).
- As ice cream sales increase, the rate of drowning deaths increases sharply. Therefore, ice cream consumption causes drowning. (Correct answer: they are both in the same context--summer).

An intelligent system will understand the causes beyond the statistical correlation and will integrate expert knowledge using various types of concept networks. The ability to understand beyond statistical correlation is an important frontier.

Handling Uncertainty

Another area of importance is the ability to handle uncertainty. This is much more acute in IoT-based applications. Unlike off-line reasoning, it is not feasible to cleanse the data before using it. Various techniques for handling uncertainty were developed in AI, and can be applied for such cases. In many cases the decision involves solving an optimization problem. While in off-line reasoning the optimal decision might be reached given enough time, in real-time reasoning there is a time constraint on arriving at a decision. For example, in intelligent transportation systems, when traffic congestion is forecast to occur 10 minutes to 15 minutes in the future, there are 30 seconds to make a decision (e.g. how to change the traffic light setting). The intelligence here is in getting the best decision that can be obtained within the given time constraints. This typically involves some kind of heuristics depending on the appropriate policy: robust (looking at worst-case scenario); probabilistic (looking at most common scenario); and simulation-based (when analytic methods cannot be obtained).

To summarize, many real-time autonomic or semi-autonomic systems require the Internet of Things for detecting the dynamic environment and deriving situations, while artificial intelligence is required along various points of the 4D cycle. We'll see more synergy between these disciplines in future applications.

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