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Executive Summary

Internet of Things (IoT) *augments human perceptions* with connected and shared data from physical devices through the Internet. Recent IoT evolution applies cognitive computing into IoT data for the purpose of *making devices intelligent*. This article provides a definition of Cognitive IoT that furthers the IoT evolution: firstly by applying cognitive computing beyond IoT data in context with data from enterprise, social and the web, for the purpose of *augmented intelligence*; and secondly by introducing closing the loop in machine intelligence with machine-generated responses, for the purpose of *personal cognitive assistance*. By putting a highly flexible and engaging human-machine collaboration layer in the hands of enterprise users, these progressions can bring forth business transformation in scale. This article discusses these elements of advancement in IoT with scenarios illustrating the progression and the increase in impact as each of these elements is added to the scope.

A Definition Scoped for Business Transformation in Scale

The evolution of IoT starts with connecting the shared device data for augmented perception, illuminating the physical realm to perceive what otherwise would remain hidden. Recent IoT progression applies cognitive computing unto IoT data, making these devices intelligent.

To enable business transformation in scale, Cognitive IoT needs to add two additional elements into its scope, namely, a comprehensive data sources beyond just IoT data and closing the loop with machine-generated responses. The following definition of cognitive IoT is therefore established.

"Cognitive Internet of Things is an intelligent system that learns at scale, **reasons** with purpose, **and analyses** to predict, to prescribe and to discover, **from massive data of interconnected** physical, social, enterprise and other **cyber entities. It closes the loop by machine-generated responses** in advice, assistance and actions, in a manner **that self-learns and adapts, for the purpose of augmented human intelligence** through human-machine collaborations."

Let's trace the steps of progression in the IoT evolution (see Figure 1).

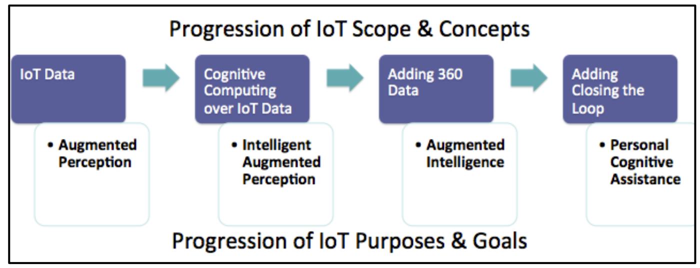

Figure 1: Progression stages of IoT

IoT Data *Enables Augmented Perception*

Internet of Things enables us to perceive the physical world with ***augmented perception*** that is otherwise invisible. This fundamentally changes the way we interact, monitor and manage our surroundings and ourselves. Let's take a look at the following examples.

> In the travel industry: IoT device that monitors our luggage on air travel and text us when it arrives at the destination, letting us know how far it is from the luggage belt. This smart luggage tag provides travellers augmented perception of their luggage in transit that would otherwise be unknown. This has great potential to fundamentally transform the experience of travellers and the airline industry.
>
> In the retail industry: Smart item tags with micro-location based capability enable retailers and shoppers alike with augmented perception to locate product items that would otherwise be very difficult to find. This has been in production for some retailers already.

Data is the currency of IoT. IoT platforms working in collaborations with the edge servers orchestrate all IoT operations, collecting and integrating data from the physical world instrumented by IoT devices [3]. As illustrated by the examples of smart luggage tags and smart item tags, IoT data is the primary data source to enable augmented perception, giving us an expanded sense of perceiving things in our physical realm that otherwise would not be brought to our awareness or attention.

Applying Cognitive Computing to IoT Data *Enables Intelligent Augmented Perception*

Applying cognitive computing to data of connected devices yields the next level of machine intelligence: intelligent augmented perception.

It is a higher form of augmented perception because by learning at scale, reason with purpose and analysis over IoT data of connected devices, it brings in machine intelligence beyond just awareness and attention. Insights and knowledge about the physical realm, predictions, prescriptions with warning and suggestions bring increased values to users. Let's continue with the previous examples.

> For example, using spatial temporal analysis over historical and real time ***device data***; not only can travellers are aware of how far is the luggage from the luggage belt, insights from device data can also inform travellers such as: "average time baggage handling time for this terminal is 5 minutes in the last four hours. With zero loss reported this week".

> In the same token, by applying analysis of ***device data*** from a smart item tag with micro-location based capabilities, a prescriptive insight such as, "average time for this item to be off the shelve is less than 48 hours" can be made. When the actual shelf time of an item turns out to be much longer, store associates therefore know that it is an anomaly and can go and investigate.

Adding Non-IoT Data *Enables 360-Augmented Intelligence*

To maximize the business impact of cognitive IoT, IoT data needs to be analyzed and processed in context with other non-IoT data sources to enable ***a 360- augmented intelligence***.

What non-IoT data is critical to be added? How are they related to the IoT data and why is it important? How can they bring in a 360- augmented intelligence?

Critical non-IoT data for business transformation to be analyzed with IoT data includes: ***enterprise data***, ***social data*** and ***other cyber entities*** from the interconnected world (See Figure 2). Let's continue with the two examples previously used.

Figure 2 Comprehensive 360 Sources of Intelligence for Cognitive IoT

> Using Social Relationship as a service, Cognitive IoT Intelligent System knows that the traveller is travelling with his wife and his two children. It will therefore yield a more intelligent response by handling smart luggage tags as a collection for this family of four. A more useful message that show such understanding of collection can be issued: "Your wife's luggage is the closest to the luggage belt. Your children's are the furthest. All four pieces of luggage will be out by 15 minutes."

> Using the airline's operational data from the airline's enterprise data services, cognitive IoT system is able to predict more accurately about workload alert in baggage handling. For example, it is possible for machine to learn that "there are 15% more flights scheduled to land in the next three days with 20% more luggage this week than the average from the past three months: Advise to add baggage handlers to schedule."

> In the same token, by accessing the retailer's customer data services and product data services from the enterprise data sources, it may reveal that 85% of purchasers of this product is by millennial. When the anomaly of this item is on the shelf much longer than expected, millennial customers registered with the retailer's loyalty program walking in the store will be sent a promotional discount of that item.

Augmented human intelligence through human-machine collaborations is the ultimate purpose of Cognitive IoT. To transform business in scale, Cognitive IoT aims to empower enterprise users to function at an intelligence level and capacity that is derived from terabytes of interconnected data; yet requires minimal or zero effort on the users' part.

The potential of business transformation for a cognitive IoT intelligence system that can see through IoT data, enterprise data, social data and other cyber entities is boundless.

Closing the Loop: *For Personal Cognitive Assistance*

Without machine-generated response, added knowledge from augmented intelligence may become extra mental burden for users. But when machine intelligence is responded by machine-generated responses, as personal cognitive assistance, either in a form of machine automation, anticipation or in a form of alerts, reminders etc., users experience augmented intelligence as a welcomed relief: a form of cognitive load reduction.

From previous example, the warning of potential baggage handling workload problem adds mental burden of the baggage handling staff. With machine-generated response, which may include machine computed schedule changes, supervisor may only need to give approval of what is proposed by machine and let the machine take care of the automatic notifications to luggage workers. Personal cognitive digital assistance becomes agents of cognitive load reduction as users appreciate the prescriptive warning and at the same time enjoy the benefit of augmented intelligence without added burden. This brings business transformation in scale.

Human-Machine Collaboration: *for Getting Stronger Over Time*

To be truly cognitive, machine-generated responses need to be self-learn and self-adapt, enhancing generated responses to become contextually more accurate and aware over time.

Human-machine collaboration is critical for cognitive era. "Men and computers (are) to cooperate in making decisions and controlling complex situations without inflexible dependence on pre-determined programs [1]".

Today, users are dependent on IoT developers to write them IoT Apps to consume IoT. Users ended up with far too many IoT Apps, one per device. Apps are not designed to be integrated or to interoperate. Further more, Apps are written for a general group of users. They are not designed to be used by users as individuals, who have individualized and situational requirements of their IoT consumption and cognitive requirements.

New human-machine collaboration interface, such as tasking technology, are emerging to enable machine learning by human strategic guidance. "Combined with the tactical acuity of machine [1]", this will bring business transformation in scale. Apps are programming artifacts of the programming era. New forms of human-machine collaborating artifacts are required for the cognitive era.

Conclusion

The success of cognitive computing will not be measured by how much a computer's ability to mimic humans. It will be measured in more practical ways like return on investment and new market opportunities [1]. This applies to cognitive IoT.

IoT data illuminates an ***augmented perception*** that would otherwise be invisible. Applying cognitive computing to IoT data makes such ***augmented perception intelligent***. Critical data that is not IoT related, such as enterprise data, social data and others, need to be added as data sources of intelligence in order to enable ***360-augmented intelligence***. Closing the loop with machine-generated responses enables personal cognitive assistance with augmented intelligence to reduce human's cognitive burden. Empowering users with a new human-machine collaboration layer makes such collaborative partnership strong and powerful for business transformation in scale.

References

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