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What is the Internet of Things (IoT)? How will this next technology mega-trend transform society?

With the arrival of a variety of notable breakthroughs, such as IBM's Watson 2011 or the Google Car 2012, we are currently entering a new era of artificial intelligence. The field of distributed artificial intelligence is an important influence on this wave of recent changes.

- The term "cyber-physical systems" (coined by Helen Gill, NSF, 2006) addresses a group of mainly technological subcomponents communicating with each other via the network of the Internet.
- The term "Internet of Things" (Kevin Ashton, MIT, 1999) refers to the extension of the "participating community" of the Internet: Participants and information contributors are no longer restricted to "humans only," but also include "things," such as the sensorics of a car, GPS signals, data from climate stations, process data for manufacturing machines, and a lot of other information-carrying systems, which are all to a certain degree directly connected and interacting with their external environments.

In both concepts, a "graph" emerges with knots representing the units of information and edges representing the communication links. The term "cyber-physical systems" focuses on the components, whereas the term "Internet of Things" is driven by the network perspective. One without the other would be of very little use. As a result, "cyber-physical systems" and the "Internet of Things" represent two views on the same phenomenon, namely, as one of the leading researchers at BOSCH Germany, Stefan Ferber, summarized in his 2012 keynote in Wuxi, China, "the outlook of connecting 50 billion devices by 2015." "Connecting them with each other and with six billion people," he could have added.

What types of intelligent robots currently exist? In what ways will cooperative and heterogeneous robotics influence human behavior in the future?

The first question to answer here is which definition of intelligence to apply when discussing intelligent robots. Understanding what intelligence is – or what it might be – is something that cannot be answered with a short response. The approaches include all virtual stages between and including two extremes, namely:

- "Biological chauvinism": in short, "only biological brains are conscious" or if we consider an even stricter definition, "only human brains are conscious." The term originates from Carl Sagan in the late 1960's and originally addressed the "carbon- and oxygen chauvinism" for potential extraterrestrial intelligences.

- “Liberal functionalism”: in short, “any behaviorally equivalent functional system is conscious” (e.g. Jackendorf 1987, Putnam 1967). Applied in a very strict fashion, even a thermostat might be classified as having some intelligence.

By and large, however, any “agent with intelligence” is usually considered to have its intelligence divided into three key parts - a “triple jump of intelligence”:

1. Recognition of external changes, that is: possessing sensory components to receive stimuli from the external environment
2. Information processing, that is: being capable of processing sensory data together with internal knowledge in order to adapt behavior
3. Actuation, that is: having the capacity to interact with the external environment, realized by actuators.

By the latter definition, the majority of industrial robots do possess a certain level of intelligence. However, this intelligence is in no way close to human intelligence since the systems do not act in a “goal-driven” manner: they do not know who they are, what their purpose is, who their neighbors are, what happens if they fail in a task, and so on. Their intelligence is restricted to basic functions like simple navigation, collision control, and basic quality control tasks (e.g. the integrated measurement of the width of a welded joint).

Two major developments emerge: First, robots conquer everyday life. While the majority of current robotic systems are embedded in specialized industrial environments, increasing numbers of robots are actually leaving these areas. And it is not only the growing popularity of vacuum cleaning, lawn mowing, and window cleaning robots that we are talking about – one of the key developments in robotics at present is in the area of autonomous cars: these are also robots! And by now, several manufacturers have presented autonomous cars or trucks. Their widespread use will only be a matter of time – especially considering the great potential they offer for increasing road safety! If the essential mobility carriers in the future are robots, then we will be surrounded by robots everywhere in our future living spaces.

Second, we increasingly aim towards an environment where robots act as a team. The reason is obvious: If humans are faced with a complicated task, they solve it via team work with members as heterogeneous as possible to leverage the mutual competencies of the team. Exactly this step is about to happen in robotics (current production systems encompass many robots, however these currently only act synchronously in time, not as a coordinated team). To achieve this, a considerable increase in “intelligence” of the systems is necessary: to cooperate, robots need to understand the entire task, their role within the task, and the role of others. Robots need an overview of the competencies available in the team, the capability to communicate their intentions to the other team members, etc.

I am especially pleased about the success of my robotics team this past July. Together with our partners, we won the world championship in the team robotics competition “Logistics League” of the 2014 RoboCup. The task at hand was to efficiently process a flow of goods between individual production machines. “Raw materials” needed to be transported in a flexible way to various processing machines to finally end up as a “finished product” at the delivery station. The main focus of the competition concerned the intelligent cooperation of completely autonomous robots as a team that is able to flexibly react to various incidents and disturbances.

Our success was based on a highly communicative approach between the robots, realized by a three-layered, very robust, multi-agent model. The advantage of this approach was so great that we played undefeated throughout the preliminary and intermediate rounds and won the finals with a 165 to 124 score - a new record in the league.

If robots increasingly replace human workers in production systems, what impact will this shift have on our education system?

Indeed, the need to implement quite extensive changes is one result of this. Therefore, it is important to realize that not only “low-qualification” jobs are affected by these changes. The elimination of assembly line workers, for example, is just what is currently at the forefront of this discussion. However, if one looks a bit beyond production technology and into all aspects of society, then one can note the massive changes that have been taking place in publishing over the past 15 years, which have destroyed many “high-qualification” jobs. The systematic “death” of large encyclopedias and their top-qualified staff, outrun by open-sourced Wikipedia, is one good example. In 2009, the Federal Cartel Office of Germany approved the takeover of Brockhaus by Bertelsmann despite its market dominance, because – literally – “the lexicon market has been shrunk into a ‘bagatelle’ market!”

Many more similar examples can be cited, e.g. in the area of travel agencies, pharmacies, and other specialist suppliers, automated journalism, and education (due to “MOOCs”). Another completely different example, namely 3-D printing technology (which has to be considered as a child of digitalization), dramatically changes the division of roles between the dentist and dental technician. Because of 3-D printing, the dentist is technically capable of producing implants and fillings of comparable quality as is currently possible in his own surgery practice. He can also produce them much faster as no transfer time occurs. So this leads to the question: What will be the purpose of highly specialized dental practices in the future?

In summary, it will be important for education to be highly qualitative. “Highly qualitative” means the following two conditions most of all: first, it has to be positioned to support the flexible assignment of a person. Individuals who are able to reorient themselves do not have to be as afraid of the future as specialists who lose their livelihood when their sector collapses. Second, it has to address human creativity – like the so-called “Swabian tinkerer gene.” The economies of high wage countries – like Germany and the U.S. – are sustained especially by innovation. Innovations can only be produced by people who are creative, take experimental approaches, and accept failure. For this, a well-developed culture of constructively dealing with mistakes and failures is important – because experiments are often accompanied by successes as well as failures. In this regard, the U.S. is ahead of

Germany and Germany could learn a lot from American culture's willingness to embrace risk.

How will distributed artificial intelligence affect our understanding of life and intelligence?

The significance of these concepts exceeds that of conventional technological evolutions in multiple ways. One aspect calls for special attention: We are facing the genesis of a new type of intelligence based on a) plurality, b) heterogeneity, and c) spatial distribution of its subcomponents – the intelligence of a distributed system. Studies directed by Thompson and Swanson 2010 (the theoretical model dating back as far as to 2003) have already provided clear evidence that the network structure of different areas of biological brains is not as fully hierarchical as previously thought. Rather, the structure is strongly reminiscent of the decentralized network structure of the Internet, e.g. the capacity for "graceful degradation." In other words, the breakdown of a subsystem does not necessarily lead to a total blackout - the remaining components are able to go on and sometimes even to compensate for the loss. This is a mutual feature of both modern distributed computer systems and the human brain. The intelligence of distributed, decentralized systems has to be investigated since indicators show that underlying principles may contribute to the understanding of the appearance of intelligent structures in general. By that, they may finally allow for new insights into the development and function of our own human brain.

Which research projects would you like to focus on next?

One of the most promising theories concerning the genesis and development of intelligence is outlined by the embodiment theory, which emerged during the 1980's following new results in the cognition sciences. According to this theory, intelligence is to a large extent based on the interplay between a body and its environment. This approach does not simply claim that the development of intelligence requires the existence of a corresponding body. Rather, it claims that the development of intelligence depends on the precise shape and figure of a body since differently figured and equipped bodies will experience different physical interactions. If the embodiment theory proves right – and there are a lot of incidents pointing to this – then a lot of questions follow, such as:

- In what sense do the components of a "cyber-physical system" form a body and how does this process differ from the development of a biological body?
- What type of intelligence develops within an entity with a nearly unlimited range and dynamic exchange of its components?
- What does the concept of "intelligence" mean in a highly distributed system?
- If consciousness forms an important part of an intelligent system (which is more or less consensus between the different research communities), what type of consciousness does such a system develop?
- Is Google conscious?

These questions are currently driving my thoughts.