Connecting Brain Computer Interface Technology with Ubiquitous Complex Event Processing – Aspects of New Applications in the Fields of Biology, Brain Research and Medicine

Extended Abstract

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Why connecting BCI with U-CEP?

The edBPM/U-CEP workshop series has so far focused on the topics of connecting Internet of Services and Things with the management of business processes and the Future and Emerging Technologies as addressed by the ISTAG Recommendations of the European FET-F 2020 and Beyond Initiative [1]. Such FET challenges are not longer limited to business processes, but focus on new ideas in order to connect processes on the basis of CEP with disciplines of Cell Biology, Epigenetics, Brain Research, Robotics, Emergency Management, SocioGeonomics, Bio- and Quantum Computing – summarized under the concept of U-CEP [2].

This 4th workshop is a thematical enhancement considering the grand challenges defined by FET-F. FET-F initiative is looking for radically new ideas, products and outcomes and U-CEP is a contribution in order to bring together the relevant Future and Emerging Technologies under one umbrella.

Connecting Brain Computer Interface (BCI) technology with Ubiquitous Complex Event Processing (U-CEP) opens a lot of new applications in the fields of biology, brain research, medicine or Human Enhancement Technologies (HET).

BCI as interface to and from the brain

BCI-technology is one of the most intensely developing areas of modern science; and has created numerous significant crossroads between neuroscience and computer science. The goal of BCI technology is to provide a direct link between the human brain and a computerized environment. The vast majority of recent BCI approaches and applications have been designed to provide the information flow from the brain to the computerized periphery. The opposite or alternative direction of flow of information (computer to brain interface – CBI) remains almost undeveloped. The BrainPort is a Computer Brain Interface that offers an alternative symmetrical technology designed to support a direct link from a computerized environment to the human brain- and to do it non-invasively. The ultimate goal of the BrainPort technology is to introduce the possibilities offered by changing the direction of information flow - from a computerized environment to the brain.

The role of U-CEP

We combine BCI with the emerging technology of U-CEP as an enhancement of CEP [5, 6, 7] for biological or HET applications [2]. The U-CEP reference model describes the connection of a global event cloud with a lot of different event types from the universe, the environment, or from "artificial" technical events of Internet of Things and Services [2]. Thereby we use the basic concepts of U-CEP like: what actually is an event or what is the difference to streaming data processing or what is a complex event, event abstracting, event hierarching, event correlation, challenges of an overall or domain-specific Event Processing Language (EPL), event context, event enriching, event filtering, difference between TOSET (Totally Ordered Set of Events) and POSET (Partly Ordered Set of Events), time windows or sliding windows, etc.

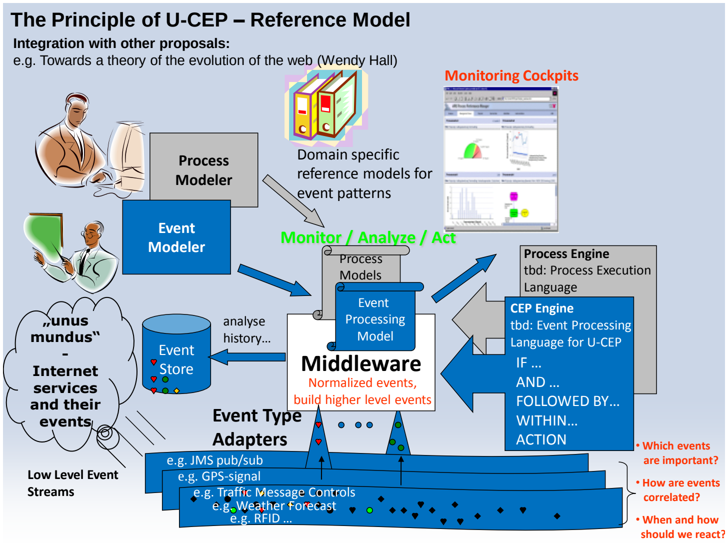

Fig. 1. The reference model of U-CEP consists of two ICT platforms which run in parallel [3]. The processes are modeled by process modelers with special skills in an application domain. The models are executed by a process engine. The other, corresponding platform monitors and processes Complex Events from different event types which are modeled as event patterns by event modelers with special skills in event modeling.

Infrastructure for connecting BCI and U-CEP: Body Area Networks and Wearable Technologies

Nowadays some new and promising technologies are invented which make it possible to communicate such event sources with living things or cells without killing them, as with former technologies. Some approaches are discussed like

- Polysaccharide bioprotonic field-effect transistor [54, http://www.nature.com/ncomms/journal/v2/n9/full/ncomms1489.html, http://forum.complexevents.com/viewtopic.php?f=13&t=261&start=20#p1230]
- Event adapters for living cells based on Genetic Cassettes [55, http://newscenter.lbl.gov/feature-stories/2010/10/20/electrical-link-to-living-cells/, http://forum.complexevents.com/viewtopic.php?f=13&t=268]
- Deep Brain Stimulation (DBS) using the theory of nonlinear control systems [57, http://www.manchesteruniversitypress.co.uk/uploads/docs/360046.pdf, http://forum.complexevents.com/viewtopic.php?f=13&t=261&start=20#p1228]

Or the reverse direction outbound from the brain, e.g. the user wears a cap of tiny electroencephalogram (EEG) electrodes, which measured his or her brain activity. This system translates the EEG signals into navigation instructions

- EEG patterns for movement and navigation [58, http://news.sciencemag.org/sciencenow/2011/09/disabled-patients-mind-meld-with.html, http://forum.complexevents.com/viewtopic.php?f=13&t=261&start=20#p1226]
- Network engineering techniques to induce self-organization of cultured networks into neuronal clusters of different sizes [59, http://www.plosone.org/article/info%3Adoi%2F10.1371%2Fjournal.pone.0014443]
- Decoding action intentions from preparatory brain activity in human parieto-Frontal Networks using functional MRI (fMRI) pattern recognition techniques [60, http://www.jneurosci.org/content/31/26/9599]
- Decoding thoughts using functional MRI (fMRI) pattern recognition techniques [61, http://de.wikipedia.org/wiki/John-Dylan_Haynes, http://www.cbs.mpg.de/staff/haynes-10438]
- Decoding movies of what the brain sees [62, 63, 64, http://www.cell.com/current-biology/abstract/S0960-9822%2811%2900937-7, http://www.spiegel.de/wissenschaft/mensch/0,1518,787867,00.html, http://www.kurzweilai.net/how-to-make-movies-of-the-brains-thoughts?utm_source=KurzweilAI+Daily+Newsletter&utm_campaign=9dc8ce7329-UA-946742-1&utm_medium=email]
- Combination of brain-scanning and feedback techniques. people can learn to consciously control their brain activity if they're shown their brain activity data in real time—a technique called real-time functional magnetic resonance imaging (fMRI). This technology is effectively used to teach people to control chronic pain and depression. Similar feedback methods are pursued to help drug users kick their addictions [65, http://www.scientificamerican.com/article.cfm?id=jacking-into-the-brain&page=1]
- Human brain as if the organ were an outsize flash drive [66, http://www.technologyreview.com/biomedicine/26768/?p1=A1]
- A collection of brain research related, U-CEP relevent links [http://forum.complexevents.com/viewtopic.php?f=13&t=257]

In this paper we focus on the real-time monitoring of biomarkers which are normally not based on the brain, but which can be measured from other "Point of Interests" of the human body. On this basis, the main challenge is the real-time management of processes to control the protein machinery and the metabolic processes.

The appropriate computing power - cognitive computing chips, combining digital 'neurons' and 'synapses'

IBM introduced an overarching cognitive computing architecture as an on-chip network of lightweight cores, creating a single integrated system of hardware and software. It represents a potentially more power-efficient architecture that has no set programming, integrates memory with processor, and mimics the brain's event-driven, distributed and parallel processing.

IBM and its university collaborators of the SyNAPSE project aim to create a system that not only analyzes complex information from multiple sensory modalities at once, but also dynamically rewires itself as it interacts with its environment — all while rivaling the brain's compact size and low power usage. Future cognitive computing chips are able to ingest information from complex, real-world environments through multiple sensory modes and act through multiple motor modes in a coordinated, context-dependent manner.
[67, http://www.ibm.com/smarterplanet/us/en/business_analytics/article/cognitive_computing.html, http://www.kurzweilai.net/ibm-unveils-cognitive-computing-chips-combining-digital-neurons-and-synapses?utm_source=KurzweilAI+Daily+Newsletter&utm_campaign=966ad22468-UA-946742-1&utm_medium=email]

The proton-based chips can have a better potential to communicate with biological processes and serve as an actuator within the human body, even the human brain. IBM HRL's proactive computing project "Proton" will probably use this natural connection: The proton system makes decisions that are carried out using the proton chip that serves as an actuator for the proton system.
[68, http://epthinking.blogspot.com/2011/09/on-proton-based-chips.html].

This now available technology might be the basis for a kind of a wearable exocortex, which we need as the computing power of the U-CEP applications related to the BCI. This is exemplified in the last part of the paper.

New applications based on connecting BCI and U-CEP

The connection between U-CEP and the approaches of the TCNL or the Deep Brain Stimulation is that we would be able to experiment with complex event patterns for stimulating the brain or the tongue very much better or even on the basis of a program logic written with a domain-specific or standardized Event Processing Language (EPL) and of arbitrary event sources - from other senses, from the environment or from the global event cloud of the Internet of Things and Services. The event modelling can take place "on the fly" during the experiment or the treatment of the patient. Additionally, in the future devices like the accelerometers will be miniaturized so much, that the "device" could be worn permanently or could be implanted in the tongue (tattooing in the depth 200 mkm) - very much smaller than a tongue piercing, what some humans already "wear" anyway. Body Area Networks and Wearable Technologies [69, viewtopic.php?f=13&t=299] would be a kind of infrastructure for that as already mentioned.

Thereby we must distinguish between:

1. Use another organ to substitute a (damaged) sense and what makes it with the brain or how is the brain recovered/reorganized/changed well, it is sensory substitution well described and proved it's efficiency
2. Enhance the sensivity range (vision to infrared or ultraviolet ranges. 360 deg field of view) of a sense what would the brain do? adapt as well? or would we become crazy because of overloading the brain or similar effects? What about completely

new senses – magnetic and electric field sensitivity, radiation, chemical pollution? Then would we need an exocortex to translate or map this additional "information" to our brain?
3. Add new or additional senses (see (2) ditto), and would we recognize a new "reality"?
4. Brain modification – memory and cognitive functions improvement, physical and athletic performance in normal subjects
5. Neurorehabilitation after brain damages and diseases, neurostimulation in pediatric population – learning disabilities, autism, cerebral palsy; age related physical and cognitive loss

We can experiment with that on the mentioned basis of U-CEP and event adapters and influence the human protein machinery based on changing complex event patterns and event processing at all. We could better heal diseases - also non-invasively and without drugs - and perhaps the brain would stably or durably change after short time, as the experiments at TCNL and others have already proved.

In the last part of the paper we exemplify the modelling aspects – in relation to the other intended workshop contributions about “Physio-environmental sensing and live modelling and the role of BCI/U-CEP” and “Disease modelling, biomarkers and virtual physiology based on BCI/U-CEP”

BrainPort technology

The BrainPort is a computer-based environment designed to represent qualitative and quantitative information on the superior surface of the tongue, by electrical stimulation through an array of surface electrodes. The electrodes form what can be considered an "electrotactile screen", upon which necessary information is represented in real time as a pattern or image with various levels of complexity. The surface of the tongue (usually the anterior third, since it is the most sensitive area), is a universally distributed and topographically organized sensory surface, where a natural array of mechanoreceptors and free nerve endings can "read" the contents of ’screen’, encode this information and then transfer it to the brain as a “tactile image”. With only minimal training the brain is capable of decoding this information (in terms of spatial, temporal, intensive, and qualitative characteristics) and utilizing it to solve an immediate need. This requires solving numerous problems of signal detection and recognition.

To detect the signal (as with the ability to detect any changes in an environment), one needs sensors of the highest absolute or differential sensitivity, e.g. luminance change, indicator arrow displacement, or the smell of burning food. Additionally, the detection of the sensory signals, especially from survival cues (about food, water, prey or predator), usually must be fast if reaction times are to be small in life threatening situations. It is important to note that the sensitivity of biological sensors is usually directly proportional to the size of the sensor and inversely proportional to the resolution of the sensorial grid. Information utilized during this type of detection task is usually qualitative information, the kind necessary to make quick alternative decisions (Yes/No), or simple categorical choices (Small/Medium/Large; Green/Yellow/Red).

The recognition process is typically based on the comparison of given stimuli (usually a complex one such as a pattern or an image, e.g. a human face) with another one (e.g. a standalone image or a set of original alphabet images). To solve the recognition problem one needs sensors with maximal precision (or maximal resolution of the sensorial grid) to gather as much information as possible about small details. Often this is related to the measurement of signal parameters, gathering quantitative information (relative differences in light intensity, color wavelength, surface curvature, speed and direction of motion, etc.), where and when precision is more important than speed.

The BrainPort is capable of noninvasive transferring both qualitative and quantitative information to the brain with different levels of a "resolution grid", providing basic information for detection and recognition tasks. The simple combination of two kinds of information (qualitative and quantitative) and two kinds of a stimulation grid (low and high resolution) results in four different application classes. Each class can be considered as a root (platform) for multiple applications in research, clinical science and industry, and are shown in the paper (see Figure … "Four classes of BrainPort applications" in the final paper).

The ultimate potential of the BrainPort for image or pattern representation has yet to be realized - as for the functional capacity of the human tongue as an information interface (as well as for sensory substitution in general), that also remains undiscovered.

An approach is discussed in the paper to use the BrainPort as a supplemental environment input for processing information. As previously mentioned, the BrainPort is capable of working in various modes of complexity: As a simple indicator (first application class) for signal detection; as a target location device (third application class) for position control of signals on a 2D BrainPort array, much like a "long range" target location radar plot; in almost all computer action games; as a simple GPS monitor.

The BrainPort can also work in more complex modes such as a vision substitution device, an infrared or ultraviolet imaging system creating complex electrotactile images using in addition to two dimensions of its electrode array, the amplitude and frequency of the main signal, the spatial and temporal frequency of the signal modulation, and a few internal parameters of the signal waveform. In other words the BrainPort is capable of creating a complex multidimensional electrotactile image – similar to that of visual imagery.

BrainPort is a unique sensory substitution device based on the electrotactile stimulation of the brain. It is also a universal Brain Computer Interface, in the sense that its' potential for application development is limited only by our imaginations. And finally, because of its ability to provide to the human brain with information about the environment far beyond limits of our natural sensory systems. It is also an "extrasensory" or augmentative device, due to its capacity to extend the limits of our natural senses, and by doing so, to create new sensory opportunities.

The BrainPort is a simple way to improve the environment of the modern human-operator, to decrease the load on visual systems and related stress factors, to increase the capacity of human resources, and, as a result – to maximize the general efficiency of the human in the loop. [8 – 53]

CN-NINM technology

Cranial-Nerve Non-Invasive NeuroModulation (CN-NINM) stimulates the brain to self-recover functionality lost to injury or disease. Many neurological diseases involve the brainstem, which regulates numerous functions in the brain and body. Brainstem structures are important for movement, attention, sleep-wakefulness, sensory-motor coordination, and control of unconscious body functions. This is one reason why brainstem damage, for example due to MS, can cause so many kinds of symptoms. CN-NINM improves function of the damaged brain by sending millions of nerve pulses from the tongue to the brainstem, at the same time with special challenge exercises. The tongue pulses help the brain to adapt to the challenges. With time, effort, and CN-NINM stimulation, the parts of the brain surrounding damaged areas self-adjust their function so that overall brain function becomes more normal.

What is neuromodulation (NM)? Neurons are brain cells that process information. They communicate with each other using chemicals called neurotransmitters. Neuromodulation is the process of regulating the level of neurotransmitters in and around neurons. These changes may be targeted to specific brain regions, structures, or functions, or they may be more global in nature. Non-Invasive Neuromodulation (NINM) is any method of neuromodulation applied from outside the body.

What is Cranial Nerve Non-Invasive NeuroModulation (CN-NINM)? CN-NINM uses controlled patterns and sequences of tactile stimuli on cranial nerve endings, located on the head (including in the mouth). CN-NINM may include electrical, mechanical, chemical, and/or thermal stimuli. All are non-invasive because they are applied to the surface of the skin or oral tissues. These tactile stimuli may be combined with other forms of sensory stimuli such as sequenced and patterned sounds, light images, or proprioception (posture and balance).

Are there other forms of NM, NINM, and CN-NINM? Most other forms of neuromodulation are invasive, for example deep brain stimulation (DBS) and vagus nerve stimulation (VNS), which use implanted pacemaker-like electrical devices. Implantation carries surgical risks including infection, allergic reaction, and tissue damage. Many drugs may also be considered chemical methods of neuromodulation. Other forms of NINM include powerful electromagnetic stimulation of the brain's cortical and subcortical structures (transcranial magnetic stimulation, TMS), or electrodes that pass electric current through the skull (TDCBS), also targeting multiple areas of the brain. We are not aware of other groups working with CN-NINM.

Why is CN-NINM important? Many kinds of physical and mental impairments result from disruptions in information transmission and regulation in the brain, whether due to trauma, loss of blood flow (stroke), or disease. Such disruptions may include physical tissue damage or disruption of the chemical environment surrounding neurons. There is growing theoretical and experimental evidence that many of these conditions might be more effectively treated with neuromodulation, including NINM. Such conditions include motor control impairments affecting balance, posture, gait, speech, and manual dexterity; cognitive disorders of memory, attention, and alertness. Specific diagnoses under investigation include multiple sclerosis, Parkinson's disease, autism, Alzheimer's disease, vertigo, depression, and insomnia. [8 – 53]

Example "Depression (or another example)": Defining biomarkers, event modelling of biosensors as event sources and process modelling for influencing the protein machinery

The following figures will be adapted or modified and explained in the paper - according to the chosen example of disease; the real-time aspects of the exocortex on the basis of the biomarkers as a permanent regulation - in difference to e.g. electro shock with a mostly non-permanent effect.

We discuss the questions which have to be investigated, e.g.

- Which cells of which organ (e.g. tongue) should be connected?
- Which types of event adapters do we need, e.g. protonic based chips or electrical links via Genetic Cassettes?
- Which biomarkers for which disease (e.g. kind of depression, major or endogenous depression, bipolar depression, etc. http://www.depression-help-resource.com/types-of-depression.htm) have to be defined?

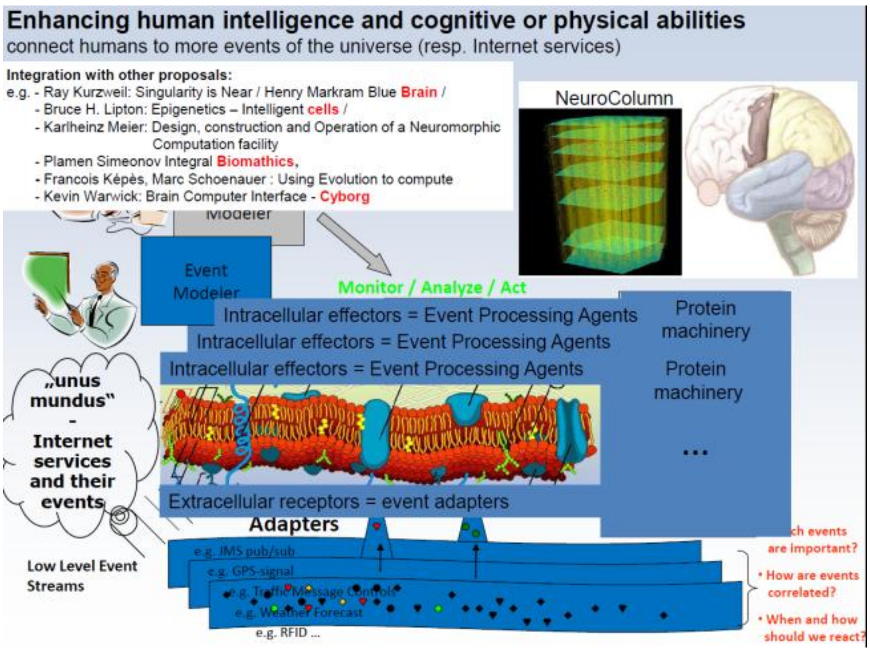

Fig. 2. Adding event adapters, e.g. to the board with the accelerometers of the tongue or as receptors to a cell membrane and the effectors trigger and control a protein machinery and so on. That way, we could experiment with diseases like depression, schizophrenia, etc., by changing the event processing or the vision of the reality

So far, this model shows a deterministic approach. We detect, monitor and manage what is defined as known patterns. But also non-deterministic scenarios in the fields of biology, healthcare and medicine or of Human Enhancement Technologies are possible – similar e.g. to real-time fraud detection and fraud management in the business world (see Fig. 3). In our paper we develop accordant scenarios and transfer such a non-deterministic approach to these new application domains.

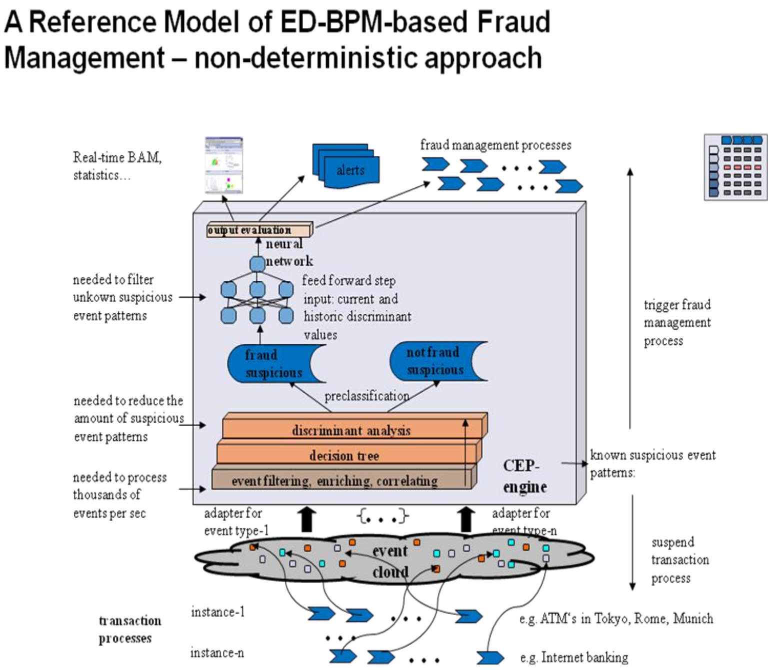

Fig. 3. A reference model for U-CEP as a combination of determistically programmed event patterns and non-deterministic, unknown or suspicious event patterns [4]. Therefore a U-CEP approach must be enhanced by Artificial Intelligence components.

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