Hierarchical attention network to manage processing resources of CPSs

Extended Abstract

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***Abstract*—Resent research and theorizing suggest that goals guide behavior through attention, and this guidance can occur outside of person's awareness. [1]. Attention is a filter helping to selectively process only relevant information and thereby apply available energetic and bodily resources efficiently for survival or for aiming other goals. Contemporary technology enables devices to be informed over their environment and self (external and internal sensors), also control power consumption (low-power modes and techniques). The same could be extended to different hierarchical and/or flat networks (e.g. IoT) where attention signal will be propagated and interpreted between the devices and hierarchy levels, influencing node functions. In this paper inspired from biology attention network is proposed for the mist-fog-cloud type Cyber Physical Systems (CPSs) and benefits of added functionality are analyzed.**

I. INTRODUCTION

The nature has over evolution fine turned various neural mechanisms to maximize species survival rate. The attention has been found to be the key feature in species with even minimal trace of intelligence or awareness. Noticing i.e. turning attention to anomalies and novelties in continuously changing environment is important in survival game. As important is the conscious or unconscious ability to keep attention and focus on activities which is the most important at the instant e.g. seeking for food, chasing the prey, escaping from danger, eating, finding a mate, etc. I.e. attention might be initialized and propagated in both directions - upward, from sensors to higher abstraction levels, and downward, initialized by higher nodes in brain hierarchy [2].

Is is also known that all living beings have limited amount of energy to be exploited for reaching own goals. In here, attention is the gatekeeper deciding where the energy should be directed to guarantee the highest probability of survival and goal pursuing. Attention itself does not process information for decision making, this is done by regular processing units, but it does guarantee processing with selected and the most relevant information related to specific situation or goal aiming.

Attention has been a subject of intensive research in neuroscience over centuries [3], whereas intelligent, adaptive and learning capable Cyber Physical Systems (CPS) have emerged as a subject of research rather recently [4], [5]. In another domain, the research of visual attention of robots has been active much longer [6], [7]. In [Novianto2009] attention in control system is compared with program counter that indicates where the process is happening right now, in more abstract notion of attention it was used to suppress, override and select responses. Attention mechanisms have used in machine vision and related tasks to focus processing on more prominent (salient) areas of visual field, e.g. in face recognition [KiSo12].

When in the simplest terms attention is just the ability of selective processing of sensory information then over the years many different forms of attention have been defined and underlaying mechanisms discovered. E.g., according to [8] the attention serves as a basic set of mechanisms that underlies our awareness of the world and the voluntary regulation of our thoughts and feelings. Ibid., three attention networks (orienting, alerting and executive) have been determined, each in relation with specific anatomical circuitry as well the biochemical modulator. Orienting network is involved in selection of information from sensory input, alerting network is varying alertness and neural activity when the executive network is involved in attentional conflict solving and variety of cognitive tasks underlying intelligence. It is concluded that attention is moderator of the activity of sensory, also cognitive and emotional systems - it's function is to influence the operation of other brain networks [8]. It is also remarkable that attention appears to be based on two interrelated mechanisms - relatively slow but once up then longer-lasting supporting focus [8] with biochemical effectors and fast, based on neural processing.

Intensive studies of attention and consciousness have shown that those two phenomena have remarkable dissociation which enables to study them separately [9]. This conclusion as the scientific consensus that attention is an early adaptation that is shared by many creatures with very basic nervous systems allows to introduce and take benefit of attentional mechanisms in various CPSs which does not possess resources to implement higher level AI features.

The initial attempt by author involvement was to introduce attention into learning, alerting and goal selection loop of a stand-alone prototype self-aware monitor [10]. In this research the aim is more holistic, covering all levels of processing hierarchy (the mist, fog, and cloud levels) and units of a large-scale networked CPSs.

II. Attention in control systems

Embedded systems have as a rule limited computational and energetic resources, usage of which wisely can guarantee fulfilling of defined purpose of the device. Also, keeping the energy consumption under control extends system autonomous lifetime and decreases maintenance costs.

To recognize anomalies or novelties the system has to be informed about its internal and external environment and dynamic processes there. The environment model could be predefined and hard-wired into the control logic but in case of CFSs we expect system to be able to study continuously changing environment and adapt to evolutionary changes there, also predict events few time steps ahead. It requires model learning and decision making ability.

Visiting once more neuroscience, then by Knudsen et al. [11] four processes fundamental to attention are important: working memory, top-down sensitivity control, competitive selection, and automatic bottom-up filtering for salient stimuli. Here, the voluntary control is involved with the first three processes. Ibid., Different information processes are competing for access to working memory where only one or few processes in time can stay and define the behavior of the entity whereas the process in working memory has the highest attentional status. Depending of the object domain different cortical areas might me additionally activated (or boosted) to find the best response to the situation.

On base of [1], [11] we can conclude the majority of attentional processes remain local, peripheral and do not reach to conscious processing before their urgency or strength is enough high to compete for the place in working memory. Still, local mechanisms at lower levels of hierarchy are reacting independently and probably will find acceptable solution from their repertoire of learned or reflective behaviors. E.g. we are able to walk on uneven terrain without consciousness attention although legs encounter continuously disturbances needing local corrections to keep the body in balance. Only more serious obstacle (hole, stone, slipping) might cause anomaly burst higher over many hierarchy levels up to working memory, agitating all nodes and their subtrees during the way.

Solving problems locally is efficient from timing (reaction speed) and energetic point of view. Moreover, boosting neocortex to solve the new situation is slow due to sequential nature of higher cognition processes.

On base of statements before the following properties of hierarchically organized CPS with attention propagation mechanism can be defined:

- Every node in hierarchy contains a **model** (hard-wired or adaptive) of own local environment;
- Every node does **real-time comparison of the input** pattern (behavior) against the model predicted pattern (behavior) and detects the difference (anomaly level).
- Every node has mechanisms to boost or suppress the information flow to node mainly over the **power control** of own components and subunits down in hierarchy. The information flow can be determined by number of streams, sampling frequency, sampling precision, preprocessing complexity etc.;
- There are **mechanisms to represent the status** of the node in terms of 'alerted', 'agitated' or 'under attention';
- There are **mechanisms to propagate attention** and alertness along the hierarchy both up- and downwards.

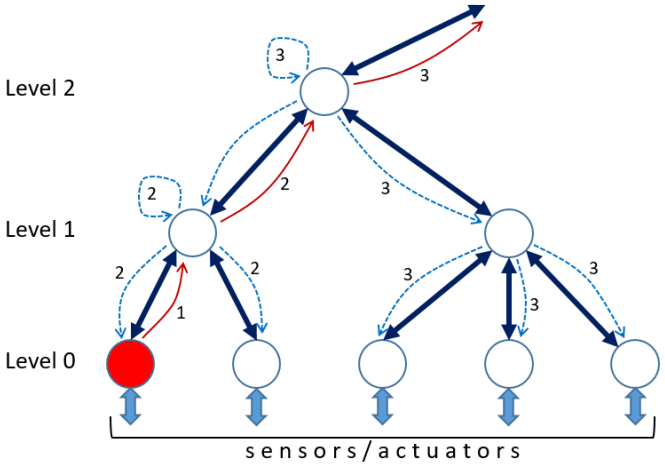

Fig. 1. Attention broadcasting between levels. Solid arrow is anomaly/alert upward broadcasting, followed by attention (dashed line) arousal in target node and downward broadcasting over the tree.

As an example, Figure 1 represents the multilevel control system, where levels 0...1 might denote the mist, fog, and cloud levels accordingly. The leftmost node detects anomaly (e.g. out of predefined range sensor reading) and becomes 'alerted'. The node can repeat the operation or use in case of availability an alternative sensor to clarify the situation but if the anomaly persists, the higher node will be become agitated (1). Node at higher level of hierarchy has more holistic (abstract) view over the situation, more complex model of own environment, more computational resources, and can propagate attention to other nodes (2) to improve the picture of the situation and also inform higher nodes, etc. Alerted or agitated node is using as much as possible own data acquisition, processing and energetic resources to solve the situation locally or at least support higher nodes with relevant and boosted information flow about the situation. The subtree of the network remains alerted until the situation becomes resolved or until suppressed by higher nodes, which might mean also that the new situation has to be learned and counted next time as a normal.

The propagation of bottom-up attention signal over the hierarchy levels is presented in Figure 2. Here, the lowest level of node (blue line) detects high anomaly exceeding the threshold. At this point on the second level (yellow line) becomes agitated (attentive). Still, the process is not instantaneous but accumulating (integrating) and only when the threshold is exceeded for the second level, the alertness signal starts to propagate further. Around at step 200 the situation recovers, anomaly level drops below the threshold, followed by fast dropping of alertness and attention all over

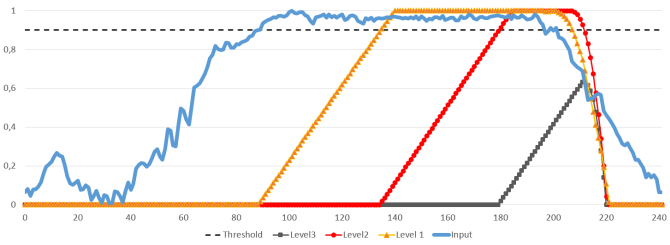

Fig. 2. Attention broadcasting to higher processing levels. Higher than threshold input anomaly likelihood at lower level of hierarchy is causing higher nodes to become attentive one after another until the cause of anomaly disappears.

the hierarchy. It can be seen that the fourth level does not reach to agitated status (does not become 'conscious' of abnormal situation) because the situation is resolved autonomously by lower level of nodes.

III. Experiments

For experiments the system with attention propagation mechanism is planned to be built on base of three-tier situation aware platform, consisting of processing entities at mist, fog, and at cloud level. Every entity or node has at least rudimentary learning capabilities depending of available processing and energetic resources. The nodes will be supplied with control circuits and functionality to exploit different low-power modes of internal and external components, as well for boosting or suppressing information flows from nodes down in hierarchy. Every node is processing a real-time input stream at own abstraction level to confirm on-line is there expected patterns (behavior) or anomalous/novel one. The last is triggering the attention propagation and solution seeking mechanisms (or just an emergency behavior) of the network.

IV. Conclusions

In neurobiology, the attention mechanisms of vertebrates and invertebrates are well studied and understood. The control mechanisms of CPSs can resemble attention related features of insects, being reactive and logical. Still, without the holistic attentional mechanisms the overall behavior of the systems remains rigid and inflexible. In opposite, the attentional control of the whole system over different abstraction levels promises more reliable behavior along with efficient utilization of limited energetic resources. The added value, which might have even higher subjective value, is the behavioral nature of the artificial systems resembling those of living beings, including ourselves.

V. Thanks

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