H.F.R.I.
Hellenic Foundation for Research & Innovation

Description of the funded research project

1st Call for H.F.R.I. Research Projects to Support Faculty Members & Researchers and Procure High-Value Research Equipment

Title of the research project: Novel Ultra Fast Cognitive Learning for Cyber-Physical Systems

Principal Investigator: Yannis Papaefstathiou

Reader-friendly title: NUCLEAR

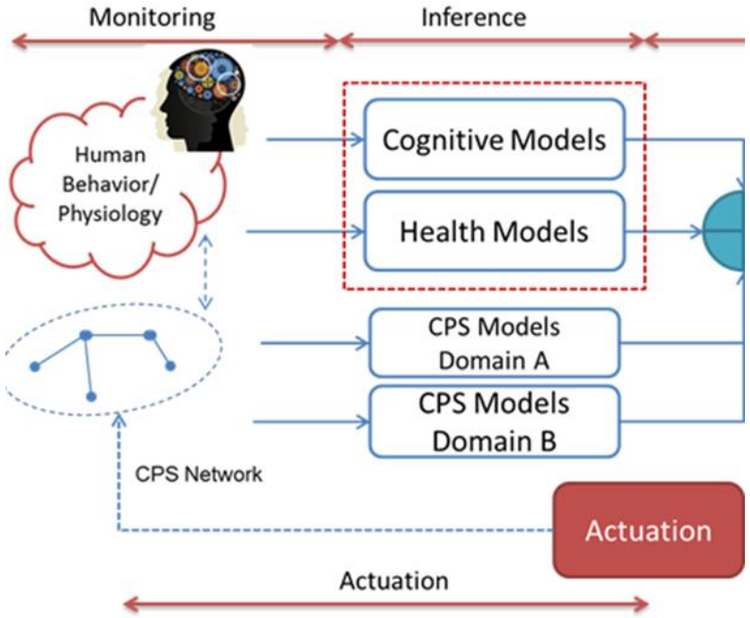
Scientific Area: Engineering Sciences and Technology

Institution and Country: Aristotle University of Thessaloniki , Greece

Host Institution: Aristotle University of Thessaloniki

Collaborating Institution(s): University of Crete

Project webpage (if applicable):



Budget: 181.984

Duration: 30

Research Project Synopsis

Cyber-Physical Systems (CPS) are smart systems that encompass computational and physical components, seamlessly integrated and closely interacting in order to sense the changing state of the real world. Furthermore, sensing technologies, machine learning(ML) and deep learning(DL) algorithms, networking, and computing availability all reached levels that allow for the first time of effective implementation of Human-In-The-Loop (HITL) systems.

The main objective of the NUCLEAR project is to develop and implement in real CPS the first known models that seamlessly utilize machine/deep learning methods and the novel transfer of learning approach (described below) for modelling and learning the time variant states of the nodes that interact with humans as well as the system as a whole. The end schemes will be able to a) model humans' behaviour, b) handle different types of HITL control, c) self-monitor their state, d) react autonomously, in real time, under changing conditions .

One of the most important challenges for developing and applying such novel models in real-world environments is the fact that they should be able to trigger the necessary response in real time while they are expected to be very complex. In order to address this very important issue we will develop an innovative CPS hardware architecture that will utilize reconfigurable hardware. The provided architecture will provide more in-node processing power so as to support all the sophisticated features of our model in a timelier, more power-efficient and more accurate manner compared to the current state-of-the-art CPS nodes while all the developed schemes, algorithms, cognitive and medical models will be optimized for execution into the proposed CPS architecture consisting of multi-core CPUs and Field Programmable Gate Arrays (FPGAs).

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Project originality

In NUCLEAR, online learning will, for the first time, permit CPS nodes' operation to be adapted to the uncertain behaviour of humans. Although online learning requires an efficient feedback mechanism, another novel feature of the NUCLEAR approach is that, the developed mechanism will utilize all CPS nodes' states that belong to the same knowledge domain (i.e. operate under similar conditions and perform similar tasks). Exploiting such a synergistic procedure, an efficient feedback mechanism can be implemented by continuously evaluating the nodes' actions and probabilistically estimate their desired states. In other words, online learning will permit the aggregation of all associated nodes' information towards the development of an efficient mechanism for selecting an optimal feedback strategy. In this way CPS will be able to discard, on its own, any information arriving from uninformative or compromised sources.

Another unique feature of the NUCLEAR approach is that the developed ML models will be analysed so as to identify the computationally intensive parts; which will be accelerated by custom circuits implemented on FPGAs. Thus NUCLEAR will :

1. develop and design, for the first time, hardware accelerators that will increase the performance of each accelerated model by more than 10x when compared with the conventional software solutions,

2. apply intelligent approaches for identifying unnecessary data and eliminate them as well as statistical compression, and other means of computational load reduction, to reduce the overall power consumption by at least 30% when compared with the existing approaches,

3. decentralize data fusion and base ML models by designing distributed algorithms and custom FPGA circuits that are spread across the distributed sensing environment, and collaborate with each other much like swarm sensors. For example, the computationally intensive parts of the learning models can nest on multiple custom circuits operating remotely, each accelerating the region-specific parts of the algorithms.

Expected results & Research Project Impact

The scientific impact is based on the fact that NUCLEAR will propose, design and implement novel and efficient models and methodologies that do not exist (and go beyond whatever it can even be proposed in the coming years), in a scientific sector that expands rapidly both in the US (as reported by NIST) and in Europe (as reported by EC). Those models and methodologies can be utilized in the vast majority of CPS research sub-sectors since most of the CPS involve humans and NUCLEAR covers efficiently this aspect.

In terms of the economical perspective, General Electric, estimates that the technical innovations of CPS could find direct application in sectors currently accounting for more than $32.3 trillion in economic activity, and with the potential to grow to $82 trillion of output by 2025 – about one half of the global economy. As a result, if a CPS achieves just a one per cent efficiency improvement in specific industries the overall financial outcome will be substantial.

In general the potential macro-economic benefit of the development and deployment of CPS systems in the coming decades is enormous, and one analysis suggests it could be comparable to the economic productivity gain attributable to the Internet revolution of the late 20th century—providing a needed and significant new growth engine for the Global economy.

The societal impact is also expected to be significant since the CPS that will utilize the NUCLEAR models and approaches will interact in a significantly more efficient way with humans, than the current systems. So in that respect the successful outcome of NUCLEAR can affect the whole society since it will allow for better health/medical devices, more efficient automotive systems, better smart homes etc.

The importance of this funding

The realization of this research project would not have been possible without HFRI's funding. We consider funding very important because it highlights the role of HFRI as the main funding source for interdisciplinary research; HFRI is being proved the main pillar of support for basic research. Due to HFRI's funding we are able to employ and empower a young scientist with a doctorate, two graduate students (at PhD level) and create synergies between the results of the basic research and their use in everyday life. Last but not least, the funding allows us to publish our research results and communicate with the international scientific community, by supporting our participation in conferences and our publications in open-access journals.

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