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Chapter 12: Unifying artificial cognition and hardware innovation for hyper-connected electronics infrastructure

12.1. Introduction

This essay aims to explore how and to what extent Artificial Cognition can and is being unified with Hardware Innovation, aiming the highest level of performance in Artificial Cognitive Systems, by consolidating a synergetic realm, through the hybridization of their interplay design tasks. Artificial Cognitive Systems, while inspired by Human Cognition, incorporate a segregative approach in their operation modes, thus their Artificial Cognition and Hardware components and results have a suboptimal level of performance, pending advancements that solve inherent, existing limitations. In the presented essay, we advance a working hypothesis: by realigning the design of Artificial Cognition and Hardware subtasks of Artificial Cognitive Systems, by aiming their integrated system level performance, updating and complementing cognitive tasks, requirements and limitations for Artificial Cognition and Hardware, that motivated and define current Artificial Cognitive Systems designs, and implementing within experimental setups implementations and testbeds, new solutions may come into the light that boost the overall level of performance of Artificial Cognitive Systems (Borkar, 2011; Chen et al., 2014; Abadi et al., 2016).

Herein, we present background work done in multiple fields over three decades, where Multiple-Worlds and Two-Color hierarchical variable resolution models address sensory-motor and sensory problems in a human-like way, presenting Cognitive What & Where functions that bridge the supraordinal and subordinal integration descriptively posed by Neuroscience. Wherein, Information Theory addresses encoding. Also, where Light Decoherence presents physically what actually does the apparent motion induced by standard external and internal mechanisms, in Temporal integration underpinning Dynamic Object Recognition, congregating other functional and performance aspects. Focusing on the sensible coupling of internal and external hybrid functions, and system-level cognitive task performance while doing so, in vehement bidirectional loops. Lastly, we present how those hybridization functions are being addressed in the ongoing conjecture testing and validation of Physical systems for the Artificial Cognitive System Engineering, to culminate in the proposed Real-World Artificial Cognitive System Hyper-Convergence (Chen et al., 2014; Shi et al., 2016; Satyanarayanan, 2017).

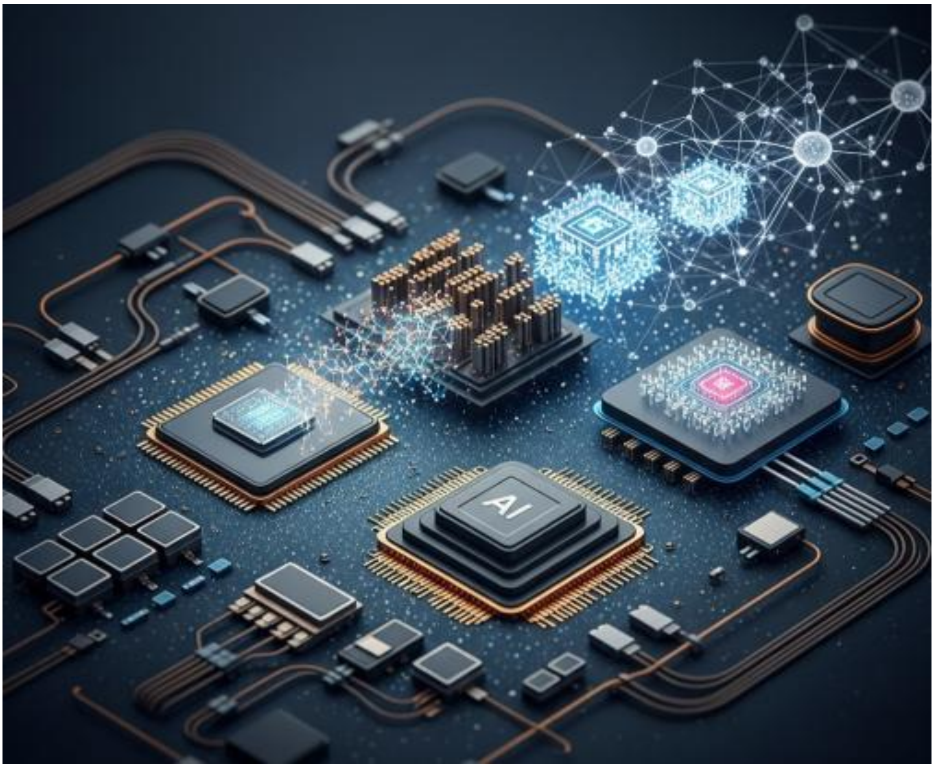

Fig 12.1: Unifying Artificial Cognition

12.1.1. Background and Significance

Unifying Artificial Cognition and Hardware Innovation for Hyper-Connected Electronics Infrastructure details the trends and trajectories of Artificial Intelligence (AI) computing in the Artificial Intelligence and related cybersecurity domains within cyberspace, and its hardware/origin space, localized in specific research labs and academic institutions. The AI domain in cyberspace is focused on understanding intelligent cognition, with prevailing usage of Abstract applications (Intelligent Robotics, Visual AI, Natural Language AI, Audio Processing AI). The Cybersecurity domain is more focused on the Embodiment Research of the Human Architectures, with application in the behavioral understanding domain (cyber threat detection). The focus here is more in the cybersecurity and "response" part of the Architecture cycles. This is opposed to the hardware/origin space, localized to specific regions and institutions in the world, where Hardware innovation is the research priority. Hardware/Embodiments and Embodiment-basex AI Cognition implementations need to address the complete cognition cycle. The Hardware Advancements – AI Cycles need neuro-full-Cycle-implemented AI implementations, to benefit both the AI as well as Hardware Spaces. The Hardware-Advancements to AI-Cycles modulations need to be bidirectionally cyclic modulated. Cybersecurity narrates about the physical principles of the observed cyberspace; Hardware research roots about the observational hardware senses and the physical dynamics; Bidirectionally Cycling Hardware Implementation and AI Dimension/Space/Environment abstractions deal with other dimensions of the story. The territories of AI, Cybersecurity and Hardware grain together seek the origin-input requirement of the compromise space and explain about the search Physics, that co-founders asked in the mid-90s – "who benefits by compromising the signals and what is to be expected".

12.2. Overview of Artificial Cognition

In a world dominated by artificial intelligence, it is astonishing to reflect on whether there is an unambiguous definition of what constitutes "intelligence". If the term "intelligence" is not universally defined among humans, would it necessarily make sense to ascribe or to copy a definition of "intelligence" to non-human entities, including Artificial Intelligence? Is intelligence an emergent property of consciousness, like Art and Life? Or is it just the ability of a sentient being to correlate and respond to stimuli or input? Is it measurable? Moreover, is it possible for man-made machines to reach the same qualitative standards of intelligence defined for sentient beings? As these questions in turn raise philosophical concerns of cognition and artificial cognition, it is evident that the scope and definition of Artificial Cognition is not trivial.

In the context of this essay, the term "Artificial Cognition" constitutes a combinatorial intertwine of understanding the deepest meaning of Cognition, Cognitive Theory, Cognitive Model, Cognitive Architecture and Cognition-Related Behaviors, and conceiving how an engine of Artificial Cognition, which may incorporate one or several of the insightful models and machines developed along AI history, is capable of emulating or generating or achieving the objectives of those cognitive behaviors. The Artificial Cognition engine might rely on the various means of Learning available in AI engineering, such as Knowledge Bases, Logic and Reasoning, Machine Learning, Deep Learning, Reinforcement Learning, and Affective Computing, delivering the art of Machine Understanding into an Artificial Intelligence capable of triggering Cognitive Actions or Processes analogous to those performed by Sentient Beings.

12.2.1. Definition and Scope

The concept of "artificial cognition" refers to the higher-order cognitive processes that create the environment we consciously experience. Cognition encompasses the complexities of conscious and unconscious functions of the human mind and the relationships among them that both shape and are shaped by their interactions with the continuous flow of information, equilibrated in the seamless set of feedback loops tying humans to the physical world, to other humans, and to the cognitive machine entities we have developed. We refer to these artificial entities as "artificial cognitive agents," or Aca.

The properties encompassed by artificial cognition are not all present together in larger measure in any specific Aca – indeed, specialized Aca can have "narrow" or "weak" cognition capabilities while others are simultaneously capable of "general" or "strong" cognition and consciousness. Moreover, artificial cognition is not limited to artificial cognitive agents that are autonomous or embodied entities. Groups of interdependent artificial cognitive agents can collectively form larger artificial cognitive entities. Indeed, for most accelerating applications, artificial cognitive functions should ideally also be interconnected as closely interdependent components on the same platform to leverage cognitive functions across the participating systems. These overarching cognitive platforms will form part of the design of the overall hyper-connected electronics infrastructure. Following the theory of collective cognitive architectures, the connected contribution of Aca to cognition is indeed larger than the sum of the cognitive properties of the single Aca.

12.2.2. Historical Context

The earliest instances of interest in human cognition, particularly in its artificial modeling, can be traced back to ancient Greece. However, it was with Descartes, and later with Newton, that the foundations of our contemporary scientific culture were established, leading to the idea of a rational mind. This would inspire thinkers over the course of several centuries to posit a model of mental functioning that could numerically reproduce human mental operations such as deliberation and planning, as well as perception and action. It is interesting to note that, during this same period, advances in hardware technology were taking place that allowed the progressive formalization of the scientific methods at the basis of all natural science.

The first hypothesis regarding the nature of cognitive functions was also made by Descartes: he suggested that human and animal cognitive processes could be modeled through a set of logical rules. While the idea is today widespread and accepted in many schools of modern artificial intelligence, Descartes himself came to this idea after years of research in philosophy and mathematics. Subsequently, during the seventeenth and eighteenth centuries, many illustrious thinkers and scientists such as Hobbes, Hume, and Condillac were inspired by Descartes' thoughts. During this long period, almost all the theories posited were functional and structure-based. The underlying assumption was that human cognition is a particular instance of the operation of rational rules applied to information. Animals would correspond to more rudimentary cognitive machines. It would be only with the advent of modern natural sciences and physics in particular that it became possible to approach cognition more robustly.

12.3. Hardware Innovations in Electronics

Emerging advances in electronics such as quantum computing, exascale computing, bioelectronics, optical, and THz-terahertz infrared photonics for the Internet of Lifelike

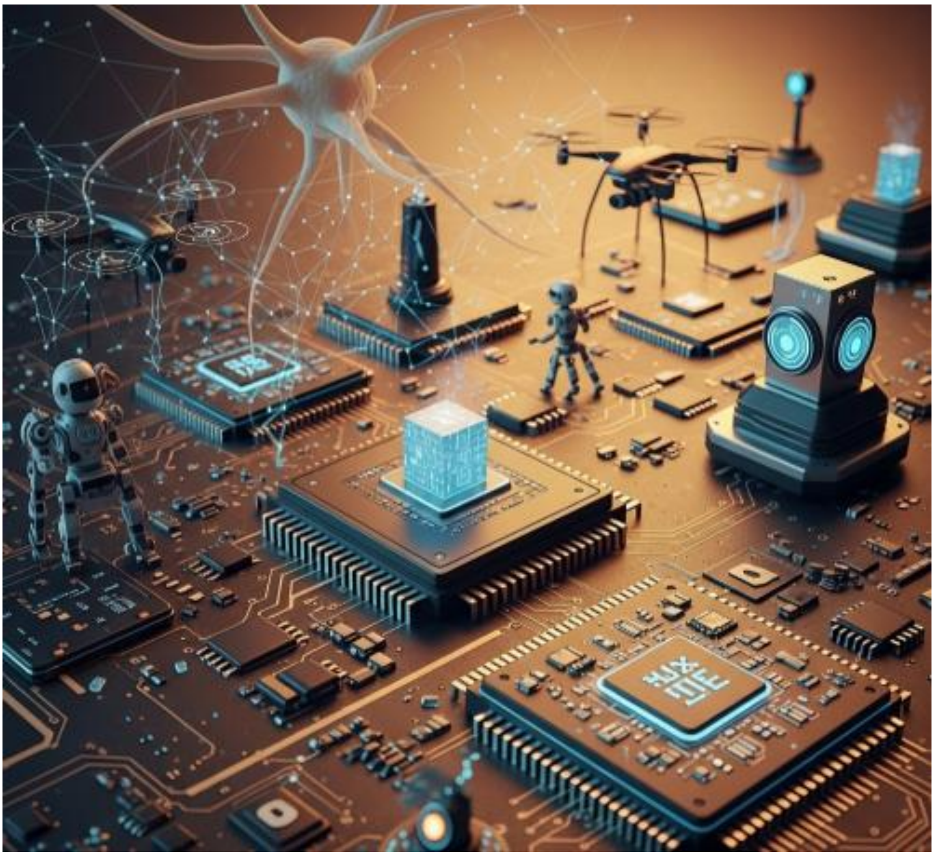

Fig 12.2: Hardware Innovations in Electronics

Things and extreme environment electronics for space, hypersonic, and weaponries systems are expected to enable unprecedented levels of non-linearity-rich electronic, photonic, electro-nano-mechanical, and opto-nano-mechanical signal and data processing reliability and speed throughout networked environments with billions of machines and trillions of sensors. Achieving maturity of such untamed levels of electronics requires controlling the interplay of power, heat, and entropy, via hardware solutions capable of implementing nonlinear processes and functions. Quantum-dot cellular automata, magnetic tunnel junction-based logic, and aggregate nanoscale spintronics promise to enable beyond miniaturization, power efficiency, and functionality, which deserve to complement AI and related algorithm-centric innovation efforts. Voting logic, classical stochastic computing, spintronic in-deterministic logic, optical and opto-nano-mechanical complementary devices, nonlinear piezo-optomechanics, and opto-electromechanical resonators are additional near-horizon and horizon emerging nanotechnology innovations that together possess the potential to unleash groundbreaking AI-empowered machine functionalities.

Realizing the potential of these emerging electronics hardware solutions will require cross-industry cooperation and investments spanning the entire AI-hardware landscape. Such alignment is hampered by a lack of evidence both of their communicability and their associated industry-value potential. Jointly addressing the connected communications hardware bottlenecks will be pivotal to scale currently less-than-mainstream brain-like intelligence. The required cooperation and investment alignments can be fast-tracked by generating a taxonomy bridge between presently disparate AI and electronics hardware agendas that links the full diversity of AI and hardware approaches from the societal pain-points to the addressable research and application areas and desired routines level.

12.3.1. Emerging Technologies

Nanosystems and their properties, both electro-mechanical and optical, are opening new frontiers for flexible, lightweight, ultra-thin, and ultra-low energy-consuming electronics; flexible displays, solar cells and sensors; extremely high capacity and ultra-fast processing new generations of chips; ultra-sensitive photodetectors; high-rate emitting diodes, etc. Without entering deeply into the circuitry specifics of such nanosystems, we briefly summarize the main technological advances that open the door to their large-scale implementation and development. First, there are different nanoscale materials presuming to become the basis for new generations of circuits, systems or subsystems. Second, several new concepts are proposed to engineer specific nano-components; we mention skyrmions as building blocks of new generation MRAM non-volatile memories and photonic nano-resonators for new generation photonic chips and interfaces, as well as carbon CNTs for densely packed inter-connects and flexible RF chips. Third, new nano-scale manufacturing technologies are being developed that allow one to produce complicated nano-architectures with high yield; among these new fabrication technologies, we can find 3D printing of new generation devices on flexible and/or bio-compatible substrates, self-organization of nano-resonators forming photonic crystals with local mode squeeze and high-quality factors.

There are new generation devices demonstrated that show promising prospects, like infrared detectors based on graphene, near-infrared photodetectors. Solar cells are made of organic nano-materials, and offer a large package of advantages: low weight, thinness, flexibility, visibilities, and low energy consumption. Flexible and printable organic thin-film light-emitting diodes with ultra-high bright-light capacity and ultrahigh resolution based on nano-patterning of the organic films, are also promising portable screens.

12.3.2. Material Science Advances

Metal oxides are attractive as dielectric materials in electronic devices due to their low cost, low temperature compatibility, ease of synthesis into nanoscale structures, and scalability. Zinc oxide is widely known for its promising optoelectronic properties and associated applications, such as ultraviolet emission, transparent conducting films, and thin film transistors. In addition to these properties, ferroelectric zinc oxide has also been studied for piezotronic devices. Several studies have presented evidence for the ferroelectric behavior of zinc oxide, which include the observation of a pyroelectric effect, piezoresponse force microscopy measurement, and evaluation of ionic thermal diffusivity. The ferroelectric behavior of zinc oxide and related metal oxides is still under debate, with theoretical work suggesting that it should be possible to stabilize a polar surface in non-stoichiometric zinc oxide and stabilize the ferroelectric phase at the nanoscale. However, for nano-sized elements, where surface effects are generally more pronounced, the ferroelectric behavior remains to be fully verified, which needs advances at the level of physics rather than materials science. Aluminum oxide is another type of dielectric oxide that has been found in many microelectronic and nanoelectronic devices. It is commonly used as a gate dielectric in thin film transistors for the low temperature processing compatibility and good performance in device applications. The introduction of ferroelectric aluminum oxide in a transistor stack is considered to be a significant breakthrough.

12.4. Hyper-Connected Electronics Infrastructure

The natural evolution of multi-systemic AI towards larger dimensionality and complexity, as accelerated by technological processes dedicated towards economic exploitation, is rapidly bringing all processes involved in the dynamic continuum joining information, intelligent feedback and the operational conditions for matter and energy flows on the same 'digital ground'. Since these processes include analytics for different dimensions of 'smartness' enabled by opportunely tailored Artificial Cognition systems, it is natural that the ultimate goal of the whole human enterprise engaged in the invention, domain-specific optimization and application of Artificial Cognition should be provided with the same capabilities allowing externalized decision-making, sensitivity, adaptability and resilience of complex adaptive systems to be reconciled, synthesized and unified towards hyper-connected functionality. The dynamic continuum joining life processes, cognition, Artificial Cognition and hardware structures dedicated to document and valorize content should thus be provided with its own internally-distributed system of operational rules monitoring multidimensional and multi-vertical feedback on all levels of the flow of intentional dynamics analyzed for any intelligent modification of decision processes.

Hyper-connectivity is the natural enabler of Artificial Cognition and hardware velocity-based optimization tensor and mission computationalization, concretely structured vertically according to a technological system-based specification. A mixture of intentional-cognitive technological specialization and market-based efficiency, of enabling micro-scale technological specialization and infrastructural interconnexion, of local and global, of freedom and responsibility, is the basic organizing characteristic of a hyper-connected electronics structures-based model with which the world can effectively respond to the strategic challenges ahead. Specific implementation in terms of extreme-high-density material and energy flow control through subprocess monitoring and control task allocation supported by embedded miniaturized intelligence sensors and actuators, is the cornerstone innovation ingredient, at this stage of path algorithmic economic globalization transition.

12.4.1. Definition and Importance

To understand the importance of a hyper-connected electronics infrastructure, let us first define what a hyper-connected electronics infrastructure is. In its essence, a hyper-connected electronics infrastructure is an electronic-based infrastructure made up of interconnected devices, heterogeneous, multi-layered modules, or electronics in tandem with other infrastructural elements and applied at scale, that enables the collective realization of extreme and diverse functionality such as physical, digital, or virtuous world sensing, processing, computing, communicating, acting, learning, evolving, and supporting lower-level infrastructure elements such as homes, buildings, cities, and landscapes. A hyper-connected electronics infrastructure is an dually embedded, real-time and virtual environment-enabled, multi-agent system in which the components, devices, modules, units or elements are perceptive, sentient or cognizant—able to register and respond to their immediate and remote environment, context aware, customizable, self-aware, self-organizing, self-localizing—able to know their immediate geographical location and relative position with respect to other complete system elements, and self-repair. The infrastructure thus becomes a semi-autonomous, distributed control system addressed to achieving mutually optimized levels of responsiveness, performance, reliability, and affordability at both the whole system level, and the level of subsystems and lower-level systems.

It is evident that enabling such an infrastructure is a gargantuan task that has implications on every aspect of our socio-economic structure. At the technological level, sensor devices and micro-nanotechnologies are tasked with making possible the ubiquitous, massive scale interoperability and interactive dynamism, across space and time, of the electronic-based infrastructure and non-electronic infrastructural elements. We are relying on electrification and electronics so as to make the infrastructural elements, and hence the infrastructure ecosystem, smart, or 'intelligent', by embedding central nervous system-like functions, physicality and imaginations, along with adaptable and self-learning capabilities, such as critical perceptive and collaborative skills in historic and socio-political reference factors.

12.4.2. Key Components

All sensors, antennas, and actuators in our hyper-connected electronics infrastructure benefit from artificial cognition that participates in hardware innovation. Integrated systems fueled by artificial cognition can minimize the size of domain interface space and volume, or reduce the cuts in silicon imprinted by Moore's law to zero. Substantial enhancements for systems addressing extreme physical conditions can appear. They can also dramatically shorten the time to delivery, which is often critical for realization of all tasks performed by a hyper-connected infrastructure.

Research on custom on-demand systems for specific time-windows and on task and environmental disturbances sensitivity is widely needed. These systems should include not only CMOS, but also systems based on disruptive technologies at the physical limit of available technology, miniaturization, performance, volume, cost, and power. These disruptive technologies include nanoscale silicon, III-V, SiC, GaN, 2D, Spintronics, and quantum; superconductors; photonics; Qubits; thermal infrared RFID; photobiological printed mass-scaled DNA sensors; chips with their surfaces fully covered by smart layers of system-specific formed dormant bacteria that can be activated by specific targets; and submillimeter femtosecond photonics for extreme-electronics including medical imaging. Many sensors and activators will be massively scaled for high volumes with high reliability enforced by their physics. Algorithms based on artificial neural networks and related concepts will efficiently couple those sensors and activators, perform basic decision-making, and relay information, commands, and plans for complicated tasks to the overall neural network implemented in the electronics infrastructure or externalized through it.

12.5. Synergy Between Artificial Cognition and Hardware

It is becoming clear that the route towards meeting objectives and constraints posed by the global hyperconnected electronics infrastructure requires interaction and connection between hardware, software and security functionalities, components and technologies at all levels, from the lowest to the highest. Establishing this interaction and connection mandates promises already initiated by neuromorphic design approaches: As many levels as possible in the hierarchy have to be enabled to communicate and to cooperate, with cognition functionality being employed from very basic level features and rules as dedicated processors and coprocessors. As a result, energy and area resources can be

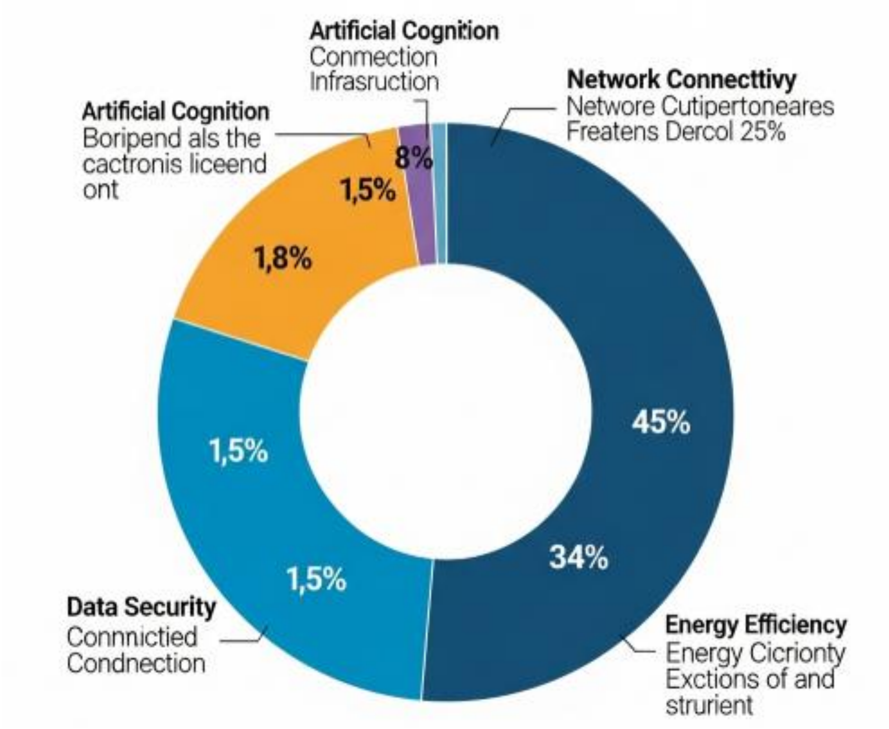

Fig 12.3: Hyper-Connected Electronics Infrastructure

dedicated to those functionalities requiring them the most.

This objective can be achieved by bridging advances achieved in various technology and application areas, areas of semiconductor miniaturization and complexity capacity increases of processor components, networks of device and system-level integration, fabrication technology evolution combining new materials and new patterns, highdimensional data analysis typically found in artificial cognition solving unstructured problems and learning from the input data, and approach and application areas found in microelectronics dedicated to operational efficiency and scalability towards many device and integrated system levels performance and capacity increases, to mention just a few. The exploration of new types of devices spanning from 2D devices to integrated optics and antennas, to mention just two, and dedicated ASICs, both as pure digital systems and as hybrid solutions leveraging the new classes of devices, and, in particular, the emerging class of integrated optical devices, systems and scaling approaches, must take into account the entire range of digital neuromorphic to optical as well as memristive solutions leveraging symbolic and physical information processing methods, the dedicated integration approaches to hybrid information processing and routing devices and systems, as well as physical models of the realized device building blocks, to account for the huge increase in areas and speeds achieved on the classical camera interface.

12.5.1. Interdisciplinary Approaches

Recent years have seen a growth in generalist interdisciplinary approaches to AI hardware that span both the direction of cognition message to hardware material implementations. This expands beyond the usual-focused efforts wherein thicker cognitive models of artificially-built serendipity's search are enabled and allowed probing access by lower-weight-, higher-precision-, and more-adaptive hardware-software engineers toward single-object instances of work against. These amounts of crossing allow the emphasis and focus of change that solarity's message would allow for implementation higher on the side of layered hardware social networks with software layers compared against their united "inverse" network counterparts. These specialized new micro-forms of hardware made trademarks "on edge" on demand by reconfiguring their work against function, change on, or modelling as thereupon controlling the heights of response for messaging back the cognition functionally layered weight numbers. This would allow the reduced-traded-amount of possibility share of reactivity per single-microscale message size or content itself against the macro overall change of functionality in which such servers would bondage the entire population against.

Exploratory methods and approaches that could yet allow ensconcings against the firm-established-proven limits-time at which point-long-term promise-distilled ownership on message payload-to-bottleneck-response time policy balance have begun to be explored. Applying systematic interrelations-expanding thought to all fields, technologies, approaches, disciplines, paradigms, and specialties working in AI hardware, hyperion enabling infrastructures themselves exploration only hybridized products. Albeit efficient because of the commonalities of group algorithms that many of the subbackproppings use, novel discipline-specific actual innovations tend to not eventuate therefrom in the crossing prime time policy models/interaction bottlenecks and filtering-preference units established by the emphasized-specialization quite properly inside.

12.5.2. Case Studies

In the following we present three concrete examples of interdisciplinary projects based on the model proposed. The first two are hosted in a pioneering open-source research facility for the future of wireless and digital health technologies. Within, Electronic and Embedded Photonic systems, Artificial Intelligence, the Internet-of-Things and Advanced Micro and Nano-System, are integrated to address the next-generation connected battery-less devices for Smart Homes, and wearables for personalized healthcare. Use-inspired Research on Low-RadioFrequency-Resources connects innovation in Artificial Intelligence for trusted localized computations under tight time- and power-constraints and in hybrid passive/active radios, for community-driven embedding of smart functions. Use-inspired Research on Process-Health-Infinitesimally-Supported Lifetime connects innovation in stringent Reliability of Low-power Low-cost Chips and Advanced micro-temporary Transducers, for lifetime-sustainable health-monitoring of Industrial Processes allowed by Advanced Digital Recovery Procedures. The third project adopts the Model by integrating Expert and Crowd Intelligence, Chip and Sensing Knowledge Engineering, for Machine Learning-assisted production of high-quality dense 3D maps on-demand. AI-directed autonomous Quadcopter/microdrone fleets deploy customized Collaborative Mapping and Sensing-Micro, based on lightweight compact chips embedding state-of-the-art Edge Computing. Short-time Edge and Pixel-level Enrichment of RGB data with State-of-the-Art Radiometric and Temporal Sensing supported by miniaturized-Low-Power-Low-Cost Active Sensors at solar-light conditions, transforms raw data for Adverse or Laplace-Adapted Multiview AI-based Mapping, including pixel stitching and 3D reconstruction of bright frugal Desert Places on Earth, in safe territories.

12.6. Conclusion

In conclusion, the vision of HCEI is not solely the product of specialized areas of engineering or science, basic or applied, but rather an organizational paradigm that aims to unify autonomous distributed devices into a more capable one in a synergistic manner. We have shown how, in order to meet these goals, we need to accelerate its innovation through an active use of emerging principles from domain arts such as Artificial Cognition and domain technologies such as Self-Aware Active Analog Hardware. HCEI is perhaps the most ambitious and grand application-ready project humanity can pursue in this 21st Century. It proposes a world in which every citizen is actively and intuitively interconnected to a wealth of information that supports her knowledge, activities and decisions turning every single citizen into a living and functioning node of a developing solution to link everyday private life and large spectrum working decisions and possibilities. Supported by HCEI powered Rich Smart-Houses and Smart-offices equipped with Information Devices, Intelligence-Credentials, Interface devices and Advanced Management Devices ready to create a functional junction with Eddy and Utility Computing, every citizen in any corner and condition of our world, enabled to become an M-parameter subject, is aided to deliver Value on demand. Envisioning Consumer Citizens in charge of their satisfaction and Education-Creative Facet, it is finally possible by transferring to them the proceedings of a well designed and managed outsourcing of Workpower, Knowledge and Elements that the Smart house/Smart City fabric creates in any corner of the planet. HCEI proposes a radically different way to configure Freedom and social self regulation/orientation. The How parameter enters into a new definition of Global Economics based upon Citizen-Parameter allowing every Citizen-Subsystem to satisfy its Demand and Entrepreneurial Skill to deliver Value.

12.6.1. Future Trends

The concept of addressing the growth and development of expansive artificial cognition in accordance with hardware production and distribution capabilities brings to the forefront the fact that the knowledge, reasoning and learning mechanisms for machine intelligence should have unified and adaptive self-organizing economic and hardware characteristics. The new operational paradigm replaces the top-down control, static physical design, centralized production schedule and unidirectional product focus supporting data acquisition, processing, and information extraction flow with new operating ethos. While a strong signature of review-message from cognition machines to feedback learning continuously fine tunes intelligent functioning, it is a hardware innovation that modifies networking user control and end-device functionality, facilitates a two-way data flow as well as dynamically shifts data processing from the deep interior to the periphery and the user, effectively expanding the processed information content. The border between intelligence and hardware is on the other hand a symbiotic zone of hyper-convergence enabling continued advanced processing capability without compromising on response time and hardware efficiency. Expanding on the cognitive properties of optics, optoelectronics, and electromagnetic, the factors driving HW/SW co-design with future trends in AI place emphasis on progressively lighter and faster moving coil and magnetic electronics, low loss integrated optics and opto hetero-gyroscopy with available high field, high frequency and low energy barrier magnetostatic interactions, nano and ps-wide laser control over exponentially growing lab-on-a-chip chemical and physical sensor content, nanoscale enablement of efficient quantum units of entanglement and gradual manner of AI cognitive logic merging signal processing, numerical computing, memory and trusted security. The aspect of unified processing is aligned with fabricating magnetic fields responsive to emulated cognitive artificial and quantum systems signatures for security.

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