Putting in Perspective Human-Machine System Theory and Modeling: From Theoretical Biology to Artifacts Integrative Design and Organization

"Artem Augmented Human Project"

Didier Fass

ICN Business School, Mosel Loria UMR CNRS 7503, Université de Lorraine
Didier.fass@loria.fr

Abstract. Thinking about human systems integration is thinking human, system and human-system for designing and organizing system of systems from human-machine level to socio-technological level. For critical human in-the-loop systems there is a strong need of reliability and consistency from modeling, development and life cycle systems. A main epistemic issue rises: does it exist a conceptual framework, both theoretical and experimental, that ensures reliability and consistency of human system integration design and organization? According to the Italian Renaissance painting perspective principles invention, our paper puts in perspective human systems integrations from theoretical biology to systems sciences, and it presents an isomorphic framework for modeling human systems integration especially adapted at the human machine level, for medicine, defense and aerospace.

Keywords: human systems integration, human-machine, theoretical biology, systems theory, isomorphic framework, perspective, modeling.

1 Introduction

"*The field of Human Factors and its many descendants - Cognitive Engineering, Human-Computer Interaction, Cognitive Ergonomics, Human-Systems Integration, ...—has made numerous, wonderful advances in the many decades since the enterprise began. But the discipline still serves many to rescue rather than to create. It is time for a change.*" Don Norman [1]

Reliable design and correctness by construction systems are two main issues for human systems integration and organization from human-machine systems to socio-technical systems especially for safety and life critical systems. With current interactive systems, from smartphone, airplane cockpit devices and bedside monitor in intensive care, to teleoperation systems, boundaries between human and artifact are fading. Within converging technologies (nano-bio-info-cogno or NBIC) [2] [3] that dynamics develops.

That disappearance of boundaries between a biological and social human and its interactive physical and information processing artifacts challenges engineering methodologies and ergonomics of systems design.

V.G. Duffy (Ed.): DHM/HCII 2013, Part I, LNCS 8025, pp. 316–325, 2013.

Current and future technical developments for enhancing human skills and capabilities or medical care and implantable devices challenge new scientific and technical knowledge and development methods. Understanding that synthetic hybridization requires an original conceptual and knowledge framework, that allows to think and model "*enhanced or augmented human*" as an integrated dynamic, structural and functional whole [4].

1.1 Human System Integration (HIS)

Originally as technical and managerial concept [5], human systems integration (HIS) was defined in the middle of the eighties by the US defense department. It is used in acquisition programs requirements definition of total system design and organization. It aims to maximize the overall system performance while ensuring a safe, efficient, and enhanced interaction between the user and the technical system [6]. Defining a system more broadly than hardware and software refer to human centered design [7] in contrast with automation and machine centered design [8].

That methodology [9] is concerned with the integration of human capabilities and performances, from individual to social level [10] into the design of complex human-machine systems supporting safe, efficient operations; there is also the question of reliability. That issue requires thinking human as an element of the system and translating it qualitatively throughout design, development and testing process [11].

Human systems integration also involves augmented human design with the objectives of enhancing human capabilities and improving human performance [12] using interactive technologies at the level of human-machine system and human machine symbiosis [13].

Today HIS refers to systems that require human interactions -human in-the-loop systems, but new automated technologies are emerging more and more integrated on the human body from wearable to implementable. The human automated machine is closer. The concept of human system integration must be revised!

1.2 Scientific and Technical Context

Human machine is currently both a techno-scientific research and development topic and a philosophical and anthropologic theme of discussion. From one side, reductionism postulates reducing the human organism to an intelligent machine and its physical (mechanical) and computational properties. On another side, some one claims for a metaphysical and transcendental humanistic ideal inherited from Italian Renaissance and Vitruvius.

Between Human, with a capital H, as a philosophical ideal and human as an abstract category of a biological system, there is life, multidimensional reality and death. Therefore, how understanding and conceiving human and human-artifact or machine nature and their scientific principles theoretically?

That question highlights some scientific and technological interdisciplinary questions:

- What does human systems integration really mean from systems sciences or general systems theory to theoretical biology and integrative physiology applied to human systems engineering?
- What is a good epistemic framework for human-machines modeling? Which system and theory of knowledge is relevant? Which ethical reasoning? Which logics?
- What is the validated scientific grounding for safety critical automation design and human systems integration?
- What is a good and reliable model of automation and integrated human machine "physiology" and behavior?
- Which are the formal and experimental method for ensuring modeling, validation and certification of human-machine system design and organization?

1.3 Epistemology and Modeling

Epistemology and modeling are causally linked. The epistemic framework structures model. They are related to knowing and representing knowledge, not only for understanding the natural or artificial world, but also for designing and organizing technologies. According its internal – logic, and external – experimental, validity that framework ensure consistency and practical validity of the model. Different epistemic frameworks might provide different models of the same object or system with a wide range of robustness and predictability. The most general is the grounding epistemic framework; the most predictable and robust is the model. It is not a metaphysical contingency but a realistic and naturalistic necessity.

It is a main issue for safety and sustainability of automation design and human system integration.

2 Historical Perspective

The way we think and conceptualize the world and the relation between its elements within its related level of organization influences our capabilities of representation, modeling, designing and organizing artifacts from human-machine to socio-technical systems.

HIS safety and predictive modeling and design need a new insight and an adapted conceptual framework.

We need a shift from an analytical and reductionist framework, based on mechanism and linear causality in witch human machine design is reduced to interactions design as an informational and computational processing to a systemic and organismic conceptual framework based on theoretical biology and general system theory.

2.1 The HSI Founding Experiment: "La tavoletta di Brunelleschi"

The general problem of human systems integration is not recent. In 1415 for helping other people being aware of the artificial perspective principles of representation as he was, Filippo Brunelleschi, a self-taught architect and certainly the central perspective inventor, made-up a special device, "la tavoletta", (Fig. 1.). The Tavoletta is the combination by two technical parts: a painted tablet and a looking-glass. The tablet is painted on its intrados with the Duomo Baptistery realistic representation according perspective principles of drawing (central point of view, skylines and converging lines). Holding the tablet and the mirror, the user was looking on the virtual reflected image trough the tablet opening trying to superimpose the virtual image on the real monument. Brunelleschi's Tavoletta is the ancestor of virtual reality and augmented reality.

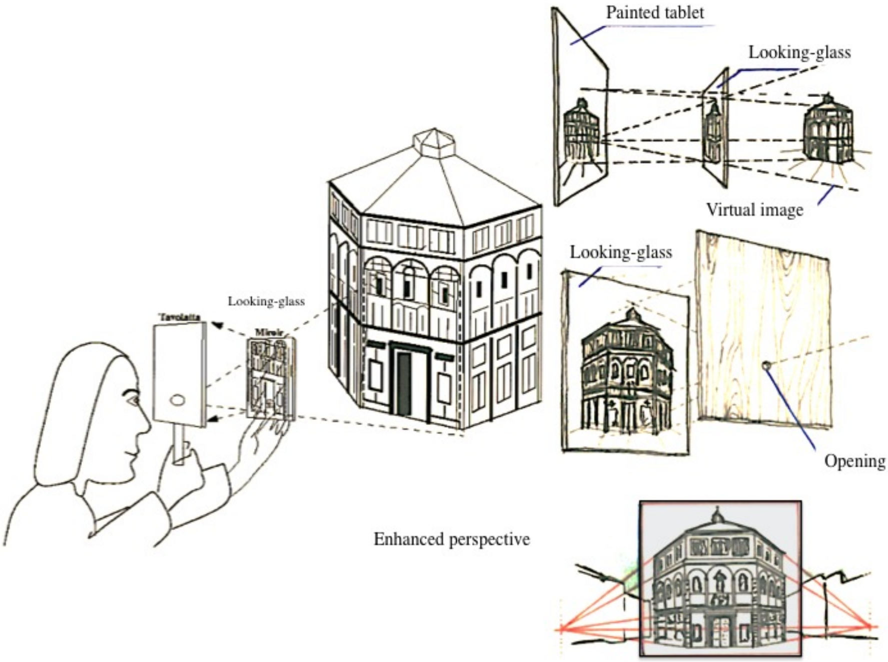

Fig. 1. Performed in the early Italian Renaissance (1415) in Florence, Filippo Brunelleschi's Tavoletta experience is the founding experiment for human systems integration and augmented reality. It demonstrated the geometrical framework of perspective conceptualization and representation.

It summarizes the modern aims of human system integration design and organization. The success of that experience depends on:

1. Designer skills for conceiving relevant abstraction of a part of reality and developing an artificial representation using artifice;

2. Formal and experimental representational medium;
3. Device shaping in relation to the required function, its design;
4. The acknowledgement of usage context or operating context;
5. Physical ergonomics of the device, its ability to induce and facilitate its handling situation (without injury);
6. The ability of the device to stimulate cognitive, imaginative and action capabilities of an operator (affordance [14])… who must understand and operate the device to realize the experience;
7. Skills and training of the user.

2.2 Cybernetics and Human Machine Systems

Cybernetics, defined by Wiener [15] as "the science of control and communication in the animal and the machine", had and has a great influence on automation design and human-machine systems concepts and development. It deals with information theory, automatic control theory, algorithm theory, regulation, stability, and homeostasis. Cybernetics is about regulation and control of a mechanical system behavior [16] and human-machine problem have been viewed as an exchange of information between the operator and the controlled object. It is concerned with the processing by a decision-making algorithm of input information into control signals, a command [17], this independently of the nature of the machine (biological, mechanical, electronic...) [18]. In that context, every good regulator of system must be a model of that system or must be isomorphic with the system being regulated [19]. Despite this theorem, cybernetics remains behaviorist and computational, i.e., postulating that information processing and computing are fundamental basis of decision-making function or knowledge the same as cognitive. But human as biological system, is not a computational or state machine [20].

2.3 Theoretical Biology and General Systems Theory

Designing and developing human machines systems using interactive and artificial technologies requires integrating artificial elements and structural design usually by artificial or artifactual functional interactions and its dynamics.

In this scientific framework, the question becomes: how to integrate the technical and human needs and requirements, biological peculiarities, into specifications of a technological system (physical and informational) design able to be used by a human (biological system) or integrated or coupled to the human body? Requiring that design and organization might ensure stability and consistency of the overall system (integrated human machine system) function and behavior in space and time?

Behind this in mind, it is necessary to develop theoretical principles of human systems integration, based on a continuous approach between biology and anthropology [15] [16] [17], taking into account the isomorphic and proven principles of general systems theory [18], and of theoretical biology and integrative physiology theory [19].

Human nature cannot be reduced to a metaphoric "model" of any kind of machine or computation even it is heuristic. Engineered artifacts have their own technical and physical requirement. The question of nature of human-machine systems is an issue of integrative design and organization.

3 Human System Integration and Modeling

"Experience without theory is blind, but theory without experience is mere intellectual play." Emmanuel Kant. According that kant's sentence we have developed a

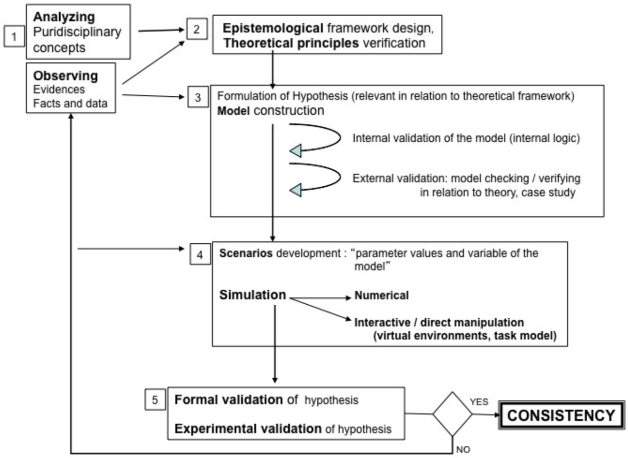

Fig. 2. Our approach associates formal and experimental methods for validating human-machine model consistency. It is first to state an multidisciplinary epistemological framework after analyzing existing multidisciplinary concepts and validate their relevance using model checking and realistic case study; secondly to validate the relevance of this epistemological framework and its ability to generate a safe and integrated modeling method, validating overhang the intrinsic quality of formal models and extrinsic validity by simulation and experimentally by comparison to reality by expert analysis and expert feedback.

HIS needs the production of a new body of knowledge and a general and reliable framework for designing, i.e., theoretical principles proven and validated description or modeling of human machine system. The purpose of the production of this new epistemological apparatus is to provide a scientific and technical framework for predictive integrative and safe modeling of human-machine systems. The challenge is to prefigure or provide a tool for designing and organizing an hybrid system from which nature is to be defined.

4 A Theoretical Framework

"*The ultimate model of a cat is of course another cat, whether it be born of still another cat or synthetized in laboratory"* Arturo Rosenblueth, Norbert Wiener and Julian Bigelow, January 1943.

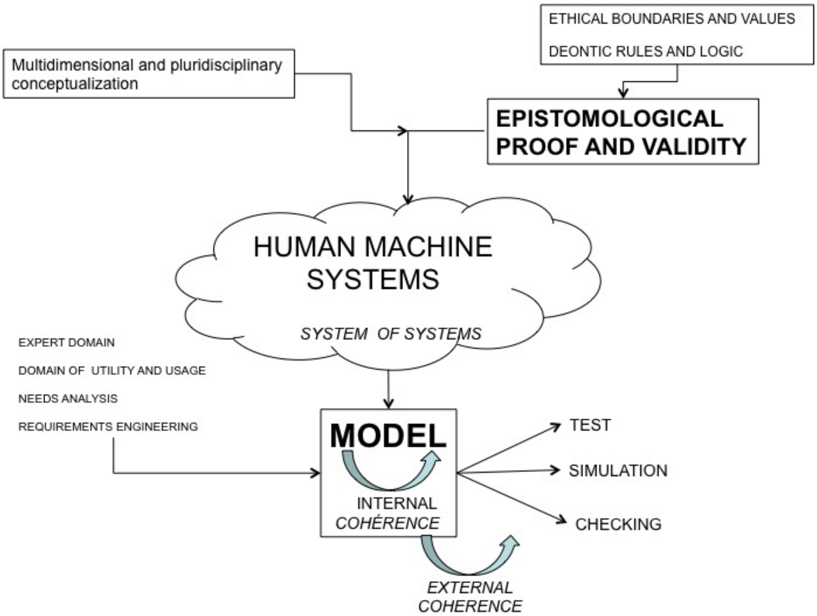

Fig. 3. Challenging human-machine system design and organization is modeling an heterogeneous system of systems (different by nature). That requires a proven and validate epistemic framework fitted to hybrid system, challenging the question of human machine system nature and ensuring human systems integration reliability.

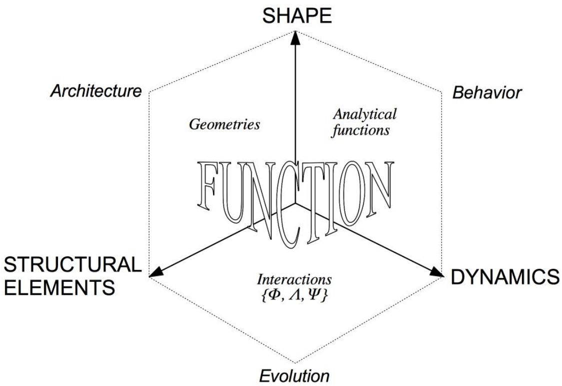

Fig. 4. Our isomorphic epistemic framework for human-machine systems integrative design and organization

4.1 Classical Epistemic Framework

From General systems theory and Cybernetics, some previous works in systems sciences and modeling have demonstrated the relation between system theory, modeling and epistemology. Some attempt to define invariant category conceptual element of general system have done, i.e., Pierre Delattre have done an epistemic analysis showing tree main categories of systems invariance: structure, function and evolution [26].

Previously, according system engineering and classical system epistemology, we have proposed to ground our modeling method of human-machine system on the concepts of structure, function and dynamics. We have defined the relation of three pair of invariant as Architecture{structure, function}; Behavior{Function, Evoution} and Evolution{Structure, Dynamics}. We have considered these three relation as three plane of an Euclidian space [27], were each invariant was a structuring axis for a system model. Nevertheless that epistemic framework of invariants was a mistake because structure and architecture are equal and function, as an issue of purpose and teleology, is not realy existing *per se*, it is related to a structural shape (a Gestalt) and the dynamic of the system. By consequences we are suggestion a new epistemic framework for modeling human-machine systems.

4.2 Our Isomorphic Epistemic Framework

For modeling human-machine systems, we have grounded our new epistemic framework on isomorphism. We have found new general categories of system elements that allow the same representation framework for integrating two systems different by nature. Our isomorphic epistemic framework is composed by three main isomorphic categories of interlocked elements: structural element, shape and dynamic.

As previously we were able to define three pair of isomorphic relation: Architecture{structural elements, shape}, Behavior{shape, dynamics} and Evolution{structural elements, dynamics}. Thus architecture is describable by a set of possible geometries, from Euclidian to no-Euclidian and other, behavior is describable by a set of functional analysis and algorithm, and evolution is describable by a set of modal interactions where each interaction might be compose on three modal parameters: physical, logical and physiological or behavioral dimensions according to Chauvet's theoretical integrative physiology [25]. It has been experimentally validated [3].

5 Conclusion and Perspective

Just like the drawing of perspective, where the correctness construction is formally ensure by structuring lines and point of view principles, human-machine system modeling must be ensure by an isomorphic framework of epistemic principal proven and validated experimentally and formally. It will be a necessary condition to the future development of human-machines systems. But it is not sufficient, future development needs also intuition, how-know, expertise and ethics.

References

1. Roco, M.C., Bainbridge, W.S.: Converging technologies for improving human performance-nanotechnology, biotechnology, information technology and cognitive science. Technical report, National ScienceFoundation (2002), http://www.wtec.org/ConvergingTechnologies/Report/NBIC_report.pdf
2. Nordmann, A.: Converging technologies - Shaping the future of european societies. Technical report, European Communities (2004)
3. Fass, D.: Augmented human engineering: a theoretical and experimental approach to human system integration. In: Cogan, B. (ed.) System Engineering – Practice and Theory, Intech, pp. 257–276. Open Access Publisher, Rijeka (2012)
4. Norman, D.: Why Human Systems Integration Fails (And Why the University Is the Problem), invited talk for the 30th anniversary of the Human-Systems Integration Board of the National Research Council. The National Academies, Washington, DC (December 2, 2010), http://www.jnd.org/dn.mss/why_human_systems_in.html
5. Haskins, C. (ed.): Systems Engineering Handbook: a guide for processes and activities. International Council on Systems Engineering (INCOSE) (2010)
6. Defense Acquisition Guidebook. Department of Defense (2012), https://dag.dau.mil
7. Ehrahart, L.E., Sage, A.P.: Handbook of human systems integration, chapter User-centrerd systems engineering framework. Series in Systems Engineering and Management, pp. 295–373. Wiley (2003)
8. Amalberti, R.: Les facteurs humains à l'aube de l'an 2000, pp. 5–12. Phoebus (1998)
9. Pew, R.W., Mavor, A.S. (ed.) Human-System Integration in the System Development Process: A New Look. The National Academies Press, committee on human-system design support for changing technology, commit- tee on human factors, national research council, national research council edition (2007), http://www.nap.edu/openbook.php?recordid=11893
10. Rousse, W.B., Boff, K.R.: Organizational Simulation. Wiley Series in Systems Engineering and Management (2005)
11. Booher, H.: Handbook of human systems integration, Introduction: Human Systems Integration. Series in Systems Engineering and Management, pp. 1–30. Wiley (2003)
12. Engelbart, D.C.: Augmenting human intellect: a conceptual framework, AFOSR-3233 Summary Report, Stanford Research Institute, Menlo Park, California 94025, USA (October 1962), http://www.dougengelbart.org/
13. Licklider, J.C.R.: Man-Computer Symbiosis. IRE Transactions on Human Factors in Electronics HFE-1, 4–11 (1960) ISSN: 0096-249X
14. Gibson, J.J.: The theory of affordance. In: Shaw, R.E., Bransford, J. (eds.) Perceiving, Acting and Knowing, pp. 67–82. Lauwrence Erlbaum Associates, Hillsdale (1997)
15. Wiener, N.: Cybernetics. John Wiley & Sons, New York (1948)
16. Parin, V.V., Bayevskiy, R.M.: Introduction to medical cybernetics, Translation of "Vvedeniye v meditsinskuyu kibernetiku."Izdatel'stvo "Meditsina," Moscow, 1966. NASA Technical Translation F-459, Washington, D. C. (1967)
17. Rosenblueth, A., Wiener, N., Bigelow, J.: Behavior, Purpose and Teleology. Philosophy of Science 10(1), 18–24 (1943)
18. Ashby, R.: An introduction to cybernetics. Chapman & Hall, London (1957)
19. Conant, R., Ashby, R.: Every good regulator of a system must be a model of that system, Int. J. Int. J. Systems Sci. 1(2), 89–97 (1970)

20. Kováč, L.: Inforamtion and knowledge in biology : time for reappraisal (2). Plant Signalling & Behavior 2, 65–73 (2007)
21. Lorenz, K.: L'envers du miroir: Une histoire naturelle de la connaissance (Behind the Mirror: A Search for a Natural History of Human Knowledge). Flammarion, Champs Sciences (1973)
22. Lyon, P.: The biogenic approach to cognition. Cognitive Processing 7(1), 11–29 (2006)
23. Edelman, G.M.: Second nature. Brain science and human knowledge. Yale University Press, New Haven and London (2006)
24. von Bertalanffy, K.L.: General System theory: Foundations, Development, Applications. George Braziller, New York (1968) (revised edition 1976)
25. Chauvet, G.: Hierarchical functional organization of formal biological systems: a dynamical approach. I, II and III. Phil. Trans. Roy. Soc. London B 3, 1471–2970 (1993) ISSN: 1471-2970
26. Delattre, P.: Système, structure, fonction, évolution - Essai d'analyse systémique, Maloine (1985)
27. Lieber, R., Fass, D.: Human Systems Integration Design: Which Generalized Rationale? In: Kurosu, M. (ed.) HCD 2011. LNCS, vol. 6776, pp. 101–109. Springer, Heidelberg (2011)