



# Human–Machine Interaction and User Experience: Models, Interfaces, and Adaptive Dynamics

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**Abstract:** Human–machine interaction (HMI) has become a central research area in the context of digital transformation and the rapid development of intelligent systems. This paper explores the theoretical foundations of HMI through an interdisciplinary perspective integrating behaviorism, cognitivism, and cybernetics. It examines how human cognitive and behavioral models converge with the evolution of machines from simple tools to adaptive and interactive systems. The study highlights the structuring role of the human–machine interface (HMI) as a mediating layer that enables bidirectional communication and coordination between users and systems. It also analyzes the impact of interaction models on user experience, particularly in terms of usability, cognitive load, satisfaction, and efficiency. The findings suggest that human–machine interaction is no longer a static process but an adaptive socio-technical system characterized by continuous co-evolution between humans and machines. Finally, the paper emphasizes the emergence of an adaptive synergy paradigm, where both human and machine adjust dynamically to optimize interaction quality and system performance.

**Keywords:** Human–machine interaction; user experience; human–machine interface; digital transformation.

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## 1. Introduction

Human–machine interaction plays a central role in our constantly evolving digital society. Technological advances, particularly in the fields of artificial intelligence and digital interfaces, have profoundly transformed the way we interact with automated systems. Therefore, understanding human–machine interaction models and their impact on user experience has become crucial for researchers, practitioners, and decision-makers.

This chapter focuses on exploring human–machine interaction models and their role in creating an enriched user experience. We will analyze the different theoretical and practical approaches that have emerged in this field, with particular emphasis on key concepts, design principles, and organizational impacts.

Human–machine interaction models are abstract representations that describe how users and machines interact with each other. They capture the cognitive, affective, and behavioral aspects of this complex interaction. These models are essential for understanding how users perceive, interact with, and feel engaged with automated systems.

User experience (UX) plays a central role in the design of interfaces and interactions. It encompasses users' perceptions, emotions, attitudes, and behaviors when interacting with a system. A positive user experience is associated with increased satisfaction, brand loyalty, and greater efficiency in the use of automated systems.

Human–machine interaction models have a significant impact on user experience. They determine usability, satisfaction, efficiency, and the quality of interactions between humans and machines. By understanding these models and integrating them appropriately into interface design, it becomes possible to improve user experience and respond more effectively to users' needs and expectations.

This chapter aims to provide an overview of human–machine interaction models and their role in user experience. By exploring these models, we seek to better understand how to design more intuitive, engaging, and satisfying interfaces and interactions for users.

## 2. Literature Review: Theoretical Foundations of Human–Machine Interaction

In the dynamic landscape of human–machine interaction, this section provides an in-depth analytical exploration of the theoretical foundations underlying this technological convergence. Guided by the objective of uncovering the complex mechanisms of this crucial interaction, this section is structured around three major axes: the human, the machine, and the analytical synergy that emerges from their convergence.

The exploration begins with a thorough examination of the human as a fundamental element of this interaction. We analyze behaviorist theories which, through their focus on observable behaviors, offer an initial perspective on understanding humans as active participants in interaction. Continuing this analysis, we delve into the fields of cybernetics and cognitivism, exploring how these perspectives have enriched our understanding of human mental processes and shaped the foundations of human–machine interaction.

Following this immersion into the human dimension, our focus shifts to the machine, the technological partner in this complex interaction. We examine the theories and advances that have shaped the development of machines, revealing their evolution from simple mechanical tools to sophisticated technological entities. This analysis of the machine sheds light on how its evolution has influenced the nature and complexity of human–machine interactions.

Finally, our exploration reaches its peak with analytical synergy, where humans and machines meet and intertwine in a complex ballet of interaction. This section highlights how the theoretical foundations of the human and the machine converge, creating a unique dynamic that drives human–machine interaction at the heart of technological convergence. We analyze the links, tensions, and synergies that emerge from this convergence, providing a deeper understanding of the interaction that shapes our digital daily life.

Thus, this section stands as an analytical chapter, revealing the theoretical foundations that illuminate and sustain the complex interaction between humans and machines in the context of technological convergence.

## **2.1. The Human: Psychological and Cognitive Foundations**

The very term psychology emerged at the end of the 16th century, marking the starting point of a shift from the previously dominant philosophy of mind toward a discipline structured according to scientific methodologies. This gradual process reached its most significant outcome in the 19th century with the emergence of genuine scientific schools of thought in the field. The relationship between psychology and anthropology became a major issue during this period in the construction of what would later become the Human and Social Sciences.

All thinking in the Human and Social Sciences is based on an anthropology and, consequently, on a psychology, whether it concerns the primacy of the individual over the group, the existence and properties of an unconscious of any nature, or the assumption of a human cognition qualitatively different from that of the rest of the animal kingdom. Therefore, the answer to the question “What is humanity?” takes as many forms as there are schools of thought. However, the structuring of psychology as an autonomous science in the 20th century led to the strengthening of certain anthropological perspectives that would shape scientific research not only in the Human and Social Sciences, but also in medicine and engineering (Jenneboer et al., 2022).

### **2.1.1. Behaviorism: A Behavior-Centered Approach**

Psychological historiography traces the founding act of behaviorism back to John B. Watson (1913), whose work is based on a radical position regarding the acceptance of the introspective method in psychology, particularly in the field of psychological research.

The main criticism directed at the introspective method lies in its fundamentally unverifiable nature, since the data it relies on cannot be compared to observable facts accessible to researchers. This marked the first behaviorist revolution and constitutes Watson’s principal legacy: establishing psychology around the study of behavior rather than the human psyche.

This rejection of the subjectivity of data, and of considering thought itself as an object of scientific study, finds its roots in earlier works such as those of William James (1904), in which James refused to consider consciousness as an entity possessing an independent existence. A debate then emerged, which continues to this day, between subjectivists—who view consciousness as an existing phenomenon manifested only privately—and objectivists, for whom it is merely a function.

Thus, even within Watson’s behaviorism, the issue was not to deny that human beings have thoughts, but rather to remove these thoughts—unobservable through the naturalistic method—from the scientific field.

Until the Second World War, behaviorism remained the dominant school of thought in the study of human behavior, particularly in the field of behavioral engineering that resulted from it. The underlying

anthropology of this doctrine considers humans as animals endowed not with unique properties, but with specific behaviors.

Consequently, if one were to define the behaviorist anthropological model, the term “man-machine” would be relatively appropriate, insofar as the human being is ultimately an animal possessing certain distinctive behaviors resulting from underlying physiological phenomena, including articulated language and thought, and these behaviors can be reinforced either positively or negatively.

Thus, all physiology forms the substrate of behavior, and everything—even sociology—can be derived from behavioral foundations. Understanding the “man-machine” in this context therefore means understanding how the behaviors of two different objects can be compatible or antagonistic (Okonkwo et al., 2021).

More recently, particularly since the work of Dermot Barnes-Holmes, Yvonne Barnes-Holmes, and Bryan Roche (2001), Relational Frame Theory (RFT) has claimed to continue this post-Skinnerian approach to the study of motivated behavior.

In John T. Blackledge (2003), an introduction to this theory is provided, which postulates the linguistic and operational status of binary conceptual relations that are difficult to describe from a purely behavioral perspective.

These relations are particularly relevant when trying to understand how individuals use and produce meaning in language without requiring a transcendence of that meaning.

Such transcendence becomes necessary when the sign is defined, following Ferdinand de Saussure (1916), as a signifier/signified pair, where the meaning of a sign is considered an internal property of the sign itself, determined more or less arbitrarily by its emitter.

While it is relatively easy to describe how one learns to recognize a class of objects through generalization from particular observations, this definition of the sign quickly becomes problematic when attempting to explain the learning of concepts—especially relational ones. This historically served as an argument in favor of certain forms of structuralist innatism.

Thanks to these linguistic approaches, it becomes possible to conceive and model these relational concepts not as fixed structures, but as dynamic processes (Chen et al., 2021).

From this perspective, the implications for human-machine interaction are significant. Indeed, knowing a relation becomes less a matter of knowing the meaning of a proposition than of being able to learn the relationship between two objects, which makes it possible to account for the analogical behaviors operating within such systems (Wang et al., 2022).

### **2.1.2. Cybernetics and Cognitivism**

Cybernetics can be considered an attempt to move beyond behaviorism “from the outside,” through the adoption of mathematics and, more specifically, information theory. From this perspective, the nervous system can be understood as equivalent to a servomechanism regulating the organism.

Interestingly, the development of behaviorism was primarily driven by university researchers in psychology and medicine. With the emergence of cybernetics, a very different approach appeared: that of an engineering science. This shift is significant when considered within its historical context. Academic science seeks to determine the principles governing observed phenomena, whereas wartime science is required to solve specific problems urgently (Lund et al., 2023).

Cybernetics therefore cannot be considered a scientific doctrine in the same way as behaviorism. While behaviorism imposes radical restrictions on what it observes, the notion of a “goal-directed system” in

cybernetic thought is an extremely broad definition—so broad that it can be seen as universal. In that case, cybernetics moves closer to philosophy than to science in the conventional sense.

The vision of the human being conveyed by this mode of thought is complex, but it rests on the duality between a physiological body and a nervous system understood as a logical transducer whose primary foundation is a model (Tran et al., 2021).

From this perspective, it becomes possible to conceive and understand the human mind as a set of algorithms that symbolically process sensory data and the representations they generate in a modular way, each corresponding to an intellectual faculty such as reason or understanding.

Thus, in Zenon Pylyshyn (1984), we find the criterion of “cognitive impenetrability,” which makes it possible to distinguish between certain software-like or hardware-like functions of human cognition based on their capacity to be influenced by the subject’s conscious thought.

This supports the thesis of Marvin Minsky (1988) in *Society of Mind*, according to which thought can be constructed from the interactions between non-thinking agents. This constitutes a refutation of the anti-representationalist argument of John Searle (1990), according to which such a position would reduce the mind to an infinite series of homunculi interpreting the representations of other homunculi.

Thus, beginning in the 1980s, computational cognitivism established itself as the dominant school of thought, largely because of its immediate proximity to applied computer science, for which a vision of the human-machine relationship as “man-robot” proved particularly convenient.

Robots and computers were no longer perceived merely as tools for data processing, but as genuine paradigms of the human being and the brain. This view is supported by the idea that the more we understand these reduced models of humanity, the more we understand humanity itself.

## **2.2. The Machine: Evolution and Conceptualization**

Until quite late in history, the very notion of a machine remained somewhat fluid, yet it retained a relatively stable core definition: a machine is a constructed system, made up of simpler parts, whose function is to convert some form of energy into mechanical energy.

At this stage, it is therefore essential to draw a clear distinction between two notions: the tool and the machine.

### **2.2.1. Definition and Distinction Between Tool and Machine**

Historically, the machine is an object of engineering; it is therefore an object of ingenuity and creation. Gilbert Simondon takes up Hero of Alexandria’s molecular mode of thought by considering the technical object as an assembly of pre-existing elements.

Thus, whereas living beings individuate themselves progressively and autonomously through biological processes, the immediate examples of technical individuals that generally come to the reader’s mind individuate themselves discretely and through the influence of an external age

### **2.2.2. Scientific Models of the Machine**

**Table 1.** Comparative Framework of 20th-Century Scientific Anthropologies

<b>Dimension</b>	<b>Behaviorism</b>	<b>Cognitivism</b>	<b>Connectionism</b>	<b>Cybernetics</b>	<b>Integrativism</b>
<b>Individual</b>	Body; mind understood through sensory organs + effectors + nervous system (John B. Watson, 1925); subvocal articulated language + memory	Biological computer + sensory organs (Zenon Pylyshyn, 1984); symbolic, specialized, and centralized information processing; memory (Jerry Fodor, 1975)	Neural network + body (Warren McCulloch and Walter Pitts); emergent activation patterns in a decentralized network (David Rumelhart & James McClelland, 1986)	Systems regulated by feedback loops (Norbert Wiener, 1948); decentralized information processing + memory	Metastable self-associated systems (Gilbert Chauvet, 2006); thought (Gerald Edelman, 1992)
<b>Architecture Constitution</b>	Mechanical element (Watson, 1925)	Independent modules managed by a central unit (Jerry Fodor, 1983)	Network architecture and reinforcement	Network of regulatory loops (Norbert Wiener, 1984)	Biological auto-stabilizing self-association (Chauvet, 1993)
<b>Behavior Cognition</b>	Articulated reaction to an external stimulus; perception as awareness of an external stimulus (Watson, 1925)	Problem-solving through symbolic manipulation according to rules; information acquisition (David Marr, 1982)	Activation of an appropriate pattern for solving an external problem (McCulloch & Pitts, 1943)	Environmental disturbance and search for equilibrium (Arturo Rosenblueth, Wiener & Bigelow, 1943; Raymond Ruyer, 1954)	Integration of sensory data (James J. Gibson, 1979); interaction of subsystems (Edelman, 2004)
<b>Evolution</b>	Action and reaction within the environment (Watson, 1925); faculty of the mind	Algorithmic sequences	Sequences and activation schemas	Regulatory coupling	Transductive coupling (Chauvet, 1993); recategorization (Edelman, 1992)
<b>Function</b>	Defined through behavior (Watson, 1925)	Linked to a module (Hilary Putnam, 1992)	Functional output of the network	Result of system activity	Result of the activity of a metastable biological system

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<b>Communication</b>	Interindividual communication (Watson, 1925)	Information theory	Physico-chemical signal	Information theory (Ruyer, 1954)	Functional interaction (Chauvet, 2006)
<b>Environment</b>	Source of stimuli (Watson, 1925)	Source of information and errors	Source of information and problems	Source of perturbation	Hypersystem

Source : Simondon G (2012) ; *Ergonomie théorique de l'humain-machine* p : 241-24

## 2.3. Analytical Synergy: Human–Machine Interaction

### 2.3.1. Definition of Interaction

The notion of interaction is defined as the “reciprocal action of two or more objects, or of two or more phenomena.”

This mode of individual existence is therefore characterized by a particular category of couplings that distinguish themselves from others and without which humans and machines could not form a system. These couplings are physical in nature if one focuses only on their interfacial dimension; however, this would once again amount to considering the systems in question as closed upon themselves.

Considering interaction from the perspective of communication between different open systems therefore requires a single vector that retains its relevance regardless of the direction taken by the interaction.

This unique vector can be understood as communication insofar as it is non-reciprocal.

### 2.3.2. The Central Role of the Human–Machine Interface (HMI)

It emerges from the definition of the Human–Machine System (HMS) that the interface constitutes the link between the technological system (including its supervision and control subsystem) and the Human Operator (HO), who, guided by specific objectives and operating under particular constraints, must be able to carry out tasks by following an established action plan.

The Human–Machine Interface (HMI) represents the primary means through which the Human Operator supervises the system and corrects it when necessary. The HMI ensures two-way communication:

- Informing the Human Operator about the proper functioning of the system components and the progress of ongoing activities. In this sense, the internal information of the system passes through the process output interface, undergoing transformations to result in a presentation that is perceptible to the operator through the HMI.
- Providing the Human Operator with the means to translate intentions into executable actions in order to modify the state of the system. In this sense, the HMI provides the physical devices made available to the operator to accomplish tasks.

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### **2.4.3. Design Limitations and Challenges**

Due to the high number of variables to be considered and the complexity of the tasks to be performed, the use of Human–Machine Interfaces (HMIs) can lead to human errors.

These errors often result from shortcomings in the analysis of Operators’ Informational Needs (OIN) for the various tasks to be accomplished, insufficient knowledge of the limitations of Human Operators (HOs), errors in the presentation and structuring of information on screens, and similar design-related issues.

Such errors can be avoided by addressing the HMI problem at its foundation—that is, at the design stage.

## **3. Methodology**

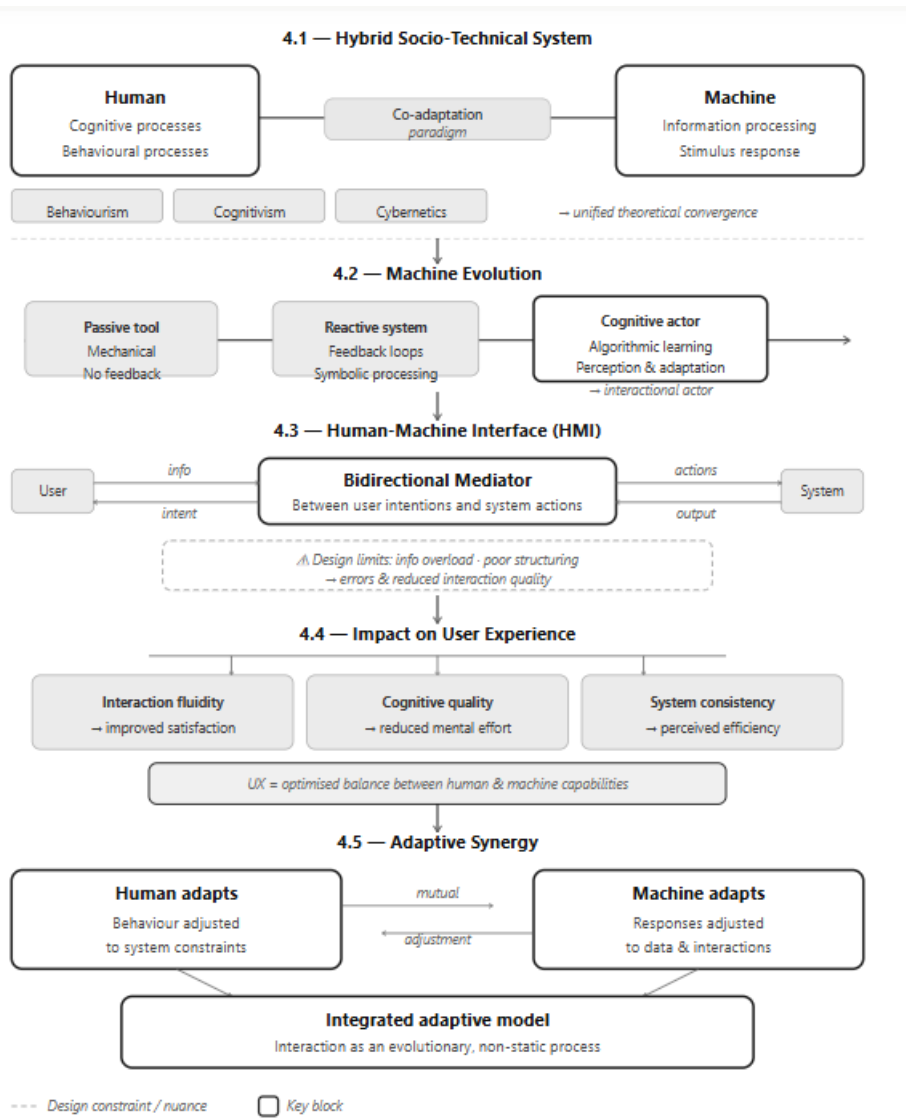
This research is based on a theoretical methodology founded on conceptual analysis and a structured literature review. It consists of identifying, selecting, and critically analyzing the main academic works related to human–machine interaction and user experience.

This approach makes it possible to compare different theoretical frameworks, highlight their convergences and divergences, and assess their relevance in the context of digital interfaces.

The objective is to build a deeper understanding of the concepts studied and to propose a coherent theoretical synthesis that serves as a foundation for analyzing the phenomenon.

#### 4. Results and Discussion

The conceptual analysis of human-machine interaction models makes it possible to identify several major findings organized around three main axes: the theoretical foundations of interaction, the transformation of machines into cognitive and interactive systems, and the implications for user experience.



**Figure 1.** Integrated Socio-Technical Model of Human–Machine Interaction: Evolution, Mediation, and Adaptive Synergy

#### **4.1. Human–Machine Interaction as a Hybrid Socio-Technical System**

The results show that human–machine interaction cannot be reduced to a simple functional relationship between a user and a technical device. It is part of a hybrid system in which humans and machines co-construct action through cognitive, behavioral, and informational processes.

Models originating from behaviorism, cognitivism, and cybernetics converge toward a view of the human as a stimulus-processing system and the machine as an information-processing system. This theoretical convergence supports the emergence of a paradigm of co-adaptation between the user and the system.

#### **4.2. The Evolution of Machines into Interactive and Cognitive Actors**

The analysis highlights a progressive evolution of the machine: from a simple mechanical tool, it becomes an intelligent system capable of perception, processing, and adaptation.

Cybernetic and cognitive approaches show that the machine is now conceptualized as a system endowed with feedback loops, symbolic processing capabilities, and even algorithmic learning.

This transformation leads to the machine being considered no longer as a passive tool, but as an interactional actor integrated into the user’s overall cognitive process.

#### **4.3. The Structuring Role of the Human–Machine Interface (HMI)**

The results highlight that the human–machine interface is a central element of human–machine synergy. It acts as a bidirectional mediator between the user and the system.

It enables both:

- the transmission of information from the system to the user,
- and the transformation of the user’s intentions into actions executable by the machine.

However, the analysis shows that limitations in interface design (information overload, poor structuring, mismatch with human cognitive capacities) can generate errors and reduce the quality of interaction.

#### **4.4. Impact on User Experience**

Human–machine interaction models directly influence user experience through several key dimensions. The results show that:

- interaction fluidity improves satisfaction,
- the cognitive quality of the interface reduces mental effort,
- and system consistency enhances perceived effectiveness.

User experience thus appears as the outcome of an optimized interaction between human capabilities and machine capabilities.

#### **4.5. Toward an Adaptive Synergy Between Humans and Machines**

Finally, the results highlight a general trend toward adaptive synergy. Human–machine interaction is no longer based solely on a logic of use, but on a logic of mutual adjustment.

Humans adapt their behavior to the system’s constraints, while the machine adjusts its responses based on data and interactions.

This dynamic confirms the emergence of an integrated model in which interaction becomes an evolving rather than a static process.

## 5. Conclusion

This study has explored human–machine interaction models through a theoretical approach based on a multidisciplinary literature review. The analysis shows that interaction between humans and machines is not limited to a simple functional exchange, but constitutes a complex system integrating cognitive, behavioral, and informational dimensions.

The results indicate that foundations drawn from behaviorism, cognitivism, and cybernetics converge toward a progressive understanding of both humans and machines as systems of processing and adaptation. This theoretical convergence has contributed to the emergence of an integrated view of interaction, in which the user and the system evolve jointly.

Moreover, the human–machine interface appears as a central element in this dynamic, ensuring mediation between human intentions and technological execution. However, its effectiveness strongly depends on its design, particularly in terms of ergonomics, clarity, and alignment with users' cognitive capacities.

Finally, the study highlights that the quality of interaction models directly influences user experience by affecting usability, cognitive load, satisfaction, and perceived efficiency. In this perspective, human–machine interaction is embedded in an evolutionary logic in which humans and machines continuously co-construct system performance.

Thus, this research underscores the need for an integrated and interdisciplinary approach to better understand and design more effective, adaptive, and user-centered interactive systems.

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