Human information processing in man-machine interaction.

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Abstract

Information and information processing are one of the most important aspects of dynamic systems. The term 'information', that is used in various contexts, might better be replaced with one that incorporates novelty, activity and learning. Many important communications of learning systems are non-ergodic. The ergodicity assumption in Shannon's communication theory restricts his and all related concepts to systems that can not learn. For learning systems that interact with their environments, the more primitive concept of 'variety' will have to be used, instead of probability. Humans have a fundamental need for variety: he or she can't permanently perceive the same context, he or she can't do always the same things. The fundamental need for variety leads to a different interpretation of human behaviour that is often classified as "errors". Variety in the relationship between a learning system and his context can be expressed as incongruity. Incongruity is the difference between internal complexity of a learning system and external complexity of the context. Traditional concepts of information processing are models of homeostasis on a basic level without learning. Activity and the learning process are driving forces that cause permanently in-homeostasis in the relationship between a learning system and his context. A suitable model for information processing of learning systems must be conceptualised on a higher level: a homeostatic model of in-homeostasis. A concept to information processing is presented that derives an inverted U-shaped curve between incongruity and information. This concept leads to important design recommendations for man-machine systems.

1. INTRODUCTION

We live in a dynamic and irreversible changing world. We are information processing systems and have a huge learning potential. What happens to humans, if they have to behave in an approximately static environment? If we need growth (in a psycho-dynamic sense) and development, how long we are able to tolerate contexts that fix and constrain our activities? There is a lot empirical evidence that humans are getting bored if the context is characterized by repetitiousness, lack of novelty, and monotony (cf. [16]). Ulich [18] differentiates between boredom and monotony. Boredom emerges from the feeling of not having enough possibilities to be active. Monotony emerges from the feeling of doing always the same things. "Monotony is a consequence of standardisation of the work process" ([18], p. 8). On the other side, there is strong empirical evidence of stressed and over-loaded workers (cf. [22]).

We have to realise and to accept that humans do not stop learning after end of school. We are compelled to learn and to make experiences our whole life. Human information processing can not be independent of these life-long learning processes. In this sense, humans are open systems. In his law of requisite variety Ashby [1] pointed out, that for a given state of the environment, an open system has to be able to respond in an adaptable way, otherwise the adaptability and the ability of the system to survive is reduced. A learning system, without input or with constant input, either decays or (in the best case) remains the same. Learning and the need for variety implies, that with constant input variety the requisite variety of the system tends to decay over time. This is a strong argument against 'one best way'-solutions in work design on a structural level (cf. [18]).

We can find in the literature different interpretations of the term 'information'. Several approaches from different point of views are done to clarify 'information' (e.g., [11], [13], [17], [19]): (1) information as a message (syntax); (2) information as the meaning of a message (semantic); (3) information as the effect of a message (pragmatic); (4) information as a process; (5) information as knowledge; (6) information as an entity of the world.

Table 1
Several terms to describe the amount of information of a message before and after reception.

before reception	after reception	Author	
degree of freedom of the decision	content of the decision	HARTLEY 1928	[8]
uncertainty	certainty	SHANNON 1949	[15]
uncertainty	information	BRILLOUIN 1964	[6]
potential information	actual information	ZUCKER 1974	[23]
entropy	amount of information	TOPSØE 1974	[17]
information	exformation	NØRRETRANDERS 1991	[11]

If we try to apply information theory to human behavior, then we have to integrate activity, perception, and learning. In this proposal we are looking for an interpretation of 'information', which is compatible with concepts of activity and learning. Going this way, we hope to avoid the paradox of 'new' information. Information before and after the reception of a message is not the same! Different concepts are introduced in the literature to 'solve' this paradox (see Table 1).

The concept proposed in this paper assumes, that information processing is an interactive concept. We also try to enclose perceptual and behavioural aspects. We suppose further on, that the stimulus effects of the environment (or context) interact with the real or potential complexity of the receiver (e.g., the complexity of the mental model). The context can be the environment beyond the human skin, the neural stimuli of extremities (e.g., arm and leg movements, motor restlessness), and mental processes like 'daydreaming', etc.

In this paper we replace in a first step the term 'information' with the term 'incongruity' to incorporate novelty and other related concepts. Our second step is to define incongruity with complexity. Finally we present a suggestive relationship between incongruity and information based on behavioural activities.

2. ACTIVITY AND INCONGRUITY

Weizsäcker [21] differentiated the concept of 'information' into two dimensions: (1.) 'Singularity of the first time', and (2.) confirmation and redundancy. For both aspects we can find two different research traditions in psychology: (1) novelty and curiosity ([4], [9], [20]), and (2) dissonance theory ([7]). Both research tracks are only loose coupled till today.

Investigators of novelty assume, that living systems (like mammals, especially humans) are motivated by an information seeking behavior. In situations, which are characterized by sensory deprivation, mammals and humans are intrinsically looking for stimulation. They increase the complexity of the context or the perception of it. On the other side, mammals try to avoid situations with a high amount of stimulation, dissonance, or stress. Hunt [9] designated this amount of increased complexity as 'incongruity'. Incongruity is the difference between the complexity of the context and the complexity of the active and learning system (see Figure 1).

If the complexity of the mental model is less complex than the complexity of the context, then mammals (e.g., humans) try to optimise this positive incongruity. Seeking behavior starts, when the positive incongruity sinks below an individual threshold or changes to negative incongruity (deprivation). Behavior of avoidance can be observed, when the positive incongruity exceeds an individual threshold (dissonance, stimulation overflow). Most of daily situations can be characterized by positive incongruity.
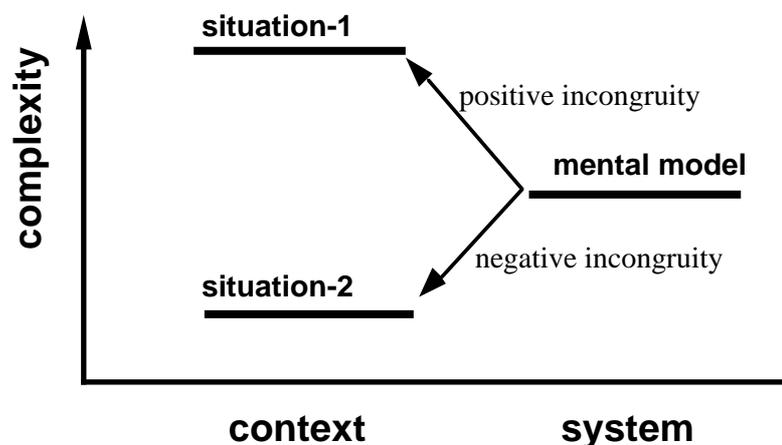
Figure 1. The difference between the complexity of the mental model and the complexity of the context is called incongruity.

The complexity of the context (e.g., the internal structure of the interactive software) can be measured (cf. [5]). The next step is to look -- from the users' point of view -- for a good measure for the complexity of the *perceived* context. This problem is difficult, because we have to differentiate between the pre-structured part of perception based on learned mental schema and the unstructured and not predictable part, which enable the human to integrate new aspects into the stored knowledge.

3. LEARNING AND ACTIVITY

Learning implies abstraction. Humans under non standardised and fixed conditions evolve during their lifetime very abstract invariants. This fact is the basis of wisdom of old humans. Actual research is done under the topic of 'meta-cognition' and 'meta-learning'. Learning as a driving force for irreversible developments is the most underestimated factor in human behaviour, especially in the work and organisational context. Bateson [3] developed a hierarchical concept of four different learning categories that reflects different levels of abstraction. The basic idea of Bateson's concept is that the variety on one level can be reduced to the invariant structure on the next higher level. This invariant structure forms the next higher, more abstract level of the memory.
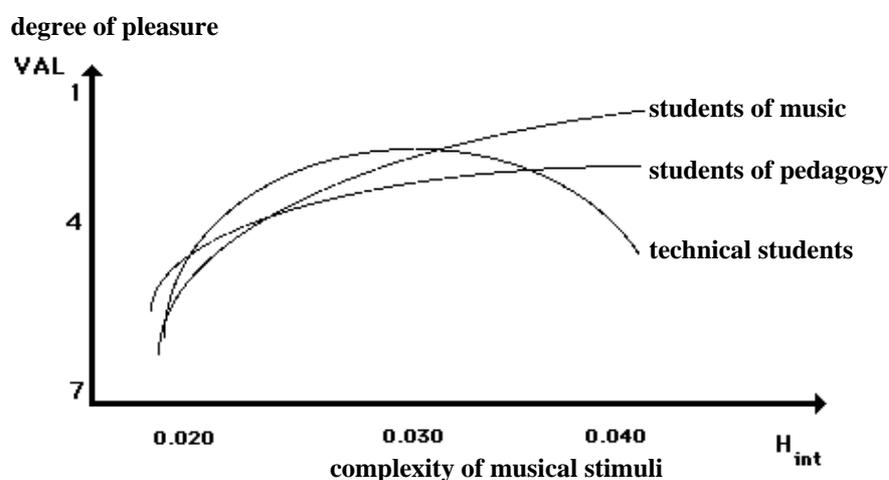

Figure 2. The inverted U-shaped function between 'informativeness' (degree of pleasure) and complexity of stimuli (H_{int}) (reproduced from [12]).

Learning is a permanent process that changes our long-term knowledge base in an irreversible way (the schemata, see Figure 3). Learning increases the complexity of the mental model [14]. The structure of our long-term memory changes to more complexity and higher abstraction. This dependency was empirical investigated by Raab and Ebner [12]. Raab and Ebner presented musical stimuli of different complexity to three groups of different experience with music: (1) technical students with low experience, (2) students of pedagogy with medium experience, and (3) students of music with large experience. Raab and Ebner got two important results: (1.) The 'informativeness' of the stimuli (degree of pleasure) has an inverted U-shaped function in relation to the complexity of the stimuli, and (2.) the optimum of this curve depends on the amount of experience (i.e. the complexity of the mental model; see Figure 2). Boreham (1993, personal communication) described the different reactions of nurses and high qualified physicians in a monitoring task during anaesthetisation. Humans with lower cognitive complexity (e.g., nurses) are more able to be satisfied informational in a context with constant variety than humans with higher cognitive complexity (e.g., physicians). The optimal incongruity level depends on the complexity of the cognitive structure.

If the complexity of the context is fixed then -- caused by learning -- the positive incongruity must decrease (see Figure 1). If the positive incongruity remains under an individual threshold then learning systems try (a) to increase the contextual complexity through activities, (b) to reduce their learning rate, or (c) to increase their perception of the contextual complexity (i.e., going into details, fantasy, hallucination, day dreaming, etc.). Neisser [10] was one of the first researcher, who tried to integrate learning, perception, and activity (see Figure 3). He emphasised that human experience depends on the stored mental schema, which guide exploring behavior and the perception of external context. This is an irreversible process. One consequence is, that the contextual complexity must increase appropriately to fit the human needs for variety and incongruity, resp.
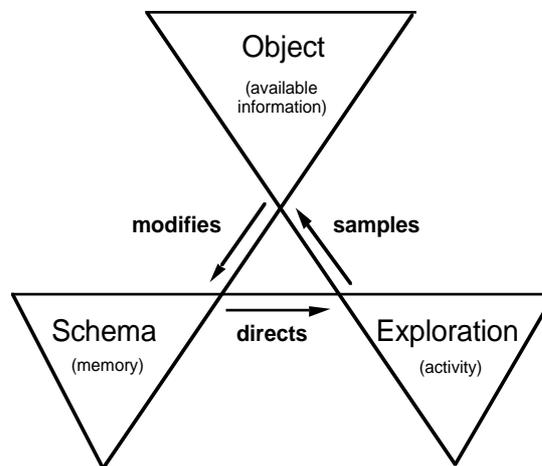

Figure 3. The perceptual cycle according to Neisser [10].

We are able to measure the complexity of human behavior (e.g., exploration activities; see [14]). The next step is to look for a good measure for the complexity of the perceived context. This problem is difficult, because we have to differentiate between the pre-structured part of perception based on learned mental schema (available information, [10]) and the unstructured and not predictable part, which enable the human to integrate new aspects into the stored knowledge (potential available information, [10]).

4. ACTIVITY AND INFORMATION

A context with sensory deprivation has not enough positive incongruity or even negative incongruity. On one side, a human will leave a context with very low incongruity (to little diffe-

rence to context complexity), and on the other side with very high incongruity (to much context complexity; see Figure 4). In between we have the range of positive emotions with behavior, which increase novelty on one side, and on the other side that increase confirmation and redundancy, or reduce dissonance, resp.
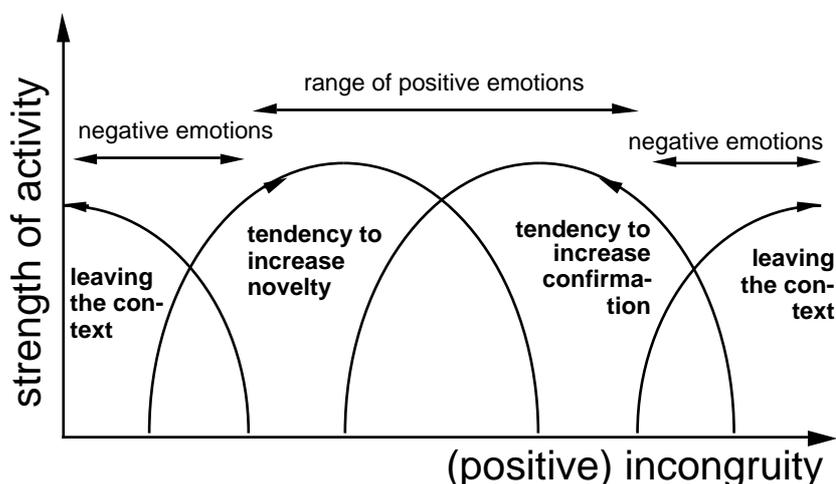

Figure 4. The coherence between positive incongruity, emotions and observable behavior.

Overall we assume a reverse U-shaped function as the summarised coherence between incongruity and information (see Figure 5). If a human has to behave for a while in a total fixed and stabile context and he has a normal learning rate, then he must start to increase the incongruity. This can be done on two different ways: (1) increasing the complexity of the context or the perception of it, and/or (2) reducing the complexity of the mental model. Way (2) implies the possibility of "forgetting", the decrease of the learning rate or the manipulation of the perception mechanisms (suppression).
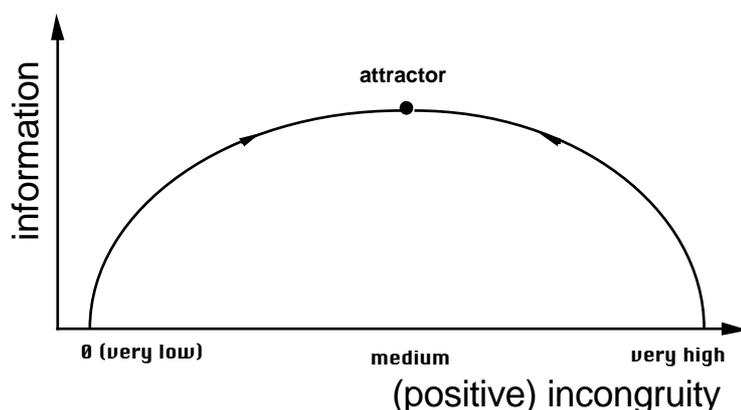

Figure 5. The summarised coherence between positive incongruity and information.

Different authors describe very clearly the problems arising when an operator has to take over a complex process during a monitoring task (the vigilance problem). To take-over process control is especially problematic when the system runs into an unknown state. Training in a simulator is one possible consequence, better is permanent on-line control in the real process. High skilled operators tend to lose the potential to be aware of the whole process. They need a special qualification to get open minded. In inescapable situations with information under-load we can interpret human failures as a subconscious strategy to increase external complexity.

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5. CONSEQUENCES FOR THE DESIGN OF MAN-MACHINE SYSTEMS

Bainbridge [2] describes very clearly the problems arising when an operator has to take over a complex process during a monitoring task (the vigilance problem). To take-over process control is especially problematic when the system runs into an unknown state. Training in a simulator is one possible consequence, better is permanent on-line control in the real process. High skilled operators tend to lose the potential to be aware of the whole process. They need a special qualification to get open minded. If incongruity is too low, then humans try to increase the contextual complexity. This perspective allows us to have an alternative interpretation of human 'failures' in inescapable situations with information under-load (e.g., process monitoring in a steady-state). To increase the signal rate of the machine system artificially is not an appropriate design strategy for man-machine systems [2]. Job rotation and job enrichment can help to reduce information under-load, but not for along time. Depending on the learning rate of the worker, we have to be aware of the monotony problematic. The best solution is to involve the worker in the task solving process, especially when the task is a 'complete task'. Operators should have on-line control over the real process [2]. To satisfy the human need for variety (and optimal information) the work system must be flexible and individualisable. Of course, this demand leads to difficulties in complex system design. But, neglecting this demand we run directly into most of the ironies described by Bainbridge [2].

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