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WEL — COPE Technical Report 1, August 2011

Human Adaptation as a Behavioural Strategy

Preliminary Considerations for Web Interaction

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In addition to explicit consequences such as learning or task completion, the interaction of individuals' with the Web has some other implicit outcomes: the behavioural strategies adopted while interacting in the Web lead individuals to a better adjustment to Web environments. This means that individuals gain problem-solving skills and knowledge, their actions become automatic and they are able to better anticipate the effect of their actions. As a result, users interact with an increased efficiency. However, attaining these skills comes at the cost of coping in the Web. The aim of the COPE project is to facilitate the skill gaining process removing the need to cope. To do so, predicting coping strategies and being able to intervene in such cases is of utmost importance. This technical report draws from diverse disciplines such as cognitive psychology, ethology, behaviourism and evolutionary biology, amongst others, to establish the theoretical foundations that lead us to achieve the goal of the project.

WEL

Web Ergonomics Lab

COPE

The aim of the COPE project is to investigate the behavioural strategies users adopt while interacting with the World Wide Web, identifying coping situations and providing technological solutions to overcome such difficulties. The COPE web pages may be found at <http://wel.cs.manchester.ac.uk/research/cope/>.

COPE Reports

This report is in the series of WEL COPE technical reports. Other reports in this series may be found in our data repository, at <http://wel-eprints.cs.manchester.ac.uk/view/subjects/cope.html>. Reports from other Web Ergonomics Lab projects are also available at <http://wel-eprints.cs.manchester.ac.uk/>.

Acknowledgements

COPE is funded by the Department of Education, Universities and Research of the Basque Government, reference BFI-2010-305.

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1 Preamble

The COPE project sets its main focus on understanding coping strategies in the Web. As coping is an adaptive strategy, the rationale behind this report is initially directed to address adaptive behaviour from a generic point of view. A cybernetics approach allows to take some distance from the phenomena and depict adaptive behaviour from an abstract and conceptual perspective (see section 4). It provides the large pieces to build a broad framework where the main actors are the *system* and the *environment*. In order to address our research goals the initial framework is transformed so that the mentioned entities are replaced by *human beings* (instead of system) and the *Web environment* (instead of the environment).

Therefore, the focus is set on human adaptive behaviour in the Web. To do so, the initial generic framework requires more specificity so that it can be accommodated to our research needs, and the entities and components that take place have to be defined. The strategy we adopt entails drawing from diverse disciplines that tackle *behaviour*, *adaptation* and *environment* (and their permutations) from different angles and target different objects of study. As a result, we get a broad and comprehensive view of the mentioned phenomena allowing us to derive the first milestone of the project. The disciplines that are analysed in a deeper way are listed as follows:

- Social psychology (see section 7.2). The strategies and tactics employed by people in different situations can give a hint on how individuals adapt to changing environments.
- Ethology (see section 3). Survival and foraging strategies, learning processes, and orientation and navigation mechanisms provide us with a number of behaviours that might be common for all species or just particular to some of them. Nevertheless, we aim at discovering the instinctive and programmatically prewired behaviours that may be adopted by humans and might be of use to help them to improve their adaptation.
- Behaviourism (see section 5.5). As opposed to ethology, behaviourists claim that all human action is behaviour and is the product of a learning process. The goal of learning is to obtain a set of tools and mechanisms for a better adjustment of individuals to the environment. Therefore, in this view, learning is the process by which humans adapt to their environment.
- Evolutionary biology (see section 7.1). Even if it occurs at a large time span, natural selection is essentially an adaptive process that may provide some suggestions about observable adaptive behaviour.
- Cognitive psychology (see section 5). Cognition and perception play a key role when it comes to interacting with the environment. The cognitive processes involved (consciousness, attention, memory, problem-solving) are paid special attention and all the traces that keep a relationship with adaptive behaviour are analysed.

- Cybernetics (4) considers adaptive behaviour as the way in which machines adapt to the environment where they operate. As our approach focuses on human-machine adaptations the models and terminology drawn from cybernetics are used (and extended) throughout this report.
- Human-Computer Interaction (see section 9). Cognition does also shape the interaction in the reduced universe of computer interfaces, which are the object of study of the COPE project. The cognitive architectures used to simulate human behaviour are also studied as they provide some hints on the adaptive character of cognition (see section 6). More specifically, due to its closeness to Web environments, the way hypermedia can be designed considering cognitive constraints is also introduced (see section 5.8).
- Stress and Appraisal Theory (see section 8 and section 7.3). Finally, the role that appraisal and coping strategies play in human behaviour under stress conditions is analysed, and common connecting points with the above disciplines are found.

All the above fields are analysed and intertwined in a coherent discourse taking particular consideration on the relationship they have with adaptive behaviour. The ultimate goal is to draw those aspects related to adaptation so that the research path this initial report establishes has solid and sound foundations in order to target adaptive human behaviour in the Web.

2 Introduction

Human adaptation is the outcome of behavioural strategies that enable a better fit of individuals in a given environment. There are many ways of observing the phenomena of adaptation and thus, depending on where the focus is set, there are different objects of study (neuron, tissue, individual, groups of people), time scales for adaptation to occur (from microseconds to next generation of siblings) and the extent of impacts caused by adaptations (at individual, social or environmental level). Therefore it is a phenomenon with multiple facets and magnitudes. That is why a number of scientific disciplines such as ethology, psychology, psychobiology or anthropology, amongst others, aim at tackling and understanding human adaptation. For instance, anthropology explores the interrelationship between behavioural adaptations and culture; psychobiology looks at the cell or neuron level to understand how the psyche works, while psychology considers the human psyche as central to study human behaviour.

Drawing from how different disciplines deal with adaptation the goal of this report is to propose a rationale to characterize human adaptation phenomena in Web environments¹. With respect to human behaviour the object of analysis will be a single individual, leaving out levels of adaptation at minor and major scales.

¹We define Web environment as the general context where the interaction with the Web occurs. In addition to Web content, it consists of the user agents used to access it and the constraints imposed by the accessing devices and the situation.

Tissue adaptation to external stimuli would be an example of the former while the latter can be viewed as the result of the strategies and decisions made by individuals to increase their survival expectations as a group. Therefore, the object of research is an individual person's behaviour. No matter how this behaviour impacts on their internal tissues or on the groups they belong to, behaviour will be analysed as the course of action that affects individuals in their environment. Hence, the effect of social relationships on behaviour will be considered as mere external stimuli from the environment, obviating its distinguishing nature. It goes without saying that human-interaction with computers can adopt a group approach for collaboration or socialization purposes. This is actively investigated and fostered by disciplines such as computer supported cooperative work (CSCW) and social network behaviour research respectively. However, these research orientations are out of the scope of this report.

As far as computers, and more precisely interfaces to operate them, and adaptation are concerned, an interface-centric adaptation approach has been pursued by current research practice. That is, the interface has to be adapted to the requirements established by systems as specified in their user models. These requirements consist of a set of features that can range from internal individual features such as abilities, preferences or learning styles to external variables like accessing device or situation. Considering both internal and external characteristics, user models are fed from the capture of user features and their circumstances. An ecological approach to gather such information would retrieve data in a natural and unobtrusive way. Unsurprisingly, a naturalistic data gathering does seldom provide the expected outcomes due to a number of reasons: individuals cannot only be defined as a list of features because they are also driven by their values, expectations and past events (both private and personal with and without technology). This makes the modeling task extremely challenging due to the highly dynamic nature of some of these facets; their abstract and uncertain meaning; and the lack of reliability of individuals' assessment of themselves. Some promising alternatives such as physiological computing are still quite invasive and unreliable [70], [17]. What is more, even if there were systems capable of modeling such facets, the way in which interventions are applied to an interface remains unclear. On the other hand, there are mechanisms to capture the external constraints imposed by the environment as the boosting sensorization of the environment and mobile devices, and the advenement of wearable computing is helping to do so. For instance, they allow to obtain the exact location of an individual in order to deploy falls detection systems or to monitor patients' health. In this case, the interventions that the interface has to make are pretty clear and therefore recommender systems or e-health applications are having not only considerable research activity but also a profitable market. Another modality for interface adaptation is adaptivity or customization techniques. In this modality, the interface will be adapted as a result of intentional and deliberate action of the user. This report will pave the way for critically discussing why interface adaptations (adaptively or adaptatively) are harmful in the way they are currently understood and conceived.

Little attention has been paid to the usefulness and effectiveness of adaptive interfaces as their theoretical advantages are often indisputable. It is often taken for

granted that interface tailoring is a desirable feature that most systems should pursue as a way to obtain more efficient and satisfactory products. As mentioned above, profiling for adaptation is quite challenging when it comes to the internal features of the user. Therefore, tailoring an interface to a profile that cannot capture and represent the salient features of the user raises some concerns on the authors of this report.

Individuals do constantly make an adaptive effort to interact with non-adaptive interfaces. There are some of these extreme situations where the adaptive effort is more evident and dramatic: for instance, when a novel user operates an interface for the first time. Nevertheless, there are a number of in-between cases where users try to adapt to a Web environment by learning, unconsciously improving their skills or trying to stabilize their psychophysiological emotional response. There is some research done on how humans adapt to interfaces [33] although the cost of adaptations in term of emotional and internal factors is yet to be explored. Not only that, but it remains open how to address the adaptation of users to adaptive interfaces. If, as we said, users do normally struggle to understand, learn and operate traditional interfaces, they will have to repeat such processes every time an adaptive interface changes/adapts, even if it is theoretically changing for the better.

This technical report will provide a common ground to discuss the appropriateness of adaptive interfaces and to more accurately understand user behaviour in the Web. Understanding how different disciplines approach human adaptation and trying to find a meeting point with Web interaction will do this. That is, we will focus on how users browse the Web not from an interface adaptation perspective but from a point of view that sets the focus on how users adapt to interfaces. To do so, we will establish what adaptation is and it is not, how it can be observed and assessed, and what are the implications for Web interaction design.

2.1 Setting Different Perspectives to Observe Adaptive Behaviour

We can observe adaptation through different frames. For instance, if we take an evolutionary perspective to analyse human behaviour there are three principal approaches:

- **Evolutionary psychology** aims to give an explanation for current behaviour based on past events that shaped current behavioural traits. Hence, it is assumed that these traits are heritable and evolutionary reasoning is applied to uncover them. One of the consequences of studying the role of past events is that developed behaviours are not adaptive anymore since current environment substantially differs from the one where they originally took place. We can draw from evolutionary psychology the focus on the psychological mechanisms and cognitive constraints that support human behaviour.
- **Behavioural ecology** posits that it is the current socioecological environment the one that shapes human behaviour. This claim is supported by the evidence of how individuals adapt with little gap to most of the current constantly changing environments. The way ecological and material constraints

determine behavioural strategies is useful because the Web and its users are also influenced by such conditioning factors.

- **Dual-inheritance theory** proposes that culture brings about evolutionary change by natural selection of culturally inherited variation, and by culturally and genetically determined decision-making. Both culture and natural selection do separately cause evolutionary change although there is a subtle but noticeable link between them.

Some authors highlight the complimentary nature of the three approaches by taking advantage of different time scales, research foci or investigation methods, creating bespoke combinations. Key characteristics of each approach have been extracted from [61] and can be found in table 1.

Table 1: Smith’s [61] summary on different evolutionary approaches to tackle adaptive human behaviour.

	Evolutionary psychology	Behavioural ecology	Dual-inheritance theory
Focus	psychological mechanisms	behavioural strategies	cultural evolution
Key constraints	cognitive, genetic	ecological, material	structural, information
Temporal scale of adaptive change	long-term (genetic)	short-term (phenotypic)	medium-term (cultural)
Expected current adaptiveness	lowest	highest	intermediate
Hypothesis generation	informal inference	optimality and ESS models	population-level models
Hypothesis-testing methods	survey, lab experiment	quantitative ethnographic observation	mathematical modeling and simulation
Favoured topics	mating, parenting, sex differences	subsistence, reproductive strategies	large-scale cooperation, maladaptation

According to the analysed features, behavioural ecology is the more reasonable approach for the research purposes of human adaptation in Web environments, mainly because its temporal scale allows observation of adaptive phenomena in a short-time span. However, the focus on the cognitive constraints adopted by evolutionary psychology and the modeling and simulation techniques used by dual-inheritance theorists, amongst others, are some of the features that can be combined for the purposes of this technical report.

The short-term time span where behavioural ecology analyses take place can be split into smaller intervals such as the ones proposed by Newell [46]. He identified four principal time bands that capture the scale of human action (see table 2) where the time scale does give an angle to observe human behaviour. First, neurons and connections of neurons, neural circuits, are located in the biological band; all the phenomena occurring within this band are unintentional and unconscious. At the upper layer, the cognitive band, human deliberation occurs by retrieving distal knowledge and choosing the right action to make and to operate with it. The rational band lies above the biological and cognitive band and encompasses all the phenom-

ena related to reasoning while individuals perform a task bearing a goal in mind. Finally, the social band covers larger scopes of time where even gene transmission from generation to next generation could theoretically be covered.

Table 2: Newell’s [46] time scale of human action.

Band	Scale (sec)	Time unit	System
Social band	10^7	months	
	10^6	weeks	
	10^5	days	
Rational band	10^4	hours	task
	10^3	10 min	task
	10^2	minutes	task
Cognitive band	10^1	10 sec	unit task
	10^0	1 sec	operations
	10^{-1}	100ms	deliberate act
Biological band	10^{-1}	10ms	neural circuit
	10^{-2}	1ms	neuron
	10^{-3}	1 μ s	organelle

For our research purposes, even if neither of both classifications (table 1 and table 2) adjust to our needs they will be regarded as a reference framework throughout the current report. Some of the focus and constraints of evolutionary human behaviour approaches will be examined at the bands described above. For example, the role that information constraints, which is the main focus of the dual-inheritance theory, have at the cognitive and rational bands will be tackled in the next sections.

The following two sections aim at giving a different view on behaviour so that a human centric approach to behaviour can be enriched with the lessons learned from animal behaviour (ethology, section 3) and machine behaviour (cybernetics, section 4). Then, a pure human centric approach to behaviour and adaptation is taken in sections that deal with cognition (section 5) and cognitive architectures (section 6). Section 7 sets the context for human-environment relationship, and section 8 analyses the role of regulatory mechanisms (appraisal and coping) in human behaviour. Finally, a computer interface centric, especially Web interface oriented, approach leads to explore how cognition and the adaptive character of the mind shape behaviour in the Web. Finally, section 10 identifies the common points of the discourse of this technical report as long as human adaptation and regulatory mechanisms are concerned, paving the way for following reports.

3 An Ethologist Perspective

Ethology seeks the answer to the causation, development, survival value and evolution of behaviour patterns². Early ethologists, as opposed to behaviourists (see section 5.5), assume that behaviour is mainly inborn and innate. This means that behaviour is determined by heredity and it is independent of individuals’ experience. This is an arguable viewpoint due to its deterministic nature. However, modern ethologists emphasize on the role of prewired programming factors even if

²Content in this section is extracted from [22] and [42].

they acknowledge that most behaviour aspects are influenced by genetic factors and experience at the same time.

Releasers, which are species-specific stimuli triggering specific responses, drive the most general behavioural strategy in animal behaviour. They enable quick reactions that remove the need for cognitive processing and allow animals to have selective attention strategies. Innate releasing mechanisms trigger fixed-action patterns, which are stereotyped coordination and patterning of motor movements that do not require further sensory input. This mechanism can be understood as an extreme case of prewired behaviour.

3.1 Programmed Learning

Most animals learn in the same way, that is, being exposed to the environment. The difference between species relies on how the learning process is organised. Some animals (e.g., bees) are programmed to learn by following a strict protocol where attention is paid to specific cues and particular releasers trigger specific behaviours. This can be considered a constrained way of learning. Alternatively, higher animals that live in complex environments have a more flexible way of learning. Not only are constrained by genes but the role of experience also leads to learning by chance or creativity. Existing programmed learning mechanisms are described as follows:

- Imprinting. Newborn animals such as geese and sheep are programmed to learn the appearance of their mother by staying close to them. Behaviour is learned throughout a critical and brief period of time where the mother's behaviour is imitated. What is learned during this period can range from nesting strategies to sexual preferences.
- Drive and motivation. These are the terms that respectively refer to the self-directed animal behaviour for short and long-term ability to switch behavioural priorities. They both serve to modulate releasers driven behavioural programmes, and they are often regulated by hormonal activity, which enables them to be ready for behaviour and to maintain it.
- Instinctive learning. From an evolutionary point of view instinctive behaviour is adaptive; natural selection acts on instinctive behaviour in the same way as it influences other genetically determined traits. In this context, instinctive learning is adaptatively programmed so that specific contexts trigger particular learning programmes. For instance, bees learn to distinguish the colour of flowers two seconds before landing on them. It can be said that instinct sets the occasion for learning.

3.2 Life Strategies

An evolutionary stable strategy is the one that cannot be improved provided that a critical number of the population adopts it. For instance, two strategies are observed when assessing a fighting rival: a hawk strategy implies to take risks by striking the balance between the increased payoff and the highly detrimental consequences of

unsuccessful trials; a dove strategy avoids to face risky situations so the individual retreats. In both cases there is an assessment of risk although the criteria for such assessment change depending on the situation. For instance, the bourgeois strategy happens when the owner of a territory adopts the dove strategy when coming in an alien territory and the hawk strategy while defending its own. There are some other variables that are considered when adopting a particular strategy. For instance, wasps decide to fight for a burrow on the basis of past investments rather than on future prospects.

The way changes are dealt in an environment leads to two different strategies, which are conservative and liberal strategies. Conservative species (e.g., mammals) are adapted to stability and live in habitats with predictable environments. As species compete for the resources available in an environment they tend to specialize as a way to compete with a smaller number of individuals. Liberal species, such as desert toads, manage to survive exploiting the instabilities of an environment. In their unpredictable environments generalist behaviours are favoured as the competition for resources is scarce. Note that there are some species that adopt both strategies as a way to optimize their reproductive success (e.g., some ferns spread spores and grow new plants from the end of their fronds at the same time).

As far as foraging is concerned, animals make decisions based on energy trade-offs between the foraging cost and energy benefit. Some species employ high-energy-cost foraging techniques that take place for a short time, while some other spend long time foraging at a low-rate energy cost. The rate at which energy is obtained depends on the availability and accessibility of food, determining the rate of return on foraging. The availability is measured as the density of preys in the environment and the time taken to recognise it. Accessibility measures the prey handling time (recognition, pursuit, kill and consumption) and the energy spent on that. Finally, the profitability of an item is the net energy value divided by handling time.

3.3 Orientation and Navigation Strategies

Spatial orientation is often obtained by a combination of methods. For instance, moths track angle changes depending on the scent concentration in the air produced by a female individual. When there is no scent or it is lost, moths fly backward and forward until they find some scent again. If the scent drops below a given threshold the moth turns in the opposite direction to the one taken in the previous turn.

When it comes to navigation, animals are known to make use of a varied number of compasses and diverse mechanisms to orient themselves in their habitats. Birds use ambient pressure as an altimeter, infrasound is used as navigational aid, odour is used to navigate from unfamiliar distant sites, geomagnetic fields are thought to help in the directional sense, birds use the path taken by the sun or the shadows it provokes as corrective measurements in their journeys, the rotation of stars is also used for orientation purposes and landmarks are important, particularly in the case of salmon, when the destination is approached. The mentioned mechanisms are not solely used but are often combined.

4 A Cybernetics Approach to Adaptation

Being a broad discipline, coarsely defined, cybernetics enquiries into how systems adjust themselves by taking action as a response to the constant checking of external stimuli coming from the environment. The paradigm that often describes such system would be a thermostat, which keeps the temperature of a space close to a desired value. We are interested in a cybernetics approach to adaptation because it has influenced the disciplines that deal with human adaptation to interfaces such as cognitive and behavioural psychology, or computing systems. Not only concepts have been inherited but also the terminology used is also quite useful and self-descriptive of the phenomenon of adaptation. One of the most influential researchers in the area was William Ashby, an English psychiatrist. In 1952 he described in *Design of a brain: the origin of adaptive behaviour* [4] how he built a *thinking machine* that adjusted to its environment, named *homeostat*. Each of the four modules of the homeostat consisted of an input switch to control the parameters (capacitance and resistance) that set a complex electromagnetic mechanism into a determined state (see figure 1). No matter which the initial unstable state was, the system was able to move to a range of determined values that denoted stability. It was so groundbreaking at that time that *TIME* magazine featured the homeostat as the machine that bore closest resemblance to a human brain³.

Figure 1: Ashby's manuscript sketch of a homeostat module. ©2008 The Estate of W. Ross Ashby.

The main entities that constitute and give adaptation capabilities to the homeostat are the *system* itself, which is defined as any set observable variables, and the *environment*, which consists of those variables that effect on the system and the ones affected by the system's behaviour. A system will have *feedback* if it can affect the environment and if, in response, the environment affects the system. The variables of the system can model behaviour from a bottom-up approach: any instance of system variables is a *state*, a *line of behaviour* comprises a sequence of states and the time interval between them and, finally, the *field* of a system consists of

³The Thinking Machine. *TIME Magazine*. Monday, Jan. 24, 1949. Available at <http://www.time.com/time/magazine/0,9263,7601490124,00.html>

the phase-space containing all the lines of behaviour. There are some physiological variables, called *essential variables*, whose change causes changes in other variables, the *parameters*. While variables lead to a change of state, the system can show as many fields (or all lines of behaviour) as values a parameter can have. Therefore, a change in the parameter values is considered a stimulus that can at the same time cause a change in the stability of the system.

According to Ashby, a system shows *adaptive behaviour* if it keeps its essential variables within physiological limits when constantly being stimulated by the environment. To do so, the feedback received from the environment can be used to correct the deviations towards a stable state by manipulating the environment. For the system, the environment is a black box that has to be operated following a trial and error strategy. It is only in this way that the system gets feedback and gathers information to accomplish successful adaptations. Figure 2 depicts the components of an adaptive system and how they operate:

Figure 2: The ultrastable system.

1. Environmental stimuli modify the values of essential variables altering the state of the system.
2. Depending on their values essential variables act on parameters, causing a change in the field of the system.
3. Changing the field brings about a modification on the behaviour of the system.
4. The changed behaviour operates the environment and gets feedback directly from it (primary loop) and indirectly through the alterations caused by the environment in its essential variables (secondary loop). The primary feedback loop is a continuous and frequent inquiry and response between the system and the environment, while the secondary feedback loop is discrete and occasional.

A system's ultrastability is demonstrated when after an impulsive stimuli the system shows adaptivity by returning to a state of equilibrium. The system shows

adaptive behaviour when a change of the parameters returns the field to a stable form.

Since organisms are set in complex environments adaptation of a system to such complex conditions implies that all subsystems in an organism should be stable. However, the terrestrial environment is mostly composed by stable subsystems in a state of equilibrium. Additionally, most environmental variables have an immediate effect only on a few variables of any organism. In an *iterated adaptation* mode the adaptation of an organism to the environment is cumulatively and progressively developed, as each subsystem will apply trial and error strategies independently of the rest. In a *serial adaptation* mode the complexity of the environment increases as all its subsystems are linked in chain. This means that all subsystem have to adapt one after another. This model suggests that the power of adaptation is beyond the capacity of an organism as long as it does not proceed by stages in a determined order, which will take a moderate time to adapt.

5 The Cognitive Aspects of Adaptation

This section deals with those time scales around the cognitive band in Newell's classification in table 2. The biological band, which resides below the cognitive band, describes the way in which nerve cells and neural circuits bring about behaviour. The cognitive band illustrates the role of cognitive processes and how they are determined by the limitations of human information processing. Finally, the lower part of the rational band shows the influence of the layer below, the cognitive band, on decision-making and problem-solving strategies.

Behaviour is defined as the way a person acts in response to internal or external stimuli, be it consciously or unconsciously. The role of consciousness is key to describe many cognitive processes and understand their nature. Two main cognitive processes can be distinguished in terms of whether they require conscious control. The **effortful information processing** is a conscious processor, which it is sensitive to mental load, is serially performed and can be easily distracted. Conversely, **automatic processing** takes place without conscious awareness, demands little attention and is performed as parallel processes.

The existence of consciousness has been long discussed by psychologist and has raised enormous controversy. James [29] took an evolutionary perspective describing consciousness as the central mechanism to natural selection that enables adaptation. The primary function of consciousness is to facilitate selection and choice to adjust oneself to modified conditions (in other words, learning) and to the environment (adaptation), to focus on certain stimuli in an information overload situation (attention) or to have the will to survive. On his intent to address ironic processes of mental control (e.g., being more awake as one tries to get asleep), Wegner [71] adopts the metaphor of the ultrastable system (see section 4) and assigns different roles to the identified regulatory processes or loops. The mental operative system (primary loop) takes actions in a conscious way to attain a desired goal, while the error detection system (secondary loop) checks the deviations to obtain such goals and sends a signal to the operative system when variables are out of the established

range. It is not the purpose of this report to deepen into the consciousness debate but to highlight how the discussion roots on its relationships with human adaptation. Accordingly, the next sections will deal with those adaptation aspects that James linked to consciousness.

5.1 Cognitive Neuroscience

Behaviour is controlled by the nervous system. The more complex the nervous system is in organisms, a wider range of responses that allow better adjustment are available. Therefore, behaviour starts at a neuron level and consequently it resides at the biological band (see table 2).

Electrochemical transmission of electric signal within a neuron, from the axon to the dendrite, takes an average of 1ms and the synaptic transmission that enables interneural communication takes $500\mu\text{s}$. At the synapse, the release of neurotransmitters excites the axons of the connecting neurons and it is only when this excitation reaches a particular threshold at the nucleus of the neuron that the ions cross the membrane. Depending on the neurotransmitter being released at the synapse not only excitation of the neuron can be caused but also inhibition, increasing the likelihood not to reach the mentioned threshold. From a behaviour point of view it is interesting to know how the type of neurotransmitter determines human behaviour. For instance, *dopamine* inhibits (most of the times) attention and learning, *epinephrine* regulates alertness and *serotonin* is involved in arousal. As we will see later, these human processes play a role in human adaptation (see section 5.4 for attention, section 5.5 for learning and section 7.2 for alertness and arousal). Finally, at a neural circuit level, a number of neurons work together to provide some function in the range of 10ms.

The structure of the nervous system is divided in two main parts: the central nervous system (CNS) and peripheral nervous system (PNS). The PNS comprises all the nerve cells but those of the brain and the spinal cord. Depending on its functionality the PNS is divided into the somatic nervous system and the autonomic nervous system. The former deals with sensory and motor nerves voluntarily, while the latter is involuntary. The autonomic nervous system is, at the same time, split into the sympathetic system, which is activated under stress, and the parasympathetic system, which is in charge of maintaining body functions such as digestion or temperature.

Sensory neurons receive information from the environment through their connection to receptor cells, while motor neurons carry information away from the spinal cord and the brain to those body parts responsible for responding to sensory input. Interneurons, which are found primarily within the CNS, serve as intermediaries between both. Under some circumstances the spinal cord directly connects receptor nerves with effector nerves, bypassing the brain in order to produce direct connection responses called *reflexes*. These automatic involuntary responses happen when the latency for cognitive processing is considered harmful. For instance, a hand reacts when it is brought closer to a flame. If it was not for the reflex mechanism and the brain had to process the signal the damage would be much worse. In functional and evolutionary terms reflexes are considered an adaptive survival mechanism.

As far as the CNS is concerned, based on the arrangement that the parts of the brain had during the gestation of the developing embryo, the brain can be divided into the *forebrain*, *midbrain* and *hindbrain*. The forebrain is the region of the brain located toward the top and front of the brain comprising the *limbic system*, *thalamus*, *hypothalamus*, *cerebral cortex* and *basal ganglia*. The limbic system comprises three interconnected cerebral structures: the *amygdala* plays a role in anger and aggression, the *septum* is involved in anger and fear, and finally the *hippocampus* deals with memory formation. Most of the sensory input into the brain passes through the *thalamus*, where incoming sensory information is projected to the corresponding region of the *cerebral cortex*. The hypothalamus interacts with the limbic system, regulates survival behaviour and it is very active in regulating emotions and reactions to stress. The midbrain, among other features, deals with eye movement and coordination, and it is involved in controlling consciousness, sleep, arousal and attention. Finally the hindbrain comprises the medulla, which controls heart activity, breathing or digestion; the *pons*, which acts as a bridge between different parts of the brain; and the *cerebellum*, which controls equilibrium or muscle tone.

For practical purposes, the cerebral cortex is divided in four lobes. Motor processing and higher thought processes such as abstract reasoning occur in the front lobe, somatosensory processing (sensation in the skin and muscles) in the parietal lobe, and auditory processing and visual processing occur in the temporal and occipital lobe respectively.

5.2 Memory

While carrying out simple tasks individuals' responses are unconscious and automatic. For accomplishing complex tasks understanding the role of memory is of utmost importance [15]. In the last years several models of memory have been proposed. For instance, the three stores model of memory [5] consists of a set of sensory registers (one for each sensory channel) which are capable of storing small amounts of information for a short period of time, a short-term store that can keep information for longer and the long-term store that has a larger capacity and can keep information for longer time.

Alternative perspectives explain that working memory is the active subset of long-term memory, being short-term memory at the same time the subset of working memory that has been recently used. While in the three stores model information flows between different storages in the alternative model all information remains in long-term memory.

Information is mainly coded acoustically in short-term memory (semantics still playing a role), while in long-term memory information is predominantly coded semantically and visually to the lesser extent. The mentioned memory models define memory in terms of information usage recency, capacity and duration while more recent studies propose a multiple memory systems model. These models are built upon the purpose of each module and are the result of extensive neuropsychological research. For instance, Squire's approach [64] illustrates a multiple memory system arranged as a taxonomy:

- *Declarative or explicit memory* keeps explicit information and it is divided

between *semantic memory*, where facts are stored, and *episodic memory*, where events are handled. Declarative memory is accessible to consciousness.

- *Nondeclarative or implicit memory* keeps implicit information and consists of *procedural memory*, where the steps to carry tasks out are stored, *nonassociative memory*, which is in charge of habituation, *priming memory*, which deals with how previous exposure to stimuli influences subsequent exposures to stimuli, and finally, *conditioning memory*'s function is to form habitual behaviour by classical conditioning.

Regarding the role that memory plays on the operation of computer interfaces and more particularly on hypertext Shneiderman [59] stated that hypertext structures resemble to the organization of data on human memory: in both cases data are semantically associated by the use of links. Miller's *magical* number suggests that seven plus or minus two is the number of chunks that humans can hold on their working memory. This does not entail that interfaces should have at most seven items or Web pages should show seven menu links but explains that humans can use seven chunks regardless how they have been built. What is more, the number only applies for uni-dimensional absolute stimuli, which are those stimuli that are isolated and cannot be perceived in relation to other stimuli.

There is some evidence suggesting that working memory capacity determines performance in those websites that favour the breadth over the depth arrangement of their Web pages [36]. More specifically it was also found that the *visuo spatial sketchpad*, the subcomponent in charge of storing spatial and visual information according to Baddeley's model of working memory [6], does also play an important role in the performance of hypertext retrieval [18]. Since the visuo spatial sketchpad is used to remember the location of objects in space or planning way-finding movements implications are important: it means that the interaction with hypertext takes place with the same spatial components of memory used for navigating in the physical world.

Oulasvirta [50] conducted an experiment to test the role of memory on two orienting tasks: navigation-orientation and content-orientation. The former is a link foraging strategy aiming at finding a Web page in a website, while the latter is a text foraging strategy that users adopt within a Web page to find a particular piece of information. In a navigation-orientation strategy, users pay attention to the surface features of link content (lexical or phonemic ones), and in a content-orientation text is semantically processed. Since lexical processing is understood as a shallow way of processing information it difficultly enables the memorization of content. Conversely, as semantic processing requires to process information more deeply it is more likely to store such content in memory. It was found that what is remembered and how is remembered is strongly tied to the orientation strategy adopted by the user. Unsurprisingly, the cues used in each strategy were better remembered: navigation elements and text elements for navigation-orientation and content-orientation respectively. When it comes to remembering the location of elements memory does not perform well in a navigation-orientation strategy. On the other hand, in a content-orientation strategy the location of content elements is better remembered due to deep processing.

Normally users operate in an automatic way and heavily rely on expectations because using them requires less cognitive effort. Recalling the specific location of links or content is a slow and an effortful process. That is why in a navigation-orientation strategy users are biased towards the left side of the screen, while in a content-orientation strategy they are biased towards the top of the screen. Therefore, the role of memory in link selection is mainly driven by explicit memory only when automatic strategies fail, as consciousness will gain control over the strategy.

5.3 Information Processing and Cognitive Modeling in Computer Interfaces

The *rationality principle* of the Human Processor [15] posits that when goals are pursued by rational action task structure, inputs of information, and processing and knowledge limitations determine individuals' behaviour. Information processing abilities constraint human behaviour while individuals try to adapt to the environment in their goal-oriented strategies. As a result, when goals are known and are attainable, the environment where the task is being conducted provides enough amount of predictive content. In order to articulate the features that determine the rationality principle the GOMS (goals, operators, methods and selection rules) model is a tool to test how the average expert user will perform conducting a task when using a particular computer interface. In GOMS, *goals* are determined by the state to be achieved and a set of methods that can be used to accomplish such state. *Operators* are the perceptual, cognitive and motor actions whose execution changes the task environment. *Methods* consist of the procedures to accomplish a goal and the *selection rules* consist of the methods selected throughout the process. GOMS is mainly used for serial execution of:

1. Human behaviour description. To do so, user observation is necessary to know how users select available methods, that is, the selection rules.
2. Time prediction given the sequence of operators **predicted**.
3. Behaviour reproduction given the sequence of operators **observed** to know how well the model fits.

In some settings such as text editing, if the dominant method is known, method selection can be predicted at a high rate. GOMS can be applied at different levels that perform in a different way depending on the pursued outcomes. For instance, the usage of lower level operators is prone to introduce greater error rates, causing a worse performance on time prediction tasks than on behaviour reproduction. The levels that range from a lower to a higher level of precision are the following:

1. The *unit task level* only considers higher level goals and operators.
2. The *functional level* consists of a sequence of unit tasks jointly with operator and methods.
3. The *argument level* is similar to the *functional level* but lower level operators are used.

4. At the *keystroke level* operators are defined at a perceptual, cognitive and motor level.

At the functional level GOMS is able to predict 80-100% of operators in a sequence, but at a higher level predictive power decreases. Even when the model fails to predict the sequence of operators, predicted time is not very far from actual time. This happens because the time prediction power that arises from new conditional behaviour opportunities is cancelled by the difficulty in predicting the sequence of operations. Moreover, there is not enough task variability to show the advantages of higher accuracy models. In conclusion, refining the grain of analysis does not intercept the sources of variability.

GOMS family of models has undergone a number of extensions aiming at solving its original weak points such as its sole focus on just skilled behaviours leaving out remaining users, the assumed flawless performance of users, consideration of serial interaction as opposed to a parallel one, the lack of attention to the learning process of users, etc. [49]. John and Kieras [30] compared the strengths and weaknesses of the pioneering GOMS models with those that extended the original approaches by addressing the mentioned limitations (especially the learning aspects, expertise level and parallel execution). There is no need to say that newer extensions and refinements that apply to current application domains have been proposed since then.

5.4 Attention and Habituation

Attention acts as a means to focus limited mental resources on the information and the cognitive processes that are most salient at a given moment. In other words, attention allows to use the limited mental resources in a sensible way. Conscious attention also serves for monitoring individuals interaction with the environment, keeping our awareness on how well they are adapting to a situation. As we will see later (see section 5.6), keeping track of the adaptation process is of key importance for a good performance.

Selective attention allows to discriminate between many sources of information and select just the one it is targeted. It is a mechanism to overcome information overload by tracking some stimuli at the expense of others. This way, one can attend to what is important in a given environment and to adaptively cope with changed circumstances. The visual and auditory channel process information sequentially and therefore both could benefit from selective and divided attention. However, it can be considered that the visual channel can easily mimic parallel processing. In the realm of computer interfaces, when adopting a *systematic search* strategy, users maximize the efficiency of foveal sweeps, where adjacent fixations capture every item in the foveal region exactly once [27]. Therefore, it is the auditory channel the one taking most advantage of selective and divided attention. The factors that play a part in selecting a specific auditory target are the distinctive features of the speech such as prosody (e.g., pitch, rhythm or loudness) and its spatial location.

In order to explain the phenomenon of selective attention different theories have been proposed. Intuitively it could be stated that selective attention happens because some signals are blocked. However, selective attention does not prevent from

distractions so instead of signal blocking models signal attenuation models are proposed. There are two main models that explain such phenomenon: early attenuation model posits that control filters attenuate the signal before it is processed by cognition [68], while later attenuation model explains that filtering happens after cognition [48]. Theories synthesizing both approaches propose that two processes, preattentive and attentive processes, govern attention [45]. The former deals with automatic and rapid processes that occur in parallel, while the latter are serially controlled and make use of memory and time resources. Automatic processes take place in an early stage of attentional processing, and controlled processes would be governed at later steps. This view is consistent with preliminary theories. Nevertheless, recent theories have moved to the attentional resources theory that establishes how the limited attentional resources are allocated to the requirements that particular tasks have. This metaphor is more suitable to explain divided attention on complex tasks where practice effects tend to happen, while the preattentive-attentive paradigm has a higher explanatory power on competing tasks.

Habituation is a non-associative learning process by which we become automatically accustomed to a stimulus by gradually noticing it less and less. It is a cognitive process that does not require conscious effort to make habituation happen, although we can consciously notice how we have habituated to some perturbations. In the process of getting used to stimuli their relative complexity is not crucial but how stimuli change over time, individuals' familiarity and their subjective arousal. Therefore, habituation can be assessed by measuring arousal as a degree of physiological excitation, responsivity and readiness for action. An example of habituation in Web interfaces is the *banner blindness* phenomena, which is caused by habituation as we learn to not to notice particular areas that have a particular shape and location. It can be understood as an attentional strategy to alleviate information overload by leaving out superfluous content. Habituation differs from the physiological phenomenon of sensory adaptation in that the latter is not subject to conscious control and occurs in the sense organ (e.g., getting used to particular smells or to light intensity), instead of occurring in the brain.

5.5 Behaviour Learning Theories

Learning can be described as the mechanism by which individuals adapt to their environments by acquiring and modifying existing behaviours. In order to gain more insight on how human adaptation may benefit from a learning perspective this section describes the fundamentals of learning, cognition and conditioning for a behaviour theory. Most behaviourist distinguish between two forms of learning:

- **Classical conditioning theory** by Pavlov [52] is based on the law of *contiguity*, which is one of the main associationist principles in addition to *similarity* and *contrast*. The principle of contiguity establishes that two ideas become associated if they occur at the same time. An unconditional stimulus (US) may trigger an unconditional response (UR) on an individual (food causes salivation). If another stimulus, the conditional stimulus (CS), occurs jointly with the US, CS and US get linked and the CS alone is able to cause a conditional response (CR) which is similar to UR. From a classical conditioning

theory perspective the CR is an adaptive response by which upcoming events are anticipated. Therefore, current Pavlovian theory focuses on how individuals search and use information about predictive stimulus-events to provide a biologically adaptive response.

- **Operant conditioning theory** by Thorndike [65] posits that what is associated on conditioning are not ideas but situations and responses. That is, for the different responses given to a situation in a trial and error strategy only those following with satisfying outcomes (satisfaction, comfort and pleasure, amongst others) will reinforce behaviour. That is why, under this perspective, reinforcement occurs when an appropriate response is given. Despite being influenced by associationists ideas, Thorndike addressed learning from a functionalist point of view by focusing on how individuals' mind adapts to the demands imposed by the environment.

Pavlov was a physiologist and was especially interested in knowing the way the brain works. Therefore, from his point of view associationist principles are controlled by the central nervous system. Pavlovian conditioning is seen as something more than reflexive learning: it is a way by which individuals learn from their experience with the predictive events of the environment and provide adaptive responses in that regard. In this scenario, CR and UR are not necessarily the same and *contingency*, which is the extent by which CS predicts US and its consequences, prevails over contiguity.

On the other hand, Thorndike was a behaviourist and his main interest was behaviour change. Thus, he focused on how individuals actively operate the environment to attain adaptation to it, and his associationist perspective is linked to investigate the connections between stimulus and response. The above-mentioned theories paved the way to modern behavioural theories of learning aiming at describing all human behaviour in what it is called *behaviourism*. For behaviourists, any physical action is considered behaviour holding no difference between overt actions and privately observable processes. They also asserted that behaviour should not rely on physiological events or constructs such as the *mind*. Note that the ideas of the main behaviourists do not have to be necessarily the same as we can observe below:

- Logical behaviourism was a school of thought that led by Hull [28] established the ways to precisely predict behaviour by means of complex axioms. Hence, it is understood that human behaviour can be modeled and measured mathematically. Adopting an operant conditioning approach it is posited that what is learned are stimulus-response connections, leaving out association of ideas or cognitive processes. From his contingency perspective individuals do compute the predictive value of stimuli and causal consequences between actions and their connections. For learning to happen the reward should reduce a biological need and it should be followed by a biologically significant consequence.
- Opposed to Hull's stimuli-response learning, Tolman [67] insisted on cognitive forms of learning with his cognitive maps theory: individuals take information

from the environment and then create a map of the world that surrounds them. Individuals are considered information processors that gather facts (stimuli) to anticipate the future so it is the map (or model) what controls behaviour, instead of reactions to external and internal stimuli. This is a clear contiguity approach. Learning has nothing to do with covering biological needs after making a response but about reinforcements that address both affective (pleasantness and painfulness) and cognitive (information on correctness and incorrectness of behaviour) dimensions.

- According to Skinner's radical behaviourism [60], behaviour is a function of environmental variables called the contingencies of reinforcement. There are three contingencies (in other words, predictors of US and their consequences): the response itself, the setting where the response takes place and the reinforcer. Therefore, learning is shaped by the outcomes produced by behaviour. From Skinner's point of view stimuli do not elicit response but set their occasion. While the reinforcement increases the frequency of the behaviour, the lack of it decreases such frequency.

The behaviourism movement was interrupted by the cognitive revolution, which has become the prevalent discipline in psychology from the second half of the twentieth century. Even if the above-mentioned theories of learning do not consider the role of cognition in learning, it is widely established that they paved the way for it. For instance, both movements share that behaviour is driven by stimuli. As a result, they should not be considered antagonistic theories but behaviourism is the precursor of cognitive psychology.

5.5.1 The Role of Anticipations

As far as adaptive behaviour is concerned anticipations play a fundamental role. The way behaviourist theories have fed today's learning theories in this regard is very diverse. For instance, the predictive value of Tolman's cognitive maps has led to the study of anticipatory behaviour. In this view, the fact that behaviour is attributed to stimuli-response is challenged by action-effect associations. The latter are more appropriate to explain a goal-driven behaviour that does not seek a reinforcement but an outcome. In this sense, a system is considered to be anticipatory when it has a predictive model that provides information about future states of the environment and the system. The predictive model establishes how to change behaviour according to its predictions. This entails that anticipatory behaviour is more than predicting future events but it is about altering behaviours according to such predictions. In this process the expectations about the outcomes of behaviour and the beliefs of individuals do affect on their current behaviour and learning. The role of anticipations is thus, amongst others, to stabilize behavioural execution as a way to find equilibrium, to allow guiding the behavioural flow, to make attentional processes react faster in order to focus on a goal and to help in quick adaptation in dynamic environments [13]. This approach resembles to Skinner's theory in that context and the outcomes of the behaviour shape the learning process.

Libet [38] found that the unconscious decides to execute all human action. He suggested that the decision to act starts after the occurrence of the so called readiness potential in the brain, which is a negative electrical potential appearing on volitional movements. He empirically demonstrated that the unconscious triggers human action and the role of consciousness is to allow or interrupt an already launched action. This means that subconsciousness drives human activity before conscious action is taken. Similar to the appraisal process (see 8.1), but in this case unconsciously, individuals built expectancies on actions. In the *primary learning process* the effect produced by executing an action is compared with the one expected, and if this comparison is satisfactory the outcome acts as a reinforcer. Additionally, in the *secondary learning process* the situational context where behaviour occurs acts as a conditioning setting. Therefore, it can be said that anticipations of what is expected and their context drive learning [26].

5.6 Problem-Solving

If we are to investigate the strategies used by individuals when interacting with the Web, and if we consider such interaction a problem that is solved by using mostly procedural knowledge, problem-solving sheds some light on how to approach a given goal. Problems are categorised depending on whether they have clear paths to solutions. *Well-structured problems* are those with clear solution paths, while those without them are *ill-structured*. Those problems that share the same structure and have different content are called *isomorphic problems*. The advantage of isomorphic problems is that similar strategies can be applied to solve them. Anyhow, being able to identify isomorphism across different contexts is not straightforward. The lifecycle of problem-solving strategies encompasses the following stages ⁴:

1. Problem identification.
2. Problem definition and representation.
3. The formulation of a strategy involves analysing a problem to break it down into small and more manageable steps. It requires synthesis to put together the steps that lead toward a solution. The problem can be approached in such a way that a set of alternative solutions is generated (divergent thinking) or by narrowing down the possible answers and choosing the best solution (convergent thinking).
4. Organization of information.
5. Resource allocation. Expert problem-solvers devote most of their mental resources planning a general strategy while novice solvers proceed in a detail-oriented local planning way. Compared to novices, experts spend more time deciding how to tackle a problem than to solving it.

⁴Note that the ones considered more valuable for this technical report's purposes are extended while the remaining ones can be considered self-explanatory.

6. Monitoring. Effective problem-solvers keep track of the situation of the problem with regard to the strategy taken to check how close they are from the goal. Strategy reassessment occurs when it is concluded that the right path has been lost somewhere on the way.
7. Evaluation. Once the goal is reached individuals make a careful thought about the recognised new problems so that existing problems can be redefined and available strategies can be used more efficiently next time.

5.6.1 Well-Structured Problems

Well-structured problems have a clear although not necessarily easy path to their solutions. The errors that can be made in such path consist of (a) moving backwards inadvertently, (b) taking bad steps and (c) not realizing of a good move. According to Newell and Simon [47], a problem-solver must be aware of the initial problem and the current state with respect the goal within a problem-space. The strategy consists of decomposing the problem-solving task into a series of events using the following heuristics:

- Means-end analysis. Once the goal is close, individuals try to reduce the distance between the current position and the goal in the current problem-space.
- Working forward. The problem is solved from start to finish.
- Working backward. Starting from a final state and working backwards.
- Generate and test. Alternative courses of action are generated and each course works as in a trial and error strategy.

5.6.2 Ill-Structured Problems

In contrast, ill-structured problems do not have well defined spaces and individuals find it difficult to model the representation of the problems and their solution. In these cases, constructing a path that will lead to a solution in a sequential way often entails to start over with a new strategy to face a given problem. In order to understand problem-solving strategies it is of paramount importance to understand how and why expert users become more skilled within a domain, as well as the mechanism they use to solve a given problem.

As far as elaboration of knowledge is concerned what distinguishes experts from novices are their schemas in a particular domain. Experts use large, highly interconnected units of knowledge organised upon their structural similarities. On the other hand, novices use small, disconnected and less cohesive units. When it comes to tackle the problem, novices often consider more strategies than experts. Experts' schemas contain more declarative and, what is more important, more procedural knowledge about their strategies. Difficulty of problems is better perceived by experts as they are more knowledgeable about the strategies they employ; they also keep track of the current status of the strategy. Additionally, the intensive use of

working memory by novices as a way to hold the possible strategies does not leave room to keep track of the state of the current strategy, hindering their performance. Experts are also more flexible when they find an unexpected issue and are able to adapt their strategy. What makes experts more efficient is the fact that they have automatized many sequences of steps within a strategy.

Automatic behaviour is obtained through practice by means of two different processes: schematization and automatization. The former is about generating rich schemas, while the latter describes the phenomena of consolidating sequences of steps into routines that can be executed unconsciously. Automatic behaviour is not always beneficial as it hinders experts' problem-solving performance when they face a structurally different problem.

5.7 Behaviour Automatization

The process by which a procedure changes from being highly conscious to being relatively automatic is called *automatization*, and it is result of practice. According to Logan's instance theory, automatization occurs because we gradually accumulate knowledge on specific responses to determined stimuli [39]. This knowledge is retrievable at every trial and is available as memory traces left by previous performances, namely instances. Section 6.1 shows how unified theories of cognition have described this phenomenon as *chunking* [55]. On the other hand, a more traditional view supports that people consolidate discrete steps into a single operation diminishing in this way the cognitive resources used [12]. While Logan's view can explain specific tasks such as arithmetic calculations, the latter view can better explain more generic automatizations.

Skilled human performance is cognitive in that perception, decision and knowledge are required. Cognition is considered to be skilful when patterned behaviours are executed competently and accurately. Cognitive behaviour can be defined using three dimensions: the processing dimension that reflects the perceptual, cognitive and motor constraints, the type of task, and the degree of skill. The skill dimension takes a continuous range starting from **problem-solving** for the less skilled performance to **skilled cognitive behaviour**. However, as Card et al. [15] point out sensory-motor skills are often the medium through which cognition gains expression. As a result, distinguishing between sensory-motor and purely mental skills is not easy.

Problem-solving takes place by searching in the problem-space, which is defined as *the universe of all possible actions that can be applied to solving a problem* [47]. Search control knowledge, the knowledge that guides a user to proceed within the problem-space, strongly determines how individuals proceed and their performance within the problem-space. With little knowledge it is difficult to take the right path through the problem-space, which leads to backtracking, to frequent pauses or to trial search. On the other hand, knowledgeable users are more likely to make the right decisions even if there is room for occasional mistakes that can be backed by fast-recovery mechanisms. Therefore, skilled behaviour can be highly predictable (see section 5.3).

There are some regularities in the process of automatization that allow to the

power law of practice [62] to model how time to perform a task decreases with practice, leading towards the skilled end of cognitive behaviour. It follows $T_n = T_1 n^\alpha$ formula where time taken in the n th trial, T_n , is calculated considering the time taken in the first one, T_1 , corrected by a constant value, α . Search control knowledge is acquired through training and experience, which causes an increased performance although working memory capacity and information limits on data, task and methods do strongly determine the acquisition rate as seen in section 5.6. That is why automatization is more likely to happen in tasks that are simple, less varied and require less cognitive effort (and thus more perceptual-motor effort). It should be emphasized that, even if most of the times automatization is beneficial, its effects are not always advantageous.

5.8 Ergonomic Hypermedia Design

Humans make heavy use of cues and landmarks when orienting themselves in the physical world. Matching the cognitive mechanisms used in the real world and in the Web is a challenging task, even if there are commonalities between the cognitive processing of both worlds. For instance, it is suggested that for hypertext retrieval purposes users use the same area of the working memory than the one used in spatial orientation and navigation (see section 5.2). There are some techniques that enable users to visualize data, structure and navigational information in such a way that an approach matching hypermedia navigation with cognition can be provided.

- As a way to overcome information overload content summarizing and simplification mechanisms [51], and the arrangement of information according to its relevance and usefulness have been proposed [41].
- Spatial hypermedia takes advantage of visual and spatial affordances for organising and interpreting information. See the VIKI framework [40] as an example that illustrates spatial hypermedia.
- Most browsers support path base browsing in the form of bookmarks, history, or backwards and forwards functionality as a way to get to information more efficiently. However, there is a lack of support for the temporal and linearly incremental way people browse. Techniques such as Walden Paths aim at addressing these issues by providing directed linear paths while allowing to explore off-path nodes [20].
- The development of familiar metaphors is intended to match human orientation and navigation skills in the physical world with computer systems. For instance, landmarks use hypertext node connectivity, access frequencies and depth as the criteria to display information that can be arranged according to geographical or graph metaphors. In this way users can be aware of their current hyperspatial location in relation to surrounding hypernodes. However, metaphors tend to explain too much and provide lots of unnecessary information that can introduce new barriers, which makes even more difficult the interaction with hypermedia [24].

6 Cognitive Architectures

The amount of theories describing particular cognitive processes drew the attention of cognitive psychologists to the lack of a theory to explain all the phenomena in a global and intertwined way. There is a growing research corpus dealing with specific and highly specialized aspects of cognition but a big picture was missing; a common ground to explain all cognitive processes from a unique perspective was needed. In this context, Newell [46] and Anderson [1] proposed their theories based on the SOAR and ACT-R models respectively. These are not the unique existing unified theories of cognition but the more influential as far as their applicability to computer interfaces is concerned.

6.1 SOAR

In a response to the need for a unifying theory, Newell proposed the *Unified Theory of Cognition* [46] as a way to explain the constraints that determine and shape the structure of our mind. The requirements by which current brain has been constrained by adaptive demands are: (1) the exhibition of adaptive behaviour by means of flexibility to obtain goals under certain conditions; and (2) learning from the environment and experience. Therefore, according to Newell, adaptive behaviour is purposeful and goal-oriented and it evolves by operating the environment. This is also stated by the rationality principle of the model human processor [15]:

A person acts so as to attain his goals through rational action, given the structure of the task and his inputs of information and bounded by limitations of his knowledge and processing ability.

The SOAR software architecture implements the set of requirements *unified* by the Unified Theory of Cognition as a way to suggest the plausibility and feasibility of the theory. In SOAR, symbols and symbol-tokens are the basis of cognition and act at the cognitive band (see table 2). Symbols are basically representational objects that provide access to distal structures located in the memory. They act as pointers to long-term memory (see section 5.2) that make possible the retrieval of symbol-tokens, which are the basic and atomic representational knowledge unit. The SOAR architecture of cognition establishes the functions and roles of such symbols to show intelligent behaviour following two non-exclusive strategies: preparation and deliberation. The former refers to those responses that are ready and available, and can be described as *knowledge search*. The latter relates to a decision-making process by analysing the consequences of possible actions through the problem-space, in other words, deliberation requires conducting *problem search*. Search control knowledge moderates this strategy (see section 5.7).

From an evolutionary point of view response time to stimuli is a crucial factor that enables adaptation, which is dramatically increased when a problem search strategy is adopted. It is suggested that this knowledge becomes available from experience. This leads to conclude that humans learn from everything they do. As learning brings about increased fitness humans are constantly (conscious or unconsciously) adapting to their environment. In this way individuals show an almost

unlimited range of adaptations. However, what is important for such adaptations is not their number but their range.

SOAR focuses mainly on cognitive aspects leaving out perception or motor behaviour. When it comes to memory only long-term memory is considered, and working memory is understood as an activated instance of long-term memory. All knowledge, be it declarative, procedural or even episodic, is treated in the same way. Intending to also propose a unified memory model this is a feature that makes SOAR distinct from other models.

In a problem-solving strategy to attain a goal state a decision entails selecting a problem-space, which is the representation of all possible tasks and states, a state within the problem-space and an operator that will lead to the next state. SOAR works as a traditional AI production system where production rules define the actions to be triggered when certain conditions are met, like $C_2, C_3 \rightarrow A_2$ (extracted from figure 3). Rules are fired when conditions are activated in memory as if they were activation patterns. When all conditions are satisfied (left-hand side elements C_1 and C_2) new elements enter into working memory (right-hand side element A_2). These new elements are the encoded knowledge that can also act as conditions in other production rules.

Figure 3: The chunking process.

During the problem-solving process the system will enter into a *impasse* phase (a) when all candidate decisions are acceptable, (b) if there are conflicts between them or (c) there are no decisions available. To solve this situation, a subgoal is dynamically created, where problem-solving will follow different paths until the *impasse* gets resolved. This means that a new production is added to long-term memory: its conditions are those active elements at working memory before the *impasse* happened and actions are those elements in memory after the *impasse*. This new production will fire next time that its conditions are activated in working memory.

Transforming goal-oriented problem-solving into long-term memory productions is the way by which SOAR learns from experience. This phenomena is called *chunking* and can be observed in figure 3, where lines between circles denote causal linkage between conditions and produced elements. According to Rosenbloom and Newell [55], chunking is a way to organise knowledge in that chunks are learned from pat-

terns of stimuli and response that occur in particular environments. Eventually there are some actions that play the role of condition (A_5, A_6, A_7, A_8) entering into an impasse (first vertical line). When the impasse is resolved there are two resulting actions in working memory, A_i and A_j . The conditions that form such actions and the actions produced after the impasse generates the $A_6, A_7, A_8 \rightarrow A_i, A_j$ production. The next time these conditions are activated (A_6, A_7, A_8) this production will replace the solving process within the impasse, gaining efficiency. In this way, time is saved and working memory is freed allowing to keep track of the ongoing problem-solving strategy. This is consistent with Logan's theorization [39] about skill learning in that skills are not gained because processing is faster but because memory traces of previous performances are retrieved (see section 5.7). As a result, from a behavioural perspective, performance and learning do happen at the same time.

6.2 Adaptive Control of Thought-Rational, ACT-R

ACT-R was first proposed by Anderson in 1976 [1] and since then it has undergone a number of revisions while it is still an ongoing project. One of the strong points of this theory relies on the application of neuroscience knowledge into a production system in that it identifies the regions of the brain with their corresponding components of the ACT-R architecture. In this way, not only the location but also the constraints that perceptual-motor modules, a goal module and the different memories impose on cognition are implemented [2]. Compared to SOAR, ACT-R makes more emphasize on perceptual-motor processing and the memory model. The former is drawn from the EPIC architecture (executive process-interactive control) by Kieras et al. [32], who coined the term *embodied cognition*. Embodied cognition highlights the need of not observing cognition as an isolated process but to consider the perceptual-motor mechanisms at the same level than cognition. As a result, embodied models should capture the interplay between situational aspects and cognition. With regard to perception, ACT-R implements a theory of visual attention as opposed to the theory of perception implemented in EPIC. When it comes to memory, ACT-R considers declarative memory and procedural memory with their particular retrieval and chunk activation constraints, while SOAR only contemplates a unified model of memory. Additionally, a goal module keeps track of individuals' intentions so that behaviour will be directed to attain such goal. At certain stages ACT-R supports multitasking by executing processes in parallel, while at some other times its behaviour is serial (e.g., retrieving knowledge from memory). Compared to SOAR, ACT can be considered a more compartmentalized and accurate approach to cognition.

7 Human Adaptation to the Environment

Human adaptation phenomena that take place at a longer time span than the ones happening at a cognitive and low-rational scale range from the upper side of the rational band to the entire social band (see table 2). Even if Newell's scale of

human action does not contemplate it, adaptations that occur from generation to next generations could also be included; in other words, evolutionary adaptations.

This section describes how individuals adapt to their environments and the strategies they use in that respect. Note that this is depicted by the primary loop of the ultrastable system in section 4. Since individuals' behaviour becomes inconsistent when situation is changed there are two main perspectives that address this issue: situationism and interactionism. As behaviour is strongly tied to the situation where it occurs situationism claims that generalization of behaviours is hardly feasible. Hence, a focus is set on those elements of the situation that cause a determined behaviour. Interactionism uncovers individuals' behaviour according to the principle of reciprocal causation. This principle states that situation affects behaviour and viceversa depicting in this way the primary loop of ultrastable systems. Therefore, no predictions of behaviour can be done from either the person or the situation alone. Interactionism can be analysed by two different disciplines:

- From an evolutionary psychology perspective (see section 2.1), sociobiology attempts to relate social traits to ecological pressures that existed during evolution, whereas behavioural genetics studies the portions of behaviour that are heritable. Both approaches use the concept of *goodness of fit* to indicate to what extent individuals' behaviour and the properties of the environment keep a balance.
- A biosocial interaction model poses that environmental events, cognitive interpretations and physiological predispositions are necessary but not sufficient to explain human behaviour. In section 7.2 the open system adaptation model [25] delves into this approach.

7.1 A Biological Approach to Adaptation

Natural selection is one of the major forces that causes evolution of species in addition to mutation, gene-flow and genetic drift. According to Darwin's theory of evolution, [16] natural selection is the mechanism by which individuals that better adapt to the environment bear traits of higher survival value. As a result, these individuals have an increased reproductive success, namely *fitness*. Therefore, the individuals that better adapt to the environment are the ones that are more likely to pass the beneficial adaptive traits to next generations. Natural selection allows the perpetuation of the traits that make individuals more adaptive to the environment with an increased survival value.

Evolutionary biologists study how a current trait is shaped as a result of natural selection throughout evolution (see section 2.1). The persistence of such trait depends on the value it has to survive and reproduce. Neither animals nor humans are likely to be driven directly by the maximization of fitness although psychological mechanisms that control their behaviour may be understood by observing the consequences that different courses of action cause to fitness [66]. Nevertheless, identifying those relevant parameters that shape the evolutionary maintenance of a trait from studies of current selection is not a trivial task because such parameters can only

be understood in relation to historical evolutionary forces. Data on current adaptiveness in a population are not actual evidence about long-term historical evolution as Darwinian adaptations are caused by selections in the past. In addition, genes alone do not determine behaviour but influence its development on the same way that environmental factors do. Thus, from an evolutionary perspective, behaviour is influenced by genetic factors and experience at the same time.

From a biological approach, adaptation is a mechanism to avoid entropy by seeking homeostatic states, whereas in those settings where social behaviour is required current conditions are changed to satisfy needs. As a result, there is a tension between the adaptation mechanisms that individuals have to deal with. This tension is lessened by internal adaptation, which is the one caused in the course of behaviour, and external behaviour. If we were to use Ashby's ultrastable system to analyse such relationship (see section 4) we could model it in such a way that tension would be channelled into equilibrium and two or more interdependent loops would describe the social environment and physiological variables of individuals.

Although most behaviour is built up on precedents, as humans have the ability to envisage sequences of behaviour, the phenomenon of preadaptation describes the coincidence between a new environmental factor and an existing trait in individuals. Gratifications can also be anticipated as stimuli of old accomplishments that feed present desire in the same way as learning reinforcements work in anticipated behaviour. When talking about behaviour in an environment anticipation is bound to foresight, memory and cognitive understanding of the consequences/contingencies of a determined behaviour. In other words, individuals have the ability to plan actions that are strongly determined by unforeseen consequences and changes in attitudes or values. The values that help assessing the consequences of an action before the adaptive event happened can be altered after such event. In other words, outcomes of actions reinforce behaviours in such a way that contingencies are cues that allow anticipations. This is described as an adaptive learning mechanism (see section 5.5.1).

From a cultural anthropology perspective, to make adaptation happen, individuals who are able to notice changes in the current ongoing phenomena have to cope to reach anticipated goals. Therefore, human relationship to its environment consists of the accumulation of coping solutions. During this process adaptive behaviour cannot be understood as an isolated behaviour as if it was not a sequence of events and temporal factors were not considered. Again, it is emphasized that for a precise understanding of human adaptation the temporal dimension is of utmost importance [7]. This is also the view supported by a transactional approach to appraisal and coping (see more in section 8.3).

7.2 The Open Systems Adaptation Model

The open systems adaptation model is a psychological framework to understand the adaptive relationships between human actions, situations and environments. According to it, individual-situation interaction occurs at three coupled levels, where adjacent levels can communicate with each other:

- Cognitive-symbolic level. The system represents situations as concepts and

behavioural means to attain a goal in terms of transformation rules. The **strategy** encompasses the particular rules to apply in a given situation.

- Control level. There are a number of **tactics** that try either maximize or minimize control to keep a state of equilibrium between cognition and behaviour. As a short-term adaptation strategy the maximizing strategy posits that when equilibrium between an individual and the environment is disturbed, *state-transition mechanisms* attempt to maximize control by limiting the conditions that lead to a disturbance. If the mechanism fails, the minimizing strategy attempts to minimize the loss of control, leading to a long-term adaptation.
- Sensorimotor operational level. At this level **behaviour** is operationalized in an overt manner aiming to transform the environment.

As a result, the strategies to attain goals and tactics to gain control over the environment determine human behaviour and cooperate to enhance individuals' adaptation to environmental conditions. Strategies are goal-oriented and deliberated, and reflect individuals' intentions to exploit or modify situations into a specific direction. Tactics are spontaneous reactions to disequilibrium that aim to remove the discrepancies between cognition and situational events by operating in either of them.

The control level plays a crucial role because acts as the intermediate level whereby cognitive and sensorimotor operational level can communicate. In this way, state-transition mechanisms or tactics act upon strategies and overt behaviour. State-transition mechanisms are represented in terms of the specific pattern of physiological reaction that is triggered (*arousal*, *effort* and *activation*) at each of the mentioned levels (see table 3). According to Priban [54], arousal processes are concerned with the regulation of input, with preparation, anticipation and feedback. Arousal can be defined as the degree of physiological excitation, responsivity, and readiness for action, relative to a baseline. Activation processes deal with the execution of plans, output regulation and forward feed, while effort is about bringing a change of intended original actions. Each state-transition can be defined as follows:

- Reflection. The conception of an initial situation is replaced by a new one that is consistent with the current environment.
- Exploration. Environment is compared with the prevailing situation and behaviour is activated to restore equilibrium.
- Uncoupling. The connection between an action and its goal is loosened and another action is taken to gain control.
- Substitution. Activates actions to enhance behaviour effectiveness.
- Redirection. The planned goal is changed directing the situation towards a new one to restore control.
- Persistence. The situation intended to be accomplished is reaffirmed.

Table 3: State-transition mechanisms, the physiological response they trigger and the application level.

	Arousal	Effort	Activation
Cognitive symbolic level	reflection	uncoupling	redirection
Sensorimotor operational level	exploration	substitution	persistence

The power of situations to regulate behaviour will determine the success or failure of transformations. Strong situations will resist transformations and in such situations the tactical system will be involved in the regulation of behaviour to restore equilibrium. Otherwise, disruptive mechanisms will take over and extreme tactics such as coping will take place.

7.3 Disruptive Adaptations to the Environment

Most of the times individuals operate consistently in an environment solving problems by applying habitual mechanisms and reacting in a predictable way. When these mechanism do not work the arising tension produces anxiety, fear and helplessness, disturbing the initial equilibrium. There are a number of factors that can influence the outcome of such crises: the previous experience with similar situations, the severity of the crisis and the degree of support individuals can find in the environment. Crises or disturbing situations on one's equilibrium are opportunities for psychological growth and a danger for psychological deterioration at the same time. At crises times individuals are more susceptible to be influenced so a minor intervention can dramatically change the ultimate outcome [44]. Caplan identified seven features of effective coping behaviour in an environment [14]:

- Active exploration of issues and search for information (problem-focused coping, henceforth pfc).
- Using of divide and conquer strategy by breaking a problem into subproblems (pfc).
- Expression of feelings and tolerance frustration (emotion-focused coping, henceforth efc).
- Active invoke for help (efc).
- Awareness of the disturbance (efc).
- Feeling mastery flexibility and will to change (efc).
- Trust on oneself and others and optimism on the outcome (efc).

Additionally, there are some factors that determine the individuals' coping response: the limits set by the environment, the nature of the stressor's intensity and its duration, and individuals' own nature in terms of personality and resistance to a particular stressor. As mentioned in section 8, coping processes are highly dynamic because situations and strategies change over time. Coping is about responding to

external situation requirements and responding to the feelings triggered by such situations in two stages: (1) minimization of the impact of the encounter; and (2) a reorganization stage where a new reality is faced.

According to White [72], it should be taken into account that adaptation is not a triumph over the environment or total surrender to it but an acceptable compromise. These strategies of adaptation do not lead to a personal equilibrium situation - rarely happening in humans - but to an increased autonomy. Adaptive behaviour in these circumstances involves the simultaneous managements of the following variables:

- Keeping adequate information about the environment. Individuals have to make sure that their cognitive field has the right amount of information as a guide to action. Depending on the situation, adaptation may require seeking for more information or just removing it.
- Maintaining satisfactory internal conditions in terms of alert and information processing enables to be ready for any event that may happen. This is key for some situational factors described later in section 8.1.3.
- Maintaining autonomy or freedom on the environment. This requires a constant monitoring of the escape ways that are available that lead to an equilibrium situation.

Items above can be considered emotion-focused coping strategies according to Lazarus' classification [37] (see more in 8.2.1). When it comes to keeping information about the environment, the main strategy is to take advantage of existing little information. Analogously, if the amount of information is overwhelming attentional strategies such as selective attention help to reduce information overload (see section 5.4). In those situations where individuals are deprived from freedom or autonomy behaviour strategies aim at maximizing the existing little operational capacity to enable adaptive behaviour. Case studies describing the way in which concentration camp prisoners, prisoners of war or people who have suffered natural catastrophes behave give some hints about the coping strategies that can be adopted in analogous situations where freedom and autonomy are lacking [44]:

- **Differential focus on the goal** makes individuals to focus on small gratifications leading to appreciation of small things.
- **Survival for some purpose** relies on finding a motivation to overcome a problem.
- **Psychological removal** entails that individuals insulate themselves from the outer world, isolating their emotions.
- **Mastery** is about being able to take advantage of the smallest portion of autonomy when this is almost non-existent.
- Having **the will** to overcome a situation.
- **Mobilization of hope** leads to believe that the problem will be over by keeping the faith on a supreme force.

- **Group affiliation** allows to keep the faith in a group of people that share a nationality, political views or job.
- **Regressive behaviour** makes individuals behave like they did in earlier stages of their life.
- **Null coping** relies on fate.
- **Surrendering to coping** is implemented as way to give up in order to lessen the perception of stress.

The above strategies are also considered emotion-focused coping strategies. The following section will shed more light on coping and appraisal.

8 The Role of Appraisal and Coping as Regulatory Mechanisms

In the ultrastable system environmental stimuli cause a disturbance on the system's essential variables (see section 4). If we consider the system to be a human being, the disturbance could be defined in terms of *stress* and essential variables would correspond to their physiological variables. To support this claim, note the similarities between the terminology used in cybernetics theory and the following biological approaches to define stress:

- A disturbance of the homeostasis.
- A set of physiological reactions to environmental demands.
- The state of an individual as a reaction to noxious stimuli and circumstances.

Even if responses to stress vary depending on the individual and especially on his vulnerability, stress produces anxiety, interferes in learning, memory, perception and performance [63]. It should be emphasized that stress should not be understood as the direct consequence of the disturbance but as the reaction to such disturbance. In other words, stress is considered an adaptational effort to maintain and restore equilibrium.

The **stimulus and response perspective** views stress as a disturbance of the homeostasis. From this point of view, it is difficult to distinguish stress from anything else that produces disturbance. Only when the disturbance level is unusual can it be attributed to stress. On the other hand, the **relational perspective** of stress takes into account the relationship between the person and the environment. Therefore, psychological stress is defined as the particular relationship between the person and the environment that is appraised by individuals as exceeding or taxing their resources, endangering their well-being. There are two processes involved in the mediation of the individual-environment relationship where stress occurs [37]:

- **Cognitive appraisal** is an evaluative process that determines why and what a transaction between the person and the environment is stressful.

- **Coping** is the process by which individuals manage the demands of the person-environment relationships that are appraised as stressful and the emotions they generate.

8.1 Cognitive Appraisal

The judgement for a particular individual-environment relationship to be considered stressful pivots on its cognitive appraisal. Appraisal is considered the individuals' evaluation of environmental stimuli, acting as a filter function. It is also a way of categorizing an encounter; it is evaluative in nature and takes place in a continuous way. If a situation is considered threatening there will be a continuous level of activation, while if it is regarded as safe the physiological response will decrease. There are two non-exclusive and non-sequential types of appraisal: in the primary appraisal the encounter is assessed, while the secondary appraisal addresses how to proceed based on the primary appraisal. Finally, reappraisal refers to an updated appraisal on the basis of new information collected from the environment.

8.1.1 Primary Appraisal

There are three types of primary appraisal:

Irrelevant appraisal means there is no harm, nothing to gain or lose in the transaction.

Positive appraisal entails that the interaction contributes to the well-being of individuals or at least it is maintained. It is characterized by emotions such as joy, happiness or peacefulness.

Stress appraisal relates to the encounters that cause harm on individuals, **loss appraisals** when self-esteem is damaged, **threat appraisals** if loss can be anticipated allowing the person to get ready for the encounter and **challenge appraisal** can result in self-growing and learning despite being a threatening event.

8.1.2 Secondary Appraisal

Secondary appraisal is an evaluative process by which individuals assess how to address a threatening event. The availability of coping mechanisms or the likelihood that a determined strategy will help to successfully handle an event is assessed during this process. Individuals' evaluation that a given behaviour will lead them to certain outcomes and the conviction that individuals can successfully execute such behaviour are the expectancies involved throughout this process.

8.1.3 Situational Factors

There are some particular factors that make the encounters potentially threatening: novelty, predictability, uncertainty and ambiguity. Additionally, temporal factors also play a role.

Novelty. Novel situations are those where individuals do not have experience. Despite the novelty of an event there may be connections between current and past experiences. If the outcome of previous encounters resulted in threatening situations, current situation will be assessed analogously. Conversely, if previous encounter produced a mastery situation where individuals felt in control, the current appraisal will result in challenge. These correspondences occur because most situations are not new, certain facets are familiar and situations do resemble among them. Therefore, novelty should be considered as a relative factor rather than an absolute one.

Predictability. This factor is related to those environmental cues that lead to discover and learn about a situation that will happen. Evidence suggests that a predictable shock is less harmful than an unpredictable one. According to the *preparatory response hypothesis*, animals prefer a longer and stronger shock if it is predictable as opposed to an unpredictable short and weak shock because the former allows to get ready for it. Alternatively, *the safety signal hypothesis* states that warnings alert individuals to avoid the stressor event suggesting that prediction of safety is more relevant than the prediction of a shock.

Event uncertainty. Environmental uncertainty is defined as the confusion of the meaning caused by the environmental configuration. Ecological situations, where the relationship between the environment and individuals takes place, tend to have a high level of uncertainty. This uncertainty determines the degree of freedom of individuals, as it has an immobilizing effect on anticipatory processes and the adjustment level. The higher uncertainty, the poorer adaptation individuals can get. In any case, it should be highlighted that uncertainty will often be the source of anxiety and tension.

Ambiguity. As opposed to uncertainty, ambiguity is defined as the lack of situational clarity. Hence, when the information required for appraisal is unclear or insufficient the environmental configuration is considered ambiguous. Increased ambiguity leads to a stronger influence of personal factors on an appraisal event. Ambiguity can intensify the perceived threat in an encounter by constraining the sense of control and increasing the sense of helplessness over the danger, causing anxiety. Some will deal with ambiguity by avoiding the threat whereas others are vigilant on the way they respond to it. When ambiguity is threatening individuals try to reduce it by searching for more information.

Temporal Factors. The time factor is the one causing more stressful situations. There are three qualities of time that should be looked carefully:

Imminence. The appraisal gets more intense, the closer it is to the event to happen. If individuals have a time constraint and are running out of time to make a decision, they take a *hypervigilant* decision-making style, scanning superficially through available options and choosing the one that lets individuals escape from

threatening situations. Because of this, individuals often fail to notice the consequences of their actions. When there are not such time constraints individuals tend to weight up the pros and cons to make a decision.

Duration. The General Adaptation Syndrome [58] describes long-term and short-term reactions to stress through three stages: an initial alarm reaction, a resistance phase and, finally, exhaustion. If the stressful event does not take long time the organism recovers from the initial alarm reaction. At the resistance phase adaptive resources aim at restoring internal balance until these resources get exhausted. When adaptation resources can eventually run out severe health problems appear. As a result, an increased anxiety and the malfunctioning of memory resources are observed at the exhaustion phase.

Temporal uncertainty. Not knowing when an event will take place is the most threatening temporal factor. To overcome this situation individuals lower their arousal levels by applying the attention deployment strategy so that the organism is ready for the stressful event. Then, when the stressful event happens arousal levels will be restored to regular levels.

8.2 Coping

From an animal biology perspective coping is the mechanism by which animals increase their survival chances, predicting and controlling the environment to avoid and overcome external threats. Animals learn to cope because the reduction of tension produced by drive acts as a positive reinforcement. Nevertheless, the fact that *escape* and *avoidance* are the mainly used strategies and drive is the central unidimensional trait considered makes the definition inappropriate for humans. On the other hand, the psychoanalytical perspective considers coping as a trait rather than a dynamic process. This view fails to capture that coping consists of an array of coping strategies, whose complexity cannot be described in a unidimensional way. While this does not mean there are not coping stabilities over time, the psychoanalytical perspective only focuses on the stable traits.

Adaptive behaviourists establish that skills are learned through experience and when these skills are automatically applied the relationship between individuals and the environment is more effective. At early stages of skill acquisition, an enormous effort and concentration is required, while at the later stages skills become gradually automatized. Coping is an adaptational activity although not all adaptational activities entail coping. That is why the process of better adjusting to the environment is not considered coping as otherwise all human behaviour would be considered coping. Coping is often required when new situations are faced and such events cannot trigger automatic responses. Even if there is a fuzzy boundary between adaptive behaviour and coping, they are normally distinguishable efforts. Cognitive control mechanisms deal with automatic behaviours, whereas coping takes place if the response is purposeful and requires effort. Both of them are adaptational activities yet coping requires effort and consciousness.

One of the misconceptions about coping is relating it to successful outcomes. Coping strategies can be good or bad depending on the individuals and their environment. Therefore, its effectiveness is determined by the effects of a given strategy on a specific event and its long-term effects. Another common misunderstanding is to consider coping as gaining mastery over the environment. Coping does not only entail applying problem-solving strategies but also managing one's emotions, which is considered equally important for adaptational purposes. Taking all this into consideration, according to Lazarus and Folkman [37] coping is defined as the

constantly changing cognitive and behavioural efforts to manage specific external or internal demands that are appraised as taxing or exceeding the resources of a person.

This definition addresses coping as a process-oriented as opposed to trait-oriented phenomenon. Coping is about psychological stress: automatized behaviour is left out to make a distinction between automatized adaptive behaviour and coping. References to mastery and coping as an outcome are also removed. Coping is related to what people do and think at a certain moment compared to what they usually do. The narrower it is the situational context defined, the easier it is to come to a valid conclusion about coping strategies. When an event unfolds the notion of change with respect to coping should be considered. The dynamics of such change are a function of continuous appraisals and reappraisals taking place as a result of the individual-environment relationship, where coping efforts are directed to the environment and to the individual.

8.2.1 Types of Coping

Emotion-focused coping aims at lessening emotional distress applying strategies such as selective attention, avoidance, minimization or distancing. **Problem-focused coping** applies strategies focused on tackling the problem, generating alternative solutions or choosing between different alternatives. According to Kahn [31], there are two main types of problem-oriented strategies: the ones directed at the environment aim at altering environmental barriers and resources; the ones directed at oneself include strategies such as finding alternative ways of gratification, developing new behavioural strategies, and learning new skills and procedures. From a theoretical point of view both types of coping can facilitate or cause conflict between each other.

8.3 A Transactional Approach to Deal with Appraisal and Coping

Appraisal and coping determine adaptational outcomes. Therefore, stress is not seen as something inherently maladaptive as it leads to develop adaptive resources individuals never though they had. This enriches the repertoire of strategies and sets them available for subsequent encounters. Traditional research on the topic has focused on how environmental conditions impact on individuals and on the role that personality traits play. These approaches are criticized because events are treated as if they were in a linear stimuli-response relationship, leaving out the consequences that individuals' operation can have on the environment.

A transactional model views the person and the environment in a dynamic and reciprocal relationship. This is linked to the unfolding of events, the environment, the person and their emotional state, and the model analyses how their relationship changes. This approach emphasizes the dynamic nature of coping.

9 Methodological Adaptationism in Human-Computer Interaction

Human behaviour and consequently human adaptation as a phenomenon occurs in a specific environment. If we aim at capturing human adaptation in Web environments in a comprehensive and accurate manner adopting an ecological psychology point of view (see section 2.1) will lead to understand human behaviour in terms of the constraints imposed by the Web environment. Rather than addressing human behaviour and Web environments in isolation an ecological perspective calls for intertwining human factors with the environment where the task takes place and technology is the means to accomplish such task. As a result, being human-computer interaction a discipline whose goal is to develop technology that will help people accomplish tasks more effectively, a human-technology-environment perspective paves the way for better understanding and improving individuals' adjustment to technology. In other words, mechanisms of cognition that blend with the external environment can form integrated cognitive systems that provide an increased ecological validity.

Some of the cognitive architectures explained in section 6 not only consider human behaviour in an isolated way but posit that individuals do not make use of the cues that are available in the environment, building what is needed on demand. For instance, Newell's architectures of cognition [46] present cognition as a system isolated from the environment. Embodied cognition theory [32] aimed to overcome such isolation by proposing a more ecological approach where the interaction between human cognition and the environment would be considered. However, some authors believe that embodied cognition theory gives such a coupled perspective on the interaction between cognition and environment that both subsystems can be considered as an integrated system. In comparison to existing mechanistic and deterministic models of cognition and perception, which are considered to provide an incomplete explanation of human behaviour, methodological adaptationism introduces a new perspective [23]. To better understand the adaptation of individuals to their environment a functional approach can better capture the complexity of the operations made by individuals in their environment.

If goal-directed behaviour is analysed from an adaptive functional perspective it is of utmost importance to consider proximal-distal relationships in an environment. This entails that distal goals can only be attained by the adaptive use of proximal information and the resources that direct to them [33]. Similarly, problem-solving is characterized as the search through a problem-space to find series of proximal actions that would lead to distal goals (see section 5.6). The role that uncertainty plays in these proximal-distal relations is of paramount importance if the adaptivity of behaviour and the interventions aimed at enforcing it are to be evaluated. Mostly because environmental uncertainty sets an upper threshold on the accuracy

of adaptive behaviour: the more uncertain an environment is, the more difficultly can adaptations occur.

9.1 Fundamentals of Functionalism

As opposed to a structural perspective that studies the configuration of the elements of the mind, functionalism focuses on the processes and particularly on individuals' adjustment to their environment making special emphasis on central-distal (cognition-environment) relationships [21]. As the adjustment to the environment involves accurate perception and effective actions, the relationship between overt distal and central variables requires:

- Bringing one's central perceptions into line with distal objects.
- Provoke distal states that meet individual' goals and desires.

Where such relationship is regarded as the adaptive character of behaviour or cognition. This indirect way of functioning demands the flexible adaptation of means to an end so that purposive behaviour can be achieved. Brunswik [11] applied to perception the stabilization of central-distal relationships via adaptable mediation. In his approach, mediating stages refer to the individuals' collection and use of sensory information rather than to overt behaviour. It is not obvious that perception requires the same adaptable mediation as goal pursuit because:

- Percepts must be inferred from proximal sensory cues to distal object's properties.
- Under different environmental conditions proximal cues must be used and selected differently as a way to perceive objects.

The lens model in figure 4 depicts the mediation process applying it to perception and overt behaviour. When applied to perception a distal stimulus at one focus (initial focal variable) emits a scatter of rays that represent proximal cues from among which individuals select a subset to be recombined into the central perceptual focus (terminal focal variable). For overt behaviour a central motivational state is the initial focal variable and the scatter line of rays represents a set of proximal means among which the organism selects different subsets of cues or means to achieve similar ends.

Vicarious functioning is the stabilizing process that produces stable relationships between central and distal variables although, mainly because of its flexibility, it is an unstable process that produces relative chaos and uncertainty in the regions intervening between focal variables. It is crucial to take into consideration individual-environment relationships when addressing mediating processes. A distinction between different types of mediating processes should take into account that the characterization of the pattern of proximal and peripheral mediation by proximal and distal foci is regarded as a **grand strategy** or **macromediation**. On the other hand, breaking down cognitive processes further into its component parts is regarded as **mediational tactics** or **micromediation**. Expressed in terms of perception *the ecological texture* of the environment means that:

Figure 4: The lens model.

- The features that correlate with the distal object for being used as peripheral cues have to be identified.
- *Ecological validities* are the strengths of the relationships between distal object and potential proximal/peripheral cues.
- Individuals' appropriate utilization of cues entails that the strength of use of a cue is correlated with its ecological validity.

Without challenging determinism, individuals usually have access to a set of proximal cues that are incomplete or inadequate to apply the laws that govern distal objects and distal-proximal relationships. Therefore, the environment is deemed to be probabilistic.

9.2 Cognitive Models of Web Navigation

Modeling requires building an approach that simulates some phenomena; it entails that a number of issues have to be left out and assumptions have to be made. The complexity of navigational models mainly depends on the cognitive models where they are deployed: the less comprehensive a cognitive model is, the more assumptions are made and the more likely is a navigational model to be error prone. When it comes to the rationale behind the choices made within a website not all existing cognitive models of Web navigation adopt a methodological adaptationist approach in an explicit way but information foraging theory. However most of them make use of *information scent* in their models as a heuristic to get to distal objects. Expressed in terms of the lens model, information scent is the quality that measures the ecological validity of cues (see section 9.1). The way information scent is measured and applied, as well as the peripheral cues used, varies among different cognitive models of Web navigation. However, the use of textual cues to measure the ecological validity of the information scent is a common denominator.

9.2.1 Information Foraging Theory

One of the most influential models to explain human behaviour in the Web is the information foraging theory [53]. This theory draws from functionalism and methodological adaptationism to apply animal foraging models to the cues in the lens model. An ecological approach to model human foraging behaviour in the Web requires understanding that both the structure of the Web environment and the goals and the heuristics used to pursue them do shape such behaviour. The foraging environment for information consumption occurs in information patches and in a Web environment the basic patch unit is a Web page. In a hypertext patch the information scent is what users use to assess the relevance of proximal cues in that they lead towards distal goals. Hyperlinks (textual or images) act as cues whereby users make decisions based on the information scent of links and surrounding contextual information. When users make decisions on their way to reach distal goals the uncertainty on the assessment of the relevance of hyperlinks introduces a probabilistic variable. Therefore, the lens model proposes an ecology where the relationship between individuals and proximal cues (cognitive strategy), and between proximal cues and distal goals (ecological validity) are of a probabilistic nature. The information foraging theory extends the lens model to accommodate it to Web environments. Proximal cues are hyperlinks in the current Web page that can be selected to reach distal Web content. Hence, browsing the Web is a task in which the user makes judgements on the suitability of proximal cues that lead to distal objects. This process is constrained with uncertainty in that users have to make predictions about the suitability of a given hyperlink to get to a distal object, that may not satisfy their information needs, based on their information scent and users' previous experience. The theory addresses these constraints by modeling the following steps:

1. Information scent of links is modeled using Bayesian analysis: the relevance of proximal cues with respect to the desired distal information is measured on a basis of the likelihood that proximal and distal textual terms can coincide in a text.
2. The Bayesian model is mapped into a spreading activation model⁵ in order to consider information scent as an activator of cognitive structures that influence on the decision-making process.
3. The information scented activation model is related to and expressed in terms of choice models⁶.

In order to understand the role of cognition when interacting with information scent the SNIF-ACT cognitive model of Web foraging introduces information foraging theory into the ACT-R cognitive production process [19]. As a result, SNIF-ACT can predict link selection and when alternative linking paths are followed. However,

⁵Spreading activation models implement networks where links between nodes have a specific weight or activation level that spreads out to those nodes that are linked. These weights dynamically change as they are propagated through the network.

⁶Choice models are tools to model decision making processes. Thus, they allow to predict the choices made by individuals and particular groups.

for the decision making modeling purposes, the spreading activation and utility models implemented in the information foraging theory are not the ones contemplated by ACT-R. Conversely, some ACT-R features are removed and replaced: the chunking activation of goals, which is used by ACT-R to retrieve relevant chunks from memory, and the utility assessment, which is based on past successes and failures. In SNIF-ACT the amount of activation produced between the goal, which in this case is regarded as the declarative knowledge represented as a set of chunks, and the chunks activated by the information scent of hyperlinks denotes their reciprocal relevance. The matching between a given production in procedural memory and the utility of goal chunks indicates the final utility of productions (see section 5.2 for memory and see section 6.2 for ACT-R chunking).

There are two versions of SNIF-ACT: they can be distinguished in that SNIF-ACT 1.0 solely relies in information scent assuming that individuals will choose the link with the higher information scent; whereas SNIF-ACT 2.0 considers how previous foraging experience influences on the final selection. SNIF 2.0 also takes into account the position of links given that the sequential judgement of all links in SNIF 1.0 is unrealistic and unaffordable for users.

When applying SNIF-ACT to predict human behaviour in a website those links with higher scent-based utility value have the higher probability to be chosen. Note that scent-based models are not deterministic but probabilistic, concretely stochastic. SNIF-ACT simulation results also suggest that users leave a given website when the aggregated scent of all links in the last visited Web page is lower than the average scent of all visited pages within the website. Hence, there is an information scent threshold below which users seek for other sources of information. This behaviour is observed in animals that leave a patch to seek for new food when the gain of foraging in a patch is lower than searching for a new one. These leavings are based on energy trade-offs between foraging cost and energy benefit (see section 3.2). Analogously, Web foragers follow a determined hyperlink when the trade-off between information gain and access cost is low.

The major limitations of SNIF-ACT are the fact that links are sequentially processed and the lack of an attentional theory that predicts navigational behaviour on different visual layouts. The way expertise level influences on decisions is not considered either. Finally, SNIF-ACT needs clear goals to be set and it cannot handle fuzzy or vague ones.

9.2.2 The CoLiDeS Family of Web Navigational Models

Another family of Web navigational models is the one based on the CoLiDeS cognitive navigational model [34]. The rationale of CoLiDeS is rooted on the existing similarities between fundamental principles of reading comprehension and information space navigation. The Cognitive Walkthrough for the Web (CWW) [8], which is based on CoLiDeS, uses Latent Semantic Analysis [35] to assess the information scent of links and headings with respect to an explicitly stated goal. This last feature makes it different from aggregated links in SNIF. CWW assumes goal-directed behaviour where choices are made based on the semantic similarity between current content and the user's goal in a two-step process:

1. A Web page is parsed into subregions that consist of headings and links beneath them. Subregions are attended following users' F-shaped fixations on Web pages.
2. Within the attended subregion a widget is selected.

An improvement of CoLiDeS based Web navigational cognitive models is CoLiDeS+ [69]. On the empirical basis that user performance is determined by their domain expertise and especially by their spatial ability, in addition to a goal description and link description, CoLiDeS+ takes into account *path description* (the path traversed so far). It is hypothesized that spatial ability is related to the capacity of bearing in mind information spaces consisting of multiple Web pages. This ability is modeled as the appropriateness of the path taken within a website, namely *path adequacy*, which is measured in terms of the semantic similarity between a navigation path and users' goal. As opposed to traditional CoLiDeS, backtracking is considered in this model and the increase on path adequacy is measured comparing the different paths taken. However, its incomplete approach to attentional processes (i.e., simulation of heading navigation) imposes a limitation on user performance and determines decision-making processes. CoLiDeS+ models these constraints by setting priority ranks to the following activation sources: (1) the current goal, (2) incoming text elements, (3) previously activated text elements, (4) domain knowledge and (5) links between current active elements.

The purpose of CWW was to evaluate the usability of headings and links while the approach applied by CoLiDeS+ aims at giving navigational support by suggesting the most appropriate link a user should follow to attain a goal. When testing the model with users it was found that those benefiting most from guidance were the users with low spatial abilities corroborating the initial hypothesis.

9.3 Other Models

The MESA navigational model [43] was proposed to evaluate the information architecture of websites. Links are evaluated serially although the model is neutral to their order and links can be selected by the following strategies:

- A threshold strategy, where users select any link above a threshold value.
- A comparison strategy that evaluates a set of links and selects the most appropriate among them.

The threshold strategy requires less cognitive (attentional and memory) resources than the comparison strategy and for this reason this is the approach taken by MESA. Depending on how improbable links are dealt (those links with low information scent but leading to the goal) the threshold strategy can be implemented in two ways: the *traverse-first strategy* will select improbable links after completing the full traversal of highly rated links; on the other hand, based on behaviour observed in real users, the *opportunistic strategy* establishes that improbable links are eventually selected after some highly scented links have been traversed. The relevance of links

is based on the distance of the actual link labels to their ideal value.

Brumby and Howes [9] propose a model to simulate search behaviour based on observed user behaviour. Using gaze fixation data from an eye-tracker they found that users select the target link immediately after its first fixation 31% of the times and after scanning a small subset within the same page 69% of the times. The local search strategy within the subset is moderated by previous assessments. These findings are consistent with the rational analysis of exploratory choice proposed by Young [73]. The role of assessments in Young's analysis is the reduction of uncertainty concerning the likelihood that each item would lead to a goal. Therefore, the approach is sensitive to previous link assessments, and the relevance of the current link is assessed with respect to previous assessments using a normalization function across all link estimates. According to Young, a rational behaviour that follows this approach entails that the most relevant link is selected when the cost of uncertainty reduction by subsequent assessments is not considered worthwhile.

Brumby and Howes deployed Young's analysis on choice behaviour onto ACT-R in their intent to model link selection behaviour when this is constrained by cognitive limitations. Young's choice model was extended with attentional focus and declarative memory constraints. However, a key assumption of this model becomes its major limitation in that just one link can lead to a goal. Therefore, this approach is useful to select items in menus although unlikely to be used in a Web environment to establish how a path of links is followed. That is, this model focuses on how a link is selected in a single page. When compared user and model behaviour, as expected by the hypothesis, the model did not attend to all links and reattended smaller and smaller subsets of items before making a selection. Even if the model performs badly with respect to predicting the number of items attended after the initial fixation of the goal item, it provides a good fit for the number of items fixated, percentage of correct trials or the time taken to make a selection.

9.4 Summary

All the above models have in common the rationality principle: all human action is driven by a goal. They are all based on cognitive models that try to simulate and predict human behaviour. As a result, cognitive navigation models aim at mimicking the ecological interplay between human cognition constraints and the Web environment. The predictive power of the described models is very variable as it can be observed in table 4. Higher fitness is obtained when larger numbers of user interaction data are paired with simulated output. This entails that models would perform worse if they aimed at predicting the interaction of just a few users. Additionally, their results are not very consistent when experimental conditions slightly change: different users, websites and parameters decrease the reliability of results. That is why some results on the last column of table 4 are that variable. This lack of fitness and lack of consistent results is due to the assumptions made and because the following factors are left out:

- Not implementing search strategies adopted by real users when browsing and selecting links. Even if MESA (threshold strategy) and CoLiDeS family of

models (headings scanning) draw on empirical evidence, they are mere coarse-grained approaches for link selection and browsing respectively.

- Adopting not feasible assumptions that diverge with what empirical evidence shows. For instance, the assumption made by SNIF 1.0 [19] that users assess all links goes against this evidence [9].
- Not taking into account comprehensive attentional models in the proposed navigational models. What is more, not making use of eye-tracking data to match user behaviour with model behaviour, except for [9].
- It has been demonstrated by Brumby and Howes [9] that the position of a link in a sequence strongly determines link selection. None of the remaining models takes this into account. What is more, none of the models takes into account the specific location of links in a visual display, which is a fundamental factor if the sequence of attended links needs to be simulated.
- Not considering the interaction context in terms of past label judgements and their cross-dependencies, except for [69] and [9].
- Obviating the effect of external perturbations and internal regulation processes on the decisions taken. For instance, we do not know what is the main reason for users to leave a page. We can hypothesize that they do it because they feel frustrated and this frustration may be caused by a lack of information scent, by stress or by both at the same time.
- The scenario that all models contemplate is that users are assumed to enter in a Web page for the first time or are conducting a new task in a familiar page. When familiar pages are used to validate the models against user interaction the validity of the models drops moderately [19]. Therefore, a model accounting for user navigation behaviour in familiar pages is missed.
- The expertise about the domain of a website plays a key role on link selection strategy, which is not addressed by existing models. Salmerón et al. [56] observed that users with low domain knowledge base their decisions on the next available link or on their personal interests.
- The skills needed to operate in a Web environment are not taken into account either.
- The rationality principle seems to be indisputable across all models. Human behaviour is often irrational so models might consider introducing irrationality traces.
- All behaviour is assumed to be goal driven but sometimes individuals navigate idly and without purpose. It is not necessary that behaviour is defined as goal driven or purposeless. Most behaviours consist of intermediate situations and sequences of actions that interlace different degrees of engagement. Another phenomenon that should be paid attention would be the role of serendipity in Web search [3].

Table 4: Cognitive Models of Web Navigation.

Model	Cognitive model	Explicit goal required	Strategies implemented	Information or ecological validities	Sensible to link location?	Purpose	Results
SNIF 1.0	ACT-R	✗	Follow all links sequentially	Bayesian Network on word co-occurrences	✗	Behaviour prediction	N/A
SNIF 2.0	ACT-R	✗	Follow links sequentially until perceived scent drops from a threshold	Bayesian Network on word co-occurrences	✗	Behaviour prediction	Regression values on link selection $R^2 = [0.64 - 0.71]$ and on backtracking $R^2 = [0.73 - 0.80]$
CWW	CoLiDeS	✓	Follow headings and links within a region	LSA between goal and headings/links	✓	Header and link appropriateness evaluation	Goal with no problems detected, [62%-89%] accuracy while detection of goals with problems [38%-68%] accuracy
Navigation Support [69]	CoLiDeS+	✓	Follow headings and links within the region	LSA between goal and headings/links	✓	User navigation support	Users took fewer navigation steps, had shorter task completion times and performed better
MESA	N/A	✓	The opportunistic strategy using thresholds	Manually rated	✗	Assess information architecture of a website	Spearman's correlation on link selection $\rho = [0.52 - 0.85]$ and performance $\rho = [0.739 - 0.881]$
Brumby and Howes [9]	ACT-R	✓	Top-bottom fashion except for reassessment that follows Salvucci's EMMA system [57]	Cross dependency normalization of label judgements based on their probability to reach the goal	✓	Behaviour prediction	Good fit for subset shift, number of items fixated, percentage of correct trials, percentage of self-terminating searches and time to selection. Bad fit for the number of items fixated after identifying the goal item

When it comes to modeling link selection and paths taken within websites, navigational models should be based on empirical evidence about the strategies followed by users. Even if they are only valid for single Web pages, the investigations conducted by Brumby and Howes [9], [10] on user search and link selection strategies establish the following facts on link scanning, assessment and selection:

- Users rarely fixate on all the available items.
- After the first fixation on the target link, most of the times a subset of adjacent links is scanned.
- Users refixate smaller and smaller subset of items before an item is selected.
- One item is more likely to be immediately selected when a higher number of items in the subset have been assessed before, especially if they are not relevant. Low quality distractors lead to rapid selection of quality links.
- The number of fixations/assessments in a subset is higher when the relevance of the items is higher. High quality distractors lead to more fixations within the subset of items. This goes against a simple threshold account that establishes that fewer items are assessed when they are relevant.
- The assessment of the relevance of a single link is interdependent on, and relative to the relevance of the subset scanned afterwards. In this way, the relevance of a candidate link will dynamically change with respect to the relevance of the links within the current subset. For instance, the relevance of a link will increase if the relevance of the subsequently assessed links is low.
- When adjacent links are scanned these are sometimes scanned consecutively and some other times links are skipped.
- Link skipping behaviour is more frequent after fixating a highly relevant or target item.

10 Implications for Web Interaction

The lesson we draw from the initial cybernetics approach to adaptation (see section 4) is that the way the ecosystem and the interactions between its components are designed gives some initial insights into adaptation to Web environments, even if it is in a coarse way. Similarly, human interaction in Web environments can be illustrated using the loops metaphor of the homeostat: the primary loop describes the strategical decisions taken when conducting a task in the Web environment. In this scenario, adaptation is close to a learning and a skill gaining process while in a secondary loop - or a subsequent one - Web interaction may cause disturbances that alter individuals physiological variables, causing stress and forcing individuals to adopt strategies that lead them, if not to a state of equilibrium, to a state where the user is autonomous and can operate with an appropriate degree of freedom. As a result, individuals will operate a Web environment aiming at conducting a task, seeking for physiological stability or both at the same time.

Next reports in the COPE series will delve into how Web browsing behaviour, as it is understood traditionally, is influenced by physiological regulation procedures. Some light will be shed not to observe browsing behaviour or Web interaction as an aseptic and insulated phenomenon that can only be depicted by the primary loop but to understand how the remaining loops interact with the individual, how is the interaction among the loops and what are the implications of a multi-loop approach to Web interaction. For instance, our proposal will be able to understand how internal regulation processes affect link search and selection. Therefore, we can hypothesize that all behavioural strategies are adaptations that address individuals' needs in terms of task completion, self-regulation or both at the same time.

10.1 Defining Human Adaptation in Web Environments

As it can be seen throughout this report, adaptation can have multiple facets. Specially if we are to define human adaptation in Web environments we need to make the following assumptions:

- Adaptive human behaviour is purposeful [46], goal-oriented and entails establishing the means to attain the established objective. All human action, even if browsing idly, is purposeful. However, sometimes goals are more specific, while some other times the goal is to provide the means to not so clear problems. Anyhow, individuals should be able to grasp what the environment demands from them.
- Humans learn and adapt from everything they do (see section 6.1), be it consciously or unconsciously. Consequently, they constantly gain knowledge to better adjust themselves to Web environments.
- Web environments impose ill-structured problem-solving since the Web does not always have clear solution paths towards attaining goals. However, users operate the environment by means of the cues that it provides.
- Isomorfism in the Web allows to successfully apply similar strategies in different Web pages. Such situations are caused by interface *familiarity* rather than on intuition. The latter is a misleading statement as the success on operating an interface has nothing to do with intuition but with the reinforcement of past outcomes and the anticipations they brought about.

Human adaptation to the Web is the longitudinal process by which users constantly learn to better attain goals in the Web environment, where cues are not always clear enough. It entails an accumulation of strategies to bypass the lack of information of the environment by applying appropriate problem-solving techniques. Learning involves being able to identify analogous situations from the past and being able to reuse strategies and knowledge that will make easier facing the current problem. As a result, the outcomes of learning are twofold: (1) improved performance due to automatization and (2) infrequent emotional disturbances or the ability for a fast overcome. Therefore, coping strategies are applied more often in those Web environments visited for the first time, where isomorfism can be detected

with more difficulty or its detection can be more misleading, and by novel users. Even if fully automated behaviour has not been gained, which is unachievable most of the times, there is always an adaptive process going on while individuals interact with the Web.

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11 Associated Files