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Knowledge Management Framework based on Brain Models and Human Physiology

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ABSTRACT

The life of humans and most living beings depend on sensation and perception for the best assessment of the surrounding world. Sensorial organs acquire a variety of stimuli that are interpreted and integrated in our brain for immediate use or stored in memory for later recall. Among the reasoning aspects, a person has to decide what to do with available information. Emotions are classifiers of collected information, assigning a personal meaning to objects, events and individuals, making part of our own identity. Emotions play a decisive role in cognitive processes as reasoning, decision and memory by assigning relevance to collected information.

The access to pervasive computing devices, empowered by the ability to sense and perceive the world, provides new forms of acquiring and integrating information. But prior to data assessment on its usefulness, systems must capture and ensure that data is properly managed for diverse possible goals. Portable and wearable devices are now able to gather and store information, from the environment and from our body, using cloud based services and Internet connections.

Systems limitations in handling sensorial data, compared with our sensorial capabilities constitute an identified problem. Another problem is the lack of interoperability between humans and devices, as they do not properly understand human's emotional states and human needs. Addressing those problems is a motivation for the present research work.

The mission hereby assumed is to include sensorial and physiological data into a Framework that will be able to manage collected data towards human cognitive functions, supported by a new data model. By learning from selected human functional and behavioural models and reasoning over collected data, the Framework aims at providing evaluation on a person's emotional state, for empowering human centric applications, along with the capability of storing episodic information on a person's life with physiologic indicators on emotional states to be used by new generation applications.

KEYWORDS

Knowledge Management, Sensorial data, Neurophysiology, Brain Models, Interoperability, Learning, Emotional Assessment

RESUMO

A vida dos seres humanos e da maioria dos seres vivos depende de sensações e da percepção para a melhor avaliação possível do mundo em redor. Os órgãos sensoriais adquirem uma variedade de estímulos que são interpretados e integrados no nosso cérebro, seja para uso imediato, seja para serem armazenados no cérebro para mais tarde serem invocados. Entre outros aspectos racionais, uma pessoa tem que decidir o que fazer com a informação disponível. As emoções são classificadores da informação recebida e atribuem um significado pessoal a objetos, eventos e pessoas, tornando-as parte da nossa própria identidade. As emoções tomam um papel decisivo em processos cognitivos tais como o raciocínio, a decisão e a memória, pelo facto de atribuírem relevância à informação adquirida.

O acesso a dispositivo computacionais de forma difundida, enriquecida pela capacidade de sentir e percepcionar o mundo providencia novas formas de adquirir e integrar informação. No entanto, ainda antes da avaliação da utilidade dos dados, os sistemas devem ser capazes de capturar esses mesmos dados e de assegurar que os dados são geridos de forma apropriada para uma variedade de possíveis objectivos. Dispositivos portáteis ou até vestíveis são capazes de adquirir e armazenar informação, do ambiente ou do nosso corpo, usando ligações à Internet e serviços na nuvem.

A limitação dos sistemas em lidar com informação sensorial quando comparada com as nossas capacidades sensoriais constitui um problema identificado. Outro problema é a falta de interoperabilidade entre humanos e dispositivos, pelo facto de que estes não captam os estados emocionais das pessoas nem as suas necessidades. Endereçar esses problemas é uma das motivações para o presente trabalho de investigação.

A missão aqui assumida é a de criar um enquadramento tecnológico que permita a inclusão de dados sensoriais e fisiológicos, que permita gerir essa informação tendo em vista as funções cognitivas dos humanos, suportado por um novo modelo de dados. Ao aprender sobre modelos funcionais e comportamentais, selecionados, dos seres humanos e processar a informação adquirida, pretende-se efectuar uma avaliação sobre os estados emocionais de uma pessoa, para proporcionar aplicações dirigidas às pessoas. Ao mesmo tempo pretende-se armazenar informação episódica da vida das pessoas, recorrendo a indicadores fisiológicos, que forneça pistas sobre os estados emocionais, as quais podem ser utilizadas numa nova geração de aplicações.

PALAVRAS CHAVE

Gestão de conhecimento, Informação Sensorial, Neurofisiologia, Modelos do Cérebro, Interoperabilidade, Ensino, Avaliação Emocional

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Acronyms

AI	Artificial Intelligence
BCI	Brain Computer Interface
CT Scan	Computerized Axial Tomography
CPS	Cyber Physical Systems
ECG	Electrocardiography
EEG	Electroencephalography
EMG	Electromyography
FOF	Factories of the Future
FI-WARE	Core Platform of the Future Internet, EC Contract No.: 285248
FITMAN	Future Internet Technologies for MANufacturing industries EC Contract No. 604674
fMRI	Functional Magnetic Resonance Image
GSR	Galvanic Skin Response (SCR)
HCI	Human Computer Interaction
HRV	Hearth Rate Variability
HTTP	Hypertext Transfer Protocol
IAPS	International Affective Picture System
IoT	Internet of Things
IPSO	IP for Smart Objects
IS	Information Systems
IT	Information Technologies
MMI	Man Machine Interface
MRI	Magnetic Resonance Image
RFID	Radio frequency Identificators
PET scan	Positron Emission Tomography
SAM	Self Assessment Manikin
SCR	Skin Conductance Response (GSR)
WWW	World Wide Web

SECTION I – INTRODUCTION TO THE RESEARCH WORK

This section makes an introduction to the research work developed and explains how the work is documented in this Dissertation. Within this section the motivation for developing the present work is explained along with the contributions it can represent in technological and social terms. It also describes the methodology that guided the present research work that provides contributions to knowledge in the presented research areas. Envisaging that goal, Section I is divided in two chapters. Chapter 1 explains what are the observations that lead to the present work and what motivated to proceed with this line of research. Chapter 1 also makes the presentation and description of how the present Dissertation is organized and what are the contents of each section. While Chapter 2 presents the work plan that guided the research work developed, describing the different steps of the scientific methodology. It presents the hypothesis and approach followed to address the research questions that will lead to the work described along the different sections of the document.

The objective is that at the end of this section becomes clear why this work started, what was the pursued objective, how the studies and experiences are presented in this document as were in the document are the different steps of the research work hereby presented leading to the conclusions and future perspectives in the final section.

1. INTRODUCTION

This Chapter introduces the research subject in a human centric context. The Introduction aims to propose a journey to the research work developed and reported in this dissertation. We start by explaining in detail all the aspects observed that gave place to the present research work, in section 1.1. We present reflexions about; our nature, the present status or our relation with knowledge and the problems identified in our relation with the Internet in what regards to knowledge management. The Chapter finishes with a summary and the presentation of the Challenges to be addressed by out research work. Then we proceed to the Motivation for developing this research work developed in section 1.2, and section 1.3 includes the Vision which inspired the research work aims to fulfil. The presentation of the research areas that are relevant for the present dissertation are on section 1.4, along with the identification of the research gaps and what are the foreseen contributions to be addresses. All those topics will be addressed in the Literature Review section in order to establish the knowledge background that represent the foundations of the presented research work. Finally the outline of the dissertation is made on section 1.5, explaining the contents of the following chapters.

Within the brain lies our ability to perceive the world, to reason and to produce responses and reactions. Our evolutionary brain acquired capacities that are so complex and so elaborated that, even with present technology, science is only starting to understand. Recent findings about brain's activities are, sometimes, just the confirmation of ancient theories [1]. Formerly, without modern imagiology technologies, theorists in scientific and social domains observed the brain as a black box with inputs and outputs that lead to inferences about what could be the inside mechanisms. Since then and until these days, theories and constructs where developed to interpret, and explain, the how and why of brain's performances, but some still to be proven (e.g. genetic relationship between myopia and intelligence [2]). Nevertheless, medical scientists' conceptualizations were made regarding consistent observations and were performed by informed researchers [3]. In this context we may think that our brain is an interesting source of inspiration for conceiving systems, after all the brain is the result of tens of thousands of years of evolution. In the current research we want to learn about how the brain acquires information producing knowledge that later we can recall to produce insights that become useful for the understanding of new situations, the so called wisdom. It matters on how we perceive the world and make decisions. In summary, research starts by understanding how we retrieve and classify acquired knowledge so that it has impact on our knowledge management. Intuitively we feel that, emotions act as a regulator for those activities and that, somehow, we understand that emotions have a role as classifiers of knowledge weighing new and existing knowledge [4]. Nevertheless, daily we experience multiple sensorial inputs, provided by our sensorial organs, which feed our decision centre, the brain, with information that triggers thoughts, feelings and actions. Based on these observations, and from our findings on how the brain performs selected tasks, as retrieving and managing knowledge, we can formulate several hypotheses on how we can improve computational-based knowledge management.

In the early studies performed for the doctoral research, wide consensus was observed over the two-stream hypothesis, as it provides a possible path for a better understanding on how the brain perceives and handles acquired information, aligning new and existing knowledge. Another relevant aspect is to comprehend how sensorial acquisitions relates with the production of new knowledge. In particular, to understand if what we are learning will increase existing knowledge or just update and transform existing knowledge.

In order to follow that track, we need to seek an understanding on the role of emotions in mediating perceptions, and its relations with existing knowledge, and how perceived information will contribute to modulate knowledge processes at the brain. Those studies are carried out taking in mind that we are, neither researching neurophysiology nor neuropsychology but, in fact, trying to learn from it to reflect those lessons learned into knowledge management in a computational environment. Taking in account those considerations, in the next sections we will explained how we go from understanding our nature, and our present context with its subjacent technical and societal problems related to a pervasive usage of Internet devices and presence on the web, to outline our proposed solution, the Knowledge Management Framework based on Brain Models and Human Physiology for acquiring, managing and recalling information. That is the case for invoking the Two-Stream Hypothesis (e.g. for vision considering a ventral stream and a dorsal stream) [5] and the usage of memory content, how it is filled, organized and recalled. All those aspects aim to promote human centric knowledge management on an Internet based environment.

1.1. Observation

Today a growing number of earth citizens regularly have a diversity of interactions with the Internet. People use the Internet for shopping, to play games, learning, work and social networking. Those actions, in online activities, assume a role that is becoming vital for personal or business success. We also know that computer systems try to understand and provide solutions to our needs [6] [7]. In that sense it is noticeable the evolution in systems' context awareness, in trying to determine what we are doing, what will we do next and which are our immediate needs. It is also noticeable that users are relying on the Internet, as source and repository of information, leading to an established believe that it is not necessary to memorise what can be found by searching the Internet [8]. We also have the idea that knowledge is vast and in the past the opportunities to increase our knowledge would consist, in general, to attend classes at school, or other specific courses, and reading books at libraries. In today's context, it is like all schools and all libraries are connected and accessible at a tap of a finger, a mouse or a keyboard, using an Internet browser or other application [9]. By my own experience I had periods in my childhood that I would read any book that was simply accessible. Obviously I can no longer have that perspective as when I browse the web I feel like swimming in an ocean of books and other sources of information and it is necessary to select the best sources and what to read. On another angle, we are using the Internet to meet with people for personal motives or in business interactions, we share ideas, emotions, photos from places we visit and we try to communicate, either asynchronously or as being in person with the other. We do business, research or leisure, we get to know people, build friendships and, eventually, find love.

But.

Existing devices impose limits to our current experience while using the Internet. We are always limited to a screen, microphone, speakers and a keyboard. Those are the generic tools of interaction via Internet. The objects we search on the Internet are text (e.g. email, messaging, documents), sound (e.g. music, soundtracks), pictures (e.g. photos, drawings, illustrations, design products, technical images) and movies (e.g. series, movies, clips, streams, personal records). When we use the Internet for watching movies we are just looking to a screen and hearing a sound. When we search for information we achieve the visualization of books, articles, webpages, blogs or social networks, all framed to our screen. When we search for music we listen in our headphones or download to a player device. When we interact with others, we post messages or emails for being checked later or live exchange messages, we talk and other times we also watch the filmed image of other person on a screen. The knowledge about places or situations consists mostly in depicted narratives of someone that presented his interpretation in a photographic or written mode, and thus conditioned to what words can express plus what cameras can capture. All those cases, text, pictures or movies are, in fact, a different experience from being there.

OUR NATURE

The proposed exercise would be to imagine living without Internet, as 40 years ago when first network approaches were designed. We would interact person to person or by fix phone, we would learn mostly by reading books or by attending classes. We would work, shop and perform most activities with none or minimal access to computer-based systems. We would listen to a teacher speaking and we would participate in experiences in laboratory. In some days we would go visit other laboratories or company facilities, we would travel to parks or went to the woods collecting samples and experiencing the environment. Of course live was much more simple those days.

Nature equipped us with sensorial organs that capture the environment and permit an evaluation on where we should go, what we should eat or whom we should meet, and also when we should go to bed or wake up. That means our brain would use all that input, plus the knowledge stored in our brain in order to decide on how to act and what new knowledge should be pursued and acquired.

THE PRESENT

These days seems like our nature is facing a change in variables. Our nature has similar characteristics and functionalities as described above and as human beings we still use our bodies' capabilities to sense the environment and to reason, as hundreds of years before. But the world changed at a fast pace. In face of that, we can reason about today's way of living and how our interaction with the reality occurs, with the pervasiveness of computerized and communicating devices supported by the Internet. All that configures an unusual exposure of humans to an ever-changing nature of the world, at different levels, as opposed to the way it used to be.

In contrast with our biological nature, these days, we are seeking for knowledge at our favourite search engine, not looking around smelling the air or listening to nature's sounds. We experience the world in documentaries about the planet, since most of us live surrounded by constructions, and we interact with others in social networks, mostly based in text, by communicating timely or asynchronously. We don't use our sensorial capacity to immediately sense the environment (i.e. is the room warm?) and we don't feel a direct presence of others (e.g. we don't handshake). We don't actually inhabit the same physical space as others. There are several advantages in this behaviour, as it is more convenient by avoiding displacements with inherent costs and time constraints, but it is also less compatible with the social skills of our developed prefrontal cortex [10].

THE PROBLEM

Internet has evolved in a top-down approach, from complex interactions in limited computational centres, to the simplicity and pervasiveness that we find these days. In fact, first Internet users had the opportunity to share some characters at military, university and research centres, then a rapid evolution was taking place until the World Wide Web become the reality that we use this days. In a progressive integration, we become users of music, games, movies and later, the so-called Web 2.0 with social networking [11]. We don't need to make the full history of Internet to notice that the interaction we have and the objects we store were progressing as the technology was allowing. There was no planning on what should be represented on the Internet nor on how our interactions should be modelled, it simply happened addressing user demand using available technologies. That is a possible reason for Web 3.0, the Semantic Web, try to attribute meaning to what is already on the web with the semantic web or why we are heading to Web 4.0, the Knowledge

Web [12]. In fact Web 4.0 it is foreseen to reason over available data predicting your needs. Web 3.0 and Web 4.0 will use much more real world connections than in Web 2.0 by involving all the new panoply of smart, wearable and pervasive computing. Web 4.0 or webOS will be such as a middleware in which will start functioning like an operating system. The webOS will be parallel to the human brain and implies a massive web of highly intelligent interactions [13]. Thus in order to have intelligent interactions it is necessary to have the most information available, more then image, text and sound, and treat information and knowledge with similarities to the most intelligent agent we know, the Human Being.

The identifiable problems in managing our information, in the context of the present research, are:

- Existing objects are: text, photos and videos, or the mixture of all of those. There is no approach likely to that of human sensorial experience and, even if some devices allow other sensorial experiences, they are scattered with no consistent representation and no link with each other (e.g. smell printers and diffusors [14]).

- From that observation we notice that there are no data models to cope with sensorial experience; manufacturers of smartphones, fitness or health devices, mass-produce their proprietary devices for specific commercial purposes.

- There is no support for physiological data to coexist with behavioural data. Devices use physiological data as source for fitness applications or health applications. Existing health data models belong to health standardized bodies [15] [16], are complex and directed towards a medical community, and thus not suitable for general purpose applications.

- Emotions are not related in a systematic way with objects or events represented at the Internet thus presenting a serious constraint to affective computing and what it could represent for Human-Computer Interactions.

- In face of the exposed, there is a lack of context-awareness enriched information that relates to human perception and physiological activity. There is no relation between existing devices or services, and objects or events represented at the Internet, which could empower context-awareness. In fact, too much of the Internet's design effort was spent on machines and computers, while the human related aspect, were strongly underrepresented in the architecture [17].

IN SUMMARY

With so many available sources of information and so many technological devices at our will, we may question if it is possible to make a better usage of those resources in empowering a human-centric Knowledge Management Framework. In that logic it is identifiable the need of a data model that could represent human related information, namely, physiological and sensorial information.

CHALLENGES

What if applications and devices could respond according to our mood and our feelings?

What if technology permits a collection of moments in our life with our whole experience including our perception of the world, the response of our body and the environment around us?

Those are same of the questions that gave rise to the research work developed that gave origin to this Dissertation.

In order to address both challenging questions it is necessary to develop a multi-context framework that can make use of different sources of information and diversified resources that can be used in different configurations for different purposes (e.g. collecting episodic data, matching physiology with emotional states). It is necessary to collect and properly handle sensory and physiological information collected with appropriated devices, some exist in the market, other being developed and soon make presence in the market. Those are the cases of fitness bands, smartphones and smartwatches, each with own characteristics, being able to collect physiological data (e.g. heartbeat, blood oxymetry, body temperature and Galvanic skin response [18]) along with the already common capture of sound and image.

The challenges lead research to the aim of promoting an evolution in the representation of objects, facts and events, so that human related information (e.g. sensorial, physiological, emotional, etc.) will be supported at the Internet, using a proposed data model, along with environmental/contextual information. In that direction, it is necessary to foreseen support for data gathering, from sensors to novel ways of interaction, yet available or not (e.g. haptic sensors by ultrasound [19]). Haptics describes the sense of touch and movement and the mechanical interactions involving these [20]. We have seen lately a growing interest in this kind of devices from the gaming industry and it seems that technology surpassed the times where the keyboard was the only haptic related device.

The challenges from the human side are related to widening the diversity and consistency of data collected reflecting on knowledge management procedures. Meaning that an enlargement of data collected to other sensory information is desirable along with physiological data. In a higher level that means the need to support implicit and explicit knowledge, being the first the kind of knowledge generated over sensorial or physiological data along with explicit knowledge from our own expression about us.

Finally, in order to take the most from existing technologies, it is important to look for opportunities within Internet of Things (IoT) services [21] that can provide rich amount of data useful to relate to a person's physiological activity (e.g. bedroom temperature and quality of sleep). In parallel, the recourse to cloud services allow the usage of ubiquitous sensing and computing services as they can be supported by cloud services leaving minimal consumption to local devices (e.g. wearable sensors). That can be implemented using specific platforms, both for data storage and services (e.g. Amazon Web Services Cloud Computing [22], Google Cloud Platform [23]). The amount of information and computing power accessible everywhere will create new context awareness paradigms by reasoning over collected and integrated data, collected analysed and deployed by a Framework for Knowledge Management based on Brain Models and Physiology.

1.2. MOTIVATION

The main motivation for this research work is to allow better usage of existing computational resources towards new expressions of the human nature in an Internet environment. By making a consistent use of online available knowledge and services, it is possible develop a framework that will support different views of available resources so that they become more useful for citizens' own knowledge management. In using such an approach there will be direct and indirect benefits for the citizens.

Motivational direct benefits are the enrichment of Internet objects and episodes with additional information attached (e.g. towards five senses, physiological or environmental) making it more complete, more realistic and easier to locate what we are searching for. The more proprieties and the more attached information an object has, the more likely it will be located when needed and become more useful at the right time for a given objective. Furthermore organization of Internet objects will be supported by new properties, other than name, size, date creation, date modified, etc.

Motivational indirect benefits result from feeding of applications with a wider range of available data so that such applications can better understand what a user is doing and what kind of information is needed to better serve users' needs at each moment. That is the case of context awareness and situational awareness or decision support systems and healthcare and fitness applications. In all those cases, applications will benefit from using enriched Internet objects or information on a person's episodic state. Using such information devices and applications can better correspond to the needs of a person's activity, emotional state or even to real-time assessment of health condition indicators.

1.3. VISION

This research work envisions development of a Framework that will promote novel knowledge acquisition, and knowledge management paradigms, by learning from human cognitive processes, physiology and selected theories about human brain.

In pursuing human inspired knowledge management, it is also considered the vision of a new representation of objects and events with physiological data along with extended sensorial information as happens in humans.

As stated in the motivation, the vision of enriched objects with multiple human dimensions and a Framework that captures, handles and deploys such information. That is per se a serious advancement towards deploying human related information, organized in a human manner, becoming accessible according to human parameters and constituting a source of information that promotes applications that will better understand us and deploy services addressing human needs.

1.4. RESEARCH AREAS – AN OVERVIEW

The region of influence for the research topics is broad and involves multiple aspects from psychology, brain functions, neurophysiology and other medical related areas to those specifics of computers and information technology; like semantics, knowledge management, artificial intelligence and others. It also includes new areas that overlap medicine and computer science like cyber-physical systems, affective computing and other emerging areas. Then, for the proposed research work, it is important to establish relations within these areas and, especially, to define some boundaries. Otherwise it would be dramatic to handle such complex areas with their multitude of aspects.

In pursuing the selected Vision it should be possible to propose new applications in different domains, and to explain its added value for citizens.

The next diagram, in Figure 1.1, with the research areas and subsequent insight on each one and its interactions will depict the environment where this research is developed.

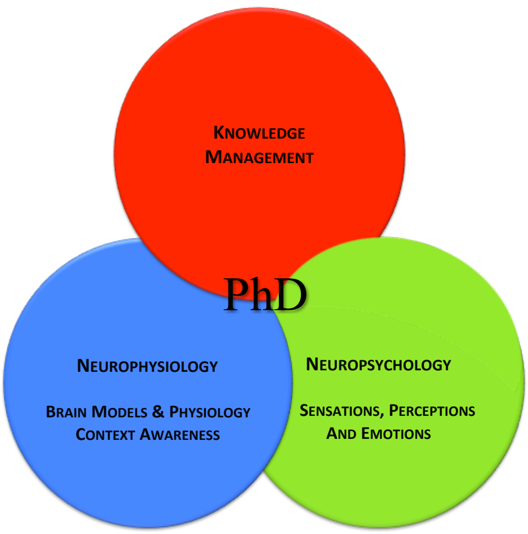
The exploitation of such vision starts with the two stream-hypothesis which supports that a visual stimuli received in our eyes, and conducted to occipital part of the brain, will trigger two different streams, one ventral, the ‘what’ stream, and one dorsal, the ‘where’ stream. When we represent an object we are defining its ‘what’ properties, whereas when we represent that object in a selected environment we are establishing its ‘where’ properties. In both cases, the brain seeks for context information to retrieve the most accurate identification and mental representation of what is seen.

The stimuli we are permanently getting from our sensorial organs are creating perceptions that make us more cognoscente, of what we already knew and are experiencing now, using many processes, as memory, association, problem solving, etc.

But humans are also equipped with the ability to have feelings and to change emotional states. When humans are exposed to environmental changes, or their own changes, they evaluate what is perceived through sensorial organs’ input and they change how they feel, with potential impact on action and cognition.

This interdependence of sensorial information, physiological response and emotions is what we propose as a key to knowledge management, in what refers to human centred systems. As in Damasio’s sentence, ‘we feel, therefore we learn’ [24].

The research work developed and reported in this document, is supported by three principal domains that are graphically defined next in Figure 1.1.



Research work developed in the PhD program results from the merging of these main areas depicted in the next figure plus some special issues like those related with memory. Knowledge Management represents the top objective plus Neuropsychology that has similarities to software and Neurophysiology that has similarities with the hardware, both from the human body perspective.

Figure 1.1 – Main areas addressed in current research

The present areas have different dimensions that apply directly to the research work (e.g. knowledge management and sensations) but there are others that combine direct with indirect impact (e.g. physiology). Physiology can provide direct measurements that reflect the health status of a person (e.g. heartbeat, blood pressure) but can also provide measures that promote other type of assessment, as is the case of inferences about a person's emotional state. That is the theme of Chapter 7 and then included in the validation work as described in Section III.

1.4.1. *Knowledge Management*

Knowledge management is a field of research deeply explored in business and enterprise management aspects. The societal developments in the last years, and in particular with the massive exposure to internet contents, have opened the access to information and knowledge to a degree that was not predictable some years ago and, also because of that, personal and educationally oriented knowledge management is not so often considered in computer science research.

The Gap: Society has evolved in a scarce information diversity and reduced media openness, based in books at libraries or, for those with reading habits and financial capacity the repositories one can have at home's shelves. Now we have broad access to contents at the Internet and we have new technologies to capture, support and deploy diverse types of information. But all that potential does not mean that systems are ready to properly handle user related information, especially if that is nonconventional human related (e.g. physiological or about smell, taste or roughness).

Foreseen Contribution: To address the need for proper knowledge management of human sensorial data, and to make contents more interoperable with human cognition processes. In overall, to improve knowledge management towards human needs by providing support for human related contents (e.g. by the inclusion of environmental, physiological and emotional information and promoting the emergence of relevant correlations).

1.4.2. *Neurophysiology, Brain Models and Physiology*

Many hypotheses have been proposed in trying to determine how the brain works. In that process researchers have developed possible brain models. Some are more reliable others still to be proven. Models tend to simplify and schematise complex brain's behaviour and that is one of the most interesting particularities for computer science (e.g. artificial intelligence and neural networks). It would be important to know how the brain captures information from the outside and what processes occur next. The first part is the study of sensation and perception but it is important to know what happens next. The images of brain activity obtained by MRI and fMRI are an important source of clues to determine those next steps. It is identifiable that two flows are activated once we see an object; at the ventral and the dorsal areas, one identifying what we are seeing and the other spatially locating it. For this late process, the brain establishes some reasoning on what we are seeing by relating it with the available information in memory thus providing a classification of what is percept in a similar way to consulting a catalogue.

The Gap: In computer science it is known the usage of Genetic algorithms and neuronal networks as heritage from knowledge about humans. Computer vision and Artificial Intelligence (A.I.) research areas have been following what happens in the brain and in human vision in order to develop robotic and other intelligent systems [25]. However little attention has been paid, in computer science, to the methods used by the brain to capture and handle information, from body's sensorial apparatus (e.g. beyond vision and audition, that could have a positive impact in knowledge management research.

Foreseen Contribution: The present work seeks for inspiration from selected conceptualizations about the brain to apply it on knowledge management. It is of particular importance to observe the way external stimuli are received by the brain and apply it towards context awareness and situation awareness (e.g. using the two-stream hypothesis as inspiration for the handling of incoming input from sensorial organs, relating that information with physiological activity).

1.4.3. *Neuropsychology, Sensations, Perceptions and Emotions*

Sensations from external world are the result of a process of energy transducing by our sensorial organs to our nervous system. The permanence of sensations is a condition for the formation of concepts and the permanence of perceptions allows as to form the notion of an object [26]. As humans, our ability to perform every task in daily life, from work to amusement or any other conscientious task, depend on our emotions. As humans, emotions play a central role as they ensure our survival and all activities from the most basic to the most elaborated tasks are dependent on emotions, whereas action in turn can generate new emotions. It's hard to imagine life without emotions [27].

Emotions evaluate the importance of the perceived information and the retrieval of the information is conditioned by emotions. In fact Damasio proposes that the relationship between learning, emotion and body state runs much deeper than many educators realize and that the original purpose for which our brains evolved was to manage our physiology, to optimize our survival, and to allow us to flourish [24].

The Gap: Lately, especially with the integration of sensors in smartphones and with new wearable devices, there have been some applications that try to get physiological data. However, the handling of such data is done by specific applications, some are not standardized or not open source, and do not fit in enlarged models that accommodate physiological data or other formats that can refer to emotions.

Foreseen Contribution: Taking the importance of sensing and perceiving the world for human cognition processes, it is relevant for the present work, to take in account the role of emotions in ranking input for knowledge acquisition and knowledge management purposes. For that, it is within the scope of the present work the inclusion of physiological and emotional data in new data models, allowing related research work to be developed. (e.g. getting sensorial information from multiple devices from the external world and being able to associate an emotional classification of objects).

1.5. Dissertation Outline

This dissertation is organized in four major sections that compose the overall contents. It starts with the Introduction, in Section I, with all relevant information on the nature of the work performed and hereby reported. Then Section II brings all the background information considered necessary as background to the research work developed. Section III has a report on the contributions and novelty of the performed research work. It includes the description of the outcomes from the research and the validation and publication of results. Finally section IV makes the closure of the research and the dissertation document, establishing the conclusions and also makes an insight on potential exploitations of the current work for a near future.

Section I Introduction to the Research Work starts with an introductory Chapter 1 that establishes the guidelines conducting to the present research work, with this last section presenting what will be the contents of the document until the final considerations and future work. It starts with observations with aspects of our current society and a Vision on how this dissertation can contribute to existing knowledge including the presentation of the main research areas; Knowledge Management, Neurophysiology, brain models and physiology, Neuropsychology, sensations, perceptions and Emotions. In Chapter 2 Work Plan it is presented the Work Plan that inherits the strategy designed at the beginning of the present research work and that was publicly presented as a Thesis Plan. It includes the method, the proposed Hypothesis and approach.

SECTION II - LITERATURE REVIEW is organized in five chapters in the following sequence, Chapter 3 Knowledge Management, has a fundamental aspect of the research work in this dissertation that is to establish ground for the development of new strategies on knowledge management. In that sense was considered appropriate to start background observation with a review on the subject of Knowledge Management with a focus towards the individual perspective. Then Chapter 4 Neurophysiology, Brain Models and Physiology, can be thought as an analysis on human hardware, it means the sensors of the body and the why a human body senses information from the outside and how the brain manages that input. In Chapter 5 Neuropsychology, Sensations, Perceptions and Emotions, a review is made on aspects more related with cognitive functions. If we relate this in a similar way with computer science, would be the analysis of the human software aspects. Chapter 6 Memory has the importance given by the storage necessities, of our perceptions and our thoughts, and on how we can learn with the brain about storage of human related knowledge. It is also important to understand how previous knowledge can be usefully used for the acquisition of new knowledge. Chapter 7 Inferring Emotions from Physiology appears next in importance by the fact that emotions play a central role in human life and have a major implication on how we acquire and manage information. In our case study we want to know how we can obtain emotional information from physiological measurements, so that it become useful to empower other applications (e.g. decision support systems, context awareness, etc.).

SECTION III - CONTRIBUTION & VALIDATION has an initial chapter 8 Emerging Research Areas that presents the areas that are growing as result of new technologies being developed and adopted these days. This is the case of the mobile, wearable and ubiquitous computing, including the concerns on our growing interaction with computers and the Internet of Things (IoT). Chapter 9 Research and Scientific Contribution, highlights the outcomes from the research executed during the doctoral program. Those include the path towards the validation of the proposed hypothesis through the research methodology adopted. Finally, along the line from background review to deployment and validation, including selected scenarios, are presented in Chapter 10 Scenarios and Validation.

SECTION IV – CLOSING & FUTURE PERSPECTIVES lead us to Chapter 11 Conclusions & Rational on Research Results that establish the main conclusions of the work developed. Then in Chapter 12 Future Work the potential legacy for the near future is presented as prospective on what can be done using the present work to go promote further developments. Then closing the document are the publications made in the scope of the research work performed, in Chapter 13 Publications and in the end is Chapter 14 with all the References used in this document.

2. Work Plan

This Chapter describes the work plan followed during the execution of this PhD research work. It starts with the formalism that was adopted and describes the different phases. Then in section 2.1 the research questions are presented. Section 2.2 brings the Hypothesis and the approach adopted in the present research work. All this observed, Chapter 2 finishes with a series of questions, much of them societal questions that the present dissertation aims to address and that impact on the selection of the research areas presented on the following chapters of Literature Review.

The adopted methodology based on which the research work was developed is based on a research strategy that follows a workflow as mentioned in the course [28] and was executed following the classical phases, in its execution scheduling.

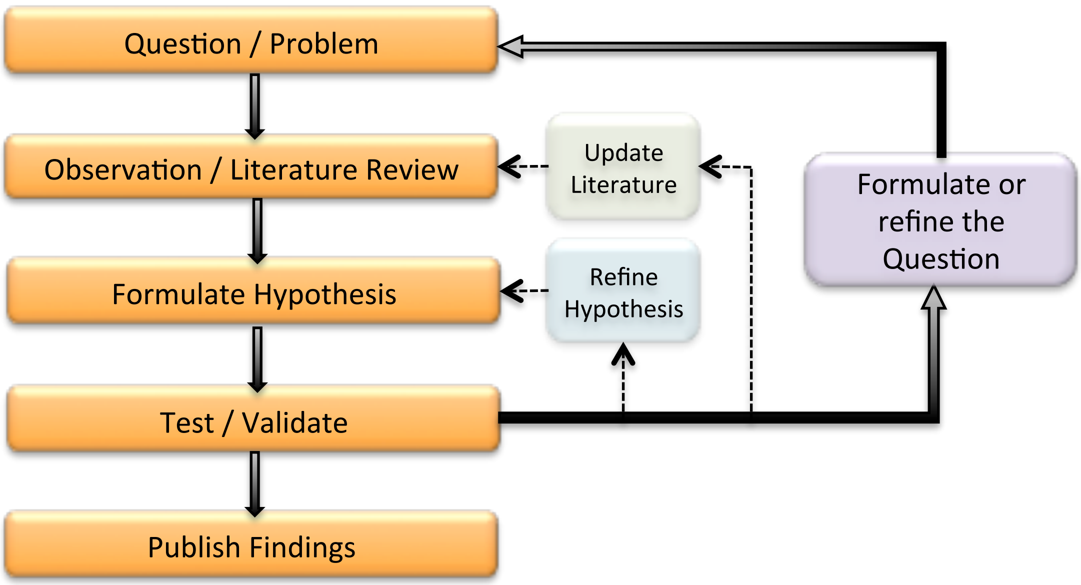


Figure 2.1 - Research methodology

The research plan was developed as explained in this section.

1. Research Question / Problem

The research question is the most import ant step in research and often comes from the thought: "What we have now is not quite right/good enough – we can do better…" [29]. This sentence can be reworded so that it captures the essence of this on-going research work; *what we have now in using Information Systems to manage knowledge and interact with humans is not quite good enough, can do better by learning from brain models and human neurophysiology and neuropsychology?*

It is a question that emerges from existing knowledge and from the recommended research areas of the PhD program. It results from an identified problem or an opportunity to advance knowledge on the subject. The research question needs to be addressable by a research development that will lead to conclusions on its feasibility or its proven value. The research question and sub-questions are presented in section 2.1.2.

2. Observation / Literature Review

From the observation of the problem and the targeted scientific environment, there should be a selected literature review covering the topics considered relevant for the execution of the proposed research work. This part covers the study of what was previously done, what is the state of the art in what relates to the on-going research and try to identify what distinguishes from previous work and with what impact in knowledge and people. Next, in Section II, a series of chapters from 3 to 7 has the literature review on different areas considered necessary for the presented research work.

3. Formulate hypothesis:

Taking the proposed problem, research conducted to the formulation of a hypothesis that was used to address that problem. It is a possibility, expressed as a conditional hypothesis, that was tested and, as partially successfully proven, becomes the thesis. The hypothesis mentioned in section 2.2 were expressed taking in account that; they should be simple and conceptually clear, capable of verification, related to the existing body of knowledge from several confluent areas and that should be operationalisable in instantiations of a proposed framework. As the scope of the work is broad and addresses several areas, would not be possible, as seen from the beginning, to make a full validation of such wide range application Framework

4. Design Experiment:

The elaboration of a validation experiment needed to include a detailed description of the methodology of the experimental phase that allowed the validation of the hypothesis towards the confirmation of thesis. The plan was designed to be feasible and will allow others to repeat it. In designing the testing setup it was necessary to identify the variables to be manipulated and measured, what outcomes will be measurable and, in summary, to develop a method to reach the necessary validation

5. Test Hypothesis / Collect Data:

Testing the hypothesis using the proposed design experiment aimed at confirm or refute that same hypothesis. Test implies the execution of the proposed solution addressing the initial question/problem that uses what was stated as a hypothesis. The analysis of collected data allowed the verification of the proposed hypothesis, proving that it is possible to improve knowledge management by collecting physiological data.

6. Interpret /Analyse Results:

The collected results were evaluated qualitatively and qualitatively using valid technics (e.g. graphical analysis, statistics, etc.). Those results were interpreted using and discussed according to known methodologies towards the research objectives and research questions.

If the followed path leads to the absence of conclusions or if the Hypothesis is proven wrong, it could be better to choose another problem to address or view the problem from another angle so that, with some literature review would be possible to successfully validate another Hypothesis. Fortunately the results come in line to what should be a positive validation of the Thesis.

7. Publishing Findings: **-** The results obtained during the research activities have been published, and will continue to be disseminated, for the benefit of the scientific community, and also to allow validation of current work from the side of peers.

2.1. *Research Question*

2.1.1. *Problem introduction*

The evolution of the Internet was supported by technological advancements in diverse industrial branches and developed as result of scientific research. The exponential growth of users along with all kinds of applications made the Internet an unavoidable tool and an asset for business research and social life. But if the Internet aims to address the needs of humans, its architecture reflects only a technological support for communication and storage of knowledge and information. In many cases it works like a business or a social network, the fact is that it doesn't mimic most of the major human characteristics, the ability to sense and perceive the environment and to feel emotions [30]. It is legitimate to raise some questions; why the Internet is oriented towards text and image ignoring the overall human sensorial perception of the world? Why emotions are not part of the foundations of information representation on the Internet? And finally would there be a benefit for addressing those questions in a human oriented approach?

2.1.2. *Research Questions and Scientific Challenges*

The research question defines the area of interest for the authors and the problem they want to address. Taking inspiration from the motivation aspects making them a point of departure to the research method, the following research question was formulated and decomposed in three main sub-questions. Those questions are based on a preliminary analysis of the research topics and it is expected that, with the insight in the research areas and literature review, those questions will raise new research topics that will reshape the formulated hypothesis. This process aims the construct of new scientific knowledge as stated in the objectives of the reported research work.

The main question provides the essence of the research work.

Question – Is it possible to improve information systems based on lessons learned from neuropsychology and brain models?

Is decomposed in the following sub-questions

SQ1 - Do sensorial and physiological information bring an added value to Internet objects for human usage?

SQ2 – Do physiological measurements allow the inference of emotional states so that we can improve knowledge management systems and better interfacing computational applications with users?

SQ3 - Would the two-stream hypothesis of the brain be suitable for taking advantage of sensorial and emotional information for knowledge management?

Rational for SQ1

Today there is a wide variety of sensors, either related to individuals or related with the environment. Would the retrieval and incorporation of physiological and sensorial data, resulting from those sensors, add value to information representation and management? Those sensors could exist, or be developed in a near future, and stand-alone or be virtually a result from a fusion. Those could belong to some IoT device in the environment (e.g. house, car, streets) or be portable or worn by an individual.

Rational for SQ2

Devices are designed to serve our needs. Applications need to have the most information about users in order to preview and address that person's needs in terms of information or functionalities. Devices can retrieve information on positioning, activity or even heartbeat, but so far they cannot infer about a person's emotional state or, at least to work on clues about that. It would be interesting to get clues on a person's emotional state for better interfacing with that person, respecting the person's feelings at that moment. That would be achieved by learning on how selected physiological measurements could provide us information about a person's emotional state.

Rational for SQ3

The Two-Stream Hypothesis is just that, a hypothesis with good acceptance but lacking final approval as a certainty. However there is no obstacle in using it as an inspiration for handling information as we do, per hypothesis, in our brain.

In order to research those questions, it is necessary to enrich objects with analogous kind of sensorial perception and emotional contextualization in handling Internet Objects or Episodes as defined in this Thesis.

Objects are defined in this Thesis as any item or living being that exists in real world that is passible of being represented by its texture, visual aspect, smell, taste or sound. This is a broad sense that can include physiology for any living being and emotions for persons. The scope is unlimited but some examples can be presented (e.g. person, hamburger, sculpture, wine, etc.).

Episodes, called in this dissertation as i-Episodes (c.f. section 10.2.1), are collections of objects or properties related with each other by a temporal link. Examples are limitless and can be related to a person, or several persons, as any of those cases are within the objectives of the research work (e.g. a moment: playing at the beach, crossing a park while jogging, drinking a coffee at morning break).

To pursue such an approach some scientific challenges need to be addressed on how to model things in the Internet with sensorial and physiological information, when possible with emotional information, for the search by the human brain. The research will take existing models of the brain and the sensorial capacities, as the objective is not to research new brain models or to give an insight over the human's brain but actually to learn with existing studies and models and to exploit their application in knowledge management.

2.2. HYPOTHESIS AND APPROACH

In order to address the research questions the next hypothesis was formulated and its validation will be pursued by the present research work.

Hypothesis: If we adopt sensorial and physiological analogies from the human body and inspiration from selected brain models to improve knowledge management, we will be able to find new ways of acquiring and representing knowledge, allowing new applications for a persons' benefit.

In order to aim at developing work towards the proposed hypothesis, and from the early analysis of the problems, we observed the next set of tools or developments.

1) A new conceptualization of knowledge representation can support sensorial and physiological information along with emotional assessment.

2) Support for meta-information can foster transitory or complimentary sensorial and emotional representation methods

3) Analogies from human physiology and cognitive functions can improve knowledge management technics

4) Inspired by the Two-Stream Hypothesis it is possible to establish a wide definition of "what" it is based on sensors and a "where" it is based in location technics

5) With the proposed approach objects will have an enriched representation and thus be identified with more confidence and matched with better accuracy.

With this in mind we will extend the sensorial information to the five senses, or at least enable that potential, also associating emotions textually expressed or device captured.

The primary goal is to facilitate better knowledge management by enabling different types of information representation and extraction based in sensorial and emotional tagging.

It is important to notice that it is frequent to find research work on knowledge management for business and for its benefit, not so often we could find information about personal knowledge management. As a contribution corollary we would like to improve the knowledge management conditions for humans inside the enterprise ecosystem, that would be an extended benefit for people to have a better understanding, in terms of knowledge interoperability, work adequacy and thus personal satisfaction.

2.3. Doctoral Research Approach

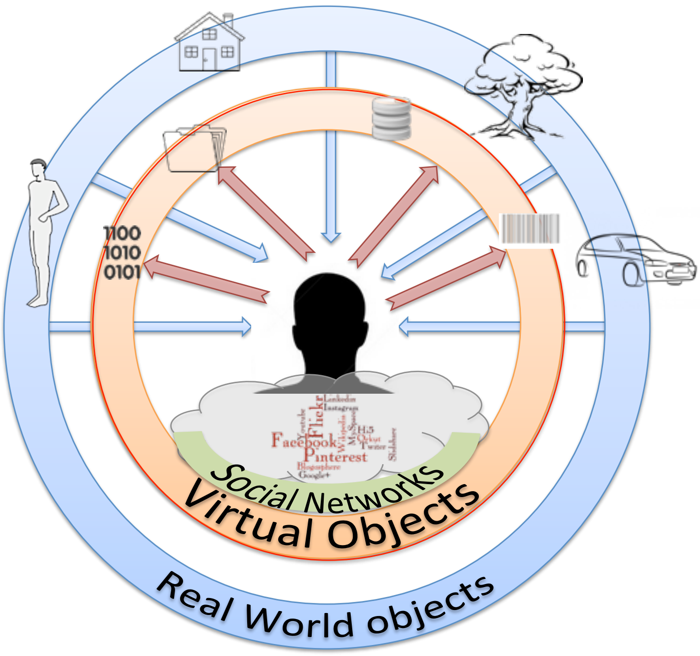
Research studies depart from the observation that the richness of the real world is perceived in a limited manner by humans that, later will try to reproduce by files with pictures, sound or textual information, in information systems and particularly on those based in the Internet. Figure 2.2 presents how people get a vision of the real world constrained by the limits of sensorial experience and will try to create representation, self-expressed or captured by proper devices (e.g. movie cameras, photographic cameras, microphones) and by textual representations.

The approach of the present research work is to understand how humans capture information from the outside, how they handle that information and ultimately learn lessons from the brain's knowledge management and apply to computer based systems, as in the Internet.

The approach intents to respond to some legitimate questions that we can pose in our lives in this paradigm shift from a so-called conventional way of living to an environment littered by connected devices.

We can summarise the approach question in: what is the relationship between such a world and the real world, what is our place in this Internet/Human/Real Worlds and how can we benefit from an Internet based pervasive computing environment of smartphones IoT and wearable devices?

Figure 2.2 presents a schematic view on how those worlds relate.



Real world (blue) provide a rich variety of information for living beings or inanimate objects. We capture that information with the limitations of our senses making our mental assessment of reality. After we can make representations, at the Internet, as virtual objects, with descriptions, image, sound or other files generated by devices (orange). Recently social networks (green) gave another dimension to representations by enabling shared images, or other conceptions, enriching object's context and description.

Figure 2.2 – Real world and representation of virtual objects

Envisaging this approach, research walks around the borders of three main research areas (e.g. Computer Science, Social Sciences, Medical Sciences related to structure and function of nervous system and brain), and, because of that, launches insights into the other areas providing new visions for older questions. The consequence is a spiral of research topics, but also, of new paradigms and new research opportunities. Thus the consequence of this fruitful entanglement of research areas is the need for a disciplined view over the research questions and consequently to establish borders that promote a deployment of the hypothesis towards solid outcomes from this research work.

The observation of current challenges and technological trends in such research areas can generate diverse questions, which must be contained into tangible problems with an identified scope of influence.

In face of such challenging questions over the borders between, sometimes distinct, areas may suggest an exercise of observing the actual trends in those technologies and think about what evolutions can emerge and what is their relevance for humans.

Information is growing at a fast pace and there is an overload of information available that is not optimized for a person's usage. There is a limited offer in terms of human sensory information, disregarding some or our sensory aptitudes (e.g. smell, taste, touch), then *how can information systems and knowledge management be improved, from the understanding of how we perceive the world with our senses?*

Technological devices are able to collect human related data (e.g. physiological from wearable devices) which are used for immediate purposes and lack in consistency with data models thus are limited in its potential use (e.g. relating physiology and emotions), then *how can humans benefit from an extended representation of objects, in information systems, which include sensations, physiology and emotional tagging?*

Individuals are using devices that are becoming more proficient in capturing sensory and physiological information with little usefulness to them, then *how can computer systems better address our needs, based on human knowledge, by promoting improved context-awareness?*

Those statements and questions imply motivation to find answers and a series of guidelines of thought for looking for answers by following the research methodology addressed in Chapter 2 where the Research Plan is presented.

Considering the identified gaps, the research work will address solutions that progress beyond some of those limitations on current technology. It is intended to support new technological deployments, taking advantage from the most recent technologies that exist or are being developed (e.g. sensors that are being developed for new smartwatches). In this work we converge towards a human oriented knowledge management framework, but also to establish ground for future research work advancements that foreseen the inclusion of sensory devices that are not available yet (e.g. devices to capture flavours and odours).

Next in Section II, the scientific areas with relevance for the present research work are presented in an objective Literature Review. In a sequence of research areas organized in five chapters, we aimed at debating relevant aspects for this Dissertation in order to establish a solid background that can support the understanding of the work developed and hereby reported.

SECTION II - LITERATURE REVIEW

The research path for this dissertation can be summarised as a route from the lessons learned over an insight on brain handling of sensations and emotions to the conception of a framework for knowledge management, passing through the existing areas that overlap computational performance and human knowledge. A primary objective of the background observations is to identify hypothesis on the brain's behaviour that can be applied to a human-oriented management of information in a new environment of Internet and mobile applications. In order to accomplish such goal, priority was given to the capture and management of information from the brain along with a concern on how to develop a computational handling of sensorial and emotional information. Then becomes necessary to converge to models based on acquired information. A strategy was designed with the purpose of applying lessons learned to the handling of knowledge in a computational environment. In effect, this would result somehow in a "technology transfer" from the brain operational models to computational knowledge management. In between, the conceptualization of such a framework is the identification of areas where computation meets sensorial information and the handling of knowledge. Those areas are presented from Chapter 3 to Chapter 7 and establish the background information needed to support the research work developed as presented next in the next Figure depicting an overview of the research areas and sub-areas.

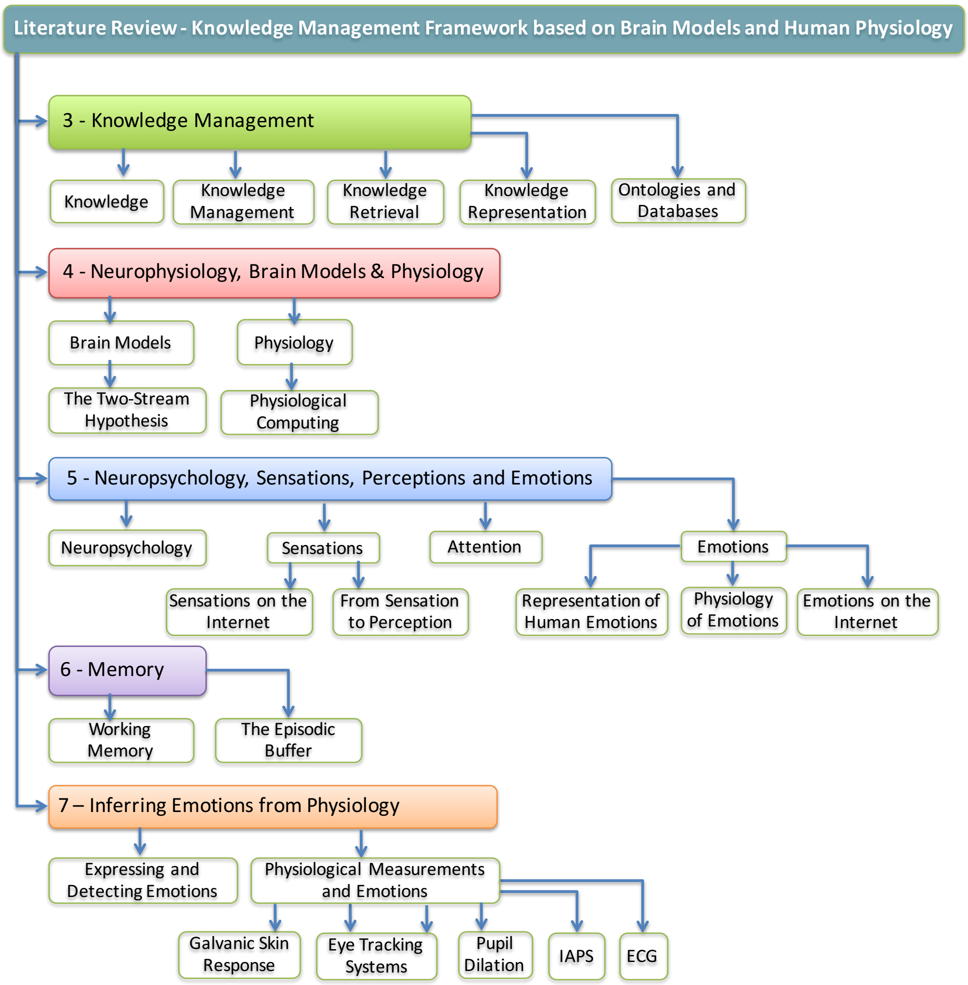


Figure II.1 - Literature Review with research areas and sub-areas

As depicted in Figure II.1, main research areas start with *Knowledge Management*, that is the ultimate goal of this thesis, to create better management of objects enriched with sensorial and physiological information but also to propose new forms of reasoning based on physiology and lessons learned from the brain. That is why we start by studying knowledge, its capture and representation all complementary aspects if we aim towards better knowledge management. Then it is explored Neurophysiology brain modes and physiology in order to learn about some aspects of our body that help on the sensorial assessment and in particular, trying to learn with selected models of the brain. *Neuropsychology, Sensations Perceptions and Emotions* is a research area that can be studied like a flow, in similarity with the input flow of information from the outside to our cognitive processes, it starts by sensing the world then trying to perceive information in context and in an higher level, to deal with the emotions as the ultimate reactions in the process. Neuropsychology is presented as the main hat then follows sensations and from that to perceptions and triggers the other cognitive functions (e.g. attention, reasoning, memory). Attention, due to its importance in our knowledge gathering, comes next and finally, in this chapter the emotions and how to represent them. *Memory* is detached from Neurophysiology and Neuropsychology as memory is related with both in terms of location of memories and the process of memorizing. Memory us importing in terms of how we store information, how we recall it and what is the role of memory in our knowledge management. Finally in *Inferring Emotions from Physiology*, we want to observe what is considered the upper level of human related knowledge management. Emotions cannot be directly measured as they relate with our feelings towards persons or situations. We can indirectly try to understand emotional states and that means to seek for physiological measurements and, from there, to infer emotional states. As that would be the corollary of the study on human related knowledge management, that area will also be object of study validation chapter of the present dissertation. The section on Emerging Research Areas is a transition chapter in literature review, as it represents some of the research areas that can contribute to or can benefit from the advancements developed in the scope of the presented doctoral research work.

3. KNOWLEDGE MANAGEMENT

This section makes the introduction to knowledge aspects, presenting the long journey of human thinkers in search for an understanding about what is human knowledge and how formerly specialisation on the topic come to its subdivision. Then related with the interest for this PhD research work, Knowledge Management is presented in section 3.2. Knowledge Management has some following sections that relate to knowledge those are Knowledge Retrieval and Knowledge Representation.

3.1. ON KNOWLEDGE

Knowledge has been a challenge for philosophers and scientists in the most diverse scientific areas. As more and more information and knowledge is created and technology develops rapidly, the world has become more knowledge-oriented [31]. Pursue of understanding is one of the most human characteristics that makes us different from all other animals. When the theme of research is knowledge, whatever the direction we follow, in a short path we reach the conclusion that dozens of thesis would be necessary to cover some of the related aspects. In order to be tangible, we defined a root to first understand what the concept covers and what most important scientific text we can find about knowledge.

First we try to know what knowledge means, a tricky questions that has the aspect of recursive iteration. However it is quite easy to associate knowledge with pursue of truth and from that point of view knowledge is an endeavour of the mind.

Socrates defends that virtue is knowledge, that vice is ignorance, and that no one does wrong knowingly [32]. In philosophy, the study of knowledge is called epistemology. In 1959 Druker coined the term knowledge worker as a person who gets paid for putting to work what one learns in school, which in the end of the 20th century become half of the American labour force [33]. He also affirms that knowledge is all and that the next society will be a knowledge society and knowledge will be a key resource [34]. For Toffler knowledge is a decisive competitive advantage and, rather than military strength or capital, knowledge is the essence of power in information age [35]. Devenport states that Knowledge is information combined with experience, context, interpretation and reflexion. He adds that knowledge is a high-value form of information, ready to apply to decisions and knowledge [36].

Scientific knowledge, in Popper’s words, bases the knowledge on experimentation and validation but he also states that some theories are so vague that cannot be put to test, he points out as an example, some astrology theories [37]. He also states that myths may be developed and become testable as historically speaking, all, or very nearly all, scientific theories originate from myths, and that a myth may contain important anticipations of scientific theories.

Knowledge can be implicit or explicit, those are unavoidable concepts associated with knowledge and the way humans retain handle or transmit knowledge. Tacit knowledge is subjective and, as experience based knowledge, which cannot be expressed in words, sentences, numbers or formulas, often because it is context specific. This also includes cognitive skills such as beliefs, images, intuition and mental models as well as technical skills such as craft and know-how. Explicit knowledge is objective, and rational, and it is knowledge that can be expressed in words, sentences, numbers or formulas (context free). It includes theoretical approaches, problem solving, manuals and databases [38]. In another perspective, tacit knowledge is the knowledge of the subconscious which is something done automatically without almost thinking. This type of knowledge is difficult to extract and elicit due to the knowledge engineering paradox. The more expert one is, the more compiled the knowledge, and the harder it is to extract this knowledge and formalize it in a knowledge repository. Explicit knowledge is another type of knowledge that is more obvious and can be more easily documented. Internalized knowledge is how the explicit knowledge is internalized, shaped, or influenced by one's own views and therefore may take a different form from one person to another [39].

The New Zealander Ministry of Economy Development, in 2004, expressed in a concise summary what are the skills needed to function productively in a knowledge society: “Know-why and know-who matters more than know-what. Know-what, or knowledge about facts, is nowadays diminishing in relevance. Know-why is knowledge about the natural world, society, and the human mind. Know-who refers to the world of social relations and is knowledge of who knows what and who can do what. Knowing key people is sometimes more important to innovation than knowing scientific principles. In addition know-where and know-when are becoming increasingly important in a flexible and dynamic economy.” [40]

Maryam and Leider go beyond those two concepts and present, in Table 3.1, selected knowledge concepts and their implications [41]

Table 3.1 - Knowledge Perspectives and their Implications

Perspectives	Definitions	Implications for Knowledge Management (KM)	Implications for Knowledge Management Systems (KMS)
Knowledge vis-à-vis data and information	Data is facts, raw numbers. Information is processed/interpreted data. Knowledge is personalized information.	KM Focuses on exposing individuals to potentially useful information and facilitating assimilation of information	KMS will not appear radically different rom existing IS but will be extended toward helping in user assimilation of information
State of mind	Knowledge is the state of knowing and understanding	KM involves enhancing individual's learning and understanding through provision of information	Role of IT is to provide access to sources of knowledge rather than knowledge itself
Object	Knowledge is an object to be stored and manipulated	Key KM issue is building and managing knowledge stocks	Role of IT involves gathering, storing and transferring knowledge
Process	Knowledge is a process of applying expertise.	KM focus is on knowledge flows and the process o creation, sharing and distributing knowledge	Role of IT is to provide link among sources of knowledge to create wider breadth and depth of knowledge flows
Access to information	Knowledge is a condition of access to information	KM focus is organized access to and retrieval of content	Role of IT is to provide effective search and retrieval mechanisms for locating relevant information
Capability	Knowledge is the potential to influence action.	KM is about building core competencies and understanding of strategic know-how	Role of IT is to enhance intellectual capital by supporting development of individual and organizational competences

The presented view shows different perspectives that range from the facts and data to the state of mind of an individual. Knowledge can also be seen as an object that can be stored and manipulated but can also be a process of applying an expertise.

The questions raised by such a range of knowledge archetypes establishes challenges for representing and using knowledge as it can assume different forms and supported either by individuals or diverse types of media.

Data in different forms can be used to generate information that can generate knowledge from which some wisdom can emerge. In fact, quantitatively it can be expressed as a pyramid or simplified in a triangle with different weights from bottom to top.

The question about the triangle with Data, Information, Knowledge and Wisdom (DIKW triangle), was first proposed by Cleveland [42]. And later Bellinger made his interpretation stating that understanding relations between Data generates information, understanding patterns of information generates knowledge and understanding principles from knowledge creates wisdom. That corresponds to an evolution on context independent assessment and better understanding [43]. Both conceptualizations are presented next in Figure 3.1.

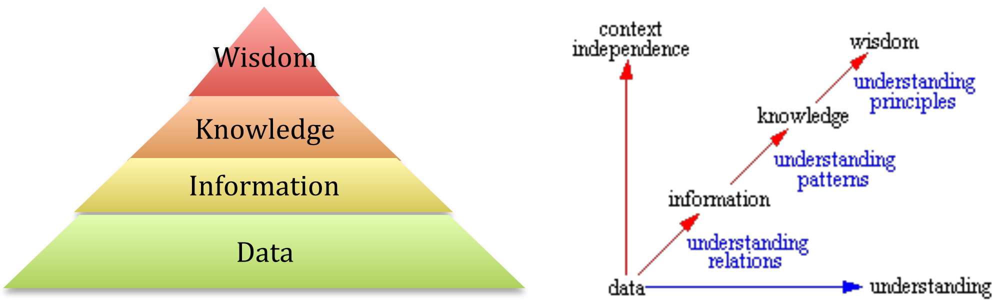


Figure 3.1 - DIKW Triangle (left) Interpretation of DIKW (right)

The DIKW triangle conceptualization proposes a hierarchy that entails a vision of continuity where data, in the base of the triangle is the result of research, creation or some other gathering. Then information has context and results from organization making possible to draw conclusions. Knowledge has the complexity of experience and is a dynamic result from different views about information along with our personal experience.

The term "cognition" refers to all processes by which the sensory input is transformed, reduced, elaborated, stored, recovered, and used. It includes processes such as memory, association, concept formation, pattern recognition, attention, perception, problem solving, mental imaginary, etc. [44].

Knowledge is not built from perception, at least not directly. Based on humans' percepts, they build schemas and mental models, which sometimes could be semantically "far" away from the perceived statement. In this case, perception only triggers the knowledge formation.

The generation of new knowledge often requires substantial investment in research and development [45]. Knowledge has the complexity of experience, which comes about by seeing it from different perspectives [46]. Finally wisdom is the ultimate knowledge of understanding but it depends on a personal understanding. Knowledge can be transmitted and contribute to wisdom but that would be referring to the person's unique understanding.

However some authors defend an opposite hierarchy [47] where data emerges only after we have information, and that information emerges only after we already have knowledge. In what regards to the same conceptualization applied to a person, this view evokes the effect of bias in human perception. Thus in this line of thought, when we consider human knowledge acquisition, it is important to consider a "personal context" that makes the same source to produce different effects in the knowledge construction process for different persons. Regarding this observation, the role of emotions (along with experience and motivation, has a role on the knowledge acquisition process, establishing a bridge between knowledge and emotion that should be considered for different activities and different environments (e.g. learning, research, training).

3.2. Knowledge Management

The main objective of knowledge management is knowledge innovation [48]. That means that we need to seek for new applications for existing knowledge and reconfigure knowledge so that it can be useful for new objectives.

Knowledge management (KM) refers to, the overall process of activities affecting, knowledge: creating, capturing, identifying, organizing, storing, representing, transferring, and reusing knowledge [31].

Knowledge management papers and articles in computer science area are centred in knowledge management for companies and for people, alone or networked, at company level [49]. That is the case of Ikujiro Nonaka and his knowledge creation company [50] and his concept of Ba [51], extensively cited in knowledge management literature (e.g. 29.772 cites, 14.624 cites, etc.). But the importance of such concepts, from the human side, is widely debated in social sciences [52][53][54] but not so broadly covered in computer science research documents.

Most of the essays and publication in knowledge management focus on enterprises and supply chains, however we should consider the relevance of the human factor in the process, which is not linear as we come to conclude. In a more generalist view of KM, the before mentioned authors [41] establish a table with the taxonomy of knowledge types, exemplifying some of the above-mentioned concepts, at different levels, and how those definitions can be found in different contexts, either for individuals or companies.

Knowledge Types	Definitions	Examples
Tacit	Knowledge is rooted in actions, experience, and involvement in specific context	Best means of dealing with specific customer
Cognitive tacit:	Mental models	Individual's belief on cause-effect relationships
Technical tacit:	Know-how applicable to specific work	Surgery skills
Explicit	Articulated, generalized knowledge	Knowledge of major customers in a region
Individual	Created by an inherent in the individual	Insights gained from completed project
Social	Created by an inherent in collective actions of a group	Norms for inter-group communication
Declarative	Know-about	What drug is appropriate for an illness
Procedural	Know-how	How to administer a particular drug
Causal	Know-why	Understanding why the drug works
Conditional	Know-when	Understanding when to prescribe the drug
Relational	Know-with	Understanding how the drug interacts with other drugs
Pragmatic	Useful knowledge for an organization	Best practices, business frameworks, project experiences, engineering drawings, market reports

Table 3.2 - Knowledge taxonomies and examples

Thus either for individuals or companies, to properly address the circumstances of those different types of knowledge it is important to consider the human factor along with the information systems used to retrieve and store knowledge. When knowledge is explicit all it takes is the usage of technical tools to design proper dictionaries, thesaurus or ontologies [55]. Then it is important to consider the human factor, what the brain and physiology tells us and look for innovative ways of acquiring and managing knowledge. This path must consider personal context and other approaches to support knowledge related to different individuals and their personal experience. The present research in this PhD program looks for other opportunities that can enrich personal knowledge by considering relevant human aspects, in a broad sense, when using information systems.

3.3. Knowledge Retrieval

Knowledge acquisition involves complex cognitive processes: perception, communication, and reasoning; while knowledge is also said to be related to the capacity of acknowledgment in human beings [56].

Human knowledge depends on reasoning, based on previous knowledge and information acquired from many sources. The process of interacting with the external world and thus gaining new insights is supported by our sensorial capacities provided by our sensorial organs. In computational systems, diverse query methods can be used according to how data structures where created and according to the structure of databases and query languages. On the other way, for the Internet, search engines are the most used service when looking for information to feed our need for input and provide the expansion of our knowledge [57].

We can consider the capture of information as a generalist process where information is always growing or a target action driven by a person's need. In computational terms, it can be seen as two faces of the same coin that are the retrieval of information for personal usage or for an entity and the other face is the retrieval by itself to information systems (IS), with or without a specific purpose. Sensors in buildings in the street or in wearable devices can acquire information. That information can be selectively captured, as would be the case for wearable devices, but can also be retrieved without a specific reason or a specific target user[58].

3.4. KNOWLEDGE REPRESENTATION

Knowledge can be represented in many different supports and not necessary hard written in some place. Knowledge can be expressed in many ways as humans can talk, move, dance or even express facially accordance or disagreement. In what regards to computer science it becomes necessary to look for formal ways to represent knowledge so that it will be understood by following the rules. That does not underrate human ways of representing knowledge as less efficient, but instead heads an effort to make it possible to hardcode in computer language and store in useful databases [59]. That is one aspect to consider, another aspect is that for a computer system, in analogy with human perception, the environmental conditions are not acquired, as happens for humans. Observing and learning (e.g. in gesture, expressions, text or sounds) make possible for humans to capture the environment and the other persons attitudes and motivations, those are aspects that would be desirable to have in robots and computer systems. Aiming at those goals computer scientists developed tool like improving computer vision and tools for understanding text and sounds. The later ones are based on ontologies, semantic analysis and other linguistic formalisms. The objective is to promote the development of tools that handle human language, address human needs for storage and transmission of data and knowledge and, ultimately, to allow computers to handle knowledge and solve problems the way we do [60].

But the importance of understanding how knowledge is represented at the brain can bring research clues on how computer systems can benefit from the result of thousands of years of human evolution but can also bring added value for users. That comes from evidence that object properties are stored throughout the brain, with specific sensory and motor-based information stored in their corresponding sensory and motor systems [61].

In order to pursue new knowledge representation technics it is necessary to step on ground research on this area. We can determine a starting point in the understanding of how humans acquire information from the world and determine how to represent such knowledge. Data Models can define the structure of databases and its relations providing a support for knowledge. However the developments made towards the usage of natural language and the need of structuring knowledge, related with specific knowledge domains, has put in evidence the ontology concepts as potential tool for knowledge representation [62].

3.4.1. *Ontologies and Databases*

In order to represent knowledge it is necessary to look for methods to perform such representation as systematic and coherent as possible so that it became useful for the specified purposes. *Semantics* is the Greek philosophic study of the nature of meaning, especially as it is expressed in language. It is the study of the signification of signs and symbols [63] and is also the branch of linguistics and logic concerned with meaning [64]. *Ontology* is another branch of Greek Philosophy concerned with identifying, in the most general terms, the kinds of things that actually exist [65]. Epistemology is the branch of philosophy concerned with the methods and the validity of knowledge or knowing. Sometimes epistemology is defined as the theory of knowledge [66]. From the two concepts it is possible to infer that Ontology tells us what exists and Semantics tells us how to describe it [67] and Epistemology tells us how to find what exists and represent such truth in a way that becomes knowledge.

Ontology can be defined as an agreement about shared, formal explicit and partial account of a conceptualization [59], [68]. Gruber, in 1993, defined an ontology as explicit specification of a conceptualization [69]. Ontologies are also like conceptual schemata in database systems. A conceptual schema provides a logical description of shared data, allowing application programs and databases to interoperate without having to share data structures. While a conceptual schema defines relations on Data, an ontology defines terms which with to represent Knowledge. As Gruber states, one can think of Data as that expressible in ground atomic facts and Knowledge as that expressible in logical sentences with existentially and universally quantified variables. An ontology defines the vocabulary used to compose complex expressions such as those used to describe resource constraints in a planning problem [70].

In computer science we find databases as a solution to the need of consistent and usable data storage. Development of a database raises the need of a data model that can serve as base for such process. Lately, ontologies become another possible way to represent and manage data by using semantic concepts. The concepts of ontology and semantics are closely related.

A new concept, the Semantic Web [71], emerged recently with the need to handle ontologies in an Internet environment. The Semantic Web as imagined by Tim Berners-Lee, the inventor of the World Wide Web, is the first step in putting data on the web in a form that machines can naturally understand, or converting it to that form. This creates what he calls the Semantic Web that, in his words, is a web of data that can be processed directly or indirectly by machines [72].

Those are the paradigms to be addressed by knowledge retrieval technics; by one side how to retrieve information to the Information System and on the other side how a user or a system can acquire the information needed [21].

4. NEUROPHYSIOLOGY, BRAIN MODELS AND PHYSIOLOGY

In this Chapter a review is made on the physiological aspects of the human body that can inspire computer-based Knowledge Management. An incursion on Brain Models refers to the beginning of the present research work where the two-stream hypothesis acted as a departing point for managing information about objects the same way the brain, hypothetically manages such information. That is exactly the contents of section 4.1.1 where the two-stream hypothesis is observed on its implications. It is immediate that some study on Physiology is needed, in section 4.2 as Neuropsychology and Brain Models are specialized areas of human physiology. Finally at the end of this chapter, in section 4.2.1 Physiological Computing is presented, it is an area that has relevance for the on-going studies as it relates physiology with computation.

The competences of a system like the human brain and its examples of success in handling so many different functions of the human body makes it a source of inspiration for computer science. If we understand, even in high level, how the brain performs when handling incoming information, process it, store it and provide appropriate response we will be able to advance towards building more competent and efficient information systems. Present research includes the usage and adaptation of brain models for knowledge management, which includes learning how physiology handles input from the outside world.

4.1. BRAIN MODELS

The cortical area of the brain has about 10 billion cells in the human cortex and 60 trillion synapses ($60x10^{12}$) and the cerebellum has an estimate 100 billion cells each making up to 100 synapses onto cerebellar nuclear and cortical cells. These numbers are so large they lose meaning [73].

The brain has capacities that allow the handling of large amounts of information from different sources, to collect, process and later reproduce information. This remarkable processor should have diverse lessons to teach to technological counterparts. Thus it would be of interest to exploit what are the existing theories about the brain and the models that can be established with lessons learn from the brains physiology and psychophysiology as it encompasses not only physiological aspects. The attempts to model the brain are mostly partial and based on specific areas or specific functionalities to be observed. There is however lessons learned that are becoming consensual among the scientific community. That is the case of the Two-stream Hypothesis presented next in section 4.1.1. But there is more to learn from the brain, as is the case of the cognitive processes, (e.g. attention, in section 5.3, perception in section 5.2.2 and storing information on memory as mentioned in chapter 6). Another interesting aspect in on how memories, resulting from perception of external stimuli, are processed and managed, with a special focus on the episodic buffer presented in section 6.2. The concept of i-episodes, presented in several sections of this thesis (e.g. Section 10.2.1) is a clustering of information that resembles that of an episodic memory event.

4.1.1. *The Two-Stream Hypothesis*

Recent developments in technical instrumentation in the last century supported by skilled professionals have revealed much information about the physiology of the brain, many new theories raised from the information collected by electroencephalography (EEG), Magnetic Resonance Imaging (MRI) and its Functional specialization (fMRI). All that equipment can generate physiological data either by image or electrical signals, which researchers can analyse and theorise. However, the impressive amount of data acquired by all those devices can be, in some perspective, deceiving as there is no general theory of the brain and no universal model, even knowing that people's brain have been illustrated and photographed in recent years, documented in books [74][75][76]. Researchers in diverse fields have established diverse brain theories, some are based in neurophysiology studies [77], others related with behaviour and interpretation [78]. From the existing theories it is possible to select the ones we find relevant and try to apply them to knowledge information systems. In this scope the Two-Stream hypothesis gives us clues about how brain processes visual information. As mentioned before, on the Internet everything is mostly visual. We receive images that are formed in the occipital region of the brain [79], then according to the two streams theory. The Dorsal Stream goes from the occipital lobe to the parietal lobe and is known as the "where stream". The Ventral Stream goes from the occipital lobe to the temporal lobe and is known as the "what stream" [80].

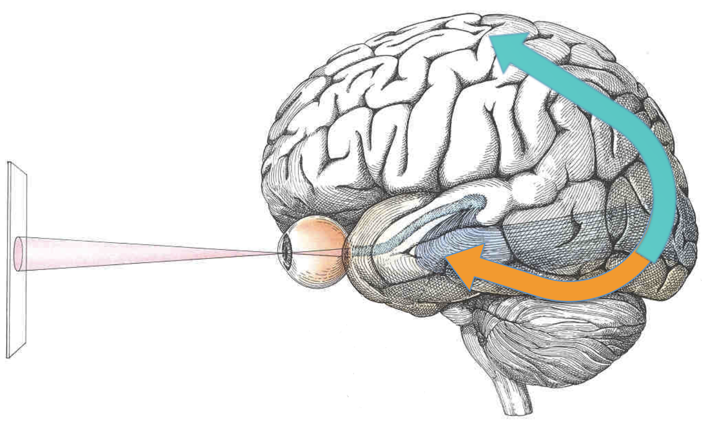


Figure 4.1 - Image at Visual Cortex triggering Ventral (orange) and Dorsal Streams (green)

Two findings are relevant in this hypothesis, first we notice that the brain tries to identify what is in the visual field mostly by comparing with memories or known records then we notice that the brain tries to give spatial context by establishing a sense of location to the visual information. This line of thought establishes a cognitive process that starts with images at the visual cortex. It follows that from the occipital region of the brain two streams of information follow a path through other regions of the brain where the same process of analysis and comparison to existing records is extended to other recorded sensorial information, thus empowering the what and where context findings. Interestingly Lauwereyns [81] goes further, he defends that rather than defining what is the "thing" that we are seeing, we evaluate the potential actual outcomes, asking "What does it mean for me?" or "What should I do about it?", as for the ventral stream, instead of seeing "where" it is, he sees that it leads to the questions on "How do I fix this?" or "Which is the best way to go there?". This vision confirms the value of the model and adds the evaluation of our present circumstances and its influence on what to decide next and what activities we should perform to be successful. Tom Wujec [82] in syntheses selects three ways the brain uses to find meaning in the ventral-stream, the dorsal-stream and limbic system that weighs the feelings we have towards that same stimuli. In observing those processes driven by human brain, we can evaluate its relevance for knowledge management and adopt lessons learned towards the improvement of information systems. By reasoning on those ways to provide meaning and aiming at developing better human centric knowledge management systems, we can produce the following assumptions: i) the "what" is a starting point but should be more then visual identification, ii) the "where" should be more then establishing a place for an object in a scenario and iii) we should perceive what is the emotional attachment of what we see or what feelings does it bring. But if the Two-stream hypothesis relies on the "what" and "where" of an object or a scene we are facing in a given circumstance, it is important to have information about the "when" of such circumstance. Because if we want to have knowledge management based on a human-like assessment, we would like to retain as much episodes as we can, The more episodes and most complete, the better our information system will become. So in order to address those questions we need to look to memory in order to learn about the "how" new objects are stored, including those who compose scenes or events and even conceptual objects that exist in our mind without a physical counterpart. That way we need to understand how memories are created and what temporal relationships are established, the "when" factor that introduces time to our storage process. Those issues are of relevance for the present studies as the data model, defined in 0 where different types of information is considered so that the model can address all the above conceptions that characterize an object a scene or a conception of mind.

4.2. Physiology

Physiology is defined as a branch of science dealing with the study of normal functions of living organisms. Human physiology is concerned with the study of normal functions of the human body. In order to rationalize the abnormalities in various deceases, it is essential that one must be very well conversant with the normal functions of the different organs and structure in the body. Hence the practical importance of study of physiology [83].

It is possible to find early roots of physiology since there was an interest in observing the inside of human body. Aristotle[1] is pointed as one of the first to produce insights into human anatomy and physiology [84][85] but Andreas Vesalius[2] with *De humani corporis fabrica* [86] is often pointed as the founder of modern physiology since he criticized Galen[3] by conducting studies only on animal physiology. Curiously, Hippocrates[4], considered the father of western medicine, knew almost nothing of human anatomy and physiology because of the Greek taboo forbidding the dissection of humans [87]. In that matter, later, Leonardo da Vinci[5] was authorized to dissect human corpses at Italian Hospitals producing over 240 detailed drawings and written work contributing significantly to knowledge in anatomy in the sixteen century.

The objective of human physiology, as a science, is to pursue explanations for the specific characteristics and mechanisms of the human body that make it a living being. The very fact that we remain alive is the result of complex control systems, for hunger makes we seek food and fear makes us seek refuge. Other forces make us look for fellowship and to reproduce. Thus, the human being is, in many ways, like an automaton, and the fact that we are sensing, feeling and knowledgeable beings is part of this automatic sequence of life; the special attributes allow us to exist under widely varying conditions [88]. In order to evaluate physiological state, there are ranges of non-invasive devices that provide image or data for specialist evaluation. Among those, EEG, ECG, CT Scan, MRI, fMRI and PET provide valuable information or image from the brain or the heart, from other organs or the whole body. However those devices need to be in a room as

[1] Greek philosopher who lived c. 384 to 322 BC.

[2] Latinized form of the Dutch Andries van Wesel, lived from 31 December 1514 to 15 October 1564.

[3] Claudius Galenus, ancient Greek who lived from AD 129 to AD 200

[4] Ancient Greek physician who lived circa 460 to 370 BC

[5] Leonardo di ser Piero da Vinci, lived from 1452 to 1519.

some are big, and heavy, structures to be held in specific medical installations (e.g. CT, MRI, fMRI and PET). But there are other types of measurements that can be performed with small portable devices (e.g. Holter for portable ECG) that are already in use for the medical practice. Holter is a portable device that can be used to perform a continuous ECG being the measurements recorded internally for posterior analysis. With current technology it is not difficult to propose lightweight solution for this type of measurement [89] including applications that take advantage of our smartphones [90]. Then it becomes an interesting task to look for existing devices, or develop new ones, that are able to perform physiologic measurements or applications that make use of existing devices for the same goal.

In some aspects related with the current work, physiological measurements could be useful for the assessment of emotions. Those measurements could be blood pressure, breathing, digestive system activity, psych-galvanic reflex measurements and adrenalin in the blood stream [91]. Another type of measurements that could be used for emotional assessment, related with physiological aspects but in a less direct form are the facial expression, gesture, vocal expression and behaviour [92]. One type of evaluation that has a body of followers is the usage of facial expressions to perform evaluation on emotions [93], others are included in the growing market of fitness bands [94] [95] [96] that allow the measurement of body gestures and activity.

In summary, physiology can provide most relevant data and information about our body's activity and our emotions and feelings. There are devices and applications in the market that can be used to continuously perform physiological measurements. Those readings could be used for determining a person's state in what regards of health status (as an advice because most of those devices are not medically certified), behaviour and emotions, which are of great relevance in the context of the present research work. Since we are looking for acquiring information for generating and managing knowledge it becomes necessary to understand how humans acquire input from the external world [97]. That input consists mostly in sensations captured, by our sensorial organs, which we need to study and learn from their physiological implications. It becomes important to know what is the state of the art on such processes and, as presented in the next section, what computational devices can be used to get information from human body.

4.2.1. *Physiological Computing*

Physiological computing represents an innovative mode of Human Computer Interaction (HCI) where system interaction is achieved by monitoring, analysing and responding to covert psychophysiological activity from the user in real-time [98]. Psychophysiology is the study of relations between psychological manipulation and resulting physiological responses, measured in the living organism, to promote understanding of the relation between mental and bodily processes [99]. In practice, psychophysiology is concerned with the measurement of physiological responses as they relate to behaviour [100]. In that sense if we to inform the computational devices or applications about what current psychological state we need to perform a psychophysiological assessment, consisting in physiological measurements and consequent inference on psychological indicators. That is why it is arguable that the design and research efforts of ubiquitous, pervasive, and collaborative computing are converging to manifest the future of computing as: wearable, personal, and sympathetic [101]. In that sense, studies defend that the development of electrophysiologically interactive computer interfaces will enable the creation of truly personal computers: systems that read and understand their users' signatory physiology. This will improve our interaction with machines as well as help us learn more about our psychophysiological selves. Combining computing with physiological sensing technologies will transform human machine interaction and usher in a wide range of new applications [102].

Physiological computing has wide implications as computer based systems become pervasive and human computer interaction become the norm rather than the exception. Thus the physiological computing approach provides means for monitoring, quantifying and representing the context of the user to the system in order to enable proactive and implicit adaptation in real-time. This approach delivers not only a means of monitoring the user, but also a method for assessing the impact of an adaptive response on the user. Such reflexive quality of physiological computing provides means by which the system may contribute to an adaptive response to the preferences of the individual user. Physiological computing does not only enable a computer system to adapt in a smart way, it also provides a means by which the system can learn about the preferences of the user [103].

Physiological computing addresses a problem that can be seen by the following prism, while a computer informs about its internal state (e.g. memory usage, running service, processor temperature) while the user provides little information about himself (e.g. emotional state, thoughts and motivations), in fact an asymmetrical relationship [104]. The absence of context provides little opportunity for the computer system to adapt in a dynamic fashion to the fluid, idiosyncratic needs of the user, a state of affairs that has led some to describe conventional HCI as two monologues rather than a dialogue. The realisation of a symmetrical HCI, where the computer system is aware of covert and overt behavioural cues from the user, is a prerequisite for the development of adaptive systems that are capable of responding to the needs of the user in real-time [105].

5. NEUROPSYCHOLOGY, SENSATIONS, PERCEPTIONS AND EMOTIONS

This Chapter explores the aspects related to the cognitive functions of the brain. It presents the process of information gathering and analysing information from the outside. It has to do with the handling and processing of such information, with corresponds to an upper layer relatively to the physiological layer. The first section of this chapter, 5.1 Neuropsychology, makes the introduction to this research area that will further be explored in specialized areas, starting by the acquisition of information from the outside, in 5.2 Sensation, that has a subsection with the focus on sensations in the Internet, how they can be retrieved and managed, 5.2.1 and another on the cognitive processes that lead from sensation to perception, in 5.2.2. Attention is the object of study in section 5.3 by its relevance in how we select what stimuli to capture integrated and managed. Finally Emotions are study as an high-level cognitive process that for the present research purposes it is needed to be represented, as discussed in 5.4.1 and for the current research, they need to be managed in information systems as in the Internet or in connected applications.

5.1. NEUROPSYCHOLOGY

Neuropsychology studies the structure and function of the brain as they relate to specific psychological processes and behaviours. In another definition, Neuropsychology is a science concerned with the integration of psychological observations on behaviour and the mind with neurological observations on the brain and nervous system [106].

Neuropsychology is in fact the study of brain-behaviour relationships. The methods on which this discipline is founded are broad and belong to a crossroad of the neurosciences, which include neurology, neuroanatomy, neurophysiology, neurochemistry, and the behavioural sciences, which include psychology and linguistics [107]. A particular branch of Neuropsychology of reference to the current work is the study on how the brain retrieves knowledge and how that process influences our behaviours. Cognitive neuropsychology is a branch of cognitive psychology that aims to understand how the structure and function of the brain relates to specific psychological processes. Cognitive psychology is the science that looks at how the brain's mental processes are responsible for our cognitive abilities to store and produce new memories, produce language, recognize people and objects, as well as our ability to reason and problem solve. It is within the scope of neuropsychology to study how the brain uses the external stimuli to increase knowledge and consequently to influence our behaviour. Thus for computational systems it is of relevance to look for how such processes occur within the brain. That study can be performed at a lower level in trying to figure out how neurons establish their networks and, eventually, how dendrites and axons connect to each other. Neural networks are an adaptation of that knowledge from an engineering perspective [108] however that lower level approach is used for systems and programming but is of less usage for the analysis of the cognitive processes from a perceptual point of view. Next we need to understand how, in the first place, we capture information from the surrounding environment and that take us to the sensorial organs as presented in the next section.

5.2. SENSATION

Sensing an evaluating the surrounding environment is a survival strategy that we share with most of animals. Beyond basic needs, humans sense the world as a need to acquire information and to choose the best way to act. How we perceive the world is our interpretation of sensorial experience, which makes our sensorial organs, in a broad sense, the informers of the brain so that it can regulate our activity and produce the best decisions. In the long past we perceived danger, we protect ourselves and we survive in a close dependence to the information gathered by our senses. Today even with current technology we still depend on our sensorial experience and that applies to daily routines but also to real danger as to cross a street in the middle of traffic.

The nervous system, and the brain, use memories along with the information gathered from sensorial organs to evaluate the outside world and to enrich its own knowledge. From a rationalist point of view it is said that senses provide data to the mind, it is the mind alone that imposes order on what is perceived, and thus gives us knowledge [109].

A human being perceives the world through all his senses simultaneously. The information potentially available is immense. In man's daily projects, however, only a small portion of his innate power to experience is called into use. In modern society man comes to rely more and more on sight [110]. People with full sensorial capacity use vision for most of the tasks assigning a secondary role to the other sensations, unless the specificity of a given activity demands other approach. When using technological devices (e.g. computers, TV, videogames) vision has the major prevalence of sensorial stimulation, for two main reasons, one is the level of detail we achieve with our eyes and the other is the major offer in terms of contents. The devices we use every day are, no doubt based on our visual capacity, from handwriting to TV, gaming and even driving cars, all depend mainly in what our eyes detect and communicate to the brain. Audition is also a sensorial experience with a wide range of stimulation, from music to movies, series and games soundtracks. But we also taste, smell and touch whenever possible. Those sensations complete our sensorial experience and if it is true that they are retrieved along with the visual experience, they are also stored in a related manner so that we can later recall them back and relate with present experience [111].

In Figure 5.1 are depicted the brain areas related with each of the five main sensorial functions. Specialization areas are identified and represented in anatomy books [80]. As we can see in the next figure, there is a correspondence from each sensorial organ to a region in the brain and that has two analogies in technology. The first analogy is that different flows occur for different organs, as it will append with different capturing devices and their storage in information systems or at the Internet. The other is that there are different regions of the brain doing the processing of that information, as it will append with dedicated processing of sensorial devices. Then we can question why not to aggregate that information, as the brain does? This is a central question for this thesis.

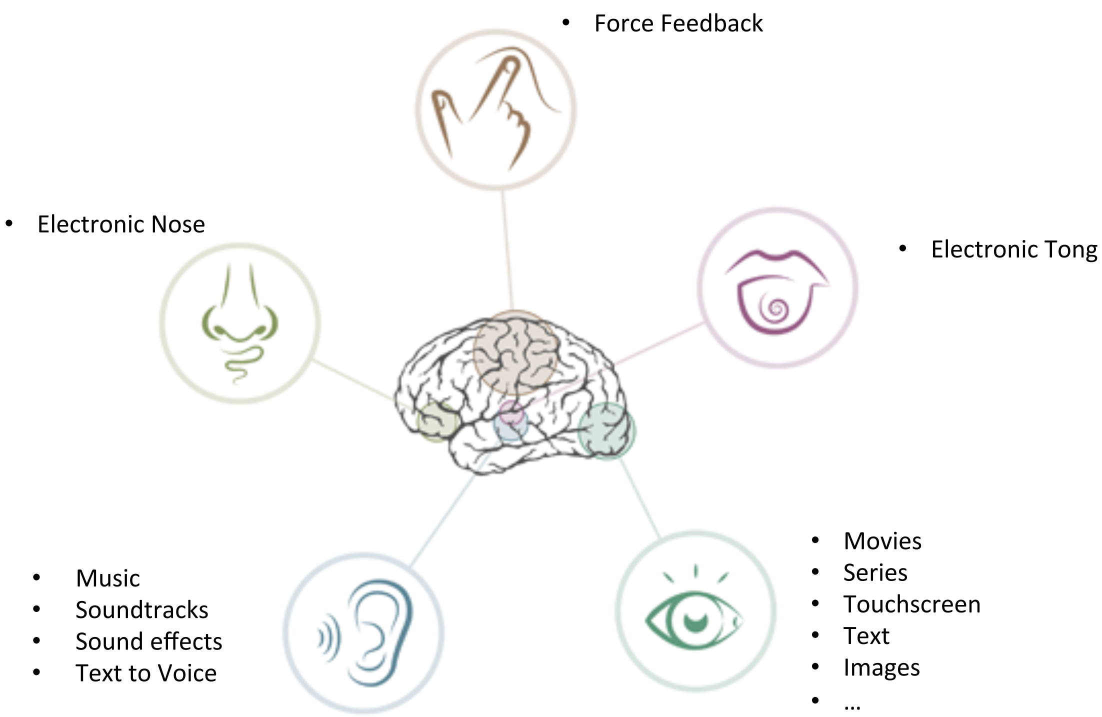


Figure 5.1 – Examples of sensorial experiences and its relation to specific regions of the brain[6]

The importance of the sensorial organs is extended by the connections established to the brain and how the information flows, as it is captured by sensorial organs, and is routed to specific areas of the brain. In our brain, according to the two-stream hypothesis, we receive a visual stimulus at the visual cortex that follows two paths: the ventral stream (to the left arrow) and the dorsal stream (to top arrow), as shown in Figure 4.1. Those streams use previous information to identify what we

[6] http://www.mindnasium.com.au/research-evidence/#neuroplasticity-brain-plasticity-and-ageing

see and where it locates [112]. The ventral stream tries to identify "what" we see in comparison to what we already know and the dorsal stream identifies "where" it belongs. The same hypothesis is being considered for the auditory stream as Hickok and Poeppel defend a dual-stream model of speech processing, whereas ventral stream processes speech signals for comprehension, a dorsal stream maps acoustic speech signals to frontal lobe articulatory networks [113]. It is also possible to find a panel of experts that extend the discussion to other areas as attention, music, memory calculation and the motor system [114].

It is important to dedicate attention to the value of smell detection as it has multiple useful roles. It influences emotional states, i.e. enthusiasm or attention. As can be seen in Figure 5.2 the olfactory cortex connects to the limbic system with the amygdala and hippocampal complex, structures that have an important role in emotions. The sensation of smell allows the control of food purity by word or warning beside bad food after remembering its association with unpleasant odours and it activates salivary and gastric emissions in response to pleasant odours.

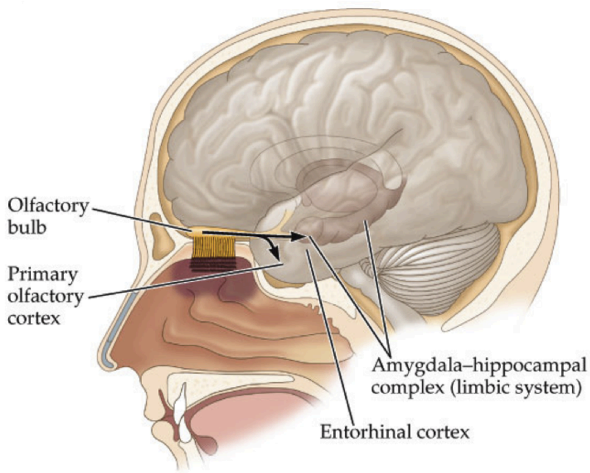


Figure 5.2 - Olfactory system and its connections to limbic system[7]

Taste and smell are highly associated with each other and favours are highly associated with each other, and flavours are composite sensations derived from primary taste and smell sensations by processes within limbic brain areas that participate in emotion. The human emotional system emerged in evolutionary terms from the olfactory brain of earlier animals and remains closely liked to taste, smell and eating behaviours [115]. Thus with such similarities with smell and without a proper way to represent taste, beyond its linkage to smell molecules, it can either be

[7] https://sciencefiles.files.wordpress.com/2014/09/olfactory-bulb.png

represented in the same way as smell, with molecular description or with textual tagging related to known flavours (e.g. sweet, sour, salty, bitter and umami).

5.2.1. *Sensations on the Internet*

We usually believe that our sensorial perception is a reliable source of beliefs about the environment [116] but it is also important to notice that from a computer's point of view perceiving a scene is more difficult than playing world championship chess [111]. Thus the strategy is to deploy such sensorial information about an Internet object/media in a manner that when we seek for an object or a scene we get also the most complete sensorial pack instead of the computer's basic tagging about that same object or scene. The main idea is to extend the regular object information with sensorial information about the five senses, by associating emotions textually expressed to the information captured [117]. In sequence of the idea of Internet as an extension of our personal representations follows the need for pursuing a representation of such artefacts, with similarities to our nature, and ultimately as our brain does. Since early times in school, children learn about the five senses. Those are obvious to children as they associate the information they get with the respective body part, the tongue, the nose, fingers, eyes and ears. However there are other senses to consider that are not so obvious and some have similarities to what we call, in electronics and computer science, the sensory fusion. Examples of those other senses are the notion we have of the air intake or sometimes the sense we have about the blood flow in arteries and veins and also the sense of movement of internal organs (e.g. when tired we can feel the heart beating or we can sense stomach contractions after a heavy meal).

In order to learn with the human sensorial apparatus we would need to retrieve sensorial information and also to store it for later usage, comparison and evaluation. That would imply the ability to manage the acquisition and storage of sensations as it happens with humans. With the development of electronic devices, it is becoming possible to transfer information from paper, and other media, to electronic format. For image representation we capture, scan or acquire with diverse devices such as cameras and scanners, which then result in a pre-determined digital image file formats. For sound we need to represent waveforms in specific formats such as waveforms or compressed formats as popular as MP3 [118] and others. Smell can be represented as molecules and chemical formula using the selected compounds; the electronic format may include graphic intensity of atoms and molecules. Scentography is the technique of creating and storing odor by artificially recreating a smell using chemical and electronic means [14].

The problem about odour, or smell production seems to be hard to solve as previous trials lead start-up companies to fail. Some known cases are the iSmell Personal Scent Synthesizer, which was a computer peripheral device developed by DigiScents in 2001 [119]. The company produces a piece of hardware to be placed in a desk with a cartridge of 128 primary odours but now is listed in the top start-up failures [120] and worst tech products of all time [121]. Maybe because of the difficulties in that field Google issued an April fools day prank announcing a product that would be the Google Nose – beta [122]. Back in 2012 IBM was presenting computers with a sense of smell as a trend for the next five years, there are two years left so that it would be accomplished on time [123]. There are some experiences with the sense of taste that are worth to be noted. In diverse domains there are experiences made with electronic tongue devices that allow to identify or differentiate between products [124] [125]. Finally, in what regards to touch, it has been a primary sense uses to enter information in a computer and for that keyboard and mouse suffered evolutions to better address and respond to human touch. In what regards to touch, wearable devices play an interesting role as they can induce sensations in the body to communicate in a different way. Mobile phone users get used to the vibration mode warning that we are receiving some message or phone call. Other information within the range of touch can be obtained from specific heat, pain and surface sensors, which then can be represented in colours or using specific scales and/or 3D surface models. Lately, the growth in usage of available 3D printers and its lowering cost makes possible the materialization of images that allow the usage of sense of touch. Information from 3D model is now more accessible thus empowering new opportunities for the usage of human's sense of touch, as is the case of sculpture like samples or new tools and devices to be developed.

As a summary of this section's observations, we notice that a most complete sensorial experience can be embodied in Internet objects. Such option is quite rare as most sensory experience we get is image and sound, mostly because devices are not able to retrieve or reproduce other sensations, but also because there is lack of interest on other sensory experiences as noticed in navigating the Internet but also in literature. That human driven sensory experience as we defend in this document, inclusive for most of our sensory experience, will be a challenge for technology in a near future.

5.2.2. *From Sensation to Perception*

Sensation is the result of activity from our sensorial organs to the human brain and feeds data into perception process. Sensation depends on physiological capacities of the organisms to collect and organize diverse stimuli from their environments.

The human communication is considered as interplay of four physiological and psychological groups of processes: sensation (physiological), perception, cognition and articulation (psychological) [126]. The human communication typically starts when the energy of some sensory stimuli is recorded by a human. It is then transformed to electrochemical signals to a human's brain. This process also involves selection of sensations and making decisions on which information is worth perceiving.

Data obtained by the sensorial organs is often unreliable. There are typical factors for the incapacities of the senses to provide data for perception and those are the environmental conditions and external noise. Also, the lack of reliability can sometimes be attributed to incapability of senses to process multiple simultaneous stimuli at a time. Without the ability to filter out some or most of that simultaneous information and focus on one or typically two at most, the brain would become overloaded.

Sensations, by themselves, are unable to provide a unique description of the world. Although the senses were traditionally viewed as passive receptors (similar to the sensors in the systems' theories), the study of illusions and ambiguous images[8] has demonstrated that the brain's perceptual systems actively and pre-consciously attempt to make sense of their input. Hence, sensation and perception cannot be considered in isolation; these two activities together are attributed with filtering (selection), organizing (grouping, categorization) even interpretation processes - organizing various stimuli into more meaningful patterns.

The process of perception begins with an object in a real world, called the distal stimulus or distal object (see Figure 5.3) [111].

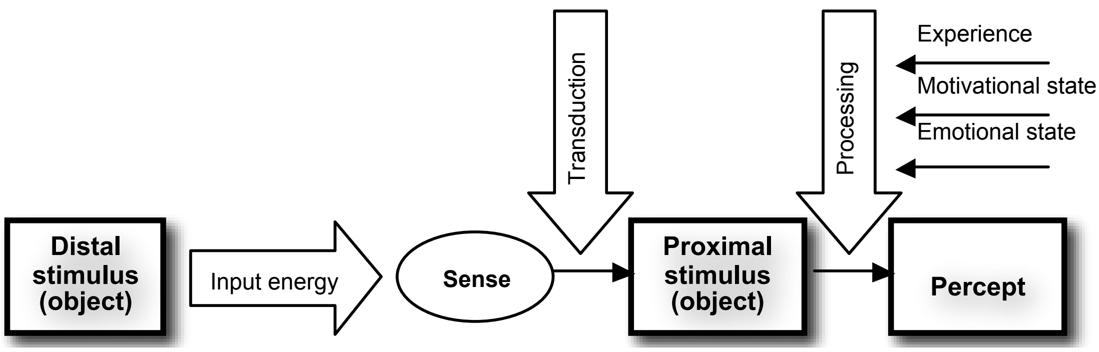


Figure 5.3 - Illustration of the perception process

[8] Refer to an example of a Rubin's vase

By means of light, sound or another physical process, the object stimulates the human's sensory organs. These sensory organs then transform the input energy into neural activity - a process called transduction [127]. The raw pattern of neural activity is called the proximal stimulus. These neural signals are transmitted to the brain and processed. The resulting mental re-creation of the distal stimulus is the percept. Perception is sometimes described as the process of constructing mental representations of distal stimuli using the information available in proximal stimuli. The processing of a proximal stimulus is crucial for the perception. It is not only subjective but it can be related to a specific context, determined by the different factors.

According to Saks and Johns, there are 3 factors that can influence the perceptions: experience, motivational state and finally emotional state [128]. In different motivational or emotional states, the perceiver will react to or perceive identical proximal stimulus in different ways. Also, in different situations a person might employ a "perceptual defence" or a "perceptual bias", where he or she tends to "see what he/she wants to see", and hence, unintentionally but consciously distorts the perception.

Perception is considered as a cyclic process, in which observation of the environment, followed by the creation of the initial percepts, is often affected by the process in which we are directing our attention for further exploration, in order to get more stimuli required for constructing the final percept [97]. Hence, the perception becomes an active process. Gregory has shown that this cycle iteratively generates, validates and consequently reduces hypotheses that explain the proximal stimulus [129].

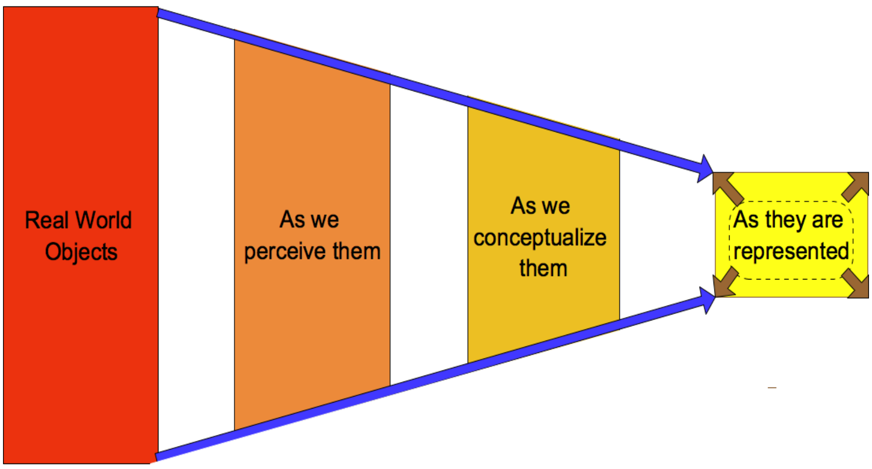
Weiten synthesized the perception factors to the notion of perceptual set or expectancy: a predisposition to perceive things in a certain way [130]. It includes experience, expectation, intent, motivation, etc. Hence, in a way, perception is both bottom-up process, taking sensorial input and a top-down process based on a perceptual set. It is important to highlight that when two communicating entities deal with similar perceptual sets, communication becomes both less explicit and less intensive. As an example, this is the case when we refer to finishing each other's sentences of two humans in a close and lasting relationship.

Although all these factors are always considered in the perception process, it does not mean that they are necessary for a correct and complete perception (whatever "correct" means). In fact, only experience is necessary, at least as a simple dictionary.

Motivational state as a perception factor is typically useful in case of ambiguity, incomplete or lack of information. This case introduces a greater need for interpretation and addition. In this case, a perceptual constancy capability is employed. It is the ability of perceptual systems to recognize one specific object by using the different sensory inputs. For example, individual people can be recognized from views, such as frontal and profile, which form very different shapes on the retina, or by the sound of their voices.

Finally, people often use so-called contrast effects to make relative judgments on some attributes of the perceived objects. Namely, if one object is extreme on some dimension, then neighbouring objects are perceived as further away from that extreme. This can sometimes lead to distorted perceptions. It is then to think that what objects are in the real world are partially captured by the sensorial organs and perceived by us, according to our bias. Each person will make his own mental image of the objects, different from others (e.g. focusing attention at different aspects). We establish concepts about perceived objects that depend on former memories, on how we retain them and how we recall most of its characteristics. In the final stage towards representing objects at the Internet we use a limited version of our objects according to the available methods and tools to represent those objects.

The limited options to represent objects at the Internet, with photos, movies and sound, make a reductionist existence of the objects, more limited then after going thru sensorial to cognitive processes in human brain. The objective of present research work is to expand the representation of objects, augmenting the range of expressivity of information about each object.



Real world objects are reach in proprieties, we perceive them within the capacities of our sensorial organs and we conceptualize and represent them with fewer properties. In this narrowing process, our objective is to intervene where we can, i.e. in expanding the quality of representation.

Figure 5.4 - From Real World Objects to their representation at the Internet

It becomes crucial to attend to the process of acquiring information from the world, and to handle it in a proper way, as that will increase the quality of information to be fed to computer based systems (e.g. context awareness and decision support systems). The importance of understanding sensation and perception in humans is of importance, both for learning with the competencies of the human body and to allow systems to better address human needs. In summary, to use high-level biomimetic innovative systems that will be able to establish better interoperability in computer and human interactions (HCI).

5.3.ATTENTION

Attention is fundamental for the cognition processes and plays a vital role in the way we perceive the world and in the way we select information to capture. By those consideration attention becomes central to how humans perform knowledge management because they select what should be attained by the existing knowledge. The acquisition of new knowledge is based in the focus of attention towards all the options presented and all the information available. What you see is determined by what you attend to. At any given time, the environment presents far more perceptual information than can be effectively processed. Visual attention allows people to select the information that is most relevant to ongoing behavior. The study of visual attention is relevant to any situation in which actions are based on visual information from the environment. For instance, driving safety critically depends on people's ability to detect and monitor stop signs, traffic lights, and other cars. Efficient and reliable attentional selection is critical because these various cues appear amidst a cluttered mosaic of other features, objects, and events [131].

According to Harold Pashler, there are two primary themes people allude to with the term attention: selectivity and capacity limitation [132]. Selectivity is apparent in a number of undeniable facts about human experience and behaviour. One is that conscious about perception is always selective. Everyone seems to agree on that, at any given moment, their awareness encompasses only a tiny portion of the stimuli impinging on their sensory systems. The second fact is that this selectivity holds not only for conscious states of mind, but also of the impact of stimuli on behaviour. Whether we are walking, driving, playing tennis, or choosing what book to pick up, the sensory stimulation, and typically only a subset of the stimuli that could potentially guide the same type of behaviours (e.g. the page contains other text that we could read; other paths are available for us to walk along). In short, the mind is continually assigning priority to some sensory information over others, and this selection process makes a profound difference for both conscious experience and behaviour. The second phenomenon is our limited ability to carry out various mental operations at the same time. Two activities that a person can easily carry out one at a time often pose tremendous problems when attempted simultaneously (e.g. listening to radio and reading a book), even when these activities are in no way physically incompatible. This applies to many kinds of mental activities, including analysing new perceptual input (as in listening to the radio and reading a book), thinking, remembering, and planning motor activity .As for the visual system, the rate of 10^7 bits stream every second from retina to the brain [133].

Processing this data in real-time is an extremely daunting task without the help of clever mechanisms to reduce the amount of erroneous visual data. High-level cognitive and complex processes such as object recognition or scene interpretation rely on data that has been transformed in such a way as to be tractable [134]. The fact that so much information is available to the sensory organs makes necessary to reduce the amount of data to be processed. That means, in practice, that a selection should be made on where to direct our available resources and thus attention assumes an important role.

The mechanism in the brain that determines which part of the multitude of sensory data is currently of most interest is called selective attention. This concept exists for each of our senses; for example, the cocktail party effect is well known in the field of auditory attention. Although a room may be full of different voices and sounds, it is possible to voluntarily concentrate on the voice of a certain person. Visual attention is sometimes compared with a spotlight in a dark room. The fovea – the centre of the retina – has the highest resolution in the eye. Thus, directing the gaze to a certain region complies with directing a spotlight to a certain part of a dark room. By moving the spotlight around, one can obtain an impression of the contents of the room, while analogously, by scanning a scene with quick eye movements, one can obtain a detailed impression of it [135].

The acquisition of knowledge is biased by our concerns or motivations and thus, naturally we filter the environment around us looking for clues or for the features we appreciate. In that sense our acquisition is conditioned, limited and partial. On the other side, devices capture what it is within range of their sensors, without limitations other than sensing capabilities and storage limits. Thus technological devices can provide additional and unfiltered information, extending a person's awareness and completing human retrieval capacity.

5.4. *EMOTIONS*

From hundreds of years most of the great classical philosophers like Plato, Aristotle, Spinoza, Descartes, Hobbes and Hume, had recognizable theories of emotion [136] and tried to develop cognitive models and understand how the mind works. Since then no theory could be assumed as definite answer to what are emotions and how can they be represented. Plutchik's wheel [137] represent one of the interesting possibilities by depicting some of the most consensual emotions that we experiment in life. Emotions play such an important role in our lives that raises the question of its importance in the cognitive process [138].

As humans, our ability to perform every task in our daily life, from work to amusement or any other conscientious task depends on our emotions. As humans emotions play a central role as they ensure our survival and all activities from the most basic to the most elaborated tasks are dependent on emotions and generate new emotions.

With so vital functions, it is relevant for the present work to take in account the role of emotions in knowledge acquisition and knowledge management. Emotions evaluate the importance of the perceived information and the retrieval of the information is conditioned by emotions. In fact Damasio proposes that the relationship between learning, emotion and body state runs much deeper than many educators realize and that the original purpose for which our brains evolved was to manage our physiology, to optimize our survival, and to allow us to flourish [24].

The different between mood and emotion is that mood is a state with low intensity but lasting longer while emotions are limited in time and related with what an individual is experiencing [139]. Any type of direct measurement of expression or any physiological parameters can provide clues on emotional states but it is less expressive of a person's mood.

It is of relevance to notice that different persons have different emotional response to same stimuli [140] and thus it is not possible to infer emotion from external stimuli per se. However, evaluations made with magnetic resonance show that the amygdala seems to perform an automatic coding of the face properties. That is the case of the decision on whether an unfamiliar person is trustworthy or not. The amygdala response increases as perceived trustworthiness decreases in a task that did not demand person evaluation and individual judgements accounted for little residual variance in the amygdala response [141].

The assessment of emotions has a particular importance for this research work, in what that implies to a person's well being but also for applications and devices to react and provide the best suited services. Applications with emotional assessment can provide a user with the best interfacing options and thus establishing better human computer interfacing. In a recent study, professor Hirose from Tokyo University (UTokyo) and his team [142], developed a setup with a pseudo-mirror that shows the face of the user with a smile. The user is serious but the image is manipulated to show a smile. What this team observed was the influence of the facial image with a smile to the person doing the experience. Taking the results from such experiment we can infer that it is possible for an application to produce a happy emotional state in a person by presenting is/her "happy-version". From this arises the need for a proper assessment of the present condition by handling properly the available data and propose a new emotional state, while respecting that person's will and current context (e.g. in a party propose a change to happy but not in a funeral).

Thus it is interesting to notice that applications exist where current research work can be applied and provide input for a better outcome for a person's benefit.

Emotions as a subject of study are as vast as the diversity of persons and their relationship with the environment including objects people and other living beings. In a low level point of view, when exposed to external stimuli a person has a physiological flow of activity and that will trigger thoughts emotions and acts in response. In high level we react to threats or to friendly situations in different ways according to our feelings or thoughts towards those persons or environments. The focus of the current PhD research areas poses two challenges, one is how to handle emotions and their associated physiological responses, how to represent them and how to manage them. The other is how to handle emotions in Human Computer Interaction (HCI) and how to enable systems and applications to handle human emotions and properly respond to human users.

5.4.1. *Representation of Human Emotions*

Human emotions have been subject of study, with different approaches by different researchers being possible to determine in 1981, at least one hundred different definitions [143], with a varying number of definitions by the same author.

There are several concepts that, in common language, sometimes are confused and used interchangeably without regard to its differences. In a simplified manner we present the main definitions relevant to this study in emotions.

Emotion Cognitive data arising from events (internal and external) used to inform responses, and attributed to concepts and states

Feeling The subjective experience of an emotion or set of emotions

Mood An overall state of emotion, which is sustained over longer periods of time and is less changeable than emotions themselves [144].

Feelings are the mental representation of the physiologic changes that occur during an emotion [145]. In humans, decisions are not just influenced by current requirements and circumstances but also by emotional states, which, in turn, are moderated by past experience. This use of moods (or emotions) as information in decision-making can sometimes be problematic, leading to errors of judgment [146] [147]. Thus emotional states play a fundamental role in the communication process. Whenever humans communicate, an assessment of each other's emotional state takes place. Our central nervous system needs to know immediately if there is a threat or an immediate risk from this encounter, even without our conscientious awareness. This primordial reaction of a human mind reflects the basic need to survive. In everyday life this need is specialized to a need to meet a simple objective. Hence, appropriate reaction to the articulated message or perceived observation also involves the factors related to a communicating entity posture, attitude, communication style and ultimately, its (his/her) emotional state.

A communicating entity may exhibit its emotional state consciously or unconsciously. There are the cases when communicating entity is determined to ensure a proper interpretation of this emotion, for example to create a sense of urgency. Furthermore, curiosity is emotion that is consciously exhibited to express the need for additional information needed to complement the existing one, with objective to perform a complete reasoning. Hence, it is obvious that there is a need for creating and maintaining a dictionary or even more complex formalisms for expressing emotions.

Unconscious demonstration of the emotional state implies the need of a receiving entity to exhibit a capability to infer about the emotions behind the message articulated by the communicating entity. For example, an approach to formalize an articulated message is evaluated by the receiving entity, in search for the emotional factors that may lead to the distortion of correctness of this message. Additionally, emotions are important in nonverbal communication, and emotions influence cognition in many ways; how we process information, our attention, and our biases towards information [148].

Computer systems can use representation of emotions Internet it is necessary to follow a pragmatic approach. For a start, would be important to know what is the starters range of emotions to be addressed. Scherer submits that there is currently no answer to that question [139]. So it is necessary to start with a list of emotions, which can be identifiable as generally known. That is the case of Plutchik's wheel in Figure 5.5 [149], representing the families of Emotions, which can be used as a reference list. This set of emotions can be available to populate an ontology that can later be expanded according to physiological response by user.

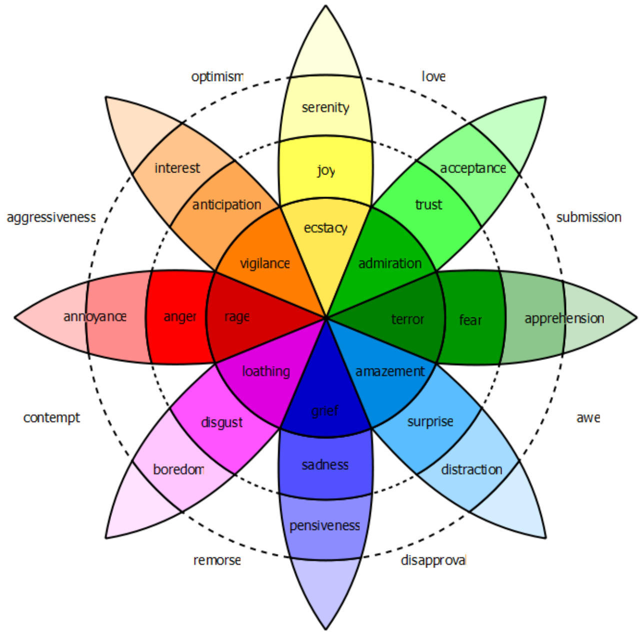


Figure 5.5 - Plutchik three-dimensional circumplex model

Emotions are something that is happening in our mind, as a result of cognitive processes and a subject has the feeling of those emotions. Beyond representing emotions it is important to identify what emotion a person is experiencing and for that, technology brought us means of measuring what is happening in the human body.

5.4.2. *Physiology of Emotions*

Humans feel and express emotions. We understand other's emotions when those are verbalized or when bodies or faces make characteristic expressions and movements. This is part of our natural adaptation to living in society and in general it is easy to establish a match between external signs and a person's emotions. Emotions are present in our lives in many ways and are expressed physiologically or, not so visible, in our minds exerting effects in our lives. We see a picture and we recall the happiness or the drama that we lived at that place, in a moment, or during a part of our live. Emotions are a human characteristic even though sometimes are hard to determine from outside as expressions vary in the type of physiological manifestation and its intensity. Emotions can otherwise be transmitted by speech or by written messages and other illustrations. Emotions have an active role in human perception as the information flow depends on emotional response that is mediated by cerebral structures, as the amygdala or the pons [150]. Activity in such regions of the brain can be observed with fMRI equipment. Those are not suitable for usage outside clinics and hospitals therefore we need more practical, and portable, ways of measuring indicators of emotional related activity. Ekman and his colleagues have provided many of the data in support of emotion-specific physiology as presented in Figure 5.6, which has the limitations of the skin temperature variance [151].

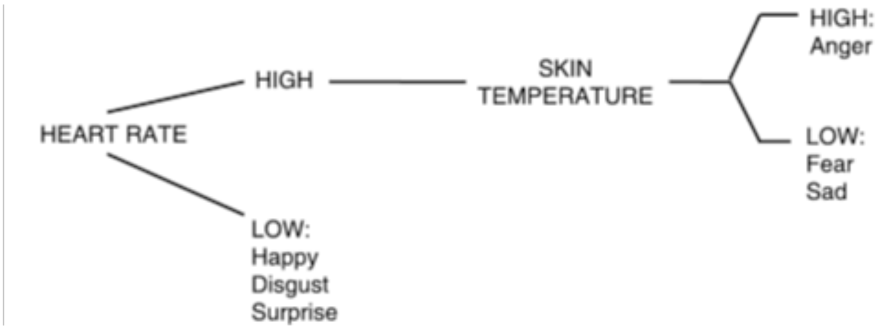


Figure 5.6 - Decision tree on basic emotions

The Circumplex Model of Affect proposes that all affective states arise from two fundamental neurophysiological systems, one related to valence (a pleasure–displeasure continuum) and the other to arousal, or alertness. Each emotion can be understood as a linear combination of these two dimensions, or as varying degrees of both valence and arousal as depicted in Figure 5.7 [152].

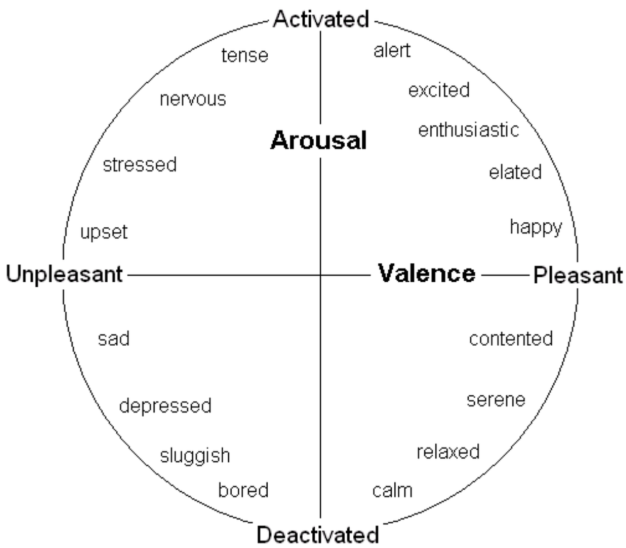


Figure 5.7 – Arousal and Valence in Circumplex Model of Affect

It is possible to observe that different levels or activation, or arousal along with different levels of pleasantness or valence, correspond to different emotional states. Joy, for example, is conceptualized as an emotional state that is the product of strong activation in the neural systems associated with positive valence or pleasure together with moderate activation in the neural systems associated with arousal. Affective states other than joy likewise arise from the same two neurophysiological systems but differ in the degree or extent of activation. Specific emotions therefore arise out of patterns of activation within these two neurophysiological systems, together with cognitive interpretations and labeling of these core physiological experiences [153].

In recent studies Ekman's theorization was confirmed by fMRI studies. In fact Anders et all state that Emotional behavior is organized along two psychophysiological dimensions: (1) valence, varying from negative to positive, and (2) arousal, varying from low to high. Behavioral responses along these dimensions are assumed to be mediated by different brain circuits [154]. By exposing volunteers to a set of emotional pictures and collecting verbal ratings of the emotional valence of arousal of each picture it was possible to identify correlations with brain activity areas. Startle reflex changes, associated with the valence of a stimulus, correlated with activity in the amygdala, while verbal reports of negative emotional valence varied with insular activity. Peripheral physiologic and verbal responses along the arousal dimension varied with thalamic and frontomedial activity. Peripheral physiologic responses along both dimensions correlated with activity in somatosensory association areas in the anterior parietal cortex. In the valence dimension, activity in the left anterior parietal cortex was associated with highly correlating peripheral physiologic and verbal responses, suggesting that verbal reports of emotional valence might depend partly on brain circuits representing peripheral physiologic changes [154].

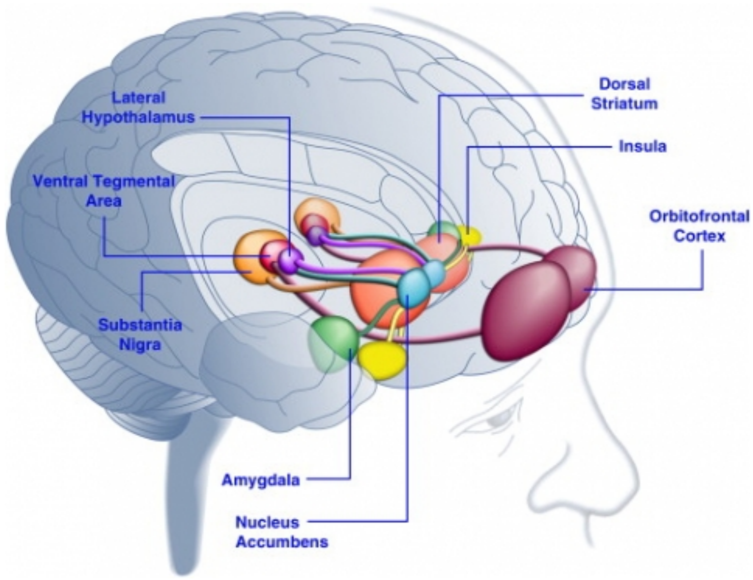


Figure 5.8 – Areas of the brain related with emotions

As emotions are experienced and communicated, cognitive interpretations are employed to identify the neurophysiological changes in the valence and arousal systems and conceptually organize these physiological changes in relation to the eliciting stimuli, memories of prior experiences, behavioral responses, and semantic knowledge [155].

Another strategy to evaluate a person's emotional state uses the assessment of facial expressions. In computer science facial expressions are most of the times studied as a manifestation of basic emotions [156]. The most reliable results are usually a result of the combination of different biometric information, sometimes in combination with facial expression evaluation. Other types of physiological signals can be captured such as heart rate, galvanic skin response, and electromyography to continuously provide measures of a user's emotional states [157]. Those measurements can be made for experiences but are not yet suitable to be used in daily life. It is possible that in a near future measurement devices for consumer products will be released, as some existing prototypes like heartbeat monitors connectable to cell phones that already available in the market [158].

5.4.3. *Emotions on the Internet*

As an alternative to all those measurements it is possible, as a departing point, to use labels that represent emotions. When writing, a text emotions are highlighted with a semantic description that is part of our vocabulary and that can describe with the desired detail what a person is experiencing in terms of emotions. Recently with email and cell phone messaging it is usual to use symbolic representations for emotions, which are also used in message exchange software and email. Those symbols can vary from punctuation signals (e.g. ;) :(=) ;) 8-)), to smiles or other pictorial representations of the author's feelings at the moment. Emotions can be assessed in text and in facial expressions. Software has been developed to execute those inferences of emotions from written text [159] and also from reading a person's face [160]. Ultimately it is possible to have a set of tags representing emotions that can be associated with Internet objects as specified by users.

The idea of Internet as an extension of our personal representations, leads to the need for pursuing a representation of such artefacts, with similarities to our nature, and ultimately as our brain does. That would imply the ability to manage the acquisition and storage of sensations and emotions as it happens with humans. At the Internet samples of diverse objects can be retrieved, as they are publicly available along with other reserved types of information and that can be managed to represent sensorial and emotional information along with other information created by users. Along with the above-mentioned technics to indirectly determine emotions and sensations, it is foreseen that in a near future it will be possible to retrieve sensations and emotions with personal devices, or others' devices in an Internet of Things (IoT) approach. Current research aims to open ground to support the representation of emotions and sensations, either by any existing representation process or for the upcoming technological advances on electronic retrieval methods.

It is important to notice that, unlike sensory expression, we cannot transmit emotions to people the same way we transmit sensory information as image, sound, and one-day smell or taste. But we can generate stimuli that induce emotions. In those cases we can include selected images (e.g. the IAPS database used in this dissertation, section 7.2.3) or selected sounds (e.g. cry of baby or sounds from horror movies) those induce emotions using diverse sensory experience. On the other way, the inference of emotions from people using information systems, as the Internet, seems much more feasible as we intent to prove in the research presented in this Dissertation. By performing physiological measurements, reading faces, mining text, we can infer a person's emotional state and allow navigation to present adequate options or the applications to react accordingly for a person's best interest.

The topic of representing emotions on the Internet makes border with the research area of Human Computer Interaction. The ability to recognize affective states of a person we are communicating with is the core of emotional intelligence [161]. Emotional intelligence is a facet of human intelligence that has been argued to be indispensable and perhaps the most important for successful interpersonal social interaction. Human-computer interaction (HCI) designs need to include the essence of emotional intelligence - the ability to recognize a user's affective states-in order to become more human-like, more effective, and more efficient. Affective arousal modulates all nonverbal communicative cues (facial expressions, body movements, and vocal and physiological reactions) [162].

In trying to understand better the relations between emotions and our sensorial capacity, we recall that in section 5.2, sensorial information was analysed from the point of view of the present research work, then in section 5.4 emotions were object of study. Finalizing this Chapter we notice how sensorial experience has impact on emotions as we are affected by what we see, the scenes or presence of other people, the pain we feel and also by the smell. The early memories a person, as defended by Proust and other, seem to be connected with smell[163]. Curiously there are some doubts about the nature of such memories, it is questioned if they are accessed primarily by smell or if indeed they are only accessible by the sense of smell. Such observations are a strong support for the consistence of the proposed data model and the Framework developed in Chapter 9 of this Dissertation as they reinforce the need to consider sensorial information along with emotions in a human driven knowledge management approach.

In this Dissertation the handling of sensorial and emotional information is taken in its widest implications that merge local physiological measurements, Internet access as communicating infrastructure along with pervasive computing. After all those are part of the same reality that we are, and will become more and more, surrounded by computing devices, connected to the Internet. The ability to communicate local measurements that can be uploaded evaluated remotely brings the opportunity to use portable, low consumption and obstructive devices to collect readings from our body and make them useful to our knowledge management, in particular in what regard to stress and other emotional states that play an important role in our daily life.

6. MEMORY

This Chapter explores the aspects related to memory. Those are relevant by the fact that the organization of knowledge in humans' brain depends on its storage in memory but also because retrieval of knew knowledge seem to depend much on existing knowledge, in memory. Then in Section 6.1, Working memory is presented as a concept related to the processing and acquisition of information in real-time. This is of importance for the present thesis specially when related to the concept of Episodic Buffer, in section 6.2, which is also applied in the presented research work as a strategy for clustering available sensorial and emotional related data, as available, in a given moment as an episode.

Memory as related with the storage of information is depending on brain structures and thus is a neurophysiological component of our nervous system and has its regions of influence in the brain. But on intervening in human cognition, memory is another important neuropsychological process. The discussion on either memory should be considered as processes, or as a structure, is controversial. We know that memories are stored somewhere in a neuronal structure but in some cases, as the storage in short term memory, some defend that it is a process and not a memory storage operation, others defend that sensory information is stored directly in short term memory [164]. Considering that active and fruitful discussion, it seemed to be opportune to review memory literature in this distinct section.

In the start of the analysis of memory, we can question how input from the outside becomes a memory in our brain. The model of Atkinson and Shiffrin provided early clues about that [165].

Atkins and Shiffrin defended a flow of information from input to long-term store that still a reference for memory studies [166]. As supported by Figure 6.1, they defend the existence of two different kinds of memory, one that is currently in conscientiousness and that are under immediate control of the subject, managed in a short-term store (STS) and the other that can be bought to consciousness only after a search of memory that was often laborious in the long-term store (LTS). The STS is in immediate control of the subject and govern the flow of information in the memory system and affect the transference and retrieval of information from the STS. Environmental input is captured by the sensory registers in the sensorial cortex and received by the STS where several processes occur. Those are the Rehearsal where information is recalled several times to avoid being forgotten, Coding where information is put in context to be remembered as in phrases or mnemonics, the Imaging when a subject makes a visual imagery of what is trying to remember and other control processes as decision rules, retrieval strategies and organizational schemes that reinforce the storage of information in memory [167].

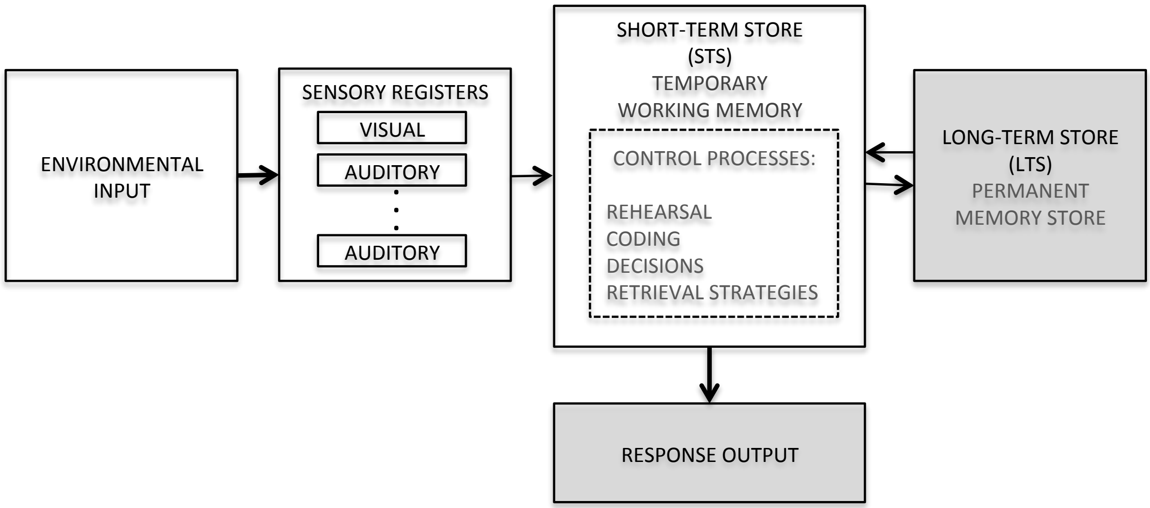


Figure 6.1 - Information flow from input to long-term store [168]

Later authors raised the defence of a single store of memory representations as the hippocampus activation correlates with successful item recognition thus accessing selectively the long-term memory thus reinforcing the role of the working memory as central for the memory operations [169].

6.1. WORKING MEMORY

Neuroscience has reached the stage where it is possible to understand how parts of the brain actually work, by combining approaches from many disciplines. Evidence on the connections and internal connectivity of each brain region and the biophysical properties of single neurons provide foundations for a computational understanding of brain functions by the established correlations of those functions with identified brain region [170]. The hippocampus is the area that allows a primate to predict the location which will be reached as a result of any specific movement from that location, and conversely, to calculate the spatial transformation necessary to go from the current location to a desired location [171]. Even with some different layers at the parahippocampal cortices a convergence can be afforded by the hippocampus into a single network. The free association of different levels of information allows arbitrary associations between any of the inputs of the hippocampus, e.g. spatial, visual object and auditory, which may all be involved in typical episodic memories.

The operation of different brain systems are involved in different types of memory, some are in the primate orbitofrontal cortex and amygdala and are involved in representing rewards and punishers. Others are involved in learning variant representations of objects and episodic memory and spatial functions are processed at the hippocampus [172]. That lower level assessment regards the areas of the brain where memory takes place as explained by neuroscience theories based on data provided by scanning devices. Going up one level to the processes involved in memory, those are commonly understood at to occur, for a person's memory, at different stages (e.g. encoding, storage and retrieval). Information is entered into memory at the encoding stage, it resides in memory during a storage state and it is brought back during the retrieval stage. This breakdown is interesting because the successful operation of memory at one stage may have little consequence for the operation of memory at another stage [173]. This is why sometimes we have the sensation of knowing something but cannot retrieve it. Memory theorists have proposed a variety of about how the stored information is organized following theorists that proposed a variety of organizational processes whereby itesm of information are not merey stored one by one but are stored as connected sets. This means that we store whole sentences and when we observe an object its properties are stored together (e.g a carot with the orange colour). When the encoding process occurs we can increment or remove those connections as, at the same time, we relate to previously stored information. This is the case when we relate to other objects with the same colour or with other vegetables but with different colour. Damasio goes further and suggests that the brain represents the outside world in terms of the modifications it causes in the body proper. Thus in this case it goes beyond a static observation of the world, as it result from seing and hearing, but a whole interpretation of the interaction of the world with a person's body: you feel you are seeing something with your eyes [77].

In what regards to th functionalities of memory, an interesting aspect is to understand how the memory is uptated with new knowledge. In a computational device, when new knowledge is entered to replace old knowledge the typical solution is to delete the former and inscribe new knowledge thus replacing it. The brain doesn't replace old knowledge by new knowledge, instead, it mantains the old knowledge and adds and reinforces new knowledge, giving more wieght then to previows knowledge. This is for instance case when we have a new path towards home, the old path is not erased but it is phaded in realtion with the new on, we do not forget the old route but the new one is reinforced [174].

But then we may ask about what kind of link is established between real world objects and its representation at the brain. Representation is by definition something that stands for or in the place of one object, being it physical or abstract. Objects in real world are perceived by a number of modalities, that annulles the unique relationship between the object and its representation. The only unique relationship established between the object and its representation is the one of identity. However, as demonstrated by patients with brain injuries, the relationship between objects and the brain is more then simbolic representation as there are cases where a person doesn't know what the object is but continues to be able to use it (e.g. a chair). In this case knowledge about the object seems to go beyond the conventional representation but in fact knowledge about the object becomes infinite with infinite, or infinite ways of knowing the object become possible [175].

Finaly, it is important to address the question of how the access of knowledge at the Internet that influences a person's memory. In 1945 Vannevar Bush proposed a futuristic machine that would mirror the cognitive processes of humans by leaving trails of associations throughout document collections [176]. This model had the objective of taking the features of computational resources to mimic the behaviour of a neuron and thus making able to reproduce its behaviour in a computational environment. Beyond the similarities of that proposed machine with what would be world wide web [www] hyperlinks proposed by Berners-Lee, the memex would be availlable as an external (to the brain) repository of information. Today with the features availlable with the search engines, the access to information has become an easy task. By typing some keywords vast amount of sources are proposed leaving us with the idea that we can find at the web what we are looking for. In recent studies [177], a group of persons were tested on their response timming and dificulty to reach information once accessed at the web. In a series of experiments people show more ability to recall information not easy to find at the web then other that can be located easily on the web. Another side of the experiment shows that exposition to information that was told not being available later was more successfully recalled than information that would be easily accessed.

The results, presented as the Google Effect, show that people change the way they store information in memory deppending on how they expect that search engines can locate that same information [178]. In that sense the experiments demonstrate that human memory adapts to the way information can be located at the Internet. Important to notice, and highlighting the importance of sensorial information for memory, some studies demonstrate that product scent (in pencils) significantly enhances memoryfor product information and that this effect persists over time [179].

6.2. THE EPISODIC BUFFER

Behaviour, neuropsychology, and neuroimaging suggest that episodic memories are constructed from interactions among the following basic systems: vision, audition, olfaction, other senses, spatial imagery, language, emotion, narrative, motor output, explicit memory, and search and retrieval [180].

In the model proposed by Baddeley et al (Figure 6.2) the episodic buffer, is a purely passive system, but one that serves a crucial integrative role because of its capacity to bind information from a number of different dimensions into unitized episodes or chunks [181]. The brain thus stores different sensorial experiences and those experiences are related to each other in a short-term memory or becoming a long-term memory. The same way we are able to recall past memories, using the proposed framework, from the exposition to an external stimuli we can refer to chunks of previous experiences that include images, sound, smell, taste and touch.

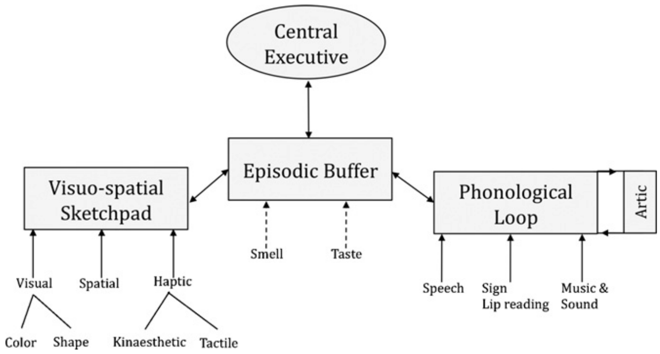


Figure 6.2 – Model of Working Memory

Intuitively we know that in our daily live, we handle the outside world by attending mostly to sound and vision and that is the direction of Baddeley's model. The Phonological loop attends and stores sound and speech from other while the Visuo-spatial sketchpad, also known as the inner eye, registers visual stimulus along with haptic sensations that could give input for spatial and visual coding.

The model of working memory just described is based on empirical evidence from a range of sources, including healthy and brain-damaged adults, and children.

Based on these assumptions, Clore and Ortony propose a model (Figure 6.3) describing how the working memory processes sensory input along with long-term memories generating emotional responses. The working memory receives a greater number of inputs, and receives inputs of a greater variety, in the presence of an emotional stimulus than in the presence of other kinds of stimuli. These extra inputs may just be what are required to add affective charge to working memory representations, and thus to turn subjective experiences into emotional experiences [182].

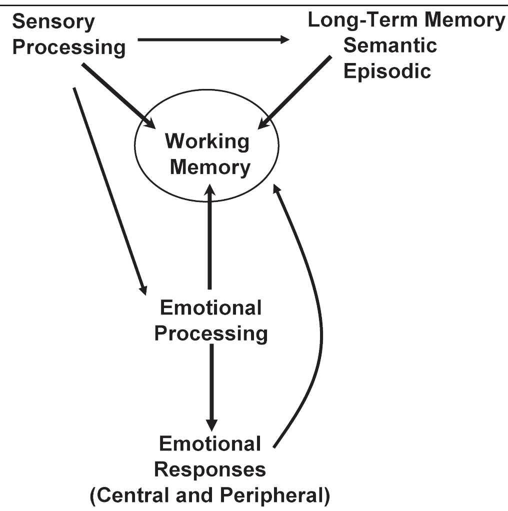


Figure 6.3 - A model of how the brain consciously experiences emotional stimuli [182]

The question raised by recent studies is that in central executive, storage in episodic buffer and processing capacity seems to be limited for concurrent events. It appears that exercising some of the most advanced abilities of the human mind causes temporary deficits in just those abilities [183]. For that reason it seems that the usage of complementary technology helping humans to recall and process information, instead of undermining brains capacities may be an important asset for better performance of our cognitive capacities.

Although there is growing knowledge about intracellular mechanisms underlying neuronal plasticity and memory consolidation and reconsolidation after retrieval, information concerning the interaction among brain areas during formation and retrieval of memory is relatively sparse and fragmented [184].

Psychological experiments indicate that the variety of the symbols is far less important than the length of the message in controlling what human subjects are able to remember. Two messages equal in length but differing in the amount of information per symbol are equally easy to memorize. This fact provides an opportunity for the effective use of recoding procedures and reveals the mental economy involved in organizing the materials we want to remember [185]. It could represent an interesting paradigm for knowledge management in information systems as the storage of concepts or episodic clusters would optimize the usage of memory. How could that be achieved? By referring to an episode has having the same importance as the importance assigned to all modules of that same episode without losing information, in other words, they would optimize memory assignment. This way it is understandable that the idea of joining information around a moment in life in the form of i-Episodes, as presented in section 10.2.1, follows the same clustering strategy as adopted by the brain.

7. INFERRING EMOTIONS FROM PHYSIOLOGY

In this Chapter the expression and detection of emotions are the first topic in section 7.1. It is considered the two faces of the same coin as, in humans, the expression from one side is detected from the other side and vice-versa. Then section 7.2 is concerned with the different types of physiological measurements that can give inferences to determine emotional states of a person. This is far from being a deterministic process as it is necessary to retrieve indications from physiology In order to reason over possible emotional states. For that purpose this section is divided in several areas each one presenting a physiological area that was considered of relevance for the present research work.

In the last decade, several efforts have tried to obtain a reliable methodology to automatically identify the emotional/mood state of a subject, starting from the analysis of facial expressions, behavioural correlates, and physiological signals. Despite such efforts, current practices still use simple mood questionnaires or interviews for emotional assessment. In mental care, for instance, the diagnosis of pathological emotional fluctuations is mainly made through the physician's experience [186].

7.1. EXPRESSING AND DETECTING EMOTIONS

Expressing and detecting emotions are two faces of the same coin.

The idea of discovering emotions from physiological measurements is a tempting one and research work has been performed in that direction. The way the brain manages information is dependent on emotions and some authors say that no one has contributed more to the psychology of emotion in the last 30 years than Paul Ekman [187].

Paul Ekman extensively describes how language does not always represent physiological reality and that reading facial expression or other facial signals can reveal a different emotional state from what is expressed by words [188]. This would be the case of a person lying (e.g. for protection or for hiding feelings) but is also the cade for cross-cultural differences in verbally expressed emotions. It establishes the advantage of using different sources for emotional assessment and also the need to improve accuracy in detecting emotions from facial expressions. But what structures of the brain are involved in recognizing emotions? A study conducted with patients with selective amygdala lesions, published in Nature in 1994, suggests that the human amygdala may be indispensable to: (1) recognize fear in facial expressions; (2) recognize multiple emotions in a single facial expression; but (3) is not required to recognize personal identity from faces [189].

Emotions are not like thoughts, which need no external sign; most emotions have expressions, which communicate to others. They inform us that something important is happening inside the person who shows emotion. Those internal changes are preparing the person to deal quickly with an important event, most often some interpersonal encounter, in a way that has been adaptive in the past. The past refers to our past as individuals, and what has been adaptive in the history of our species [190].

There is considerable evidence indicating distinct, prototypical facial signals across a variety of cultures can be reliably recognized as corresponding to at least six different emotions (happiness, sadness, surprise, disgust, anger and fear) and possibly others, including interest, shame and contempt [191].

7.2. Physiological Measurements and Emotions

The external stimuli can trigger a number of physiological responses. In Figure 7.1 diverse behavioural responses are presented and identified as signs of or and anxiety as a result from external stimuli. The schematic diagram shows direct connection between the central nucleus of the amygdala and a variety of hypothalamic and brainstem target areas that may be involved indifferent animal tests of fear and anxiety. Projections to the basal forebrain that may be involved in attention also are shown [192].

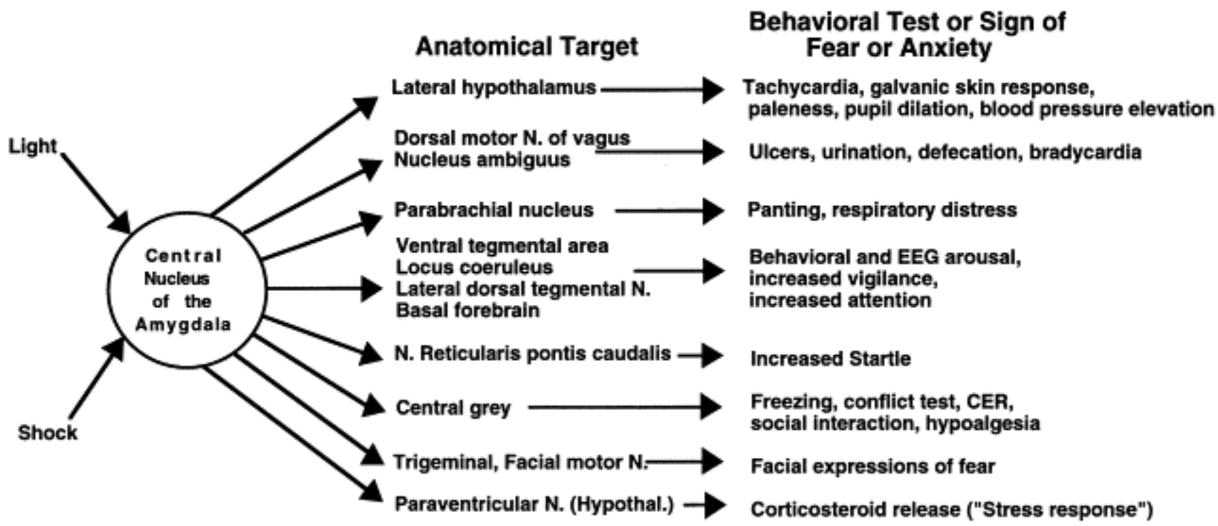


Figure 7.1 - Schematic diagram showing direct connection between the central nucleus of the amygdala and a variety of hypothalamic and brainstem target areas [192]

Those tests provide relevant information about the processes associated with Fear and Anxiety. From those connections between stimuli and body reaction it is possible to establish what measurements could provide information about those emotional states. In Pantic et al it is proposed an 2003 an ideal automatic analyser of human affective feedback [162] . At that time, twelve years ago this could have been an ideal setup with the existing technological means, but things changed since then in many aspect (e.g. mobile Internet and broad band, pervasive computing, sensor networks)

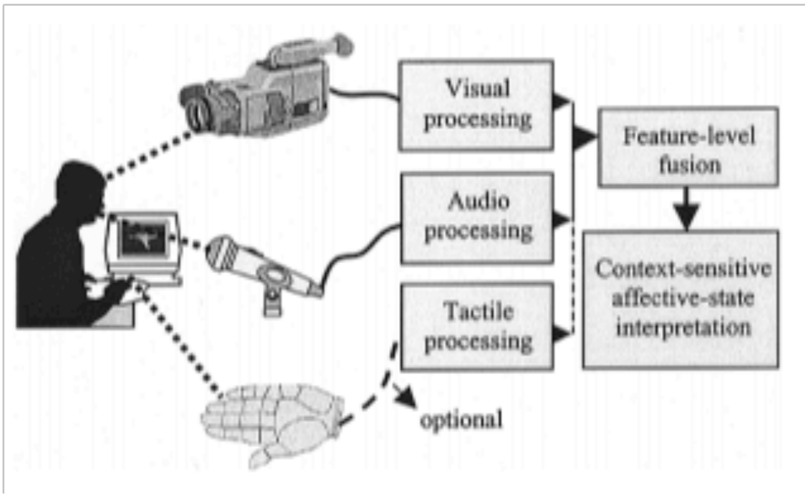


Figure 7.2 - Architecture of an "ideal" automatic analyzer of human affective feedback [162]

In current research it is aimed to go beyond this "ideal" automatic analyser by means of the proposed Framework and the experiments on affect assessment in the validation scenario.

7.2.1. *Galvanic Skin Response*

Skin conductance, also known as galvanic skin response (GSR), electrodermal response (EDA), psycho galvanic reflex (PGR), skin conductance response (SCR), or skin conductance level (SCL), is a method of measuring the electrical conductance of the skin, which varies depending on the amount of sweat-induced moisture on the skin [193]. Electrodermal activity is one of the most frequently used psychophysiological evaluations in psychology research. Arousal of the ANS influences sweat glands to produce more sweat; consequently, skin conductivity increases. GSR is an autonomic variable hence, it can not be controlled by the user [194].

Skin conductance It is based in the primitive 'fight or flight' response, whereby the body prepares itself for the exertion needed to deal with a perceived threat by increasing sweat activity to cool itself. At low levels, this happens all the time, as the mind experiences thoughts and emotion.

A special application of psychophysiological measures in HCI is their use for adapting computer behavior to human emotions. Because of its presumed specificity for indicating negatively tune emotional states, is especially suitable to determine adverse emotional states during HCI that might be counteracted by appropriate computer actions. Although primarily referred to anxiety and stress, this activity in the hippocampus may presumably be elicited by all kinds of negatively tuned emotions [195].

Skin conductance It is based in the primitive 'fight or flight' response, whereby the body prepares itself for the exertion needed to deal with a perceived threat by increasing sweat activity to cool itself. At low levels, this happens all the time, as the mind experiences thoughts and emotion. Sensitive response to thoughts is only found at two places on the body, the hand and foot. Two sites on the hand may be used, medial phalange of the fingers, or palm. To measure SC, a very small voltage is applied across these electrodes (0.5V). By measuring the current that flows, conductance can be measured. By Ohms law, Resistance = Voltage divided by Current, therefore Conductance = Current divided by voltage, the reciprocal of resistance. The unit of resistance is the Ohm, and Conductance used to be expressed as Mho, but the preferred unit of conductance is microSiemens [196].

7.2.2. *EYE TRACKING SYSTEMS*

Eye tracking is the process of measuring either the point of gaze (“where we are looking”) or the motion of an eye relative to the head. An eye tracker is a device for measuring eye positions and eye movement. A wide variety of disciplines use eye-tracking techniques, including cognitive science, psychology (notably psycholinguistics, the visual world paradigm), human-computer interaction, marketing research, and medical research (neurological diagnosis). Specific applications include tracking eye movement in language reading, music reading, human activity recognition, the perception of advertising, and assisting people with disabilities. Eye-tracking systems are useful in helping researchers analyse usability designs or human psychology from gaze information as presented in Figure 7.3 [197].

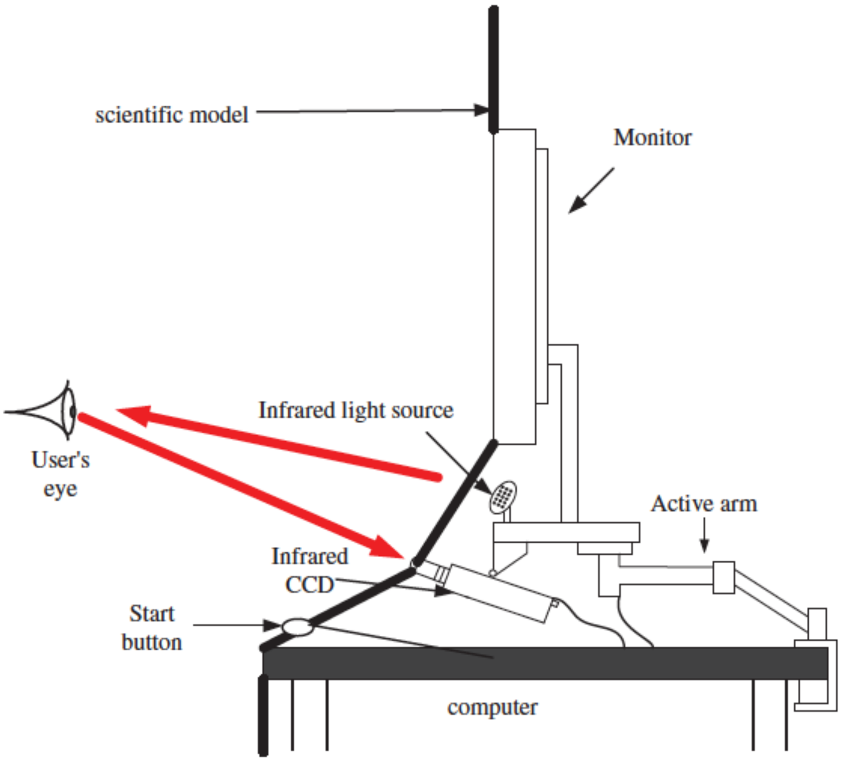


Figure 7.3 - An Eye Tracking setup for public display [197]

Eye tracking has been used for applications like the evaluation of websites, measurements of fatigue and emotional states, among other applications.

In general there are 4 classes of measurement to be made in eye-tracking evaluation [198]:

Movement measures – which are concerned with a whole variety of eye-movements through space, and the properties of these movements.

Position measures – which deal only with where a participant has or has not been looking, and the properties of the eye-movements at spatial locations.

Latency measures – which pertain to the number, proportion, or rate of any countable eye-movement event.

Numerosity measures – express the duration from the onset of one event to the onset of a second event. Measures of this type also appear in the form of spatial distances.

7.2.2.1. *PUPIL DILATION*

The pupil is the opening through which light enters the eye and begins the process of visual perception. The diameter of that opening is determined by the relative contraction of two opposing sets of muscles within the iris, the sphincter and dilator pupillae, and is determined primarily by the light and accommodation reflexes. But in addition to reflexive control of the pupillary size there are also tiny, cognitively related, visually insignificant fluctuations in pupillary diameter that appear to serve no functional purpose whatsoever. These miniature pupillary movements, usually less than 0.5 mm in extent, appear to be attenuated reflections of changes in brain activation systems that underlie human cognition. These small but ubiquitous pupillary fluctuations form the basis of cognitive pupillometry, providing a unique psychophysiological index of dynamic brain activity in human cognition [199].

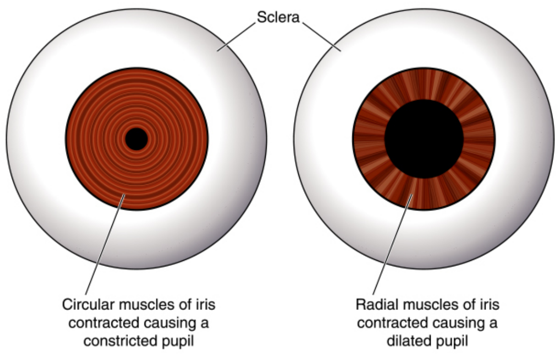


Figure 7.4 - Pupil Dilation[9]

A natural approach in the search for alternative and better means for human–computer interaction (HCI) is the understanding of centrally important factors in intraindividual and intraindividual human communication and behaviour [200]. Pupil dilation is connected with emotions and for that it provides new means of mediate HCI by verifying and adapting output to users. In a study by Greg et al, depressed individuals were especially slow to name the emotionality of, positive information, and displayed greater sustained, processing (pupil dilation) than non-depressed individuals, when their attention was directed toward emotional aspects, of information. Contrary to predictions, depressed, participants did not dilate more to negative than positive, stimuli, compared to non-depressed participants [201].

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[9] http://discoveryeye.org/blog/pupils-respond-to-more-than-light/

The problem with using pupil dilation to infer emotions is that, regarding pupil dilation and contraction, nobody really knows for sure what these changes do says Stuart Steinhauer, director of the Biometrics Research Lab at the University of Pittsburgh School of Medicine [202]. Also written by Joss Fong in the sentence “What do an orgasm, a multiplication problem and a photo of a dead body have in common? Each induces a slight, irrepressible expansion of the pupils in our eyes, giving careful observers a subtle but meaningful signal that thoughts and feelings are afoot” [203].

7.2.3. *International Affective Picture System (IAPS)*

Emotional response can be measured in at least three different systems, in affective reports, physiological reactivity and overt behavioural acts [204]. The choice for a physiological or behavioural measure can be relatively easy as the available technology and methodology will establish a preference. The selection among available affective report measures is a daunting task as there are dozens of affective inventories. Another thread long existing in psychology is the difficult question of what to assess when measuring people’s reports of internal feeling states [205]. The thread is that differences in affective meaning among stimuli, words, objects or events, can succinctly be described by three basic dimensions, in its original, lust (pleasure), spanning (tension), and beruhigung (inhibition) [206]. In following that work, the categories of pleasure, arousal and dominance are widely accepted as pervasive in organizing human judgements. The differential scale proposed by Mehrabian and Russell is a widely accepted instrument for assessing the 3-dimensional structure of objects, events and situations. It consists of a set of 18 bipolar adjective pairs (Unhappy-Happy, Annoyed-Pleased, Unsatisfied-Satisfied, etc.) each related along a 9-point scale. The major problem with this verbal rating scale is that its results constitute a large database difficult to analyse and, and difficult to apply to non-English speaking cultures. Also, the adjectives are not that suitable for children or people with some kind of impairments. To address this issues, Lang et al devised a picture oriented instrument called the Self-Assessment Manikin (SAM) to directly assess the pleasure, arousal, and dominance associated in response to an object or event [207].

Most of the research on universals in facial expression of emotion has focused on one method; showing pictures of facial expressions to observers in different cultures, who are asked to judge what emotion is shown. If the observers in the different cultures label the expressions with the same term, it has been interpreted as evidence of universality. Most of the challenges have been against this type of evidence, arguing that the lack of total agreement is evidence of cultural difference [208].

In Figure 7.5 it is displayed the three series of manikins as proposed by Peter Lang in 1980 [209]. The self Assessment Manikin (SAM) concept is used to rate the affective dimensions of valence (top panel), arousal (middle panel), and dominance (bottom panel). The scale proposed to users ranges from 1, lower values, to 9 higher values for valence, arousal and dominance. The scale is obtained by choosing one of the five manikins or one of the four spaces between them composing a 1 to 9 scale.

SAM has been used effectively to measure emotional responses in a variety of situations, including reactions to pictures [210].

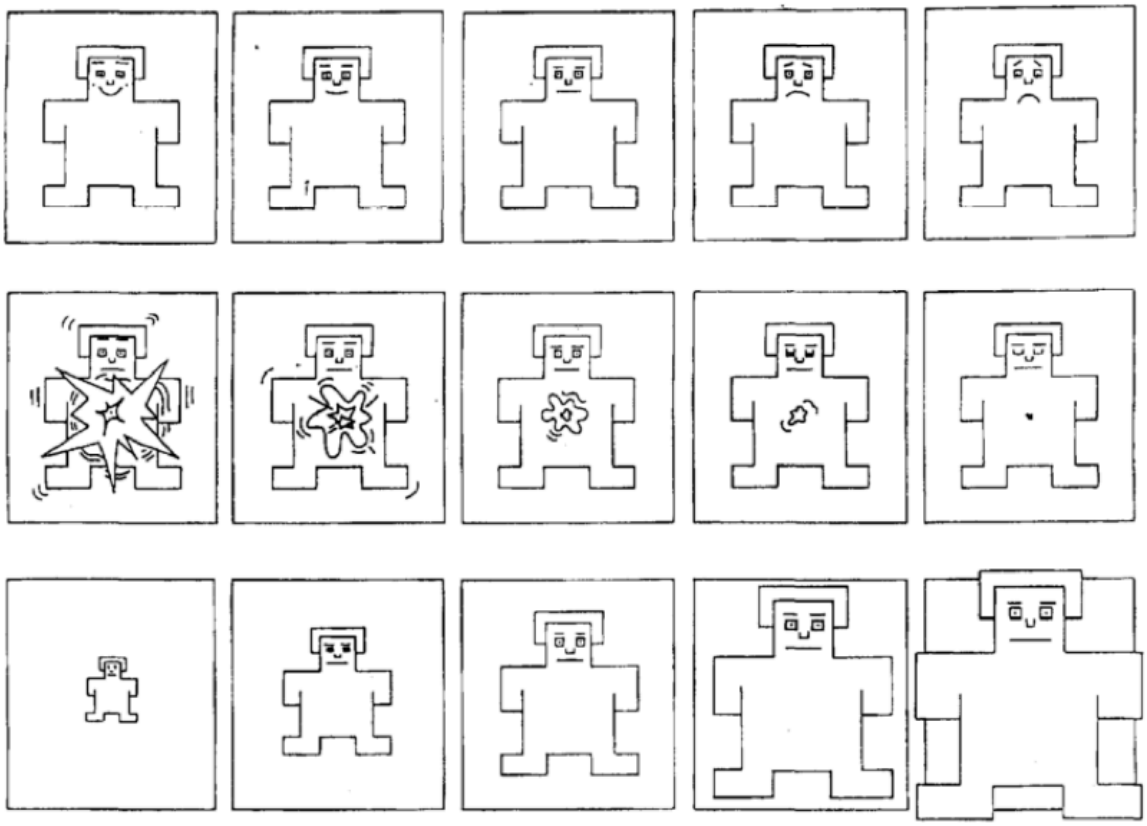

Figure 7.5 – The self Assessment Manikin (SAM) used to rate the affective dimensions of valence, arousal and dominance [209]

The International Affective Picture System (IAPS) provides normative ratings of emotion (pleasure, arousal, and dominance) for a set of color photographs that provide a set of normative emotional stimuli for experimental investigations of emotion and attention. This set is being developed and distributed by the NIMH Center for Emotion and Attention (CSEA) at the University of Florida in order to provide standardized materials that are available to researchers in the study of emotion and attention. The existence of these collections of normatively rated affective stimuli should:

1) Allow better experimental control in the selection of emotional stimuli;

2) Facilitate the comparison of results across different studies conducted in the same or different laboratory, and;

3) Encourage and allow exact replications within and across research labs who are assessing basic and applied problems in psychological science.

In an undertaking of this nature, choices have to be made regarding the emotional judgments selected for standardization. It began by relying on a relatively simple dimensional view, which assumes emotion can be defined by a coincidence of values on a number of different strategic dimensions. The two primary dimensions were one of affective valence (ranging from pleasant to unpleasant) and one of arousal (ranging from calm to excited). A third, less strongly-related dimension was variously called 'dominance' or 'control' [211].

Emotional expression can offer two opportunities for research being made in human emotions. The expression of emotions can be used to infer about a person's emotional state, as we intuitively know that we express in our faces what we are feeling. On the other hand we can use exposition to faces to suggest or lead to a person's emotional state.

Brain imaging studies consistently show regions of the brain activated by both positive and negative emotions, including the insula, striatum, orbitofrontal cortex, nucleus accumbens and amygdala [212][213]. For that there are some arguments on how we may need to consider the whole body along with the face to discriminate between intense positive and negative emotions [214].

7.2.4. *Electrocardiography (ECG)*

Emotion is the excited mental state of a person caused by internal and external factors and the heart rate is predominant in deciding the emotion of a person [215]. Emotion recognition through computational modelling and analysis of physiological signals has been widely investigated in the last decade. Most of the proposed emotion recognition systems require relatively long-time series [186]. Electrocardiography (ECG) measurements have been used long for hearth pathology detection but they reveal to be useful to measure relevant information about fatigue and sleep stages [216]. There are portable methods for measuring the ECG as is the case of the Holter monitors which are able to record heart's electrical activity during 24 or 48 areas allowing diagnose of many heart pathologies (e.g. Atrial fibrillation or flutter, Multifocal atrial tachycardia, Palpitations, Paroxysmal supraventricular tachycardia, etc.)[217].

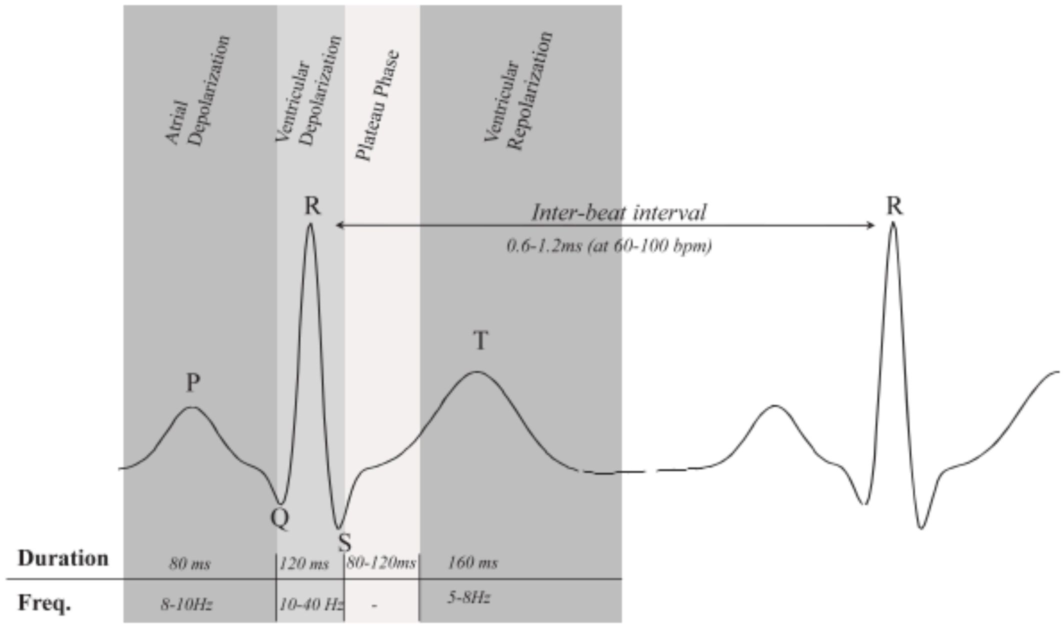

Figure 7.6 - Main components of an ECG Heart beat [218]

In emotion research, it is very important to collect meaningful data. It is very difficult to design an experimental setup that can induce the same emotion in every subject, especially if the same stimuli are used across all subjects. Different characters, varying moods, and the inability to accurately self-report an emotional experience may significantly affect the outcome of a study. In particular, when internal modalities like the ECG are examined, data labeling is very subjective and can only be verified by the participants themselves.

Within the cardiac muscle, the nerve-endings of the Autonomic Nervous System (ANS) play a major role in the cardiac output because they affect the rhythm at which the muscle pumps blood. The fibers of the sympathetic system run along the atria and the ventricles and, when activated, stimulate the cardiac muscle to increase the heart rate.

Despite the difficulties, establishing emotions from internal manifestations of the body is worthwhile for human computer interaction systems. Although ECG has been extensively employed in affect research, little attention has been paid so far to the waveform patterns under emotional activity. A typical approach is to extract the R-R intervals for the computation of the HRV (Heart Rate Variability) and treat the remaining signal as redundant. However, given that the ANS has endings in each of the four chambers of the heart, it is expected that ECG will exhibit emotion specific patterns [218].

SECTION III – CONTRIBUTION & VALIDATION

In this section it is presented the outcomes and the scientific relevance of the research work developed, including the validation in scientific setup experimented by users and also by published wok. In Chapter 8, five emerging research areas are presented with an explanation of their relevance to this dissertation. Then in Chapter 9 the major outcomes are presented in the form of a Data Model and a Framework. Finally in Chapter 10 a presentation and description is made on the experiment, attended by people that develop a validation work of the presented Framework, tested by people that, due to the dimension and implications of the Framework, represent a partial validation of the Framework. As complement to such validation, Chapter 10 presents 4 validation scenarios that where published, either in journals and conferences that represent both the dissemination of the research work along with a validation by peers.

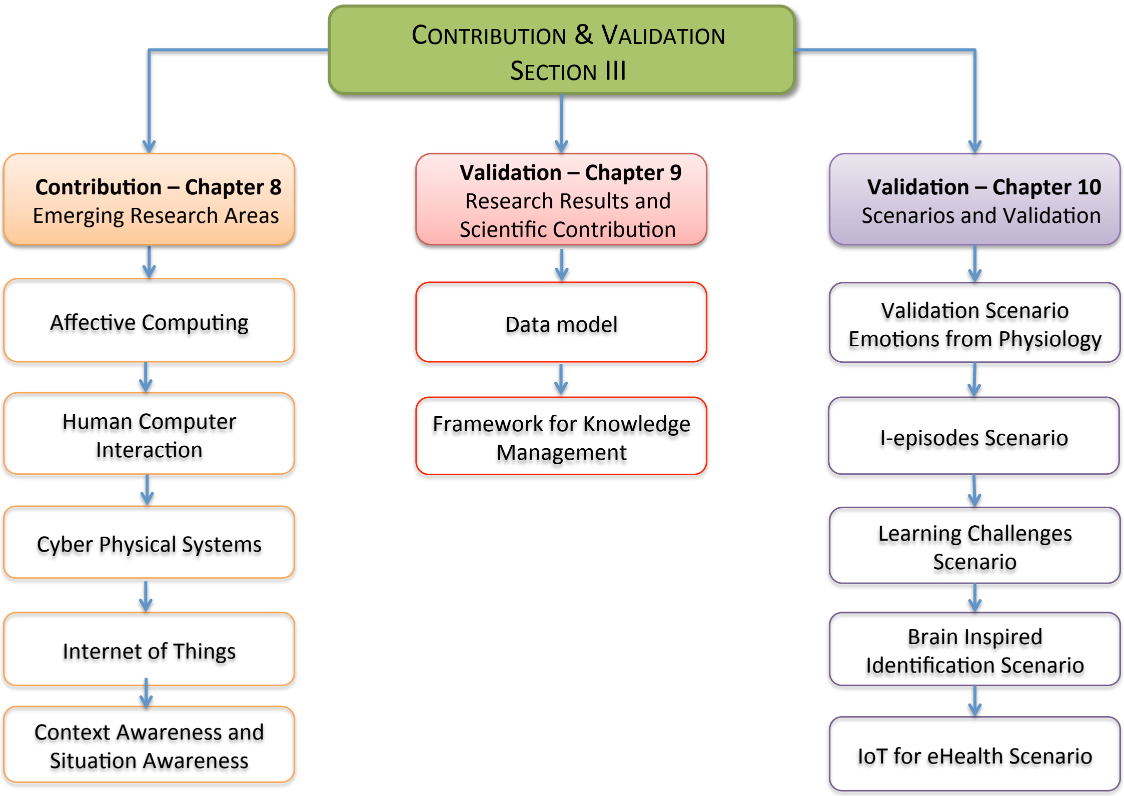

Figure III.1 – Contribution and Validation

The result from the research process documented in this Dissertation is presented in Figure III.1 by its impact in emergent research areas, and its validation in different formats. The left column presents the potential impact in emerging research areas of the research results achieved so far. That will be presented in Chapter 8 where the state of art for each area is presented with a specific section with the potential impact in that area. The middle column presents the Data Model and Framework for Knowledge Management that where developed and constitute the central scientific contribution. Those are presented in Chapter 9. The left column presents the deployment scenarios that make use of the research results. The first scenario develops the usage of the Framework with real devices and human volunteers as the others present conceptual usages of the Framework. All the presented scenarios are accepted by peers and where published in indexed International conferences and Journals.

8. EMERGING RESEARCH AREAS

This Chapter presents emerging areas that benefit from the technologies that are being developed and adopted at the beginning of XXI century. This Chapter is the next step after the literature review because along with the background observations a section is presented on the impact of this research work on that specific area. The areas were selected by their technological relevance and linkage to this doctoral research Those include, in 8.1, one of the most relevant topics, Affective Computing which, in general terms, deals with the emotional states retrieved or caused by computational devices then in section 8.2, Human-Computer Interaction, another research with a longer history, since computers emerged and people started to interact with computers it become an area of study that become more active this days where it has been created a diverse set of options for humans to interact with computers. This section has a highlight on its appliance on education, as it is an area that was considered of relevance in the research performed last years. Section 8.3, Cyber-physical Systems presents another area that has a significant growth in attention and investment due to its importance to many areas where the objective is to promote new forms of interaction with the environment via computational devices, which covers many areas of application. Among the presented areas, the most debated in business and research is probably the Internet of Things that is presented in section 8.4 in general it represents the goal of having most of the objects we deal everyday as a connected device with internet identity and selected functionalities. Finally in 8.5 Context Awareness and Situation Awareness has to do with the capacity of the systems to perceive the circumstances and react accordingly, it is an area that has a confluence of all the presented areas with relevance towards a better interaction with humans. The areas presented in this section are also an insight in the faster growing research areas currently and in a near future.

The analysis of the scientific areas performed for the reported research work focused in selected research areas that are well established in the science community for decades or centuries. There are however a set of new research areas, related with technologies that emerged in the last decade, resulting from mobile and wearable devices, new services and pervasive computing.

In this Chapter those areas are analysed by their importance for the present research work and for their foreseen growing impact in science and technology for the years to come.

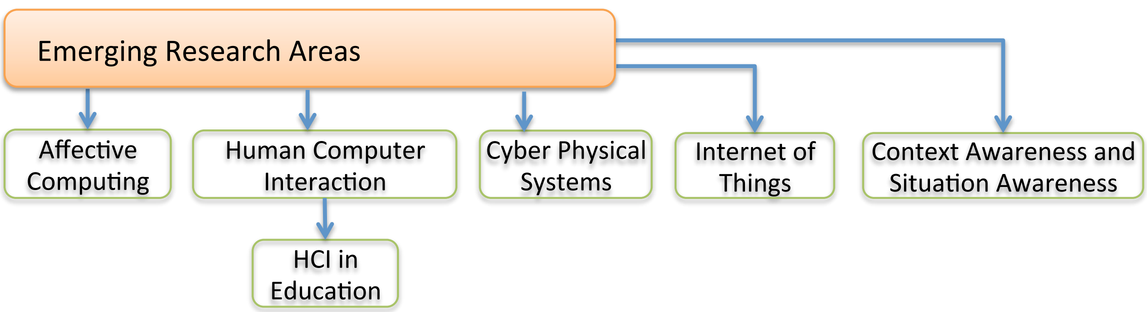

Figure 8.1 - Emerging Research Areas with relevance to this Research Work

8.1. AFFECTIVE COMPUTING

The life of humans and their interaction with each other are ruled by affects. In a more generic way, affective computing is computing that relates to, arises from, or deliberately influences emotion or other affective phenomena [219]. Affect refers to the experience of feeling or emotion and is a key part of the process of an individual's interaction with environmental stimuli [220].

Descartes[10] proposes that emotions are, like colours, based on fundamental components. All other emotions will derive from six pure components; love, hate, astonishment, desire, joy and sorrow [221]. Immanuel Kant[11] proposed five basic emotions: love, hope, modesty, joy and sorrow. Later William James[12] narrowed the category down to four basic emotions: love, fear, grief and rage. All other emotions, he argued, were variations on those four emotions [222]. These different schools propose models to classify emotions and in more than half a century, emotion researchers have attempted to establish the dimensional space that most economically accounts for similarities and differences in emotional experience. Today, many researchers focus exclusively on two-dimensional models involving valence and arousal. Adopting a theoretically based approach, Fontaine et al. identified on the basis of the applicability of 144 features representing the six components of emotions: 1- appraisals of events, 2- psychophysiological changes, (bodily sensation) 3- motor expressions (face, voice, gestures) 4- action tendencies, 5- subjective experiences (feelings) and 6- emotion regulation [223]. In conversation, people tend continuously to mimic and synchronize their movements with the facial expressions, voices, postures, and instrumental behaviours of others. Peoples emotional experience may be influenced by awareness or their the central nervous system commands that direct such mimicry/synchrony in the first place or the afferent feedback from such facial, vocal and postural expressions [224].

Emotions are a characteristic of human beings but in our interaction with the environment we feel emotions that are triggered by what we sense from the outside but depend on our inner previous experiences. In interacting with computers we experience different kind of emotional responses

[10] (1596-1650)

[11] (1724-1804)

[12] (1842-1910)

that could be used for different purposes, either to improve our experience or to make an assessment of our mental states while using computers.

Affective computing has two sides of relevance for this dissertation. For one side it matters how materials thus presented in a computer environment can affect the user depending on the richness of the objects. On the other side is the need to measure moods and emotions from computational devices and promote a usage and configuration of devices and applications that meet users' emotional states adequately. Attending both cases should promote better interoperability between humans and computers and thus fewer disturbances motivated by misadjusted activity from devices or applications.

Companies dedicated to marketing and neuromarketing[13] make studies on human behaviour, with a level of secrecy due to ethical problems involved. However in a less complicated way there are studies that can be carried out even by a person with her own laptop. One recent example is the Smile Suggest[14] add on, that using the computer camera makes an assessment of our smile towards what we are seeing and then, with a rating of 1to 10 in happiness can suggest pages by their rank.

There are also techniques that enable recognition and classification of emotional states from speech. Emotional speech recognition aims at automatically identifying the emotional or physical state of a human being from his or her voice [225]. However, those techniques need to be brought to a higher level of maturity, before being routine in our smartphones or other communicating devices because it is well known that the introduction of acoustic background distortion and the variability resulting from environmentally induced stress causes speech recognition algorithms to fail [226]. Finally in state of the art, we can consider the recently launched to the market, with little adoption so far, of the pressure sensing keyboards that can be used for the emotion recognition based on keystroke dynamics [227].

Affective Computing studies are usually performed by multidisciplinary teams as it is a crossing area from computation to psychology sociology and other social sciences and in this matter it crosses Emotions, as human study, and the affective side of Human Computer Interaction.

[13] http://www.salesbrain.com/

[14] http://www.smilesuggest.com/

8.1.1. CONTRIBUTION TO AFFECTIVE COMPUTING

Inspired by the inextricable link between emotions and cognition, the field of Affective Computing aspires to narrow the communicative gap between the highly emotional human and the emotionally challenged computer by developing computational systems that recognize and respond to the affective states (e.g., moods and emotions) of the user [228]. The research developed so far and reported in this dissertation contributes with a new step towards recognition of human emotions. The contribution has several dimensions 1) a data model that includes physiological information that can be used either for studies on emotional assessment and physiological

The novelty of the work presented in Section 10.1 is that several measurements are used to get information with potential relevance to affect along with each person's assessment expressed in a scale from 1 to 9. The measurements used for the experiment have no similar report in literature, even specific cases related to affect assessment. Those measurements used in our experiments are Galvanic Skin Response, Heartbeat, pupil dilation and eye tracking, along with the Self-Assessment Manikin scale (SAM).

Some background studies try to evaluate arousal and valence by itself and by those measurements, along with the known classification of the stimuli to infer emotions. In this case, it was used a known scale (IAPS) but combined the analysis of physiological data along with the self-assessment made by persons.

8.2. HUMAN COMPUTER INTERACTION (HCI)

Nowadays the usage of computational systems makes humans and computers to interact daily, sometimes in a very close relationship. Those computational systems, or other so-called smart devices, humans have different types of interfaces providing different types of interaction.

In traditional interactive computing, users have an impoverished mechanism for providing input to computers [229]. Humans type instructions, move mouse devices or tap over pad areas that execute actions. In the vast majority of human computer interaction humans use vision to retrieve information and the fingers to type or select forms of interaction with the computational systems. Robotics, on the other way, tries to ease this relationship by building robotic systems that perform useful and dangerous activities (e.g. hazardous transportation, shop-floor line assembly, etc.) or they try to build machines that resemble human bodies and human movements. The idea is that ultimately they can be part of our livings with minimum disturbance as is defended by some science fiction authors [230]. Until recently affective communication was not implemented in human computer interfaces. Nowadays researchers in human‑computer interaction (HCI) have recognized the importance of emotional aspects and started to include them in the design of new interfaces using one of two possible approaches, either as evaluation indicators or as components to be inserted in the human‑computer loop [231]. It is no surprise, following those thought, that some defend that HCI should follow the basic principles of communication among human beings [232].

In the line of knowledge pursue, computers are becoming part of humans' process of learning and become an important presence in classrooms or in every student learning activities or while performing work for classes. Following that line of reasoning, it is important to notice the growing importance of computational systems in education how it coexists with traditional methods and what added value could HCI bring to students and to the teaching process.

8.2.1. *HCI IN EDUCATION*

The ages of paper and pencil, board and chalk or overhead projectors are overpast. In traditional interactive computing, users have an impoverished mechanism for providing input to computers [229]. With the diversity of online contents and multimedia options, it is plausible to question at what point paper books will remain confined to libraries as objects of the past. Whatever the option each educator takes, the need to adjust contents to students was in the past a choice for the right books, and is today the choice for selected links. Nevertheless this is a reductionist question as with the growth of Internet contents, doubling every 18 months [233], it is necessary to address, not the existence of contents but, the right contents for each student under specific teaching circumstance. Next, we can assume that, if contents are diverse and adequate, attention should be provided to the process of transferring information and knowledge to learners. Since Internet information is accessed from a computer device, being a laptop or a portable device with computational capabilities, it is important to turn attention to Human-Computer Interaction (HCI). The relationships between people (e.g. students and teachers) can have better moments and can be easier between some duplets of persons interacting. Nevertheless, people have the ability to sense how others are receiving the message and identifying the peaks of interaction. If other persons are bored or restless, it is within teacher's perceptional capacities to identify those states and react accordingly in order to re-establish the learning process (e.g. change attitude, change message or even pause interaction).

Beyond any sociological study or psychological analysis of the changes in the last decades with the introduction of computational systems, it becomes important to understand what is the value of computational systems in the learning process and how can it be improved by those emerging technologies. That is part of the study carried out in the present research studies.

8.2.2. *HUMAN COMPUTER INTERACTION IN ENTERPRISE INTEROPERABILITY*

Enterprises are complex live organisms of humans and networked machines including diverse types of computational devices. Enterprise interoperability promotes the interaction between companies based in the interoperability between companies and between devices in the company. Knowledge management is another important aspect that is extensively observed in the dynamic enterprise ecosystem. It is understandable that studies make different types of assessment for machines and people. In this sense we can ask on the interest of studying humans along machines in the chain of collaboration inside the Enterprise interoperability Ecosystem. What we propose is establish measures to promote interoperability between computational devices and humans, at the same time that we can promote interoperability between humans using computational devices to interact between each other.

Today an enterprise's competitiveness is to a large extent determined by its ability to seamlessly interoperate with others. The advantage of one enterprise over another stems from the way it manages its process of innovation. Enterprise Interoperability (EI) has therefore become an important area of research to ensure the competitiveness and growth of European enterprises [234]. The activities within an enterprise are complex as companies manufacture a variety of products using different production methods to satisfy different customers. An enterprise model is defined as ''the art of externalising enterprise knowledge, which adds value to the enterprise or needs to be shared''[235]. The word interoperability has many wide uses. The term interoperability is increasingly used in enterprise engineering and its related standardization activities [236]. While interoperable systems can function independently, an integrated system loses significant functionality if the flow of services is interrupted. An integrated family of systems must, of necessity, be interoperable, but interoperable systems need not be integrated. Integration also deals with organisational issues, in possibly a less formalised manner due to dealing with people, but integration is much more difficult to solve, while interoperability is more of a technical issue. Compatibility is something less than interoperability. It means that systems/units do not interfere with each other's functioning. But it does not imply the ability to exchange services. Interoperable systems are by necessity compatible, but the converse is not necessarily true. To realize the power of networking through robust information exchange, one must go beyond compatibility. [237]. In what regards to the human aspect we should not expect that difficulties with one person could interfere to the whole network and the knowledge exchange process within the enterprise. By knowledge we can consider the Individual Knowledge that can be found in the hands of an individual worker who serves as a fundamental unit in the process of knowledge creation, storage, and use within the enterprise. Many times this knowledge is tacit and therefore not well documented. Group knowledge is more powerful than the sum of the knowledge acquired by an individual. This knowledge can be both formal and informal and is frequently intangible but is one of the most important knowledge assets within a company. Organizational knowledge in the organization, in turn, serves as a storehouse of knowledge with its own peculiar structure and divisions of functions, with multiple processes and activities to aid in the search for knowledge [238].

MEDIATED HUMAN TO HUMAN INTERACTION AND HUMAN COMPUTER INTERACTION

The most distinguishing characteristic of humans, apart from the body, is the fact that humans feel emotions. Alan Turing back in 1950, questioned if a machine can think and for that he elaborated a test that is still in use and that could evaluate if machines can think [239]. At the same time, Jefferson was saying that "Not until a machine can write a sonnet or compose a concerto because of thoughts and emotions felt, and not by the chance fall of symbols, could we agree that machine equals brain that is, not only write it but know that it had written it. No mechanism could feel (and not merely artificially signal, an easy contrivance) pleasure at its successes, grief when its valves fuse, be warmed by flattery, be made miserable by its mistakes, be charmed by sex, be angry or depressed when it cannot get what it wants" what has become none as Jefferson's Oration [240]. Machines can fake the appearance of an emotion quite well, without having any feelings similar to those we would have: They can separate expression from feeling. With a machine it is easy to see how emotion expression does not imply "having" the underlying feeling [241]. As emotions play an important role in our life it is important to consider their role in human computer interaction (HCI). Affective computing is a research area developed by Rosalind Picard since the decade of ninety that addresses affective aspects in HCI. In her definition, affective computing is computing that relates to, arises from, or influences emotions [242]. In a broad sense means that for one side how emotions influence our behaviour in interacting with computational devices and how that interaction influences our emotions. In affective computing, we can separately examine functions that are not so easily separated in humans [243] which enables a computational handle of affect related measurements. Several measurements can be performed, integrating data acquired from physical environment which will increases the factor for unreliability to the overall system because of the unpredictable behaviours of the physical world [244]. Thus if we want to assess a person's emotional cues, it is necessary to develop a methodology that enables the evaluation of physiological, information and correlate that information with known emotional states so that, later, becomes possible to infer emotional states from such measurements. In order to be used in the enterprise ecosystem, such measurement should be the less invasive, and disturbing of daily activity, as possible. The objective would be, to monitor how interaction with computational environment affects humans' emotional states and how the interaction of humans by means of using computational channels can be evaluated and mediated if needed. Envisaging this non-disturbing approach, measurement of heartbeat seems to be an interesting option, from the ergonomic point of view, as today there are many of such devices on the market that can be used for fitness and are used like a normal watch (e.g. Nike+ Fuelband[15], Fitbit[16], Jawbone[17]).

It is also relevant to notice that emotional states can bias judgement and can alter perceptions. Emotions often seem to overpower us and to influence our judgements in profound ways. Our decisions and our actions when we feel angry or frightened or enthusiastic appear not to agree with the dictates of reason and prudence [245]. According to Saks and Johns, there are 3 factors that can influence the perceptions: experience, motivational state and finally emotional state [128]. Emotional states can diminish workers judgment and diminish conscientious decision capacity; in some cases it can also put them at risk. Finally, and also important, assessing emotional states can be a most relevant step for business as Nobel prize Daniel Kahneman stated, the study of peoples well-being can have a profound impact on economy [246].

This section is almost mandatory as the research work for this Dissertation was developed along with the research work in European Projects at the Group for Research in Interoperability of Systems in the Centre for Technology and Systems at UNINOVA institute.

8.2.3. *Contribution to Human Computer Interaction*

Human computer interaction is a matter of study from decades since people interact with computers. In this case, a special attention is given to education, by the envisaged growing importance of HCI in Education and by the background of the author, in the last 18 years, in teaching using technological devices.

[15] http://www.nike.com/us/en_us/c/nikeplus-fuelband

[16] http://www.fitbit.com/

[17] https://jawbone.com/up

The proposed framework can provide support for students' emotional assessment, in real-time, providing indication of teaching effectiveness. Those indications can be of value for a teacher to change course of the happenings in a classroom, modifying attitudes or making use of other teaching tools, but can also provide guidance for teaching contents reformulation or tool adaptation. Those possibilities were published in thematic conferences and are further presented in one of the present scenarios, in section 10.3.

Contribution to HCI for Enterprise Interoperability departs from the analysis on the enterprise environment and has the goal of analysing and promoting the human side of Interoperability. That is pursued with an overview of the emotions as distinguishing characteristic of the humans. By establishing relationship between physiology and emotions, the present work will contribute to the improvement of interactions Human-to-Human (H2H) and Human computer Interaction HCI. In a human centric approach, the research work aims at developing tools that, in a less-obstructive manner, allow an evaluation and improvement of personal integration in the Enterprise Environment.

8.3. Cyber Physical Systems (CPS)

Cyber-physical systems (CPS) are physical and engineered systems, whose operations are monitored, coordinated, controlled and integrated by a computing and communication core. Just as the internet transformed how humans interact with one another, cyber-physical systems will transform how we interact with the physical world around us [247]. Cyber-Physical Systems are integrations of computation with physical processes. Embedded computers and networks monitor and control the physical processes, usually with feedback loops where physical processes affect computations and vice versa. In the physical world, the passage of time is inexorable and concurrency is intrinsic. Neither of these properties is present in today's computing and networking abstractions [248]. The European Commission, at the Digital Agenda for Europe states, "embedded systems are the electronics that are invisible to us and only indirectly accessible through the use of higher end products". That means all the electronic for engine control systems, accurate control of speed, dynamic ride control, or the anti-lock braking system (ABS) monitor in cars [249].

There is still a serious gap between the cyber world, where information is exchanged and transformed, and the physical world in which we live. The emerging cyber-physical systems shall enable a modern grand vision for societal-level services that transcend space and time at scales never possible before [250]. The usage of CPS needs a better understanding of human capacities and human way of perceiving and interacting with the world. Those systems can benefit from a better understanding of human physiology and human cognitive and motor functions as a source of inspiration for designers. Also those physical systems can provide new resources for humans as long as, in their interaction with humans, they establish a proper human computer interfaces (HCI). CPS systems can be used, to same extent, to mimic and to simulate human systems' behaviour and in medical related areas provide compliment to human physiological processes. CPS can provide a better interaction of computational systems with humans and can complement human activity.

8.3.1. *Contribution to Cyber Physical Systems*

The work developed has a strong relationship with cyber-physical systems (CPS). For one side CPS can produce input for the framework as being able to sense data from the real world. On the other side, objects and actions with a wider sensorial description are a valuable source of information for the effectiveness of CPS.

The proposed data model will make easier for the CPS systems to understand the characteristics od the objects and consequently the physics of interactions with the real objects. That means that objects with a larger description will have a better potential of being properly handled by CPS systems. The other type of interaction is that information generated by CPS systems can be used to mount information over objects as proposed by the Framework. Such objects would benefit from data generated by sensors and by the interactions generated by CPS systems to better characterize those objects.

8.4. Internet of Things (IoT)

Internet of Things proposes an environment littered with communicating objects, with a pervasive presence around us of a variety of things, or objects, such as Radio-Frequency Identification (RFID), tags, sensors, actuators, mobile phones, etc. These networked objects will be visible in both working and domestic fields, with possible scenarios in domotics, assisted living, e-health and enhanced learning as possible examples of this new paradigm with a leading role in a near future [251].

IoT is extension of the Internet into the physical world, to involve interaction with a physical entity in the ambient environment. The entity constitutes 'things' in the Internet of Things and could be a human, animal, car, store or logistic chain item, electronic appliance or a closed or open environment. The 'entity' is the main focus of interactions by humans and/or software agents. This interaction is made possible by a hardware component, a 'device', which either attaches to an entity or is part of the environment of an entity so it can monitor it. The device allows the entity to be part of the digital world by mediating the interactions [21].

By 2025 Internet nodes may reside in everyday things; food packages, furniture, paper documents, and more. Today's developments point to future opportunities and risks that will arise when people can remotely control, locate, and monitor even the most mundane devices and articles [252]. In Figure 8.2, the main concepts, technologies and standards are highlighted and classified with reference to the IoT vision/s they contribute to characterize best. From such an illustration, it clearly appears that the IoT paradigm shall be the result of the convergence of the three main visions addressed above.

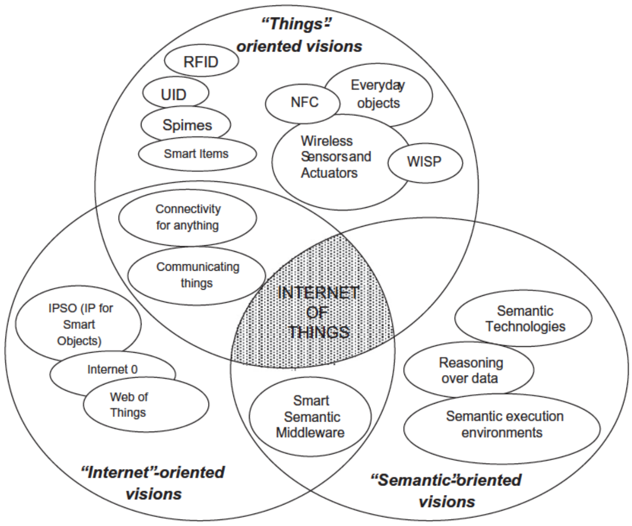

Figure 8.2 - "Internet of Things" paradigm as a convergence of different visions [251]

This paradigm depicted in Figure 8.2 presents IoT as the convergence of the Things that we encounter in what can be called smart objects that we use everyday or are used in technological objects (e.g. smart phones, tags, wireless sensors and actuators). The other vision, Interned oriented, is based mainly in IP for smart objects (IPSO) and the web of things. Finally the Semantic oriented vision refers mainly to semantic technologies and its relations with reasoning and middleware.

In another view we can consider the proposed different layers for an IoT architecture, it can be designed with a path starting on a Perception layer, with its main function is to identify objects and gather information. It is formed mainly by sensors and actuators, monitoring stations (such as cell phone, tablet PC, smart phone, PDA, etc.), nano-nodes, RFID tags and readers/writers [58].

8.4.1. *Contribution to Internet of Things*

Internet of things (IoT) has a potential interest in many areas in society and business. Those are already outlined, for comfort and home assistance, in the form of communications between devices at home and its configuration towards a person's needs. The remote access with smartphones or other smart devices to lighting and kitchen machines is already an appeal to develop new strategies in home planning. In business we assist to the evolution of data collection from the shop floor and to better logistics by the usage of sensors and other IoT devices, not to mention machine-to-machine interaction (M2M). The list could go on in many other areas but we are particularly interested in a human centred aspect of IoT. That was object of study in the publication Internet of persons and things inspired in brain models and neurophysiology [253] which points to a human centric capture of information, from portable devices or devices in the environment that, among other possibilities, can be used for the enrichment of a person's information.

In sequence of the interest of IoT for humans, the data model developed in this research work fits the purpose of collecting data and makes it available to a person's personal information or for applications that make the best use of it to address a person's needs. On the other side, the developed Framework makes use of devices and thus increases the meaning of IoT for a person in the sense that all information related to the environment or the wearable and portable devices in the perimeter of a person in a selected timeframe can be of use to enrich a person's personal information. That information collected according to the proposed data model and gathered together according to the mechanisms proposed by the Framework constitute a leap forward in the usage of IoT towards the improvement of personal knowledge management.

8.5. Context Awareness and Situation Awareness

Context awareness is an important assessment to determine what the person's circumstances are and, in that matter we need to question; what are context awareness and situation awareness [254]. Why should it be considered for this Framework? How can context be assessed? And what is the importance of context for a person?

The importance of context can be traceable in all situations of our life. The acts, attitudes and overall decisions in our life are based in context and are applicable according to context. We all know the importance of context in our life and the consequences of the wrong act according to context (e.g. wearing a T-shirt while visiting the polar dome at the zoo) or a good act in the wrong context (e.g. to offer a flower to someone allergic to its scent). It is plausible that most of human acts are not wrong by themselves but sometimes; placed in the wrong context, result in a bad experience.

In trying to use as much context as useful for developing proper applications, or proper behaviour for systems, it is necessary to collect relevant context information that can feed artificial intelligence algorithms. If users are requested to provide input on that could be tedious and inefficient as they can provide information that is not so relevant leaving aside information needed. For that the solution could be to make available or mine the most possible information and that can only occur by automatic processes.

But, what can we define by context and how far should extend the definition of context?

In human relations it is expected a right assessment of the implicit situational information, or context, that goes beyond time or place, requiring sensibility towards other's emotional state. In psychology, emotional intelligent and emotional quotient has assumed a growing prominence that has been matched in importance with intelligence quotient [161]. In line with that, we find the importance of the notion of context for disciplines such as philosophy of language [255], cognitive science [256] or linguistics [257]. For computer systems to attend user's needs in context with what is happening it is necessary to be aligned with such situational ambient and emotional state. Instantiating this concept in a phone device (e.g. a smart phone), it can choose the best topic according to the environment (e.g. a phone would ring differently if user is in a beach, sleeping or in a meeting) or a person's emotional state (e.g. happy music while heading to a party, soft sounds waiting for a test result).

8.5.1. *Definitions of Context*

The work that introduces the term 'context-aware' by Schilit and Theimer [258] refers to context as location, identities of nearby people and objects, and changes to those objects. Brown [259] defined context to be the elements of the user's environment that the user's computer knows about and Hull *et al.* [260] included the entire environment by defining context to be aspects of the current situation.

As a corollary to most of previous definitions, Dey and Abowd make a sectional analysis of those definitions by defining context to be the constantly changing execution environment, including the following pieces of the environment:

- *Computing environment* available processors, devices accessible for user input and display, network capacity, connectivity, and costs of computing

- *User environment* location, collection of nearby people, and social situation
- *Physical environment* lighting and noise level

By identifying some of the gaps and exaggerations of that definition they propose their own definition that addresses most of the needs in terms of contextual information for computer systems.

Context is any information that can be used to characterize the situation of an entity. An entity is a person, place, or object that is considered relevant to the interaction between a user and an application including the user and applications themselves [229].

After literature review of past definitions some issues are raised by the current research in this PhD. An interesting question to be addressed is the context of different participants in the scenario. We can argue if the 'Person' should be the only subject of a contextual analysis or if we should think on the analysis for the devices, what is the context for a cell phone? Was he forgotten? Is he heating or drying battery and become damaged or inoperative soon? And what for a Car is that applicable too? Is the car with some maintenance problem? Some verification needs to me made? Is there a software update or some new part that can improve performance?

On the other hand Context can be raised to a next level by considering different human subjects; If a system (e.g. computer or wireless device) is being used by more then one user, what is context and which is the relevance of the information for each user's context? In case of divergence how can the device respond in context? And following that line, if there are diverse users in the same space are they in the same context? If not how can context be achieved for each and all of them as they can be performing different activities and feeling different needs (e.g. one speaking on the phone, drinking, eating…)?

The research in this PhD dissertation addresses those issues by introducing more variables that enhance context, like the sensorial and physiological data that can help establishing more precise context and thus better addressing user's needs.

8.5.2. *Context and Artificial Intelligence*

The relevance of being in context to elaborate wise decisions and act wisely leads to the assumption that context may be essential for Artificial Intelligence. In fact relevance context was introduced for Artificial Intelligence (AI) in 1980 by Weyhrauch [261] establishing formalism toward the description of reasoning about beliefs in context and multicontext systems [262].

Following that idea of a contextual approach to reasoning, Ghidini and Giunchuglia [263] provided ,what they call, a foundation to reasoning that is still opportune;

1) Reasoning is mainly local and uses only part of what is potentially available.

2) There is compatibility among the reasoning performed in different contexts.

McCarthy and Buvać establish the basic relations ist(c, p) meaning that the proposition *p* is true in the context *c*, and value(c, e) designating the value of the term *e* in the context [264] Introducing contexts as formal objects will permit axiomatizations in limited contexts to be expanded to transcend the original limitations. This seems necessary to provide AI programs using logic with certain capabilities that human fact representation and human reasoning possess. As a corollary of different trials on formalizing context, Akman and Surav [265].

Context-awareness and situation awareness, taking human evaluation parameters, will allow an evaluation of the control and capability of a subject for carrying out a task correctly. This is particularly important when the subject has to perform a high-responsibility task. It is the case for car, us, truck and train drivers, but also pilots, air traffic controllers and controllers of nuclear reactors. The arousal and vigilance levels and time course is particularly useful for the control and safety of these professional tasks. Usually, the multiparametric approach is used for increasing the reliability of decision taking account of the basis of the measurements [266].

8.5.3. *Contribution to Context Awareness and Situation Awareness*

The need to understand context started so early in the live of human specie that it is understandable how it become a central concept in technology these days. Developers of applications and devices are most concerned on how technology will better understand context to properly address business and human needs.

Context awareness will be the most accurate the better an assessment is made on the environmental and individual conditions and that depends on the quality of information and the diversity of data parameters available for a given circumstance. The present work addresses those needs by providing a framework that captures and manages data so that it can be aggregated according to the purposes established and can provide input for diverse types of applications. That is the case of the i-Episode (c.f. section 10.2.1), one of the central concepts proposed by this research work that as the main characteristic of clustering gathered information in a moment in time for a given individual. It envisages diverse type of utilizations, including support for context aware assessment by the usage of diverse type of variables.

9. Research and Scientific Contribution

This Chapter presents contributions from the PhD research work. It starts by establishing a rational about the analysis that leads to such contributions, presenting a schematic description of all those contributions in section 9.1. Section 9.2 describes one important contribution, the Data Model with its formal representation. Then in section 9.3 the Framework is described as a central contribution from the research work. It includes also an instantiation of the Conceptual Framework into a Technical Architecture thoroughly described in its high-level details. Both these contributions will lead to the practical instantiation of the validation scenario that will be described in Chapter 10 with an analysis of the results obtained.

9.1. Aimed contribution

This section describes how the reasoning over the research questions supported by the background observations lead to the produced results that, once validated, confirm the proposed hypothesis.

"If we adopt sensorial and physiological analogies from the human body and inspiration from selected brain models to improve knowledge management, we will be able to find new ways of acquiring and representing knowledge, allowing new applications for a persons' benefit."

9.1.1. *Rational on the proposed solution*

The strategy to improve knowledge management is to extend existing methods to handle human related data, information and knowledge in the direction of supporting human needs and improving human computer interaction (HCI). It is where the emotional side takes special relevance. In that direction it is understood the importance on assessing emotional state of users for a better HCI. That means an improvement in context awareness taking in consideration, not only the environment (e.g. place, circumstances, agenda, etc.) but also the personal emotional state, in a new paradigm of Internet of Things with emotional information, could save risky situations for individuals (e.g. is the person stressed, sleeping, feeling danger, etc.) [267]. Taking that in account it is possible for devices (e.g. computers, mobile devices, robots) to react accordingly in a less disturbing fashion or even proactive towards human needs. In times where Internet of Things is being materialized in home or even connected cars [268] with an expectancy of 220 million cars connected by 2020 .This would promote a valuation of the benchmarks in computer science for the benefit of personal knowledge management and application development. Thus it is aimed to promote a more human-like usage of Information Systems as those supported by the Internet.

9.1.2. *Identified Gaps in Current Knowledge and Technological Applications*

The analysis made for the different research areas, section 1.4 enumerates a number of gaps in current technology and applications over the web, including mobile devices. This section provides a synthesis on those identified gaps that will be addressed by the developments proposed in the next sections.

- Systems and Information over the Internet lack in adequacy of user related information, especially if that is nonconventional human related (e.g. about smell taste or roughness).
- Technological devices are able to collect human related data (e.g. physiological from wearable devices) which are used for immediate purposes and lack in consistency with data models thus are limited in its potential use (e.g. relating physiology and emotions).
- Individuals are using devices that are becoming more proficient in capturing sensory and physiological information with little usefulness to them.
- Little attention has been paid to brain models and physiology in what concerns with capturing and managing information, which could have a positive impact in knowledge management research. This way would be interesting to know if we can learn from brain models and physiology to improve information systems.

The impact of the current research work in addressing this questions is debated later in section 11.2.

9.1.3. *Proposed Contribution:*

- A new Data Model inspired in the Two-Stream Hypothesis, and proposing the concept of i-Episodes (c.f. section 10.2.1) envisaging support for sensorial, physiological and emotional data with the following objectives
  - To improve human centric knowledge management
  - To allow new information representation methods that include
    - Support for sensorial data representation on information systems and at the Internet

- Support for physiological data representation on information systems and at the Internet

- A Framework designed for multiple applications, based on that data model, that can be instantiated in systems and applications that perform;
    - Data collection from sensors
    - Data collection from devices (e.g. personal, wearable, health)
    - Data collection from services (e.g. webcams, meteorology)
    - Emotional data inference from physiology or from self-assessment methods
    - Reasoning on data collection for decision support systems
    - Reasoning on data collection for improved context and situation awareness

In overall, the proposed contribution aims at improving Human Computer Interaction, which in a strict sense means better interoperability between computers and people and that would be achieved by taking in consideration physiological readings or self-assessment from people. That is one of the key innovative features of the present research work with a wide impact in personal management and business implications.

9.1.4. *A Framework to Represent Objects with Extended Properties*

At the Internet, samples of diverse objects related to a restriction of senses (e.g. sound, image, text) can be retrieved, as they are publicly available along with other reserved types of information. The present research develops the concept of a framework to manage objects in the Internet with information about the different sensations. That challenging concept requires the ability to acquire sensorial information about objects or the external world, to manage them as personal or collective information that later could be deployed as requested. Sensorial information will be written or depicted, as a first approach, but the framework aims to foster ground to whenever, in a near future, devices are able to capture our full experience in electronic support.

Interoperability is a fundamental issue of the framework for two main reasons; first through a public or semi-public databank of sensations the need for standardized sensorial representation formats, it will be an interoperability enabler for the framework. The second is that the framework will promote the interoperability between cerebral memories and Internet based memories in a convergence process along with the development of new technologies for acquiring sensorial information.

The representation of knowledge can be optimized with the use of an Ontology that properly defines the domain of use and allows a structure behind the object's database representation. Ontology design for the framework will need structured sensorial information that will support the extension of data modelling to the five senses as it happens in human nature along with the representation of emotions as exposed ahead.

The possibility of gathering and representing sensorial information by users or in a semi-automatic approach is the major motivation to establish such a framework as developed within the current research work.

9.1.5. *NEW DATA MODEL INCLUDING SENSORIAL INFORMATION*

In the most diverse aspects of society, data has become an important aspect to be analysed. Business needs data to be analyses in order to understand patterns of the market, being suppliers or consumers. Scientists need data to produce scientific results, being those, forecast of weather or evolution of decease or even to analyse data from experiments. Data has become central in many governance aspects and new reasoning technics, such as big data and algorithm development, are generating new tools and thus new vision for the understanding of the world we live from nano-scale to macroscopic dimensions.

The gathering of information is currently an exercise of searching the Internet, as most information can be retrieved from the Internet at a pace that was not possible to follow by other, non connected, systems. Sources can be more specific, as the trade information on markets or more generalist as dictionaries and wikis, the most known, the Wikipedia[18]. The usage of the Internet implies to face a monitor and retrieve what is written or depicted. That means a visual capture of information that has some similarities with our natural experience of the world, to observe and seek for information. In our interaction with the web, we make our searches and then we evaluate if that fits what we were looking for using, implicitly, the before-mentioned Two-Stream Hypothesis (c.f. 4.1.1). In what concerns to sensorial experience, we want to transfer some lessons learned from the brain to the Internet as the case of sensorial association between the

[18] http://en.wikipedia.org/, http://pt.wikipedia.org/

current experience and the memories stored at the brain and also the concept of episodic memories of our life that will motivate the new concept of I-Episodes [117] at the Internet (c.f. section 10.2.1).

The ability to interrelate existing stores of information is a fundamental property of human memory. This flexible process of association allows for the realization of novel relationships within previously learned sets of information [269].

In the current work, using an analogous strategy, the objective of retrieving existing elements from the knowledge base, is pursued adopting a two-stream approach. As an example, if we find a picture of our own or from other Internet source we have our "what" properly addressed, then when we recall an existing I-Episode it corresponds to a "where" of that Internet object, as it addresses a contextualization of that same object. Regarding this last aspect, what we learn from the brain are the relations between senses, as in our experience an event can contain diverse types of sensorial information (e.g. a sound can invoke a complete scene of our live). Those relations complete the sensorial scenario as other senses are also recalled as associated to what we see and where it locates, thus representing a person's sensorial experience of the world.

The transition from the concept of episodic buffer in working memory (c.f. Section 6.1) to the i-Episodes (c.f. Section 10.2.1) is another important element towards the knowledge management based on brain models. In working memory the different stimuli from the outside are gathered in chunks at the Episodic Buffer and later transferred to long-term memories, as we want to do with the i-Episodes. This is possible because in the outside world we use diverse media that are becoming able to store sensorial information that can be maintained with established connections, the i-Episodes concept. Those different inputs are grouped in chunks establishing permanent relations between those features as the brain does, initially in the Episodic Buffer. Such relations can also be characterized by its intensity, which means the focus of attention attributed to each related event. Consider, for example, your episodic memory of a day at a recent scientific meeting. You might recall a specific encounter with a colleague, your discussion about personal matters and about specific presentations you and she/he had heard at the conference. Each event within this episodic memory includes a combination of features: yourself, your colleague, what she/he and you said, and where the conversation took place. In addition, a vivid episodic representation for the encounter is organized according to the order of events; it unfolds as a "mental replay" of the encounter extended over time [270]. Thus, that memory can be deconstructed into a series of *associative representations*, wherein each discrete event includes the relevant people, their actions, and the place where that event occurred, and these representations are *sequentially organized* to compose the flow of events in that unique experience. In addition, episodic memories do not exist in isolation, but instead share many features with other memories that bear common or closely related information. You met that colleague on previous occasions and in different places, and you have discussed related scientific work on each of those occasions. During the current encounter, you can recall both specific previous discussions and general information that you have accrued from many related experiences. A simple and effective way to organize both the specific (episodic) memories and the common (semantic) information accrued across memories is to encode common features of related experiences into the same representational elements as represented in Figure 9.1. The network is composed of two episodic memories (A and B), each construed as a sequence of elements (1-6) that represent the conjunction of an event and the place where it occurred. C is an element that contains the same future in both episodes. D is an element that contains only some of the common information.

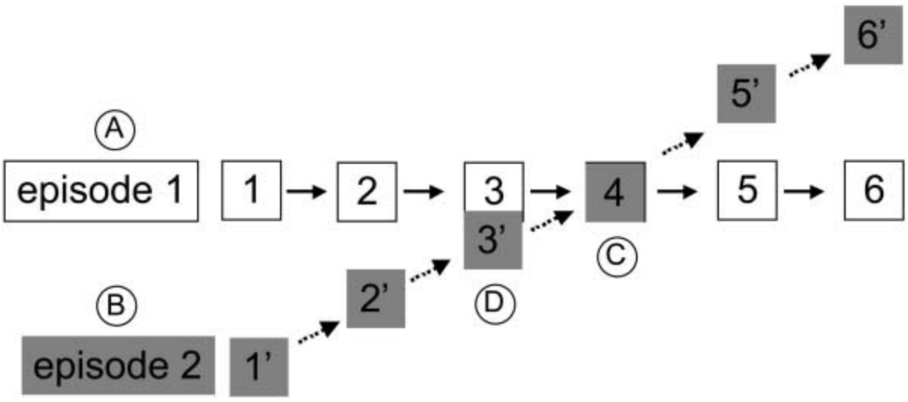

Figure 9.1 - Schematic Diagram of a Simple Relational Network [271]

The network is composed of two episodic memories (A and B). These elements organize memories into a relational network that offers two potentially quite useful properties. First, memories for the common features become "timeless" semantic elements, not bound to any particular episode in which they were acquired. Second, the elements that encode common features link memories to one another, allowing one to compare and contrast memories and to make inferences among indirectly related events [271].

The description of episodic memories fits the proposed framework in the presence of the elements stored and made available to be used, or not, as building blocks of i-Episodes (c.f. section 10.2.1). The existence of such elements again fit in the usage of such those within the framework as proposed in Scenario 4, by trying to find an inference between a new object and existing elements.

POSSIBLE EXPLOITATIONS ON THE INTERNET

In order to complete the reasoning around the selected research theme, it is complementary to think in possible exploitations that are aimed to make possible by the proposed developments.

At personal level: It is aimed to support retrieval and representation of human sensations along with human emotions and physiologic readings while represent it in adequate manner. It will enhance the representation of objects or moments of life along with the possibility of extracting emotional information from physiology and better establish a person's circumstances (i.e. improve context awareness)

At Business Level: It is aimed to allow new product representation at business level thus supporting new business models. The benefit for companies car arise from the need of new devices and new services to offer thus opening new business opportunities in a human oriented context.

KEY BENEFITS CAN BE LISTED AS BELOW:

For People: It is expected for people will be able to representation of clusters of information of moments in life providing the existence of richer biographic repositories. A person can have and share personal databases with sensorial representation of events, which will allow people to share vivid memories to friends, family or others. It is possible to create an enriched heritage from work and for life with memories that can share knowledge and vivid experiences for the offspring's and for future memory.

For Scientific proposes: It will support context awareness extension by adopting sensorial and physiological parameters. Support adaptive reasoning on physiological parameters to infer about emotional states. Allow new research areas as those who include mobile and wearable devices. Motivate the development of new scientific research areas in the boundaries of presented areas

For Business: It is intended to allow better information about products. Support enhanced description to products with sensorial information Allow the capture of emotional information about products and services

ADVANTAGES / FUTURE APPLICATIONS OF SUCH MODELS

The proposed framework has a wide scope of application and can be deployed in different configurations according to the proposed goals to be addresses.

As proposed in the i-Episodes Scenario (section 10.2), close to reality i-episode capturing can be used for personal use or for sharing. (e.g. live book of memories, sharing moments online, events' legacy post-living)

Extended Situation Awareness (e.g. real reporting of body status during an event in sports or works, enabling simulation of working conditions or emergency situations) – this could be achieved with environment creation and/or dummy physiological animation.

Recording of personal live journey and enabling health alarms. By collecting physiological data and retrieving input from the environment it is possible to asses a person's health condition, especially relevant if the person has a signalled condition (e.g. heart or vascular problems and dangerous situations as drowning or suffering a car accident.

Training or real-time monitoring - using recorded data with sensorial and physiological data will be possible to compare what is happening with what was supposed to happen and make a reality check.

It is important to remark that when someone suffers a stroke it happens to damage parts of the brain, which also happens by accidents with brain injury. The plasticity of the brain allows different types of recovery [77]. One of the recovery technics is to present a photo album or to talk with the person about moments in her life [272].

It would be of most interest to test the usage of a live book of memories and the impact it could have in recovering the memory. However the technology is not developed at the point that a most complete instantiation of the framework could be used in a daily bases and for sure it is not feasible within the scope of a PhD research work.

The Main Research Areas cover Brain Models in what regards to observing how information is captured and retained by the brain. Three aspects are considered as inspiring for the research work:

1) The Two-Stream Hypothesis with verifiable adherence from the scientific community [112], [273]–[276].

2) The episodic buffer in working memory and the relevance of emotions in cognition processes [277].

3) The usage of memory for the identification of objects based on existing records from the past [278].

Neurophysiology covers several areas related to brain and bodily functions relevant to the flows of information in humans. Physiological monitoring allows retrieval of information about a person's body functions. Physiology is important both to provide information about a person's inner state but also to identify physiological response from the person to external experience (e.g. does this situation/activity makes me sweat or speedup my heartbeat). A person can express Emotions (e.g. I am happy, sad, euphoric) in a textual manner, (e.g. tagging or making comments) but can also be assessed by inference from physiological measures. This is a difficult correlation to establish and, for that, the proposed framework aims at giving opportunities for the establishment between measurements and expressed emotions. That process has the objective of improving the reliability of the correspondence between measurements and emotional classification for a person.

Neuropsychology provides clues about how all these correlations are established and about the processes of cognition in humans: attention, memory, reasoning all aspects of significance on how people acquire and manage knowledge. Finally Knowledge Management is presented here as personal knowledge management, or a person's driven knowledge management. It is intended that knowledge is captured according to a previous analysis on knowledge is acquired, naturally, by humans and how can we adapt information systems and the Internet to pursue such formats and such channels. In trying to help such goals, inspiration from models conceived to describe such aspects of the human (e.g. sensation, perception, information flow, storage and retrieval in memory) are used to provide examples on how that can be done in technological systems.

Next in Figure 9.2 it is schematic described the work developed. First, to achieve the proposed objectives, two main developments were made, a Framework for knowledge management attending the proposed objectives supported by the also developed Data Model. Those are scientific and technological contributions by enabling support for new data to be collected and new devices to be adopted. Then a set of outcomes are presented at the bottom, they are the publication, which in fact is a validation by pears and dissemination to the community, the validation was based on the results retrieved in the pilot scenario with the participation of 30 volunteers, and other four possible application scenarios.

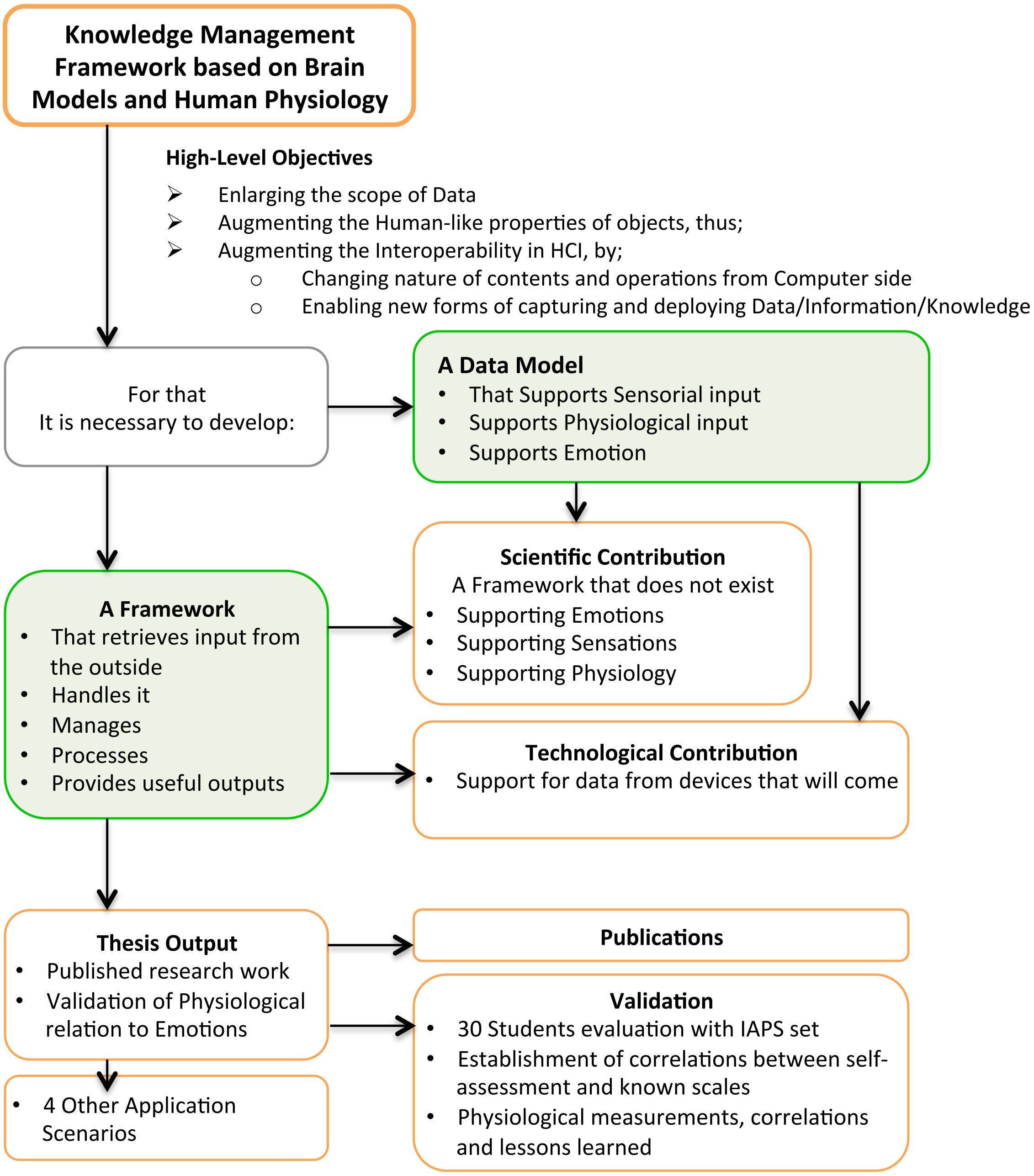

Figure 9.2 – Research work developments and outcomes

9.2. A New Data Model

The development of the proposed framework increases the need for new data models that can have more information relevant to the framework but also that can host the needed information for new proposed features. In this case, the proposed extension to existing data models has the objective of allowing extended representation of sensorial and physiological information, in a clustered way taking a human centric approach. This does not mean that existing information will not be supported or that much information is needed to uphold this new model. On the contrary, the objective is to give support for new features coping with the existing ones.

Internet objects are supported by a multitude of formats depending on the type of object (e.g. image, sound, movie) and are available with oriented goals (e.g. site of a manufacturer or an article seller) or for undefined purposes like to be watch or to be read (e.g. videos on YouTube, online newspapers and magazines). But if the goal is to manage information on a person centric approach we will be looking mostly to specific types of information, like a person's pictures or a person's health records, either from medical events or fitness exercise measurements. In the framework proposed in the current research work we aim for this last type of information. Thus we want to ensure that the person has his captures or measurements, here called features, recorded in an organized manner, which means we know what is being recorded and where that happens, as in the two-stream hypothesis, and we need to know when it happened. This is how memory handles information, as time is an important element in way the brain stores and organizes information.

As can be seen in Figure 9.3, the proposed data model has six fields that where considered the adequate to represent a person's position, timing of the records and the record itself.

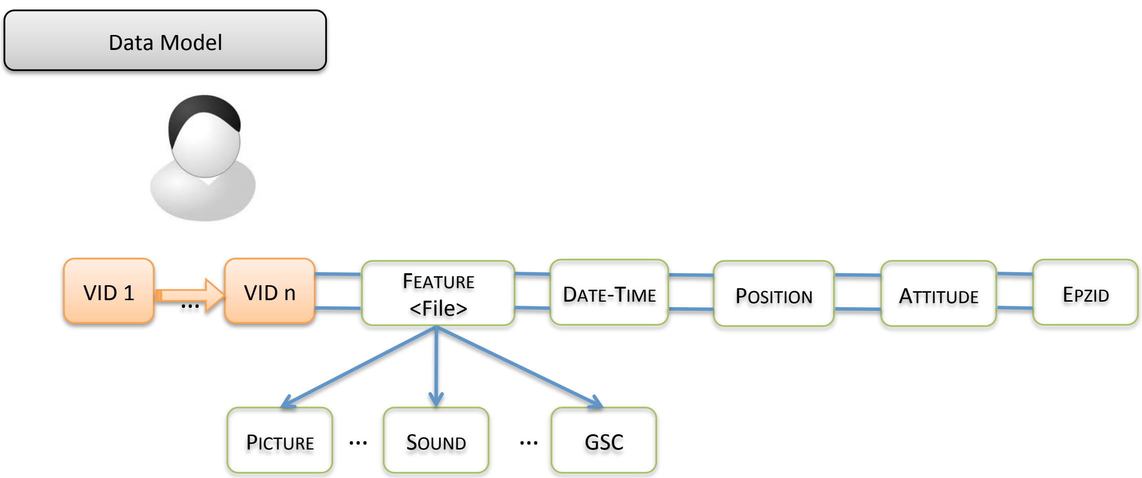

Figure 9.3 – Illustration of the proposed data model

The first fields, that can be various, establish the link with the true identity of the subject and can ensure the privacy of the person by enabling different identities for different purposes. The field Feature holds the content of the data instance and can be a sound, a picture or other sensorial or physiological instance.

The proposed data model is based on Data Elements that have the following configuration.

Data Element = [*VID, Feature, Date-Time, Position, Attitude, EPZID*]

Description of every field code:

VID – (Integer) - Virtual Identification of the subject – This is an identifier of each element of data. The VID is not bidirectional with the person's ID and there could be diverse VIDs for each person according to the circumstances and the service being used. VID allows anonymization of data so case that information is uploaded to the cloud or shared by other means the real identification of the individual is preserved. This means that studies can be carried out with data collected from several individuals preserving, nevertheless, their real identity. Privacy and security become compartmentalized under one virtual identity and a real person can have as many virtual identities as needed [17].

Date-Time - (HH:MM:SS, DD:MM:YYYY) – Data and time of the event, episode, measurement, reading, etc. As stated by Hannigan and Reinitz a fundamental goal of memory is to encode a coherent story of an event as a whole, rather than simply to encode individually experienced items [279]. Time registry is essential to sequence actions and reference temporally a record or an episode.

Position – (list of 3 real coordinates & coordinate system) – Those are the coordinates of the subject's location. According to the two streams hypothesis (cf. section 4.1.1), upon information arrival at the occipital region, a ventral stream tries to identify what we are looking at and a dorsal stream tries to place it in context, i.e. locating it spatially in a scene. In this case context will be referenced geographically but may imply further contextualization by enrichment with available information about that place.

Attitude – (list of 3 real coordinates) - the normal of a person's face. The fact that this element is not frequently seen in literature, and not in this context, leads to a challenging innovation. Instead of a complex analysis of sensors (e.g. accelerometers) to determine the position and kind of movement, we assume that the determination of the normal (e.g. by sensorial fusion) will represent an advantage for the model by allowing the assessment about a person's body position. Thus if the person is running and now is facing up probably something append. On the other hand if a person is standing she cannot be sleeping so a variation on heartbeat will be more acceptable due to a non-sleep condition.

EPZID – (type natural) - Episode Identification is a local increasing integer sequencing all the episodes for that person. It is meaningless without the coupling with VID, which identifies the person to which the Episode refers. This way the model offers two levels of privacy for the individual; first the data collected has a virtual ID that is only understood by the right collector; second the Episode number, as an integrator of information, will appear repeated across other person's collected data items but has meaning only for a known VID for each person.

Data type of each field code:

Virtual Identification: VID = [1… n]

Feature: Finite set of one property

Examples of Features for Sensorial Information:

Emotions: E= $\{e_1, e_2,\ldots, e_n\}$

Sensation(Image): Si= $\{Si_1, Si_2, \ldots , Si_n\}$, [jpg/png/tiff]

Sensation(Sound): Ss= $\{Ss_1, Ss_2, \ldots , Ss_n\}$, [hz/mp3/wav]

Sensation(Flavour): Sf= $\{Sf_1, Sf_2, \ldots , Sf_n\}$

Sensation(Odour): So= $\{So_1, So_2, \ldots , So_n\}$

Sensation(Touch): St= $\{St_1, St_2, \ldots , St_n\}$

Examples of Features for Physiological Measurements[19]

Physiology(Heartbeat) = PhiHB= {Time, Frequency}, [second, hertz]

Physiology(Galvanic Skin Response) = PhiGSR= {Time, Conductance}, [siemens]

Physiology(Pupil Dilation) = PhPD = {Time, Amplitude}, [second, meter]

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[19] Formally units are in International System however most of devices provide units like millisecond, millimetre , microSiemens

Time: T = [HH:MM:SS_DD:MM:YYYY] ε N

Position: [Latitude: Longitude] ε R

Coordinates are in World Geodetic System, WGS 84[20] ε R

Attitude: Vector normal to a person AV= [X,Y,Z] X,Y,Z ε R

Episode Identification: EpisID= [1… n] ε N

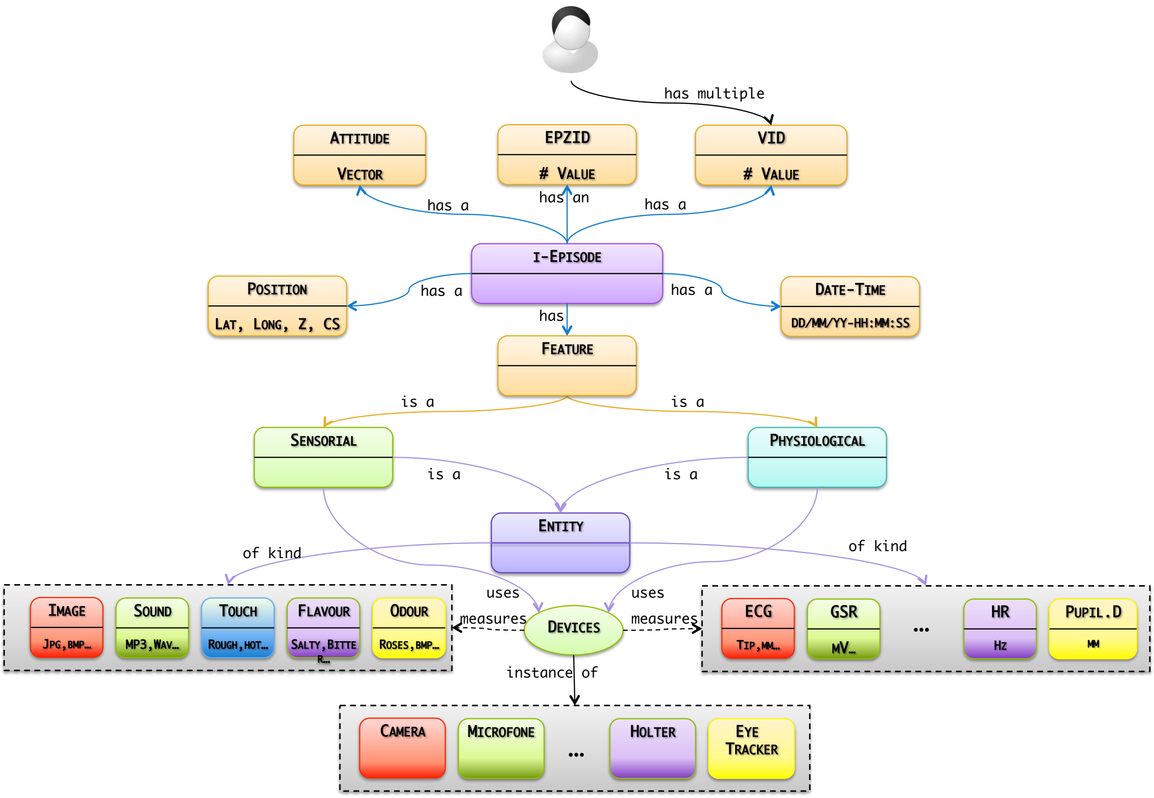


Figure 9.4 – Formal representation for proposed Data Model

The new Data Model will provide means to capture, store and manage relationships between components. It is necessary to develop the Framework as described in the next section.

[20] WGS 84 – World Geodetic System is a standard for use in cartography, geodesy, and navigation, was established in 1984 and last revised in 2004 and is the reference coordinate system used by the Global Positioning System (GPS).

9.3. A KNOWLEDGE MANAGEMENT FRAMEWORK BASED ON BRAIN MODELS AND HUMAN PHYSIOLOGY

In this section it is described the path from the objectives to the proposed

9.3.1. FROM THE BRAIN TO A FRAMEWORK

The objective of establishing a valuable framework for the proposes goals, we tried first to understand what is in fact a Framework and how it can properly be defined, beyond the intuition that we have about what a framework is. So we looked for several definition as follows: 1) "A framework is a reusable design for solutions to problems in some particular problem domain" [280]. 2) "A framework is also a system of rules, ideas, or beliefs that is used to plan or decide something" [281]. 3) " A framework is a unit or organization of units that collectively serves to define a coordinate system with respect to which certain properties of all objects, including the phenomena self are gauged." [282]. 4) "A framework is an extensible structure for describing a set of concepts, methods, technologies, and cultural changes necessary for a complete product design and manufacturing process"[283].

The Knowledge Management Framework based on Brain Models and Human Physiology that we want to develop, should have a reusable design for the problem of how to manage (e.g. gather, store, handle) human-like information in computational systems and the web. In this sense, the Framework will promote the interoperability between humans and computers. This will be achieved by making computers able to retrieve consistent information about the user and in the other direction, will foster the management of Internet objects that tend to have most of the characteristics humans retain from objects in real world.

By using the Framework, the collected information will converge to the information handled by the brain, that feeds all cognitive processes. That input would be constantly expanding along with the capabilities provided by devices that are entering the market or being developed as those in a context of Internet of Things (e.g. environment sensors, smartwatches with physiological sensors.

The first schema relates an overview of how inspiration from selected human systems contributes to the proposed framework.

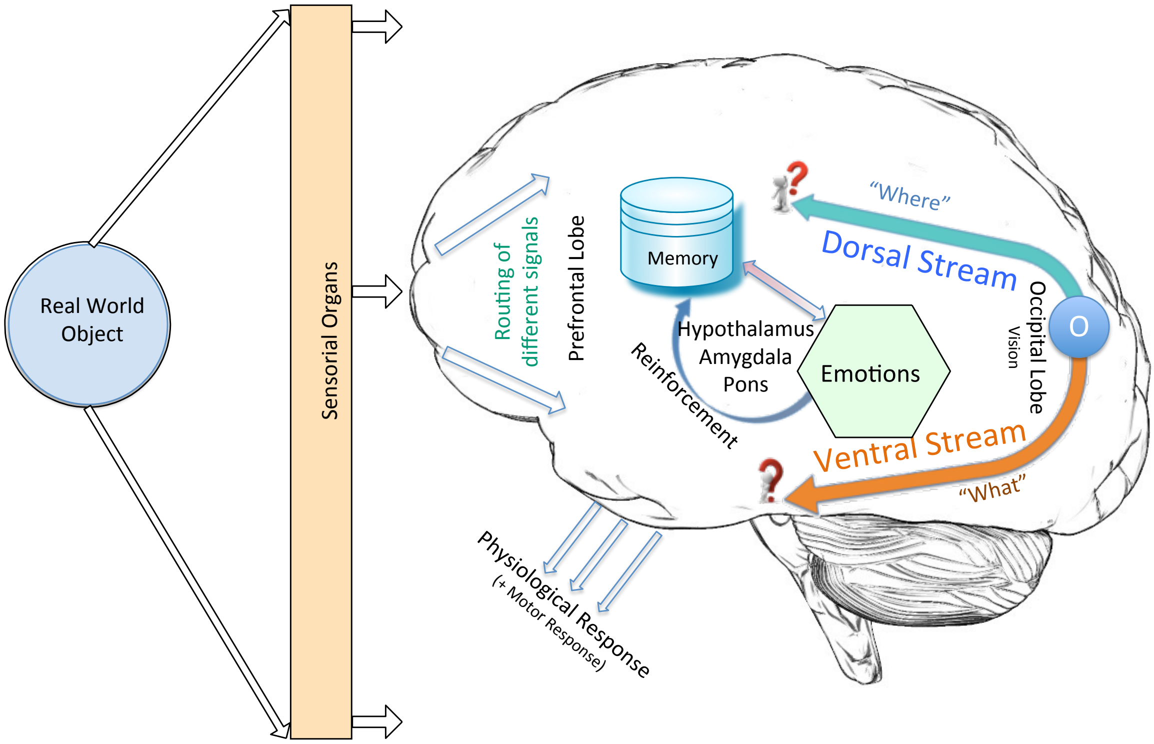


Figure 9.5 - Schema that synthesizes how the brain captures and handles information from outside

Our sensorial organs capture the information from the real world. In Figure 11 is depicted a simplified view of the information flowing to the brain and paying particular attention to the two streams that are generated from the perceived object "o". In this case the representation is positioned where image forms but, as stated before, would apply to the other sensorial organs. Ventral Stream identifies what is being perceived, objects, living beings or just stimuli (e.g. smell, sound) are scrutinized in search for an identification of what is in our presence. As for the Dorsal Stream it tries to figure where that same object is located (e.g. for vision) or where provides from (e.g. roar of an animal). Those stimuli will be interpreted and generate a physiologic response and, eventually, a motor response. On the other why, that response is mediated by emotions as the emotions shape how stimuli affect us and how it will be recorded in memory, to be recalled. Reinforcement is a mechanism that makes a memory become more intense than others and plays an important role in giving relevance to stored episodes, or objects, with impact in how they will be later recalled. This is a simplified and schematic view of some human aspects; next it is presented an example on how to retrieve information from here to computational systems, namely those based on the Internet.

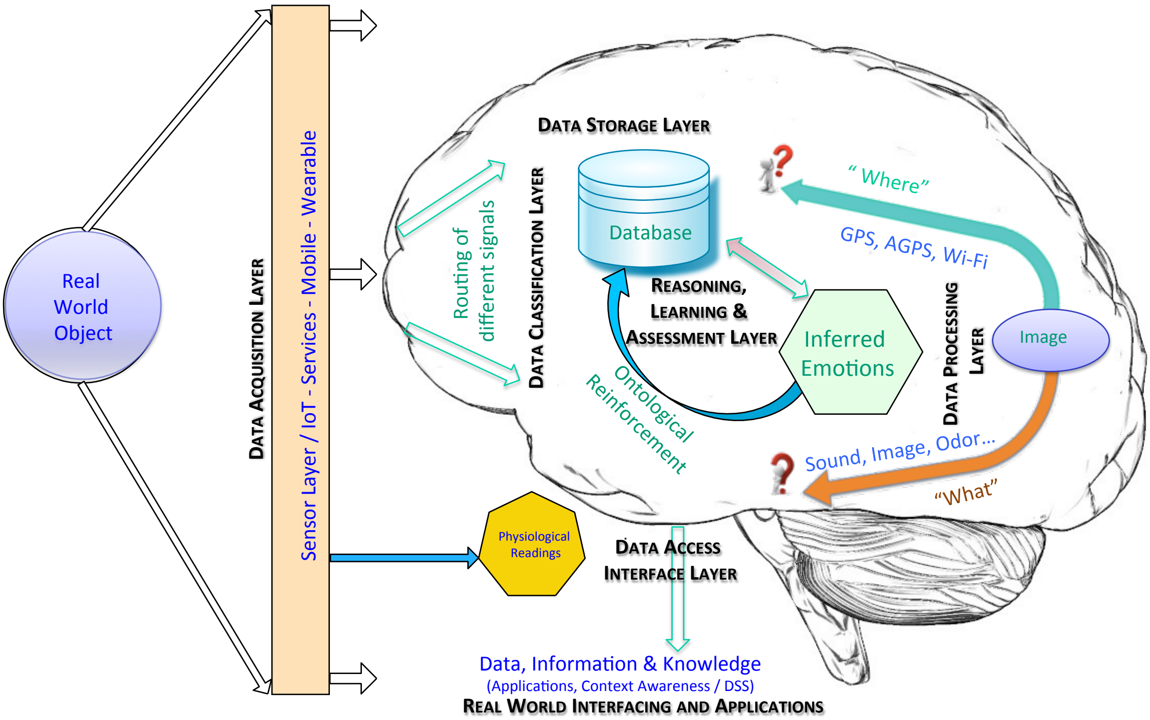


Figure 9.6 –Framework Layers inspired in brain models

In trying to get inspiration from human systems it is modelled a conceptual approach as represented above in Figure 12. It starts with the same objects in real world but then, instead of sensorial organs; it is used sensor devices like those used in mobile devices (e.g. smartphones, in wearable devices (e.g. smart watches), in the IoT devices or networks (e.g. connected devices from cars to home appliances, etc.) including available services (e.g. street cameras, air quality monitors, etc.). The input is then handled in the same, first identifying what are the objects, like for the ventral steam, (e.g. image or sound of a car) and then with the other stream, locating them, but this time location is not a mere replication of the *mise en scene* operated by the dorsal stream, but actually establishing a geospatial positioning as can be ensured by GPS, AGPS in devices complemented with Wi-Fi, 3G or 4G positioning from antennas. That information is than reasoned by the processing unit, as it does the brain in a person. Then the result is store in the database and information or knowledge generated is made available to applications (e.g. to establish context awareness or be used Decision Support Systems). Data can be made available and database should keep raw data along with results of processing.

There are a growing number of devices that can retrieve physiological data from users. That input can give information related to emotions (e.g. arousal and valence) and could establish the ground for trying to determine a person's emotions. That information can be used to reinforce contents in the database in what we call Ontological Reinforcement.

In order to make sense of the information retrieved by different sensorial organs we recall here the concept of i-Episodes (c.f. section 10.2.1) as the database should be able to keep relations between input gathered at the same place, not only related by time, but keeping a consistency that assists in later make easy to find some i-Episode by given characteristics and relating it to the same person.

In fact the i-episode hereby presented has similarity with the concept of Episodic Memory proposed by Conway for the memory at the human brain. The function of episodic memories is to provide a basis for the adaptive pursuit of short-term goals. Access to episodic memories is lost fairly quickly but if a memory or set of memories become integrated with the conceptual system, particularly that part of it that represents autobiographical knowledge (e.g. lifetime periods and general events), and then access may be maintained over long periods of time. By this view episodic memory is a species wide adaptation and the main differentiating feature of human episodic memory is its embedding in a complex personal conceptual system [284].

The concepts presented so far result from the vision and motivation and the development of the scientific methodology. That means a thorough background analysis in the Literature review section, along with new concepts proposed within the scope of the present research work. In order to operationalize, such conceptions and to materialize theoretical developments, it is important to converge to a technical presentation of a framework, able to address all those conceptualizations including the brain inspired schematization. That is the objective of the architecture represented in Figure 9.9 a schema of the framework that can assume several configurations, according to the technology to be deployed and the objective of the implementation.

9.3.2. *A CONCEPTUAL FRAMEWORK*

The study performed on brain models and human physiology was continuously enforcing the response to the research question by modelling the information as proposed in the data model and ensuring the need for an adequate framework. That framework should be able to handle data and perform the operations needed so that the data collected could be of best interest for individuals.

From the several definitions presented in 9.3.1, we reached our own definition as we want to develop the Framework as an extensible structure, providing a generic design solution to a certain problem, describing the elements involved, being those units or organization of units aiming to address an established purpose. The objective is do define a Knowledge Management Framework based on Brain Models and Human Physiology. It means that the ultimate objective is to manage knowledge in a innovative way so that we learn from what happens in the human body from data collection from the outside world to the reasoning that supports cognitive processes, leading to thoughts, memories, decisions and acts.

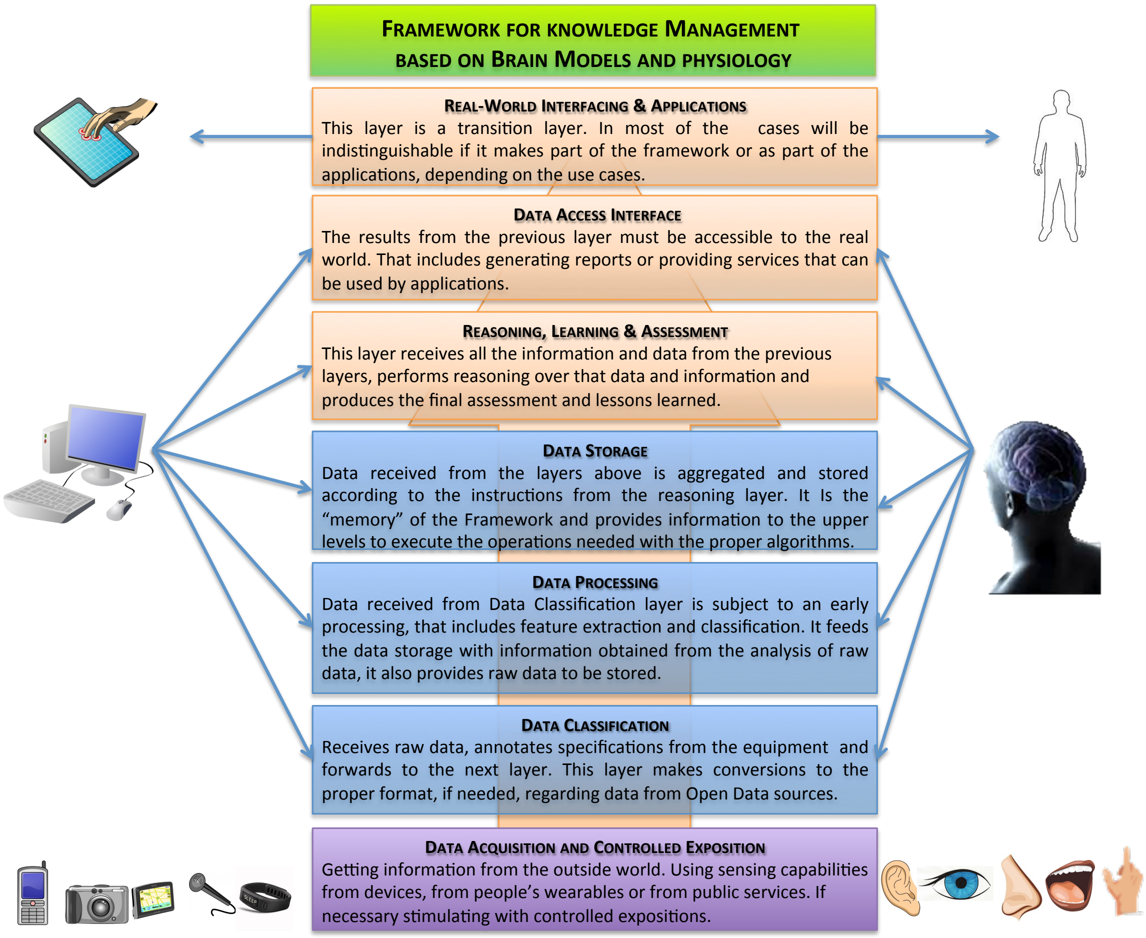


Figure 9.7 - Conceptual Framework for Knowledge Management

The proposed conceptual framework was conceived to address the problem of knowledge management based on brain models and physiology, in a way that could be instantiated by humans, by humans with simple tools or by computer based applications, supported by internet of things, cloud computing, new sensors and new devices and whatever technological devices are about to come in a near future.

The conceptual architecture is designed so that each level can be interchangeably operated by a person, by a person with tools (computational or not) or the system being completely based on computer systems and applications as explicit in Figure 9.8. What we want to emphasize is that, technology is the ultimate goal to free humans from operations and to provide opportunities to develop better technology, but the framework to be conceived is not dependable in others than humans, at any level.

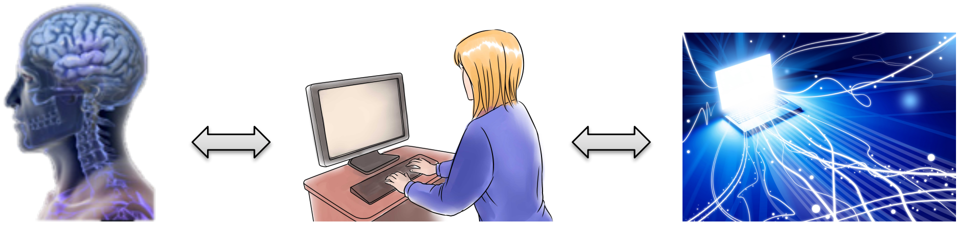


Figure 9.8 - Framework based on Humans, Humans with tools or completely computational

In the left case, in Figure 9.8, humans are specialized in capturing sensorial information from the outside world and to "read" emotions from other people. In fact humans have the best system so far to acquire sensorial information, relate it with previous information and to evaluate emotional contents.

The middle case is the most common these days, humans use computerized systems and tools to support their knowledge management and the operations needed to help their reasoning and storage of information. Those are the case of storing images from camera, using worksheets or more complex analysis programs and also connect with devices to extract information (e.g. attaching devices to download image, sound or physiological readings from wearables.

The last case in the right of Figure 9.8 represents the full computational process that can be achieved once a futuristic instantiation of the framework is constructed, using state of the art technologies along with technologies that are yet to be developed (e.g. smell and taste capture and production is yet to be maturated).

From state of the art and the assessment made so far we feel that is of most interest to develop the basis for a futuristic deployment, to be made real once suitable technological tools are available.

9.3.3. *INSTANTIATING IN THE DEVELOPMENT OF AN ADVANCED TECHNICAL ARCHITECTURE*

The next exercise, within present research, was to conceptualize an Architectural Framework, as presented in Figure 9.9, so that the Framework could be used in more demanding cases, either in an autonomous application setup or involving human participation. As described before, part of the activity presented in our scenarios and case study can be performed in part or completely by individuals or by computer based applications. In fact, the components of the framework correspond to cognitive functions studied within the neurophysiological and neuropsychological sciences about human beings and that we can, progressively, migrate to computer based systems and applications. The layers of the conceptual architecture are developed in this section as a technical architecture that can be implemented in computer based systems, previewing human contribution as needed, in some operations, to ensure safety and expert advice.

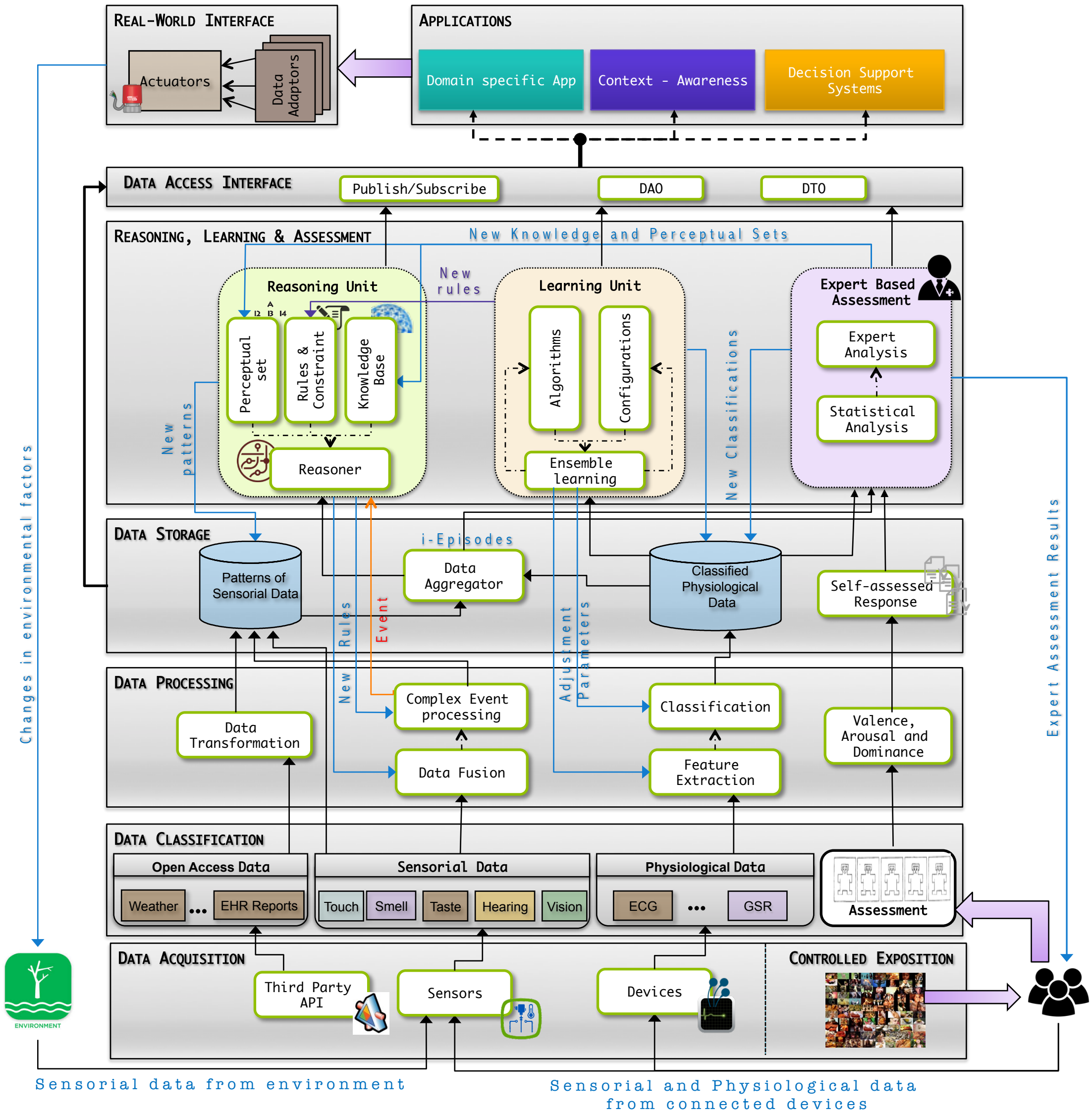


Figure 9.9 – Conceptualization of the Framework with a Technical Architecture

The Technical Architecture presented in Figure 9.9 schematically presents a partial view of the outcomes of the research developed in the PhD work using what exists and what can be developed with future technologies. The Architecture is highly scalable and relies on a modular architecture that can be customized for different purposes and, as mentioned above, each layer can be computer based or performed, as successfully done in the last million years, by humans.

9.3.4. *The Layers of the Technical Architecture*

In order to present a rational structure that also permits future deployments, the conceptual components are organized in six different layers that will be presented in the next sections. The layers are described from the bottom to top of the framework schema, representing the flow of the acquisition of data until the potential applications that appear on top.

The entrance frontier of the framework with the real world is established at the Data Acquisition Layer, as in Figure 9.10. This layer makes use of different approaches to ensure the acquisition of data from the environment or the body.

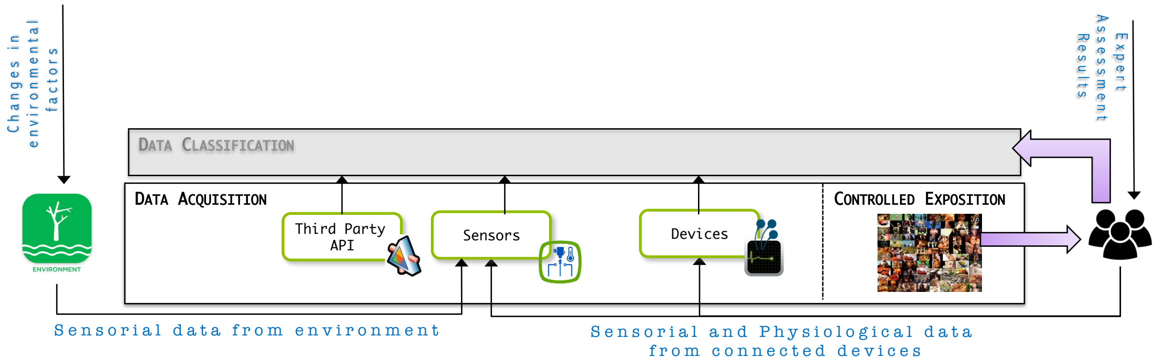


Figure 9.10 - Data Acquisition Layer and Controlled Exposition

Data Acquisition Layer includes all devices and service able to provide data and information from the outside world, including those from the environment, from the body and from third party service providers by making use of devices and other available interfaces. Data or information retrieval can result from existing services, provided by third party applications (e.g. traffic cameras [285], weather information [286], etc.). It can also make use of data generated from sensors (e.g. home ambiance sensors [287], car sensors [288], etc.). Sensors are devices that are capable of reading physical and physiological parameters. A sensor *S* can be defined by a tuple *<D, C>* where *D* represents data-stream and *C* the context of the sensor. *D* will have a data-type and an ordered set of readings obtained at various time which can be represented as $D=<DataType, \{R_1,...,R_n\}>$. *C* is used for understanding the contextual use of the sensor and can have an URI to an external Sensor Networks Ontology [289] or can also be linked with other instances of metadata resources. According to the structure of this data model D will have the values that characterize the Data Element = [*VID, Feature, Date-Time, Position, Attitude, EPZID*], according to the definitions in section 9.2.

Information can be gathered from sensors, devices and services. Sensors can be used individually, as in lab experiences, or we can gain access to sensors in devices (e.g. open sources or SDK provided). When using devices, they are chosen according with the type of information to be retrieved and it can make use of devices that play as sensors by the fact that they make data available for the framework. In that category are the range of sensors available in cell phones (e.g. GPS, accelerometers, etc.) but it can also make use of the capabilities of existing devices, like health devices (e.g. Heart rate monitors [290], Holter [217]) or fitness devices (e.g. fitness bands

[94][95], smartwatches [291][292], etc.). On another view, and in the case where the objective is to induce emotional states, external stimuli can take the form of stimulation sources, like selected pictures (e.g. IAPS [211] c.f. section 7.2.3) but it can also consist in selected sounds and songs [293] or it can make use of the stimulus generated by watching movies [294].

Also to notice that sometimes we want to read data from sensors or devices for a person subjected to a selected stimulus or range of stimulus. In that case, we establish the kind of setup adequate to take measurements from that controlled exposition to stimuli. Because of that interdependency the Controlled Exposition feature is included in the same layer as the Data Acquisition as the exposition aims at a measurement or a set of readings from sensors and devices.

DATA CLASSIFICATION LAYER

The Data Classification Layer, depicted in Figure 9.11, handles all kinds of data received from the Data Acquisition Layer and feeds the Data Processing Layer.

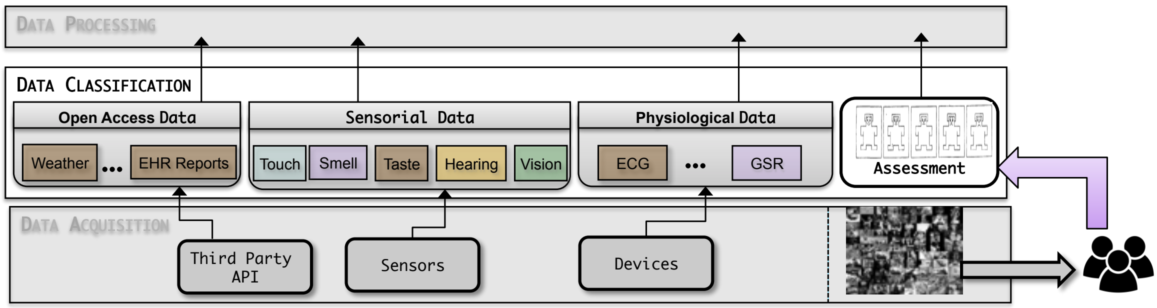


Figure 9.11 - Data Classification Layer

This layer makes use of data generated by the sensors and devices that sense the environment, or from a person's body, as is the case of wearable, mobile or other IoT technological devices or other sources of open data interfaces. This layer can be seen as a data receiver that generates information or simply forwards raw data or add context to the collected data, as needed. In this layer signals collected by the sensors are adapted to a proper model, as presented in section 9.2. They are represented with proper notation, generated within the framework or received by external sources as in the case of EHR reports or physiological data from devices. In this layer it is also foreseen the inclusion of self-assessment data expressed by users (e.g. keyboard typing or selection, response to questionnaires and filling forms, etc.). Classification procedures will enrich the data to be fed to the processing layer and subsequent layers, those will result from automatic tagging, device self-explaining codes or manual tagging as in the case of human operated procedures. In the cases of self-assessment, in the present example, the responses are presented as arousal, valence or dominance as uses to be the cases for IAPS setups. Those responses are, usually, a number between one and nine corresponding to a selection of one of the five manikins plus the four spaces between them. That will be the response from users exposed to a sequence of stimuli with pre-evaluated images, sound or movies. Other types of responses will also be possible to integrate in the framework as they will be clustered as self-assessment input and analysed by experts. Data from self-assessment need no processing but the other types of data will need to be staged in the Data Processing Layer as in the next section.

DATA PROCESSING LAYER

The next layer makes use of received data to proceed with different types of analysis and reasoning, in the most adequate unit, as depicted in Figure 9.12.

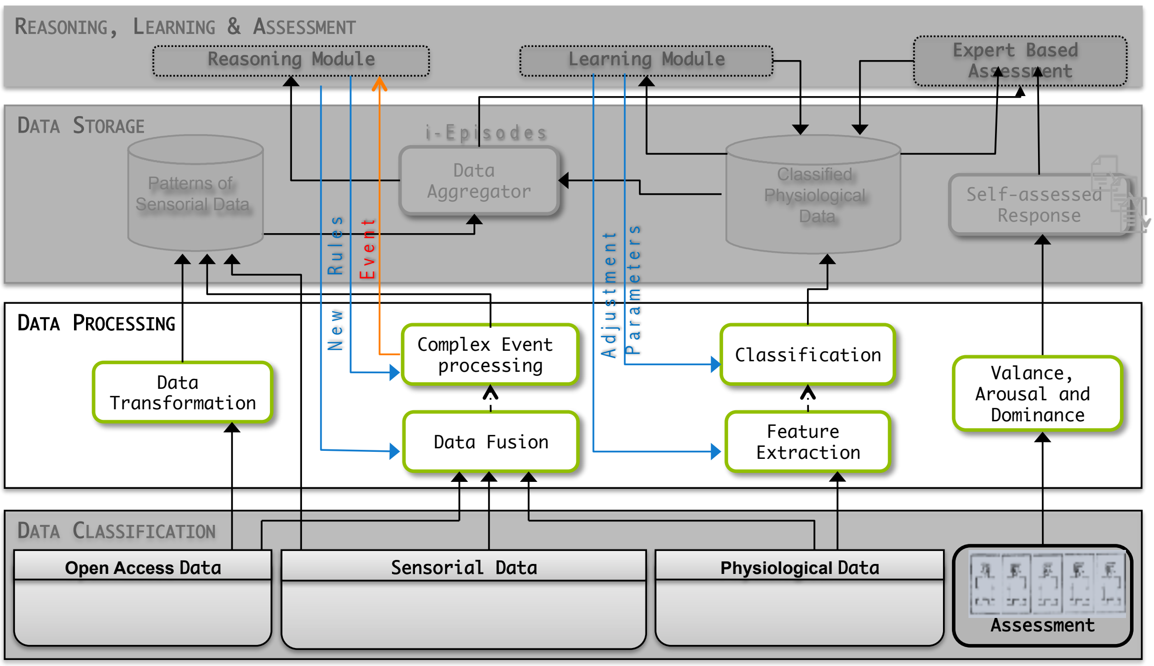


Figure 9.12 - Data Processing Layer

This layer has a fundamental processing activity that can generate information and triggers events to the upper level. Nevertheless, raw data from sensors is also provided, to be stored in the database, and used as needed. The core level receives information from the sensor layer and, using domain specific knowledge bases, makes the processing of the information received, relating with existing information either from the knowledge base or from previous reasoning by the system.

Data from sensors and external services can be transformed so that it adapts to the framework requirements. Processed data is then rooted to the proper storage places and becomes useful to the overall knowledge management framework.

Data Transformation

Data from open access services comes in the original format as provided by the service. Data Transformation component provided methods to transform data acquired from heterogeneous data sources into a uniform format so that the upper layers can process the data by making use of same data processing engines. This component will provide interoperability between the open access data and other components of data processing layers and higher layers the framework. Various data transformation techniques can be implemented in this component, specifically XSLT based data transformation because most common data format in open data access services in XML.

Data Fusion

Data collected from individual sensors provide useful information. At the same time fusing data from different sensors is important to infer correctly regarding the state of the environment. Data fusion component provides functionality for sensorial data fusion, which is also termed as configuring Virtual Sensors (VS). VS are termed virtual because they do not have physical occurrence but are formed by logical infusion of various sensors. Methodology for generation of virtual sensors is achieved by generating new datasets from input datasets from individual sensors based on some defined operators. So, a VS can be defined by a relation ϴ s.t. VS= Sx ϴ Sy, where Sx and Sy are sensors. The relation ϴ can have different syntax and semantics as needed based on the type of data infusion that should be established between sensors. For instance if VS is used for taking into consideration humidity and temperature of a body part (e.g. arm, armpit) at the same time then a one to one union over the reading of the sensors for humidity and temperature will give an ordered set of reading for this new VS. And if the operator is to find the difference of the reading of two sensors (e.g. environment and body temperature) then the ordered difference between each element of the reading of two sensors will give the dataset for the VS. Note that the context of VS can always be obtained by the union of the individual contexts of the sensors forming the VS.

Also we note that the operator ϴ can have applicable constraints and rules, which can be configured, based on the necessity of data fusion scenario. So, this component is capable to apply renewed rules as instructed by the reasoning unit. In case some fusion is not relevant (e.g. sound and heart beat), data fusion can be reconfigured to another setting (e.g. fusion of heart beat and GSR).

Complex Event processing

CEP (Complex Event Processing) is a widely accepted term, which is used to combine data from multiple sources (e.g. sensors or virtual sensors) to infer events by observing specific patterns over observed data. Thus the functionality of this component is to make reasoning over collected data, thus looking for both regions of interest or simply finding events that may become interesting. In the case of sensorial data, it is necessary to identify and extract known features that can provide information about collected data and, based on pre-programed guidance, will generate classification of those features, according to the type of data collected and the requirements of the framework This is important to identify meaningful events or threats by observing a series of patterns and possible application of rules. For instance if it is observed that a person is having heart rate above a given threshold and the difference between the outside and body temperature crossed a defined limit, then an abnormal event signal could be issued to the reasoning unit. Then the reasoning unit, by comparing to similar patterns recorded for that person or by consulting the knowledge base, a warning signal should be issued to the Application Layer via Data ACCESS Interface Layer, signaling what kind of warning is being issued and, if some danger was identified, the warning becomes an advice that some immediate action has to be taken. Also note that based on the concept of adding context to the sensors and propagated to Virtual Sensors (VS) (at the Data Fusion Layer) will be determinant for CEP to take into consideration the context of the environment. Same patterns can raise different scenarios in different contexts thus adding more value to the CEP. The configuration of the CEP unit can also be updated with new rules, as by expert indication, new algorithms could be necessary to implement for complex event processing.

Feature Extraction

This component examines physiological data in trying to identify features that will generate useful information about the person. Data collected go through the process of feature extraction and classification, which are handled by feature extractor and classification algorithms implementation, respectively. This process will remove errors from the collected data and are classified based on the needs and type of emotional assessment to be performed. Also note that the parameters and/or weight of the parameters need to be adjusted over time based on the output of the learning unit. Thus the feedback loop from the learning unit into the data processing unit is important towards realization of learning system, such that the feature extraction and data classification will be improved over time. Physiological data has its values according to some pre-established ranges. Those ranges allow the extraction of features that will be indicators of what is the activity of the person or the health status. There are parameters accepted (e.g. 60 < Heart rate

> 100 depending on age and health condition) and there are parameters that should be taken as abnormal. Feature Extraction component performs analysis of those regions of interest, passing the results for the classification component where such results are evaluated. This component will remove instrumental and/or human errors from the collected data and are classified based on the needs and type of emotional assessment to be performed. Also note that the parameters and/or weight of the parameters need to be adjusted over time based on the output of the learning unit. Thus the feedback loop from the learning unit into the feature extraction component is important towards realization of learning system, such that the feature extraction and data classification will be improved over time.

Here, time and frequency domains features are extracted. In the time domain, statistical features namely maximum value, minimum value, arithmetic mean and standard deviation are calculated. To extract the frequency domain features, first the power spectral density is calculated from the squared amplitude of the discrete Fourier transformation value of the data using the fast Fourier transform (FFT) algorithm and then scale it to a sampling frequency range (e.g. [295]).

Classification

The extracted features are passed through classification component so that the collected features are correctly classified based on the information inherited by them. Information is classified based on pre-defined rules and cases such that for each signal, a solution is received considering the top most similar cases from each case-library. A weighted similarity function is used to combine the solutions and hence the system gets the final classification. For the classification of the signals the approach works in two ways: (1) signals classification using decision-level classification; and (2) signals classification using data-level classification. In Decision-level fusion, features are classified for signal separately through the traditional classification approaches i.e., considering time and frequency domains features. In the data-level fusion, the signals are combined by means of a Multivariate Multiscale Entropy (MMSE) algorithm where the algorithm provides us with a number of features [296].

This component is thus used to build a collection of cases, which are then forwarded to be properly stored and retrieved by learning unit to improve classification over time. The classification methodology will ensure information about data to be placed in storage and associated with other kinds of information for that same person.

Valence, Arousal and Dominance

This component is responsible for the specific data from self-assessment, treating and compiling it, so it becomes self-assessment reports.in the Data Storage Layer. This data results from the assessment performed voluntarily by users when exposed to selected known stimuli and classified with a calibrated stimuli system (e.g. IAPS), in the case of the pilot developed in this Dissertation it was used the Self Assessment Manikin (c.f. 7.2.3).

DATA STORAGE LAYER

In Figure 9.13 the storage modules of the framework are highlighted in the Data Storage Layer. This is the "memory" of the Framework as it stores patterns classified data and aggregated data (i.e. i-Episodes) it also feeds the next layer with all the information needed for processing.

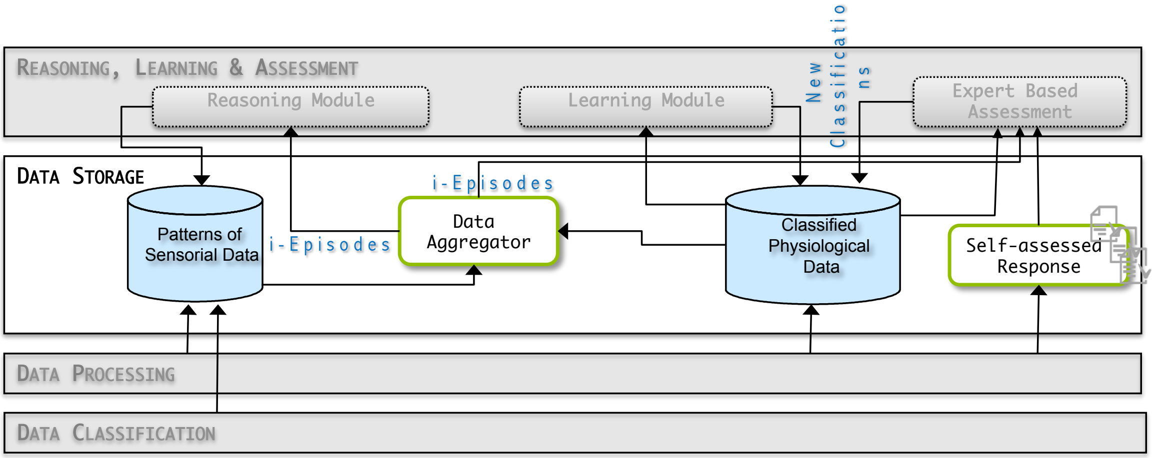


Figure 9.13 - Data Storage Letter

All types of information regarding the framework are stored in the Data Storage Layer. The Data Aggregator Component is the fundamental piece for the Data Storage Layer.

Data Aggregator

This component clusters information by time and place regarding one person. It forms the so-called concept of, a concept developed within this Thesis and published in several conference proceedings and journal articles. The idea is that a person experiencing an event in a given time collects all information available, sensorial and physiological, in the form of an i-episode. That same person can have an endless number of rich i-Episodes (c.f. Section 10.2.1), aggregated by this component, representing events of her life like formerly would be recorded as pictures. Instead of single pictures, all information available will be collected and clustered in that i-Episode. According to the proposed data model, the target definition of a Data Element (DE) to be integrated in an i-Episode should be DE = [*VID, Feature, Time, Position, Attitude, EPZID*] (according to section 9.2). In this case we would have Virtual Identification for the person (VID), a measurement of what should be retrieved (Feature), an identification of the coordinates where the information is collected (Position), an indication about the normal of the subject (Attitude) and finally the classification on which i-Episode that Feature belongs to (EPZID).

Patterns of Sensorial Data

This repository will store all available sensorial data about that person. Data to be stored is received from services as from the person's devices, mobile or wearables. It can be raw data, transformed data from the external services (e.g. weather reports and traffic cameras) or information prepared by the complex event processing. The reasoning component will send ne patens to be identified for improved results, as needed.

Classified Physiological Data

This repository stores physiological processed data whose features were already identifies and properly classified. It will provide information for the experts that, in return, will issue ne methodologies for data classification. New classification rules will come both from experts and from the learning component.

REASONING, LEARNING AND ASSESSMENT LAYER

The layer responsible for the reasoning on available information, the learning aspects and the expert assessment is depicted in Figure 9.15.

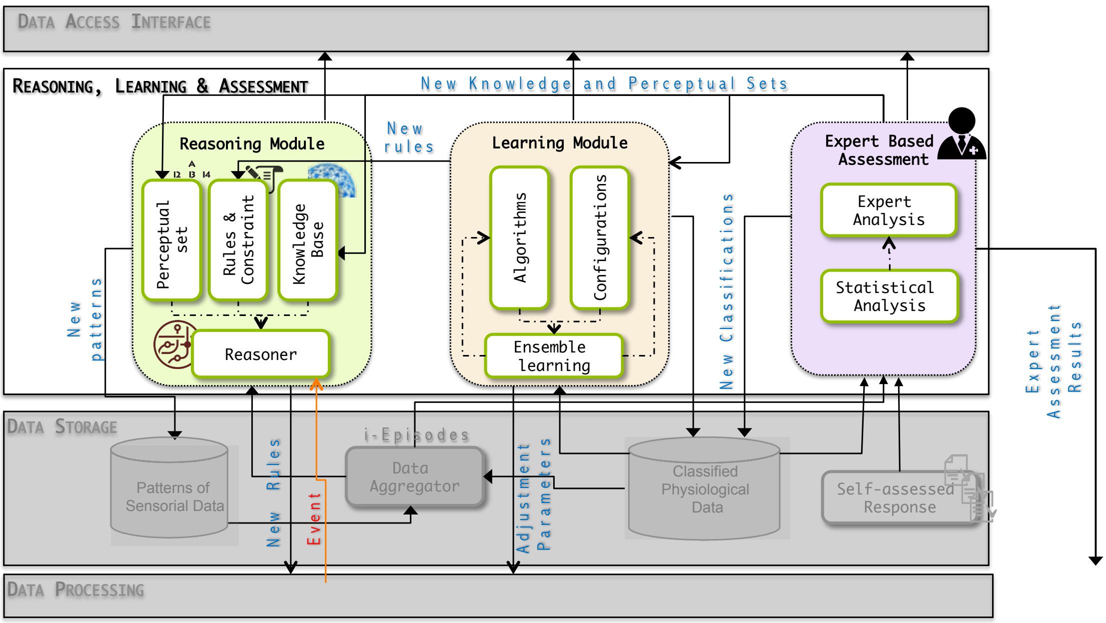


Figure 9.14 – Reasoning, learning and assessment layer

The knowledge then generated is provided to the upper level, the Application Layer that makes use of Data from sensors, information from pre-processing at sensor layer and Knowledge generated by the core system. The applications can use this information to determine a person's activity (e.g. is running, is walking, etc.) and also, with some physiologic measurements, the health status (e.g. it is hyperventilating, has an irregular heartbeat). This knowledge can generate alarms or could be used, at the application level, to establish context awareness, situational awareness or to decision support systems.

REASONING MODULE

This module makes evaluation of the data collected and reasons over such data referring to existing knowledge bases. This module has differentiated components that perform the needed tasks: Perceptual set, Rules & Constraints, Knowledge base and Reasoner. Those are described in the next paragraphs.

Perceptual Set

This component will organize sets of information that have a meaning so that they will be stored in relation to that person. Perceptual sets are very specific to individuals and are based on tendency to view things only in a certain way. Perceptual sets can impact how we interpret and respond to the world around us and can be influenced by a number of different factors. Expert assessment will determine what is a perceptual record so that it will be retrieved and organized for that same person.

Rules and Constraints

The need for rules on how to retrieve information is determined by the Rules and Constraints component. These rules and constraints can be adjusted according to the domain in which the framework is instantiated. Various rules and constraints specification languages can be implemented in this component based on the form of data storage chosen during the instantiation.

Reasoner

The Reasoner takes information from all the modules and from the expert based assessment and produces the output of such inferences and rule application. This is the component that ultimately generates information after all operations are executed. Reasoning is a powerful tool for inferring useful information from existing facts. This component is not only important for inference of new facts or cases but also provides quick and efficient way for checking inconsistencies generated and detection of abnormal situations.

Learning unit takes into consideration different datasets collected through various devices and direct inputs from self- assessment by end users. This unit makes use of the data fusion component to merge diverse data, because it is well accepted that emotional assessment over only one type of physiological data does not provide interesting results. Data fusion components implement methodology for combination of features from different datasets of physiological data. Datasets to be chosen and fused are defined in the configurations. Configurations and algorithms components provide the base for other two components of this unit, so that the best data fusion and learning algorithm can be applied as required by the type of emotional assessment and available datasets. Ensemble learning methodology makes use of multiple learning algorithms to obtain better predictive performance than could be obtained from any of the constituent learning algorithms. This approach is different from statistical methodology by considering a finite set of alternative models and allows a much more flexible structure to exist between those alternatives. Bayes optimal classifier, Bayesian model averaging, Bayesian model combination, stacked generalization etc. are some of the most common ensembles. This framework allows dynamic use of ensemble to meet the needs of emotional assessment because not all ensembles work the same way over the type and size of datasets. With the purpose of establishing the relationship between physiological readings and self- assessment on emotions, the purposed framework was configured to make use of galvanic skin response sensor ($deivice_1$) and skin conductance response sensor ($device_2$). The self-assessment manikins (SAM scales for valance) are used in the self-assessment unit and Bayesian model averaging is implemented for the learning methodology. The details regarding the experimental setup and the results are presented in the following sections. Thus this module makes use of data collected from lower layers and generates new classifications based on lessons learned. It also adjusts parameters so that new methodologies and new ranges will be applied for future data collection to become more efficient.

Algorithms

This component provides acts as the factory for selection and instantiation of algorithms as defined in the configuration settings to be executed over collected data and extract useful dataset, behaviours and new possible configurations by observing set of data over long period of time. Different types of algorithms are necessary to process the heterogeneous data from different devices working on varying conditions. This is the case when it is needed to process known rules over data sets in order to extract conclusions that will generate information about collected data.

Machine Learning (ML), is useful when trying to establish relationships between multiple features. ML can be used for improving the efficiency of systems and the designs of machines specifically in the case of systems with feedback loop. Every instance in any dataset used by ML algorithms is represented using the same set of features. If instances are given with known labels (the corresponding correct outputs) then the learning is called supervised learning (also known as predictive learning ref [297] for further discussion) which is different from other probabilistic methods. Predictive methodologies are getting in the medical domain to prevent further chronic problems and could lead to a decision about prognosis [298]. This approach includes feature extraction, training and testing steps while performing the prediction of the data behaviour and has been applied for prediction blood glucose level prediction [299], mortality prediction by clustering electronic health data [300] etc. So, various predictive models have been explored on different domain of health with an attempt to find a method that can accurately predict new observations.

Configurations

This component establishes the right configuration on how to organize data and what type of data should be collected and the algorithms to be applied based on the experimental setup.

Ensemble Learning

This component is responsible for assessment done over the execution of algorithms, simultaneously, over different sets of data and learning from those executions. Ensemble learning will allow complex interactions among different sets of data. Machine Learning (ML), is useful when trying to establish relationships between multiple features. ML can be used for improving the efficiency of systems and the designs of machines specifically in the case of systems with feedback loop. Every instance in any dataset used by ML algorithms is represented using the same set of features. If instances are given with known labels (the corresponding correct outputs) then the learning is called supervised learning (also known as predictive learning ref [297] for further discussion) which is different from other probabilistic methods. Predictive methodologies are getting in the medical domain to prevent further chronic problems and could lead to a decision about prognosis [298]. This approach includes feature extraction, training and testing steps while performing the prediction of the data behaviour and has been applied for prediction blood glucose level prediction [299], mortality prediction by clustering electronic health data [300] etc. So, various predictive models have been explored on different domain of health with an attempt to find a method that can accurately predict new observations. Combining independently constructed models that have different structures may be an appropriate technique to improve prediction and classification performance is termed as ensemble modelling [301]. The main advantage of forming an ensemble model is that if one of the models makes an error, it is likely others will correct this error. The process of ensemble modelling in the scope of this research work is to independently construct multiple single models that differentiate only in its modelling structure using the same predictors resulting in different outcomes. Then two or more of the individual models are combined into one using different ensemble approaches.

EXPERT BASED ASSESSMENT MODULE

This module comprehends the recourse to human experts that can be decisive in critical situations as is the case of healthcare or other situations that can involve risk. The processes can be automated but having the possibility of expert assessment before decisions are taken

Expert Analysis

This Module will be used in cases where expert analysis is requested. That is the case for questionnaires or assessment made over new information gathered from users.

Statistical Analysis

This component consists in the application of statistical rules over collected or stored data. This analysis will then be fed to experts so that they will decide how it will affect the overall system or if will be discarded.

DATA ACCESS INTERFACE LAYER

In the top of the Framework, the Data Access Interface Layer in Figure 9.15 allows the establishment of links with applications and the real world, in general by deploying results from the framework or by accepting requests from those applications.

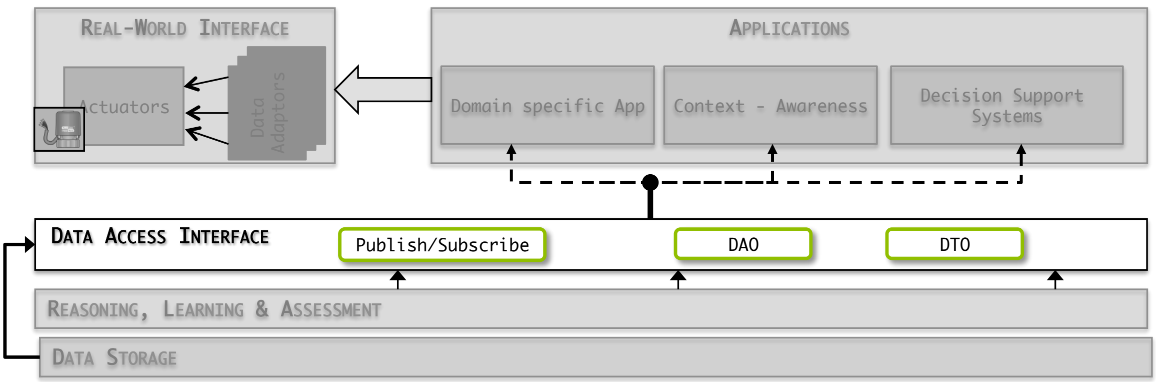


Figure 9.15 - Data Access Interface Layer

This layer acts as the interface between the Reasoning, Learning & Assessment and the client applications. It also accesses the Data Storage Layer so that stored data can be provided to the Applications that will make use of the Framework. The main purpose of this layer is to provide a uniform methodology for retrieving chunks of data from storage and to deploy data to the applications according to specific requests. This layer can be prepared make use of Data Access Objects (DAO) and Data Transfer Objects (DTO) to enable uniformity over various data management systems, thus avoiding dependencies for other components that generate and access data. DAO provides an abstract interface to database or other persistence mechanism. By mapping data access calls to the persistence layer, DAO provide operations over data without exposing details of the database. This isolation separates what data accesses in terms of domain-specific objects and data types. DTOs are objects that carry data between processes and provide functionality of just access and storage of only its own data, thus avoiding unnecessary modification of data caused by faulty implementations. This methodology implemented in data access component will lead towards the realization of a more robust system and also provide easy expansion towards different data types, as needed for wider set of physiological data and storage mechanisms.

Applications Layer & Real World Interfacing

The top layer of the Framework is presented in Figure 9.16. It provides an overview of possible exploitations of the Framework for the usage in applications. In fact this could be considered as an outside layer of the Framework.

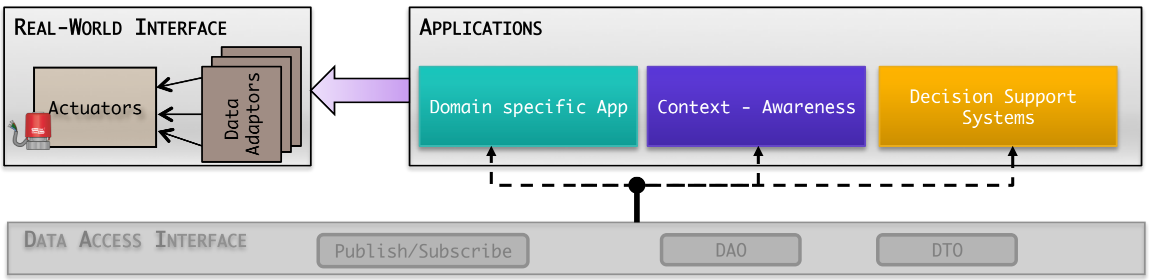


Figure 9.16 - Applications Layer and interfacing with Real-World

In general terms, results from the framework can be customised for domain specific applications, which can benefit from a wide range of inputs (e.g. physiologic parameters, adaptive value extraction by sensorial fusion).

The information extracted and managed by the framework can feed decision support systems, being those medical or any other system that needs the richest source of information to best respond to proposed objectives. Special cases of decision support systems are those that take in account the context or situation awareness. Context awareness has been one of the growing areas, in part due to mobile devices that, by the reason of being present all the time, they need to adapt and provide best services according to the specific circumstance of one person. That results in the need of using the most relevant information available in order to produce the best response to a user needs. In that direction, applications can respond more effectively if hey took in account diverse kinds of information. That is the case of silencing a phone if the person needs silence (e.g. being in a class, in a meeting or sleeping) or the case a person needs assistance (e.g. detecting a fall or irregular heartbeat sequences). Another example is situation awareness where systems take advantage of context awareness information along with rich knowledge bases to determine the circumstances and react properly. That is the case of critical or risky scenarios where the proper decision depends on how accurately the contexts are evaluated (e.g. flight deck, nuclear power plant management, critical surgeries).

10. Scenarios and Validation

This Chapter presents the Scenarios built with the research performed within the present research work of these doctoral studies. The presented scenarios where all published in international conferences and Research Journals and where selected to publish and disseminate results and applications from the current research work. The first scenario to be presented in section 10.1, the validation scenario, has a particular significance as it corresponds to a scientific experiment developed with human protagonists that performed tests in a proposed setup. These tests correspond to the validation of an important part of the proposed framework that is, the inference of emotions from physiological data. Then the scenarios presented next in sections 10.2 to 10.5 are potential explorations of the research work developed and where published and presented to the peers as, per its acceptance, constitute also an important part of the dissemination and validation strategy.

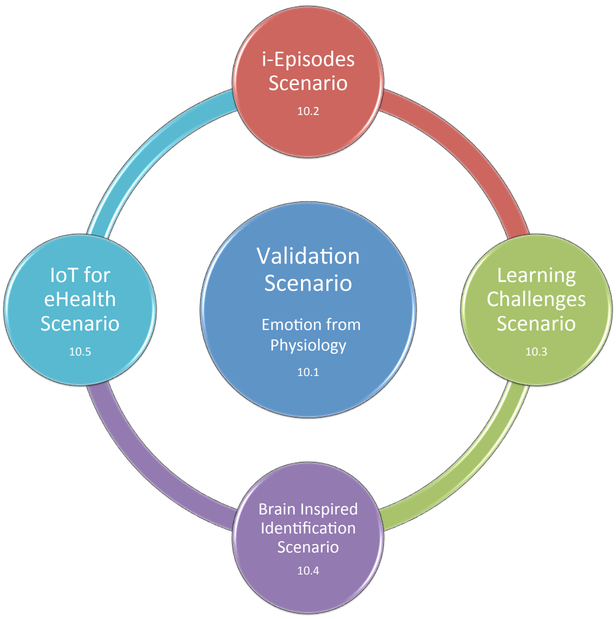


Figure 10.1 – Validation and other published scenarios

As presented in Figure 10.1 a main validation scenario was developed and presented with the most relevant conclusions for validation purposes. Then several application scenarios are presented. Those scenarios are aimed to demonstrate how the work developed can be used for different technological and societal purposes and serve as an inspiration for other potential applications.

The validation of the proposed framework and demonstrator was performed in the context of on-going research projects of our Research Group and through acceptance and validation through reputable Journal and International Conference publications.

The proposed Knowledge Management Framework based on Brain Models and Human Physiology has two main contributions, the new Data Model to include sensorial and physiological information and the Conceptual Framework that can have multiple instantiations and potentially configured for the different management steps, from data capture to reasoning and advice for external application usage.

Publishing is an important parcel of validation as it makes research procedures and results available peers. Published material was evaluated by scientific experts and, by means of that approval from the scientific community, becomes published scientific knowledge. Furthermore, publishing fulfils an important attribution of scientific researchers: to disseminate and share knowledge and acquired competences.

For the validation proposes it is necessary to demonstrate the relevance, and added value, of the Framework in application scenarios. Validation can be achieved by three identified modes, with a theoretical development, by a simulation process or using real devices and people.

The kind of validation developed in the current research work aims at knowledge management in a human centric perspective and because of that it seemed reasonable to perform validation with real devices and volunteers. Another important reason for such approach is that the framework aims at providing services for people and, for that reason, makes all the sense to make a validation with people that, ultimately, those are who should benefit from the operations based on the Framework. The next reason is that using real people to perform the tests would override the need of generate artificial data or make a theoretical modelling on something that, more than scientific outcomes, has a practical and pragmatic objective. Finally it was understood the scientific and technological benefits that could be obtained from the contribution of users' self-assessment to validate the process of correlating emotional stimuli with physiological measurements.

10.1. EMOTIONS FROM PHYSIOLOGY - PILOT SCENARIO FOR VALIDATION

Validation was performed with an experimental setup that makes proof of concept of one relevant aspect of the proposed framework architecture; the possibility of obtaining information about a person by physiological measurements, in particular, generating information about a person's emotional state by collecting physiological data.

As clearly exposed in the beginning of the previous chapter (c.f. section 9.3.1) the framework can be human operated, machine based, or a coexistence of human and computational support. That is what we opted to do as a fully computational demonstrator would require a large scale implementation that would require a great workload or a wide spectrum of time to be performed by a single person in a PhD program. Thus the solution adopted to validate was computer based with sensors and devices but not fully automated, as that would not be a viable option for the supposedly limited scope of duration of a PhD program.

Then it was decided to create an added value to the demonstration of the Framework that was by inviting volunteers, university students, to perform the experiment with real individuals. The validation of the different layers of the framework was mostly based in sensors and computational support with the intervention of humans to overcome the operations that would be, otherwise, implemented in computers, devices and cloud based services.

The execution of the experiments and collection of data was performed with a population of 30 young adults, considered reasonable for the proposed goals by analogy to other similar studies (e.g. in Nature May 2014) [186]. The goal was to generate physiological data to be analysed and lead to conclusions about subject's emotional states.

Peers also performed validation, with about sixteen publications made in International Conferences and selected Journals, during the scope of the doctoral program. Validation experiments where also published in two International Conferences (i.e. ICE 2015[21] and IWEI 2015[22]).

10.1.1. *On the importance of Emotional Evaluation*

The idea that we take the time and invest the effort to produce a list of advantages and disadvantages, or costs and benefits for all alternatives in each single decision and decide on the basis of a rational calculation of those, is not only at odds with introspection, but would also not constitute an advantageous strategy. We simply do not have the time and ability to do so. That is were emotions come in handy. The importance of emotion for decision-making is also important in the fact that decision making itself is often an emotional process. Emotions evaluate our decision outcomes and thus our well-being [302].

This is another case of adoption of a lesson learned from neurophysiology and brain models to improve knowledge management. Thus the emotional tagging and emotional correlations are, in fact, direct applications of what we learn from human brain's knowledge management strategies.

[21] http://www.ice-conference.org/

[22] http://iwei2015.mines-ales.fr/

10.1.2. VALIDATION OF AN HYPOTHESIS FROM A QUESTION

Generically, validation addresses the validation of the hypothesis in addressing the research questions. In this case we need to validate the usage of the proposed framework and data model towards validation of research question by means of a sub-question. The research work was extensively published, as described in Chapter 13, addressing different Journals and Conferences in different research areas such as Human Computer Interfacing, Enterprise Interoperability and Affective Computing and others with a broad spectrum such as the ICE conference or the ASME conferences and many others (c.f. Table 13.2)

Research Question – Is it possible to improve information systems based on lessons learned from neuropsychology and brain models?

We pursue that goal by effectively adopting lessons leaned from neurophysiology and brain models and questioning if physiological measurements allow the inference of emotional states so that we can improve knowledge management systems and better interfacing computational applications with users.

Hypothesis: If we adopt sensorial and physiological analogies from the human body and inspiration from selected brain models to improve knowledge management, we will be able to find new ways of acquiring and representing knowledge, allowing new applications for a persons' benefit.

Rational: If that hypothesis proves to be valid, the framework will be possible to customize Human Computer Interaction in applications, it will be possible to classify i-Episodes (c.f. Section 10.2.1) as proposed in the framework development and the framework can be used, in a scalable manner, to receive physiological data from existing or new types of sensors that will contribute for data classification and user's emotional assessment. Knowledge management will be empowered by enriching information elements with knowledge about the user's emotional state and being able to provide better interfacing and knowledge deployment to users by knowing about their actual affective state.

The proposed scenario aims at verify and validate the possibility of inferring emotions from physiological signs. This scenario was developed in laboratory environment conducted with a group of people, university students, that were exposed to a set of pictures from the IAPS database (c.f. section 7.2) and their reaction was measured in a systematic way with specialized devices. Results were collected and analysed with the objective of validating a setup of deployment of the framework. In this scenario, de term setup presents a scope of applications that it is not restricted to a single purpose but that has a multitude of applications.

After this brief introduction a description of the scenario, its execution and results are presented. Therefore this validation provides one scenario for application: the inference of emotions from physiological measurements. But we can mention further results, this scenario also provides a conformation of the initial motivation for this work; the added value of learning from brain models and physiology for knowledge management, as it empowers a strategy for classification and emotional tagging and it also provides knowledge for context awareness applications and human computer interfacing among other possible purposes that fit in the premise of human centric application.

Emotions are an abstraction of our mind that cannot be measured directly but their result affect humans and produce emotional responses that can be assessed. Because of that, the study of emotions has two major sources; physiological measurements (e.g. galvanic skin response, heartbeat, etc.) or report from the person (e.g. I am sad, I am happy, etc.). Retrieval of information about emotions, on the second option, would imply the questioning (e.g. by an application), filling of forms or voluntary reporting (e.g. now I am writing and I am calm, now I am driving to work and I am becoming stressed). Daniel Kahneman, 2002 Nobel Prize in economic sciences, is one of the scientists doing research in this field. In his published survey method for characterizing daily life experience [303], he states that a great advancement was made by the development of the Experience Sampling Method (ESM), as it marked a notable advance in the measurement of the quality of people's lives In such studies, participants are prompted to record where they are, what they are doing, and how they feel several times throughout the day. This technique provides a rich description of a sample of moments in respondents' lives, while avoiding the distortions that affect the delayed recall and evaluation of experiences. However, experience sampling is expensive, involves high levels of participant burden, and provides little information about uncommon or brief events, which are rarely sampled. Furthermore he rises questions about the disruption this registries causes in daily activities. In this sense he presents the Day Reconstruction Method (DRM), which is a hybrid approach that basically consists in reporting at the end of the day the most relevant events, when they happened and what were the feelings associated.

In either case, ESM or DRM, there are problems that need to be carefully addressed. That is the case of lack of precision or mistaken assessment in personal reporting. In a review on belief and feeling in self reporting, by Michael Robinson and Geral Glore, it is developed a model that specifies the types of factors that contribute to emotional self report under different reporting conditions [304]. In this study they make an important distinction between emotion, which is episodic, experiential, and contextual, and beliefs about emotion, which are semantic, conceptual, and decontextualized. Because beliefs are abstract representations, whereas emotions are episodic occurrences, emotional experience and beliefs about emotion often diverge.

The approach proposed in this thesis, defends a way of collecting clues about the emotions a person experiences during the day by making physiological measurements and, occasionally make use of reported emotional experience to learn and adjust inference correlation parameters. In line with what Kahneman proposes, we can reduce the need of written expression if episodically self-reporting on emotions is obtained and validated with collected physiological data.

The equipment to be used lacks portability and it is lab-oriented, has size and components that are note suited for carrying or wearing unobtrusively in daily life. That aspect would raise a question about its usefulness for citizens and its future application. However technology is stepping towards seamless integration of such components in the environment or in objects that are in use in our pockets or our wrists, as is the case for smartphones or smartwatches. In such technological advancements, we can already include fitness bands that measure heart rate, a type of measurement that surprisingly can also be achieved unobtrusively from the environment. That is the case of research presented in an article from Institute of Physics Journal (IOP Science). In that article it is proposed a promising method for monitoring the vital signs of patients without attaching any electrodes or sensors to them. Most of the papers in the literature on non-contact vital sign monitoring report results on human volunteers in controlled environments. But they were able to obtain estimates of heart rate and respiratory rate and preliminary results on changes in oxygen saturation from a video camera positioned one meter away from the patient's face [305]. Research will converge in direction of the usage of such wearable or environmental equipment as soon as they are available in the market. As a scientific challenge, the objective of the proposed scenario is to demonstrate the validity of the concept of inferring emotions from physiological readings, thus making it useful for HCI improvement and improve knowledge management frameworks.

Thus if we want to manage knowledge with emotional tagging or to improve computational awareness of a person's emotional state we need to have physiological or measurements, or other automatic measurements (e.g. facial or postural), validate its results with a person's self expression and foreseen strategies for future improvements of that model.

The International Affective Picture System (IAPS) is widely used in studies of emotion and has been characterized primarily along the dimensions of valence, arousal, and dominance. Even though research has shown that the IAPS is useful in the study of discrete emotions, the categorical structure of the IAPS has not been characterized thoroughly [306]. The purpose of the present research work was to collect descriptive and physiological emotionally related categories of data on subsets of the IAPS, in an effort to establish a match between physiological data and emotional states.

10.1.3. *Framework instantiation to the Pilot Scenario*

In this section we depart from conceptualizations developed in previous section and move to instantiation in a real case scenario. The conceptual Framework (c.f. 9.3.2) has a generalist character, by definition of framework (c.f. 9.3.1) and aims at a large scope of utilizations.

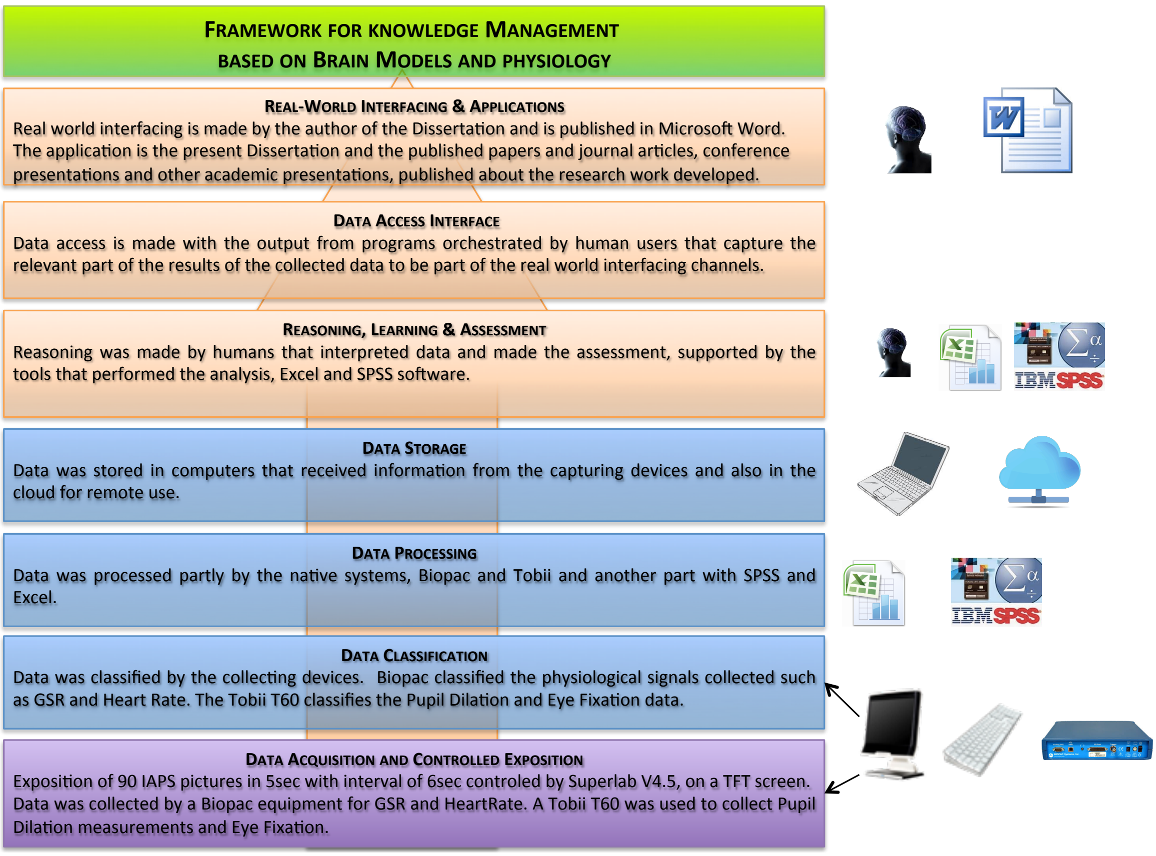


Figure 10.2 - Framework instantiation for the Pilot Scenario

The instantiation of the Framework makes use of diverse equipment and software tools available in the market and for that the presented experience is fully replicable. That is a milestone that was aimed to be achieved so that the present work becomes a legacy for those willing to follow the same approach. The layers can use interchangeable equipment and in a near future it is possible to have all that equipment condensed in an integrated environment on a smartphone or smart watch. The Eye tracking equipment could be made with a set of Google Glasses or other equivalent equipment with a more affordable cost. In fact the same company that produces the equipment in the pilot experiment (Tobii) has a much less expensive eye tracker in a set of glasses.

10.1.4. *Method*

Stimulus selection and presentation

The stimuli were selected from the International Affective Picture System (IAPS; Lang et al., 1997) according to Valence and Arousal ratings of the original study. The images were chosen within three different categories: (1) food; (2) animals; and (3) people including images from men and women, couples, children and babies.

The complete set is made of three series of 30 images of each of those categories, making a set of 90 images in total. The images were chosen with high activation ratings (< 3 points), divided in: 10 positive images (valence ratings < 3 points), 10 neutral images (valence ratings between 4 and 5 points), and 10 negative images (valence ratings > 6 points). A mosaic with all the pictures used is depicted in Figure 10.3.

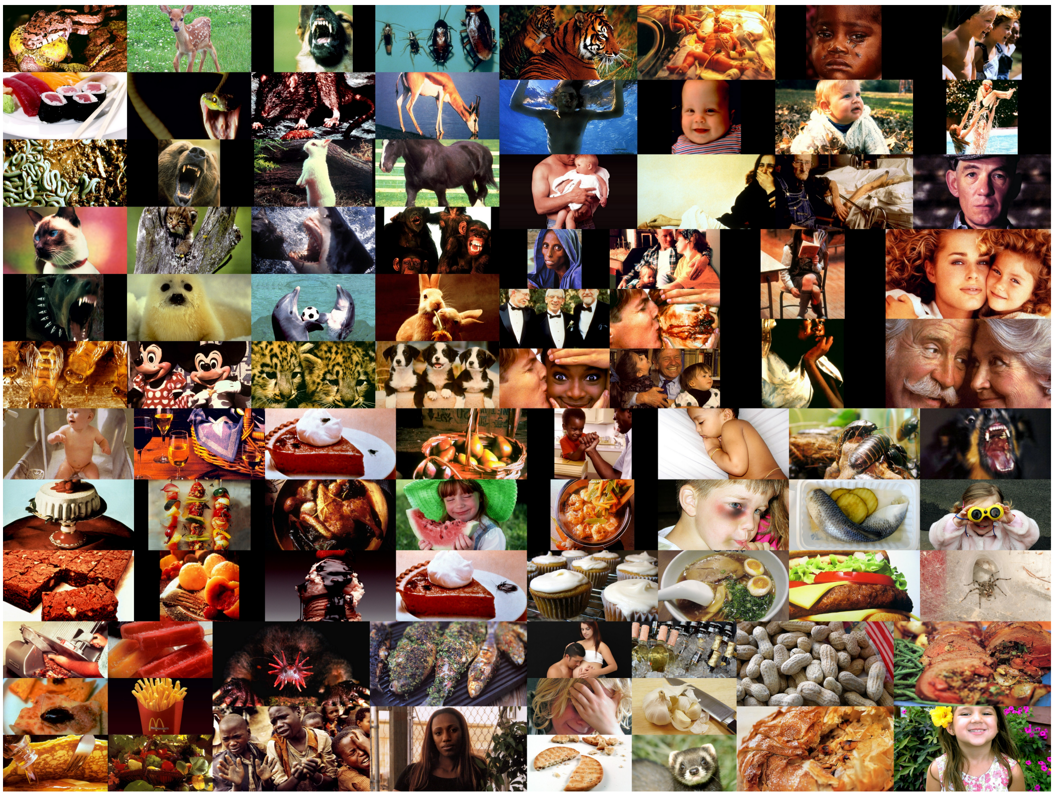


Figure 10.3 – Mosaic with 90 IAPS images used as stimulus in the experiment

The stimulus presentation was performed using Superlab v4.5 (from Cedrus Corporation). Each trial in Superlab comprised a small fixation cross that was presented in the middle of the screen for 500 millisecond (ms) that preceded the presentation of each image, which was presented for 6000 ms.

These stimuli were followed by the presentation of 3 Self-Assessment Manikin (SAM scales for valence, arousal and dominance). Each of the SAM scales was on the screen until a response was given (by the number pad keys from 1 to 9) with the right hand.

10.1.5. *Instantiation of the Framework*

The experimental scenario developed with an instrumental setup and performed by people represents one vision of the framework. The validation scenario, presented in Figure 10.4, becomes an instantiation of the framework and uses some of the components already mentioned in the architecture in Figure 9.9.

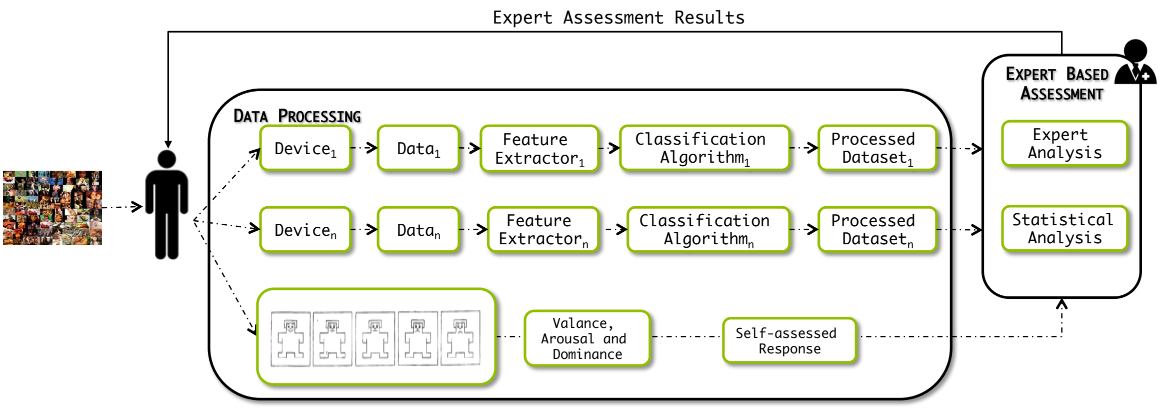


Figure 10.4 - Instantiation of the Framework for the validation scenario

The proposed scenario starts with the stimuli from the outside with the slides being exposed to the people involved in the experiment. Then the description of the flow goes from left to right (in instantiation of Figure 9.9, it can be observed from bottom to top). The person being exposed to the images will have devices ($device_1$…$device_n$) performing physiological measurements, in the instantiated scenario those devices are the Biopac for GSR and ECG and the Tobii T60 eyetracker for Pupil Dilation and Eye Fixation measurements. The system is made of a TFT screen with the infrared and cameras embedded in the monitor frame.

The data collected will be used for feature extraction where only the requested features are recorded. Classification algorithms transform collected data into datasets that are then organized and sent for expert assessment. Performing statistical analysis by the described methods, the datasets feed those statistics that, ultimately, are presented as graphical representations that summarize the results obtained. The expert analysis is a need to provide insights over the statistical results and, according to the initial hypothesis, to verify what type of validation results are being obtained by the experiment.

10.1.6. *Scientific Apparatus*

In the lab experiment, visual stimuli were selected from the International Affective Picture System (IAPS) according to arousal (most extreme, i.e., < 4) and valence (both positive and negative) ratings [307]. The stimulus presentation was carried out using software adaptable for the needs of this experience, the Superlab v4.5. Each picture was presented during 5 seconds periods, preceded by a black fixation cross (500 millisecond), with an inter-stimulus interval of 3 seconds. The images where presented to the volunteers in a monitor as in Figure 10.5 (left) and recordings visualized in real-time for heartbeat and skin conductance as depicted in Figure 10.5 (right).

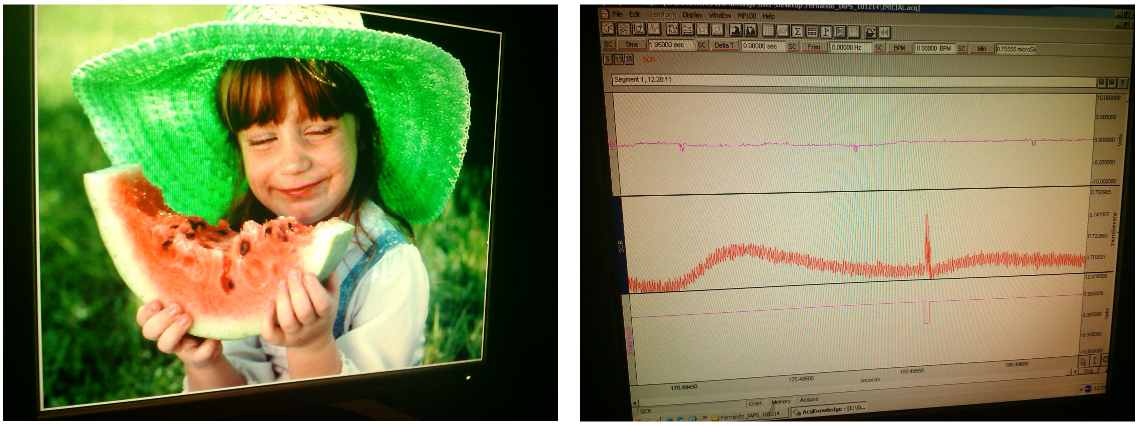


Figure 10.5 – Screen with image being shown (left) heartbeat and galvanic skin response (right)

The psychophysiological and behavioural measures were recorded during the visual stimulus presentation. The eye-movements were recorded with a T60 Eye Tracking System (Tobii Technology AB, Sweden). The device is visible within the screen in Figure 10.6. The experiment starts with a briefing from the person in charge that explains the procedure, how the experience is performed and how the subject is suppose to proceed.

The execution then begins with the explanation of all the proceedings to the volunteers, describing the sequences and how they should respond with using a computer keyboard. Then it is necessary to proceed with the calibration of the eye tracking equipment in the standing position of the person in front of the screen, once the equipment depends on the infrared lights that lighten the pupils. This proceeding aims also to ensure that the person is in front of the camera and that the camera is monitoring the pupil of both eyes. Thus the whole protocol is a fundamental part of the procedure and must be followed in order to ensure the quality and accuracy of the data collected.

With the volunteer in position and aware of the proceedings it is possible to start the exposition of each picture, as before mentioned, the experiment is performed with a set of 90 pictures, The experiment starts with the equipment collecting the physiological data from GSR and Hearth rate along the recording of gaze data of both eyes, at 60 Hz, during the exposure to each picture. The software used to record and analyse gaze data was the Tobii Studio v.3.0 developed by the same company that manufactures the Eye tracker thus ensuring the best adequacy between both.

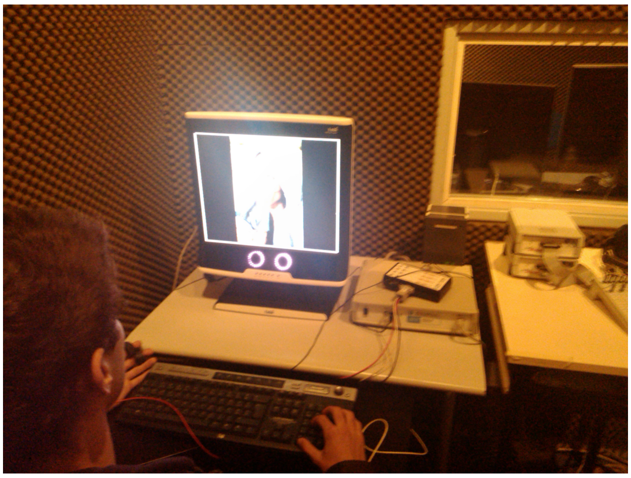


Figure 10.6 - Subject performing the experience in laboratory with Tobii (left) and Biopac (center)

The peripheral measures were based on skin conductance responses and heart rate activity. These measures were collected with a TEL100C device connected to a Biopac MP100 platform (Biopac Systems, Inc.) as visible in Figure 10.7.

Figure 10.7 - Device setup used in the experience Tell 100C (left), Biopac (right)

10.1.7. *Data Analysis*

In Figure 10.8 are presented sets of data reading with Heartbeat and galvanic skin response and time of exposition (from top to bottom). In the bottom of the image it is possible to verify two expositions of IAPS images (the two inverted tops). On the top row, the ECG data in the sample displayed is not revealing, apparently, detectable physiological changes that could be identified at a glance, towards the images displayed but that will be object of analysis. In the middle row it is possible to observe how the GSR data reveals changes in the person that is doing the test.

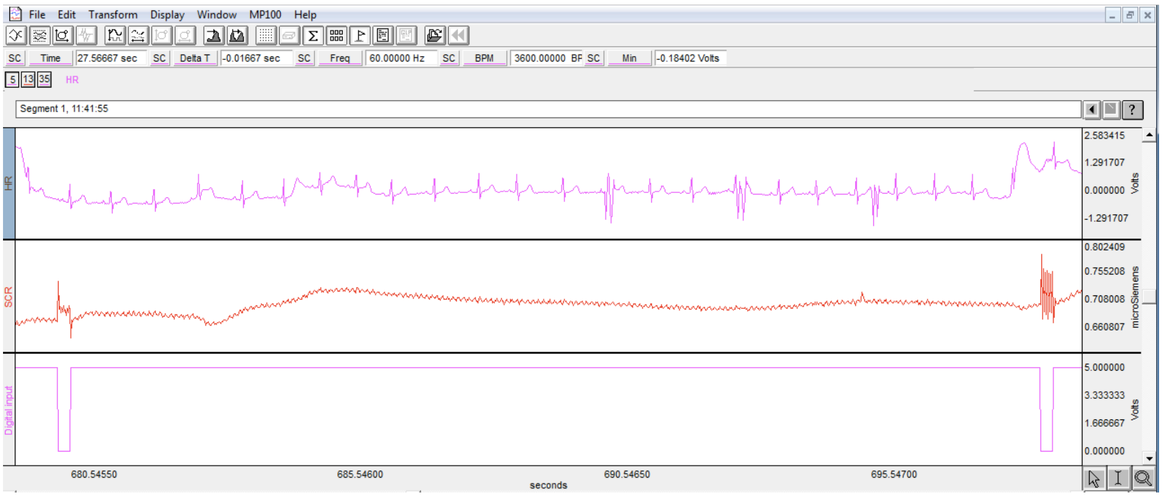


Figure 10.8 – Data captured with two expositions of IAPS images

The readings between expositions are then taken as baseline for the exposition measurements. In the case of the heat beat the focus of the observation are the observation, volunteers were sometimes restless and for that some peaks could be observed due to movement on the cabling, however they were advised to stay quiet during expositions. That was verified all the time while we were monitoring the tests.

10.1.8. *Measurements*

The assessment of the stimuli was based on two different response types: subjective ratings and objectives measures from peripheral psychophysiology. Subjective ratings were collected after the presentation of each image using a keyboard while displaying three SAM scales, one for valence, other for arousal and another dominance (c.f. Figure 7.5). The peripheral responses were collected for heart rate, pupil dilation, gaze and skin conductance response, all during stimulus presentation. Next in figure Figure 10.9 are represented the measurements made at the volunteers for ECG and GSR.

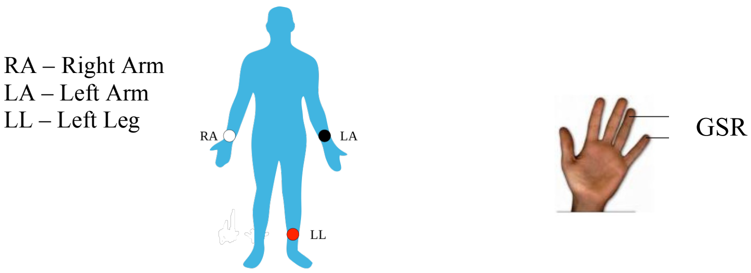


Figure 10.9 - Measurement setups Heart rate (left) Galvanic Skin Response (right)

The heart rate was collected with 3 electrodes mounted in derivation II, whereas SCR with bipolar montage connected in the middle phalanx of the index and middle finger of the non-dominant hand (usually left-hand).

The Skin Conductance Response (SCR) was recorded using 200 samples per second with on-line filtering of 0.05Hz. Heart rate was measured in Beats per Minute (BPM) whereas the SCR in microSiemens for the response amplitude, both responses were evaluated during the 6000ms of exposure to each stimulus.

Pupil dilation was measured in millimeters and it was sampled at a rate of 60Hz capturing 60 samples in each second.

In early studies we found that data from Skin Conductance Response was actively changing each time a picture was displayed, heart rate changes were imperceptible for the naked eye and pupil dilation was presenting values with no visible correlation with the contents. It was identified that pupil dilation would be a problem for the chosen set, IAPS, as the images are not calibrated in terms of intensity and contrast. Without that relevant factor it was decided to proceed anyway because IAPS is the most used and the most complete set of pictures for the aimed purpose. For the same reason analysis started with Heartbeat and Skin Conductance Response as those could be suitable for validation, unlike the eye tracking samples that we will analyse afterwards.

10.1.9. *Statistical Analysis*

The main objectives for the analysis performed over the collected data were:

1) To identify if the set of pictures is relevant for the people involved in the study as the set was created at the end of XX century for the American population

2) To capture relevant information on the subjects' physiological response and to verify if the chosen physiological measurements reveal response to the exposition of stimuli from the chosen set

3) To identify if there are relationships between physiological measurements and subjective responses by the participants to the pictures presented and from there to conclude if correlations can be established between measurements and the individual's emotional states.

The measurements hereby analysed are the physiological responses, in this experiment it was collected data from the skin conductance, heart rate and using the eye-tracker, it was collected pupil dilation and eye fixation (gaze) all during stimulus presentation.

It was organized a set of pictures including images from three different categories: animals, humans and food pictures. In those collections different types of stimuli were included and for that the collections were organized in positive, neutral and negative stimuli according to the scores provided by Lang et al in their Manual for the IAPS [211].

Regarding the first objective, it was necessary to proceed with statistical studies that could show if the IAPS dataset was suitable to be used in the Portuguese population, as it would be the case of the involved volunteers. If the set proves to be useful, using statistical analysis, that would be a result that reaches beyond the present work and validates the usage of SAM for this kind of studies. It is a challenging question that it is aimed to verify within this study and to be documented.

The second objective is central to the validation process as the main objective is to understand if physiological measurements can be used to get information about a person's emotional state. As mentioned before, there are many devices that capture physiological information for fitness and for sports. If this objective achieves successful outcomes it indicates that physiological measurements can provide clues about a person's emotional state.

The third objective is like an extra feature of this work. It comes from the fact that it is known that, different people have different emotional reactions, and that each person is affected in different manners according to personal life and experience (c.f. section 5.4).

Proceeding to first objective, it was expected that negative and positive pictures, independently of their category, would increase the physiological response and the subjective rating through the SAM scales in comparison to neutral pictures. The physiological response would be related to the activation in the peripheral nervous system, namely in the sympathetic division of the

Autonomous Nervous System (ANS), that reflects a somatic response to emotional stimuli. It would be expected that different types of physiological response would be impacted differently, during the experience, in the same manner that a person's physiological response occurs differently.

It is also expected that these physiological responses would be related with the subjective assessment of the pictures through the SAM scale, and thus providing clues about the effectiveness of such measurements to the assessment of emotional states in persons. However it is not expected that a classification of emotions would result from such measurements, as that is not within the scope of the present study as it would me a matter of debate from professionals in the social and medical sciences (e.g. psychologists, psychiatrists, sociologists).

To test these hypotheses, two different statistical procedures were carried out. For the first objective was to test the validity of the set of pictures for the population involved in the study. It was performed an ANOVA with repeated measures with two with-subjects factors: the stimulus category with 3 levels (animals vs. humans vs. food) and the valence of these stimuli also with 3 levels (positive vs. neutral vs. negative). The main effects of each factor were analysed further using multiple comparisons with Bonferroni comparisons and the interaction effects between factors with simple main effects also with Bonferroni correction given the small sample size. The ANOVA is a F-test based on the F probability distribution.

The F is estimated according to the Sum of Squares (SS) between groups dividing by the SS within groups. The SS are given as in Figure 10.10.

$$\sum_i n_i(\bar{Y_{i\cdot}} - \bar{Y})^2/(K-1)$$

Figure 10.10 - Sum of the squares between groups

In this formula the Y_i denotes the sample mean, whereas the n_i is the number of observations in the group. The Y denotes the overall mean of the data, and K denotes the number of groups in comparison.

For the within-group variability or the SS within-group, the following formula in Figure 10.11 :

$$\sum_{ij}(Y_{ij} - \bar{Y_{i\cdot}})^2/(N-K),$$

Figure 10.11 - Variability of the SS within-group

The responses in the SAM scales were assessed independently for valence, pleasure and dominance.

10.1.9.1. *SELF-ASSESSMENT EVALUATION FOR VALENCE*

The self-assessment for the SAM scale is first evaluated for the valence category. It is aimed to know if the volunteers respond according to the classification of the same scale in terms of valence. As explained to the participating persons, valence is a measure of how a person likes or not the stimuli and in what degree that happens.

The SAM scale is classified between 1 and 9, 1 value for each manikin and space between manikins also counts for a value. In the case of valence the higher classification means more negative valence as the scale starts on the left (value 1) and finishes on the right manikin (value 9) as in Figure 10.12.

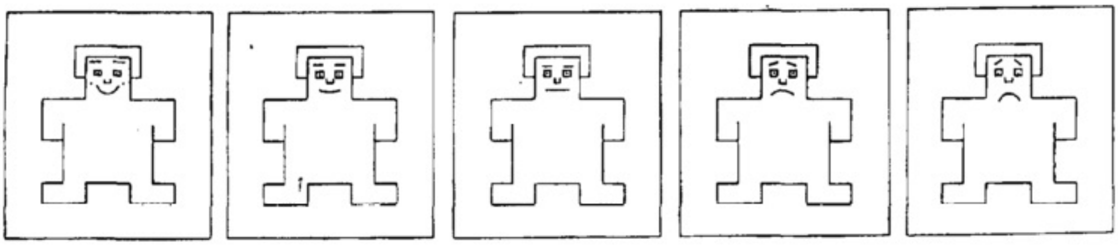


Figure 10.12 - SAM Scale for Valence

The results in this analysis revealed a statistically significant interaction effect between factors for valence ($F(4, 112) = 8.471$; $p < 0.001$)

Degrees of freedom are 4 from 2 variables (categories and valence) with 3 categories each [(humans or food or animals) and (positive, neutral negative)], resulting in N-1+N-1=4.

As for the 112 it is a result of the sum of Degrees of Freedom for each variable; Category and Valence. We have k=3 categories with S=29 subjects N=87. So Df total is (N-K)-(S-1) = (87-3)-(29-1)=56. For Valence we have the same account thus we get the total of degrees of freedom as DfCat+DfVal= 56 + 56 = 112. The same reasoning applies to the calculations for the categories in the next sections.

The level of significance (and degree of confidence) $p<0.001$ which correspond to 99,9% confidence resulting from an ANOVA value of Fisher of F=8.471.

The ANOVA value obtained suggests that we can with a higher degree of confidence (99,9%) that, for instance, the obtained more negative classification for pictures that involve people with negative content (e.g. violence) has a match with the SAM classification scale. The ANOVA value applies to all the categories in the same manner and thus validating the graphic in Figure 10.13. We also can conclude that what people dislike the most is to see humans in bad conditions.

The Self Assessment Manikin was used for the indication of the Valence scale for the presented stimuli. Data was collected and analysed with ANOVA providing the values presented next in Table 10.1

Table 10.1 - Self assessment for Valence

Valence					
				99,9% Confidence Interval	
Cat valence		Mean	Std. Error	Lower Bound	Upper Bound
1	1	3,580	,325	2,386	4,774
	2	3,286	,316	2,124	4,448
	3	3,813	,239	2,934	4,692
2	1	4,662	,228	3,823	5,501
	2	4,062	,183	3,391	4,733
	3	4,552	,219	3,746	5,357
3	1	6,082	,298	4,986	7,178
	2	6,659	,349	5,376	7,943
	3	5,534	,215	4,743	6,326

For the category Valence the confidence interval of 99.9% reveals a strong the relationship between stimuli and self-assessment for the three categories.

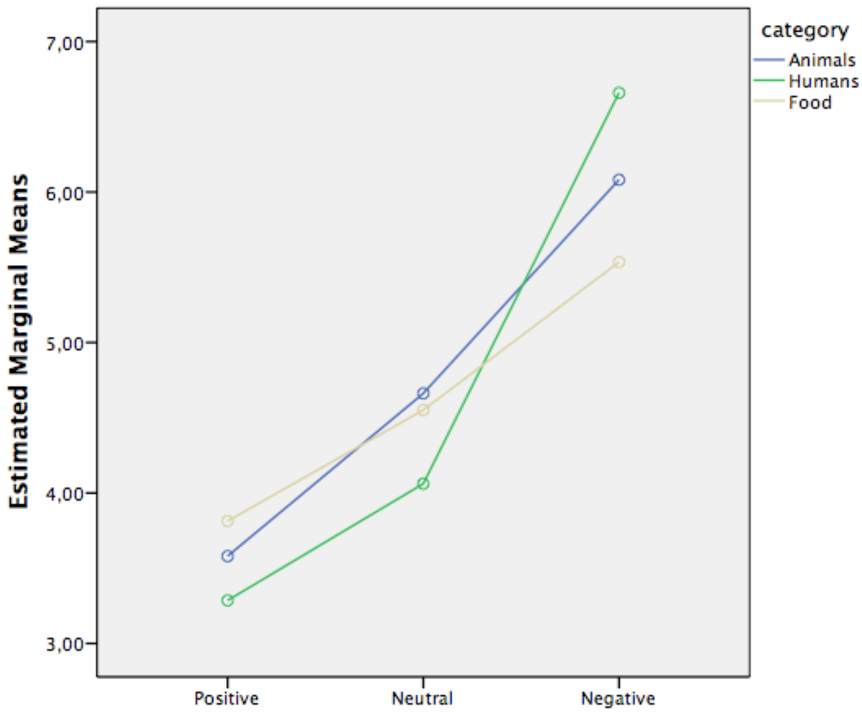


Figure 10.13 – Estimated Marginal Means for Valence

In this graphic the response from the population has the same evaluation of the scale classification, even with some variations between categories (crossing lines).

10.1.9.2. *SELF-ASSESSMENT EVALUATION FOR AROUSAL*

As for the Arousal, the same interaction effect was found between factors ($F(4, 112) = 4.897$; $p < 0.01$).

In this case an F of 4.897 results in a $p<0.01$, meaning that we have a degree of confidence of 99.0% which is highly confident.

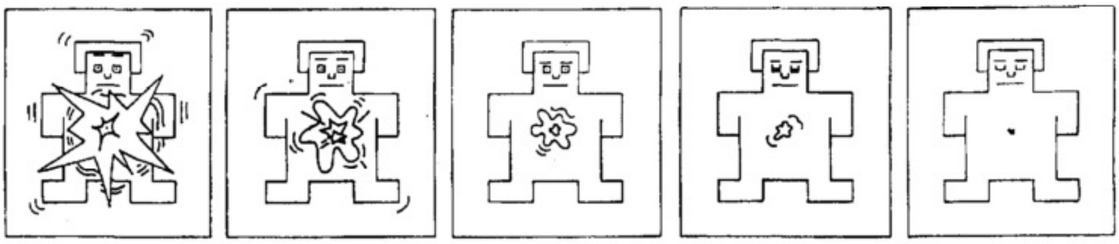


Figure 10.14 - SAM Scale for Arousal

In this case the SAM scale also works between 1 and 9 and that the higher classification means less subjective activation as reported by the person.

This result describes that arousal was higher for the same category than in the previous analysis; humans in a negative context are a more activating stimuli than in the other categories (

Figure 10.15). It indicates also that people feel more disturbed with humans in bad conditions then any other case.

Table 10.2 - Self-Assessment for Arousal

Arousal					
				99% Confidence Interval	
val	cat	Mean	Std. Error	Lower Bound	Upper Bound
1	1	4,970	,286	4,180	5,761
	2	4,762	,356	3,779	5,745
	3	5,356	,325	4,457	6,255
2	1	4,848	,251	4,153	5,543
	2	5,097	,288	4,302	5,893
	3	5,629	,344	4,680	6,579
3	1	4,951	,310	4,094	5,808
	2	4,031	,340	3,091	4,971
	3	5,345	,268	4,604	6,085

The values obtained for arousal are presented in the next graphic Figure 10.15.

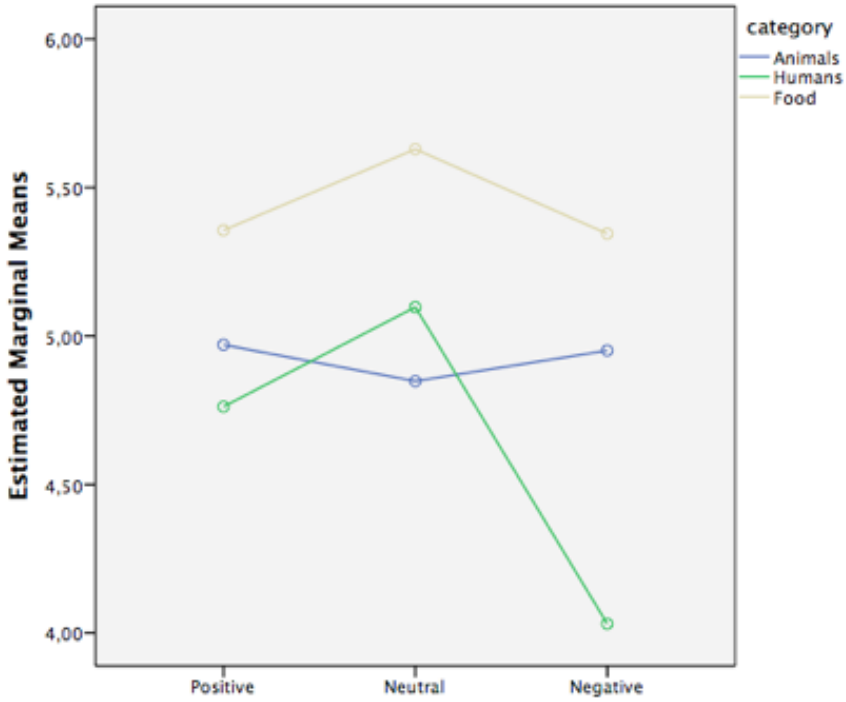


Figure 10.15 – Estimated Marginal Means for Arousal

The category of food has less arousal than the others and not so expected images of animals do not have much variance in arousal for the different types of stimuli.

10.1.9.3. *Self-assessment evaluation for Dominance*

The results of the SAM scale for dominance were different and showed only a main effect of the category ($F(2, 112) = 6.986$; $p < 0.01$), no interaction or main effects of valence were found ($p > 0.05$). The significant result of the category was analysed with Bonferroni correction and revealed that the category of pictures with people were stronger in dominance than the remaining categories (animals and food), as shown in (Figure 10.17).

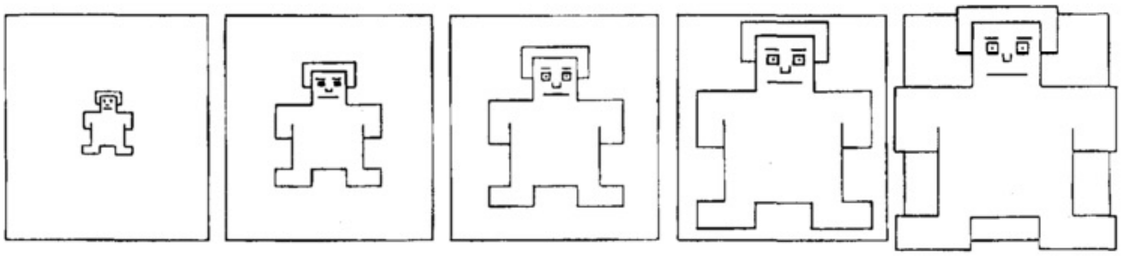


Figure 10.16 - SAM Scale for Dominance

In this case, as explained to the volunteers, it was explained that Dominance means at what degree the person feels connected, or involved, in the scene. Which means if it captures more attention and makes the person somehow ignore the rest (e.g. stop thinking in what to do next).

As for the Food category, the positive stimuli are more significant than for the negative in contrast of what happens with Human category. In the case of Animals the results show less prevalence for the different classes of stimuli than for the former two. The more Dominance of Food positive stimuli could be related to the timing of the experiments, close to lunch hour.

Table 10.3 - Self Assessment for Dominance

val	cat	Mean	Std. Error	99% Confidence Interval	
				Lower Bound	Upper Bound
1	1	5,261	,323	4,370	6,152
	2	5,600	,350	4,634	6,566
	3	5,356	,325	4,457	6,255
2	1	5,024	,291	4,219	5,829
	2	5,240	,290	4,439	6,040
	3	4,302	,321	3,415	5,189
3	1	5,142	,369	4,122	6,163
	2	5,877	,416	4,728	7,026
	3	4,624	,324	3,730	5,519

The collected values for Self-Assessment in Dominance scale are presented next in Figure 10.17.

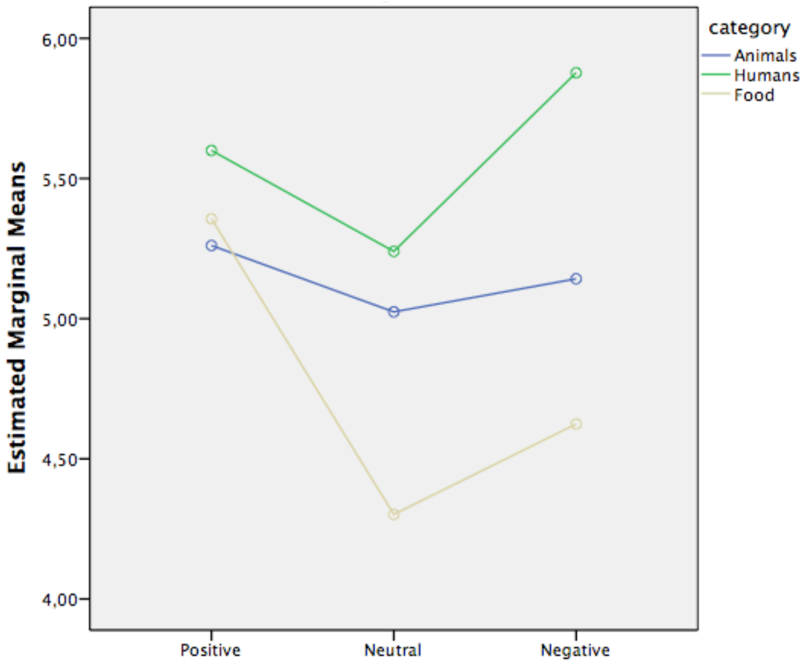


Figure 10.17 – Estimated Marginal Means for Dominance

For the second objective there were several measurements to evaluate physiological responses from individuals. The analysis for the Heart rate showed a main effect of category ($F(2, 44) = 6.277$; $p < 0.05$), which indicates that in general the pictures with animals induced a slightly upper activation over the remaining categories especially in the positive cases (Figure 10.18).

Table 10.4 - Physiological measurement – Heart rate

Heart Rate				
			95% Confidence Interval	
cat	Mean	Std. Error	Lower Bound	Upper Bound
1	78,878	1,898	74,951	82,805
2	77,973	1,933	73,975	81,972
3	78,469	1,940	74,456	82,482

These values are presented next in Figure 10.18, with the three different categories.

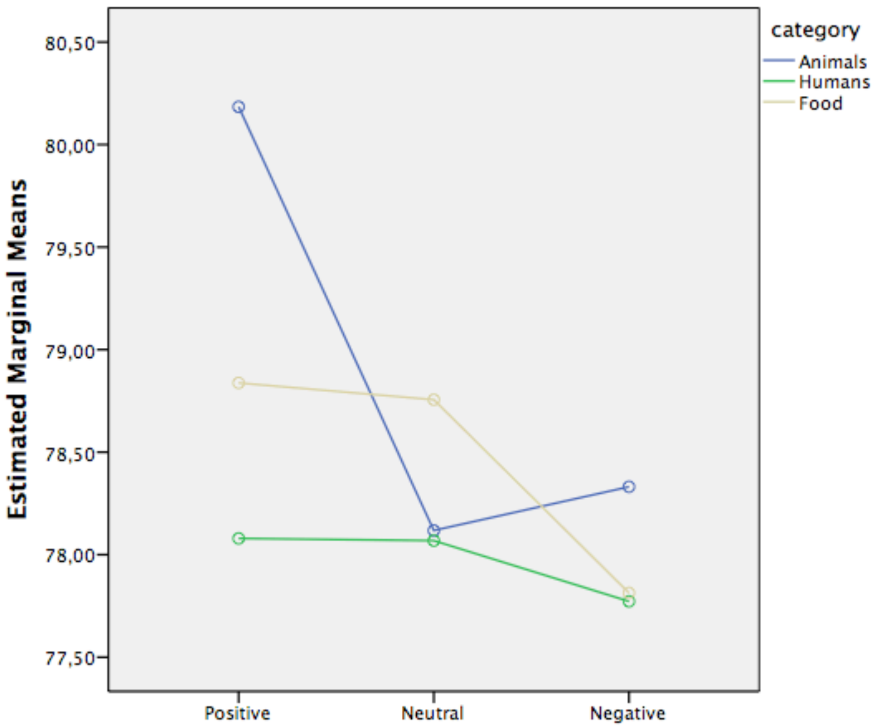


Figure 10.18 – Estimated Marginal Means for Heart Rate

10.1.9.5. *PHYSIOLOGICAL MEASUREMENTS – SKIN GALVANIC RESPONSE*

For the skin conductance responses through the peak-to-peak indicator, no statistical effects ($p > 0.05$) were observed of the independent variables (Figure 10.19).

Table 10.5 - Physiological measurement – Galvanic Skin Response

val	cat	Mean	Std. Error
1	1	,090	,029
	2	,092	,030
	3	,106	,033
2	1	,094	,029
	2	,094	,031
	3	,093	,033
3	1	,089	,033
	2	,086	,031
	3	,088	,027

The results for Galvanic skin response are presented next in Figure 10.19.

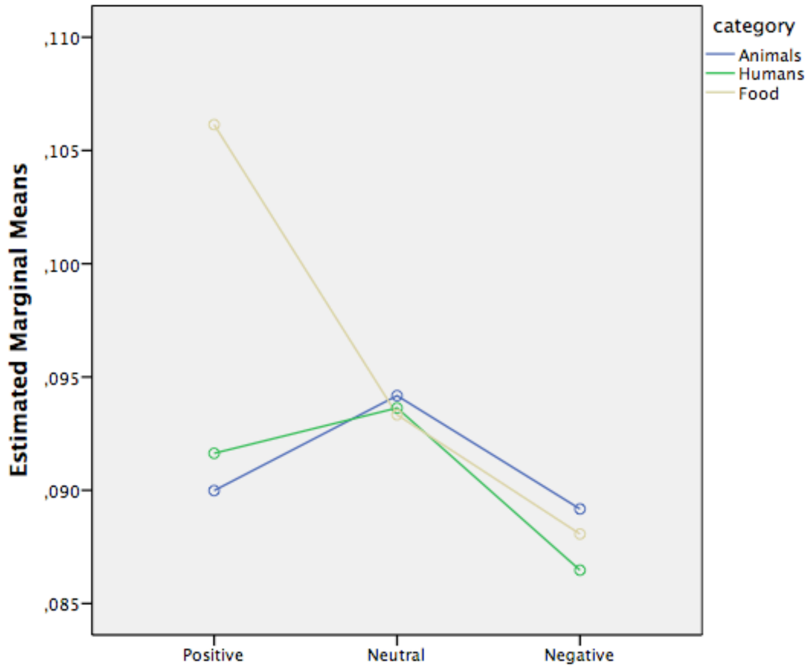


Figure 10.19 – Estimated Marginal Means for Galvanic Skin Response

From this graphics we conclude that the physiological response from volunteers do not significantly vary between categories.

10.1.9.6. *PHYSIOLOGICAL MEASUREMENTS – EYE FIXATIONS*

The eye fixations' data was analysed from fixations on the areas of interest (AOI) during the presentation of each picture. The AOI were defined as the central region of the screen. Given the differences in layout for each picture, a central region of the screen with 400X600 pixels was chosen for each stimulus.

The frequency of fixations on the AOI was calculated using TobiiStudio. These values were then exported to IBM SPSS for statistical analysis.

A repeated measure ANOVA was used to estimate the differences by condition: 1) category (animals vs. humans vs. food) and 2) valence (positive vs. neutral vs. negative). The results showed a main effect of category ($F(2, 108) = 5.085$; $p = 0.05$), indicating more fixations for pictures with food content than pictures depicting humans or animals. No main effects of valence or interactions were found in this analysis that is graphically displayed next in Figure 10.20.

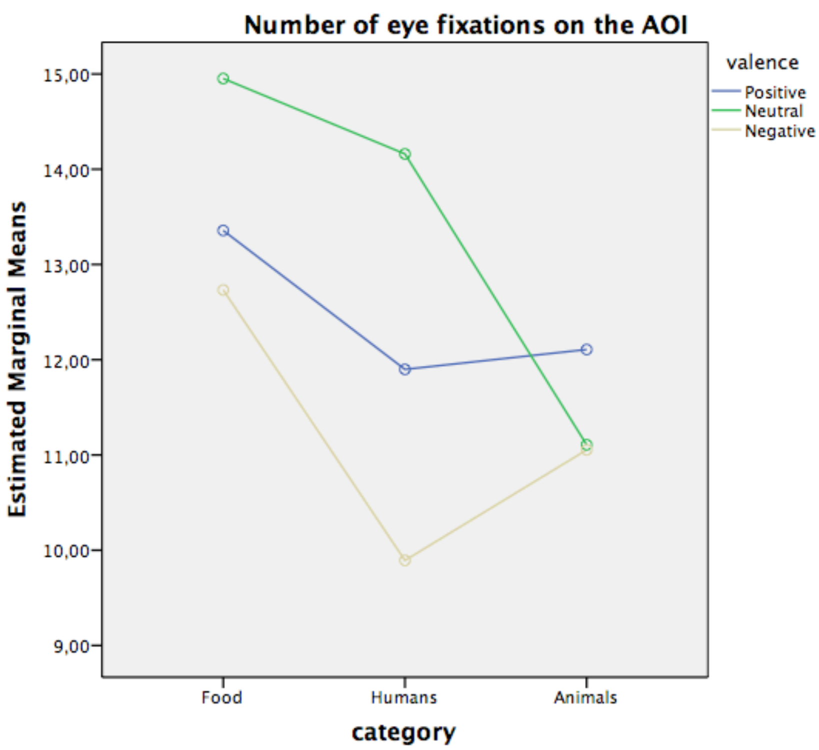


Figure 10.20 – Number of fixations by category in Areas of Interest

10.1.9.7. *PHYSIOLOGICAL MEASUREMENTS – PUPIL RESPONSES*

It measures one very specific physiological activity which meaning is still matter of speculation, namely on the cognitive reasons related with pupil dilation. Pupil responses were estimated from the eye tracker during the presentation of each picture. Pupil data was recorded for all participants revealing two major aspects, for one side the variations have a relatively small amplitude variation and in an early evaluation they do not present revealing results. That will be a matter of discussion in the next section. In Figure 10.21 are presented the evaluated results for a randomly chosen participant from the whole sample. The data was collected from the Tobii T60 device, recording pupil data in 60Hz (i.e., 60 samples/second).

The recording of eye data was segmented into different periods according to the stimuli that were presented to this participant. A different segment was created for each picture. This data was then exported to an Excel file in order to allow an analysis of the mean pupil response for each picture according to stimulus category and valence. Considering that this data is related to the responses from one participant, the statistical procedures were based only in descriptive statistics. The descriptive analysis showed a larger pupil response (dilation) for pictures with negatively classified pictures depicting animals (4.63 mm).

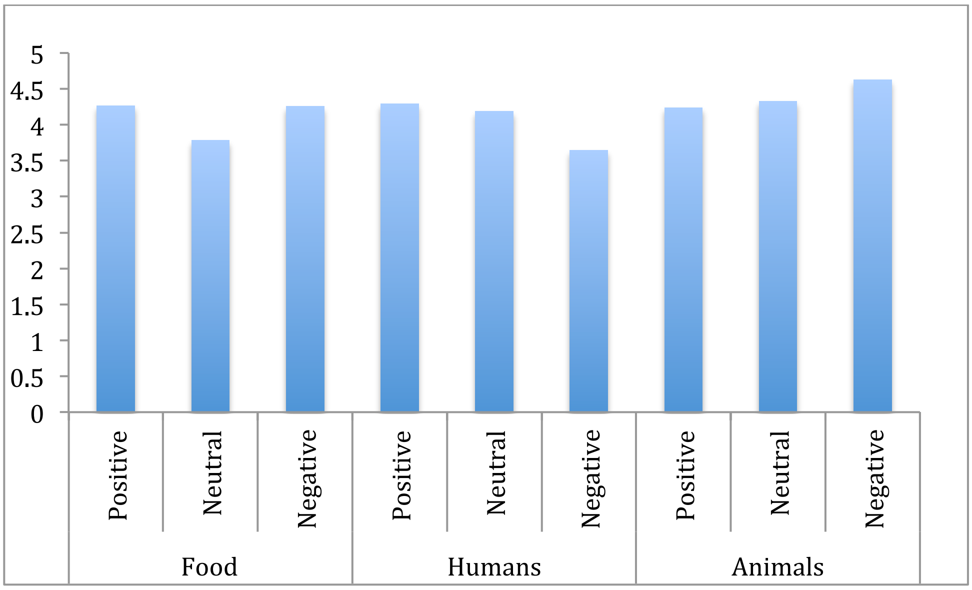


Figure 10.21 – Average pupil dilation by categories

In the graphic it is possible to observe some diversified results as for the positive, neutral or negative stimuli in different categories pupil dilation shows no consistent correlation (e.g. negative stimuli in humans have the less impact and a major impact in animal category).

10.1.10. *Physiological Correlations*

For the third objective was tested with Person r correlations to determine the relations between subjective (SAM) and objective (physiological) assessments. The bivariate Person coefficient, in

Figure 10.22, measures the strength and direction of a linear association between two different variables. This association is calculated according to the common variance between variables (i.e. covariance). The Pearson coefficient (r) ranges between -1 and 1, in which the negative values reflect inverse associations between variables and the positives as direct associations. Values close to -1 or 1 indicate stronger associations. The r coefficient is a standardized measure that is calculated by dividing the covariance between two variables by the standard deviation for each variable, according to the following expression, in which the X is the observations and the X-bar is the mean value for variable 1 or variable 2.

$$r = \frac{\sum_{i=1}^{n}(x1i - \overline{x}1)(x2i - \overline{x}2)}{\sqrt{\sum_{i=1}^{n}(x1i - \overline{x}1)^2}\sqrt{\sum_{i=1}^{n}(x2i - \overline{x}2)^2}}$$

Figure 10.22 – Bivariate Person coefficient

The numerator expresses the covariance between both variables and the denominator the standard deviation for each variable.

In this analysis values from physiology, Heart rate values, where correlated with self-expressed Arousal. Each value in the graphic corresponds to a person and in the left we have the heart rate measurement and in the bottom the self-assessment value (between 1 and 9).

The correlations between these variables were significant for an alpha level of 0.05 and the Pearson r coefficient ranged between 0.41 and .63 for the significant correlations. These values are positive, which reflect direct associations between the physiological and self-reports for valence. Moreover, as regards to the strength of the correlation, it is agreed that r values from 0 to 0.30 are weak, 0.40 to 0.60 are moderate, 0.70 to 0.90 are strong, while r = 1 describes a perfect correlation. Therefore, these values obtained show also that the variables are moderately associated. However, the most reliable indicator of the subjective assessments through the SAM scales was obtained for the heart rate that was moderately correlated with the subjective arousal ($r = .41$; $p < 0.05$), as seen in Figure 10.23.

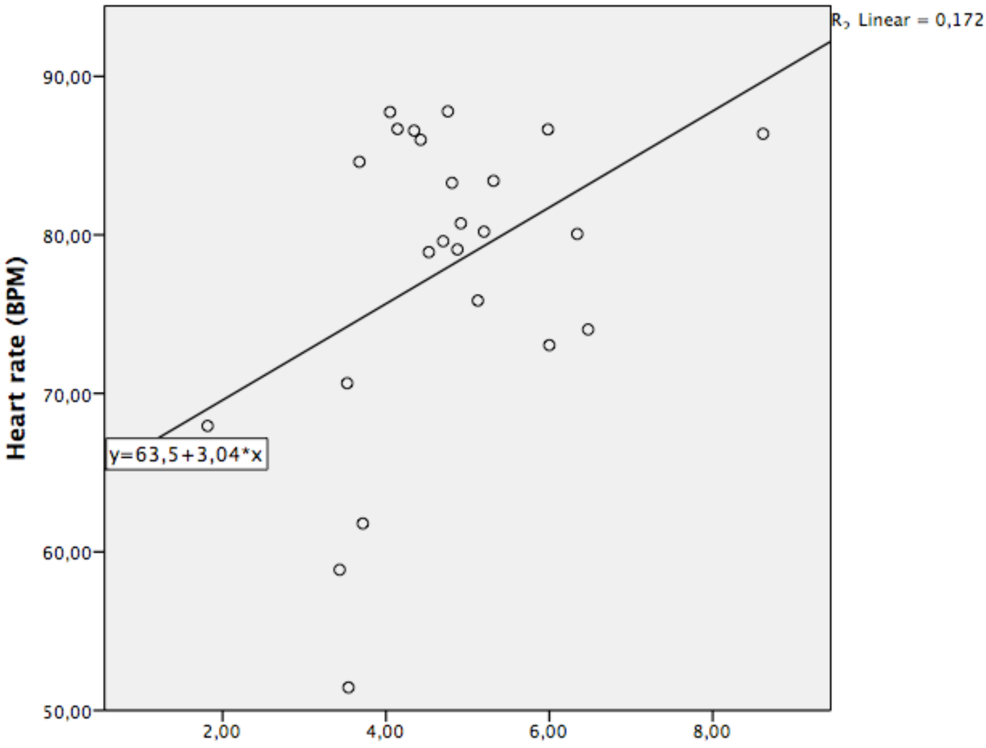


Figure 10.23 – SAM Arousal related with Heart rate

Example of readings: the dot in the bottom is a person that reports much arousal but in fact he is physiological measurements show the opposite, his hear rate is not much affected while he expresses that he is quite aroused.

The results showed significant associations between the physiological and the SAM assessments for valence, arousal and dominance.

The results also present a minor number of individuals that have correlations far from the line equation. Those are persons that make an assessment different from what results from the physiological measurements, which present a challenge for applications in this domain.

As an example in figure 10.24 are presented a scale of Galvanic Skin Response and Arousal for the Category Humans with negative contents. It is a mere example showing that there are some correlations but not with the desired scientific value. In some individuals there is correspondence but not in a generalized way.

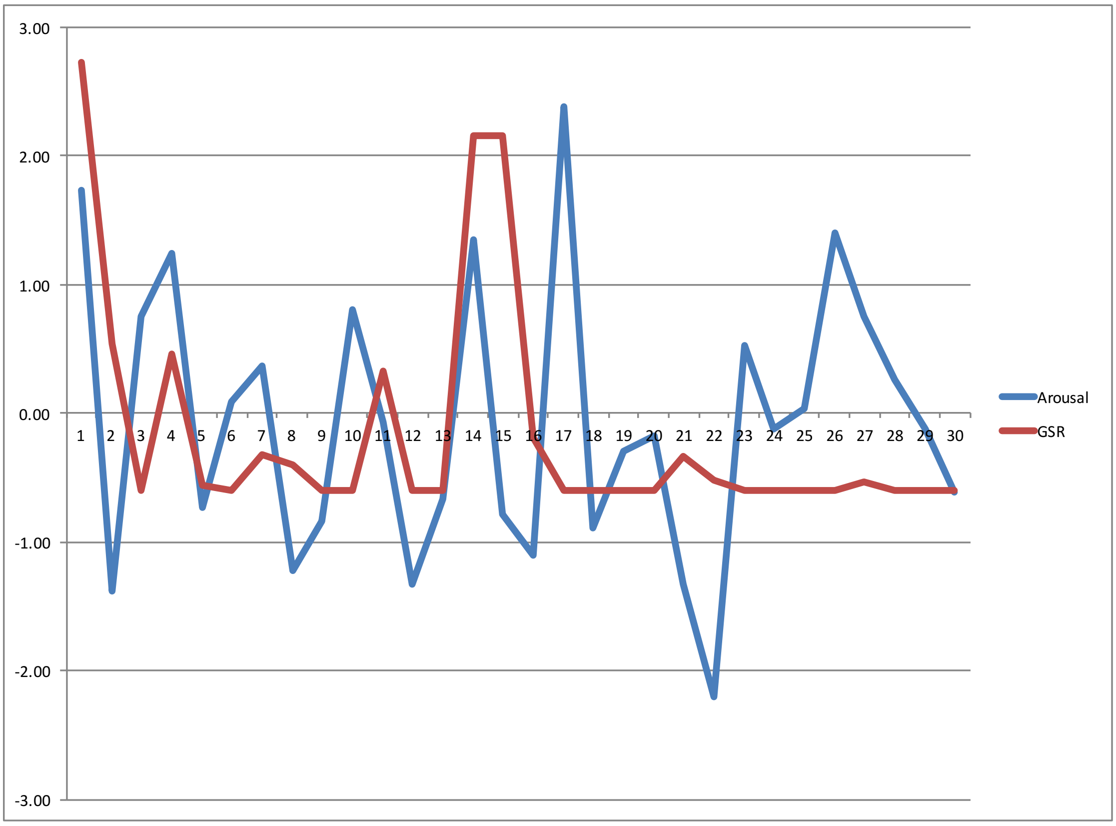


Figure 10.24 – GSR and Arousal for the category Humans with negative classification

10.1.11. *Discussion on ECG and GSR*

For ECG, the analysis made on Heart rate shows an interesting correlation between stimuli Arousal and Heart rate measurements (c.f. Figure 10.23).

The correlation obtained denotes an interesting adhesion from the expressed self-assessment and the physiological measurements for Heart rate. For Galvanic Skin Response that connection is not so clear for all subjects as exemplified in the previous figure. However emotional activation can be monitored by physiological measurements, either heart beat or Galvanic Skin Response.

It is important to notice that, even if the match is not so clear between self assessment and Galvanic skin response as it is for the Heart beat, the fact is that an immediate response is obtained from a person's Galvanic Skin Response even If we are not able to determine, precisely, if it is a positive or a negative stimuli. That can be seen if Figure 10.8 with observable changes in GSR for both expositions represented in the graphic.

The dispersed values in the graphics can have diverse reasons. For instance they can result from persons that, even without notice, were affected by the images. On the other side there should be individuals that think that pictures are impressing, but their body didn't react in the same way.

10.1.12. *Discussion on Eye Fixation*

Eye fixation is an innovative measurement that recent technology made possible to be developed. The exam can be performed with a specific setup as mentioned in section 7.2.2 using cameras and infrared lights. Eye tracking operates over an area of interest (AOI), mostly to evaluate how readers look to webpages, being those textual or imagery. In terms of emotions it is not clear how emotions will interfere in eye fixation. In the proposed setup images where differentiated in its content in categories and in positive, neutral or negative but when such images are presented to one user there are no choices in terms of content for one single image. So fixation will be directed to determinant parts of the image that contain information but not necessarily revealing any emotional content. It is no surprise that, with that analytic view of the setup and in face of the results, it is not permitted to take relevant conclusions from Eye Fixation data. The study was included in this research work, mostly by its innovative character and, as an open path to future studies.

The present work suggests that using different images (e.g. a collage of IAPS pictures) to evaluate which of those attract more fixations and correlating that with other data would be possible to seek for emotional classification of each image areas. Eye fixation is also a promising area in evaluating many cognitive processes. In general terms and according to the proposed Framework, Eye Fixation can provide a valuable physiological tagging method for collected information and it fits properly both in the Data model and in the Framework. In the follow up of current validation strategy, studying attention by measuring fixation over parts of images, linked with other physiological measurements could become an interesting research subject, contributing to emotional assessment.

10.1.13. *Discussion on Pupil Dilation*

Pupil response was introduced in this study as a valuable physiological measurement and by its novelty in such research setup. The values obtained have no relevant meaning other than the above mentioned dilation top dilation for negative stimuli in animals. On the contrary of what would be expected the negative stimuli for the class humans have less dilation than for food. The study carried out in this subject does not reveal interesting conditions also because it is known that presented images have non-harmonised levels of brightness. That is partly explained by the fact that the used set from IAPS is not calibrated in terms of luminosity. It would be necessary to develop a new set of homogenised pictures, in terms of brightness and luminosity in order to get scientifically relevant pupil dilation measurements.

Pupil dilation is a physiological measurement that is suited for both developments proposed in this research Dissertation, the Data Model and the Framework (c.f. sections 9.2 and 9.3). But there are still technological limitations to an immediate use of pupil dilation in human physiology towards emotional assessment. From lessons leaned in this study we highlight the next issues.

1 – Pupil dilation is reactive and intrinsically physiological thus it is not so controlled by thought and emotion. That means it becomes necessary to verify if other factors exist affecting the physiological response (e.g. medication and drugs).

2 – Pupil dilation depends on illumination and in the properties of the image or scene to be exposed, thus it becomes difficult to determine if pupil dilated, or contracted, because of an emotional change or if from illumination conditions or colour characteristics of the image (e.g. brightness and contrast).

3 – Measuring pupil dilation needs devices that, with current technology, are not yet suitable to use in the street or in other daily life conditions.

In summary, a very controlled environment is requested in order to have measures of pupil dilation. Because of that it is not realistic to consider that such measurements can be performed without disturbing a person's life and that those measurements can be performed in outside lab environments. This insight into the topic it is a first step, expecting that one day such measurements can executed in less controlled environments, as new technology is being developed. Probably it will be necessary to evaluate ambient light and eye sensibility in order to determine the proper relations between pupil dilation and cognitive functions. In that case we believe it will be possible, and useful, to use pupil dilation measurements for emotional evaluation by physiological cues.

10.1.14. *Conclusions from the Pilot Scenario*

The pilot scenario was conceived with the objective of validating the hypothesis (c.f. section 2.2) and for that to verify about the possibility of adopting new ways for acquiring and representing knowledge, for a person's benefit, and allowing in that sense the development of new applications.

As a first conclusion the scenario application supports the capture of physiological information and self-assessment from a person in order to assess his/her physiological state, or physiological changes, promoting development of new applications. The identification of emotional changes promote the development of the most different applications, from decision support systems to applications that more adequately react according to a person's emotional status.

The lessons learned in this pilot scenario have been discussed in previous sections and are diverse and revealing of new paradigms for the present work and as lessons learned for future applications.

It becomes evident that physiological measurements can identify a person's emotional changes as clearly observed in Figure 10.8 for galvanic skin response when stimuli are presented.

In the work performed the objective was not to determine is a person is happy, sad, with fear or in euphoria. But it was aimed to analyse if people are interoperable in the sense that they share the same physiological manifestation towards equivalent stimuli.

The measurements of pupil dilation need specific setups to be performed attending illumination and other circumstances that can influence data collection (e.g. medication).

The measurements of eye fixation need a specific characterization of the scene. Even considering that some stimuli can cause eye fixation patterns, it is more likely that images with different stimuli (e.g. different faces, different scenes) are more likely to be subjected to eye fixation measurements.

The results obtained show a promising path towards emotional assessment based on physiological readings. The results show that physiological measurements are not detached from the indications given by a person's self expression, however there is a path towards getting more accurate values that could be generalized for diverse users. There are individuals that have different physiological values and that could come from the measurement conditions or from the individual's physiology.

The measurements were made with a set of images within those three categories; it is possible that other images, like those related to sexual content, could produce improved effects. However in almost two decades (IAPS dataset is from 1999) the patterns of beauty or disgust change as the society changes in time with new trends and new contexts.

From the previous observation results that the IAPS Dataset should be updated to modern times and probably taking in account cultural specificities. However, an important result from the present work is that the selected pictures (90) from the IAPS dataset showed correspondence to the volunteers' self-expression, thus making it suitable for this kind of experiments or other applications.

10.1.15. *Privacy Statement*

The proposed framework has the potential of collecting and using personal data. In general applications, data collected, either sensorial or physiological will be kept in a person's computer or personal device. Knowledge bases are consulted in one direction to obtain information to the personal device. In the other direction, from the personal devices, data will be shared only with personal agreement under strict rules. Access to the Cloud will be made under standard security procedures with encrypted data and distribution over different clouds. Data will be anonymized when possible or circulate over secure services, protected by firewall, as represented in Scenario IoT for eHealth Supported by the Cloud – Other Application Scenario (section 10.5). The trials executed with the framework, in this pilot application, are supported by informed consent signed by every participant in the trial and data was anonymized with a single identifier, thus without the existence of any link between data and the individual participating in the trial.

Other Application Scenarios Exploiting the Research Developments

The validation scenario, presented before, establishes an opportunity for a wide range of applications either technological deployments or in the research domains. The objective of the next scenarios is to propose specific utilities of the Framework and the validation scenario for business or other societal purposes. For that matter they show several paths that can be used to improve knowledge management for a person's benefit using the results of the present research work.

10.2. Episodes Information about People – Other Application Scenario

This scenario is symbolically related to the motivation for the present research work. In fact it represents the inspiration from the brain models, in particular the two-stream hypothesis [275] in retrieving the information and situating it spatially. Furthermore it uses the emotional classification as it appends within the brain provided by specialized structures (e.g. anxiety is strongly dependent on the connection between amygdala and medial prefrontal cortex) [308].

This research study was developed in order to use the Framework for the handling information inspired in selected models of behaviour from the brain, creating innovative and fertile knowledge bases. In order to accomplish that objective, it was pursued a new modelling of Things similar to what our brain does and that is an interesting bridge between the developed research and the Internet of Things conceptualizations. In this case, the connected Things can provide additional information to a person's repository. That approach smoothly merges the storage of information, guided by the two-stream hypothesis, with the storage in chunks similar to those used by the Episodic Buffer in the working memory model proposed by Baddeley et al, [309]. The result is a merge of the connection between the 'where' it was and 'what' is represented mediated by the emotional tagging as depicted in Figure 10.25.

Using the proposed scenario, databases or ontologies can be instantiated as a knowledge base that progressively can be harmonised and become inclusive of existing information In that case, it will promote the coexistence of sensorial and emotional information, both in new and existing information, both compliant with the new data model. The new information gathered now or in the future can benefit from the validation scenario in instantiating Things emotionally classified. On the other side, existing objects can be upgraded to the new data model by properly instantiate with collected knowledge (e.g. physiological measuring while viewing pictures) or by voluntary tagging in a self-assessment exercise. This could be backed by semantically-based Web Map

Mediation Services a core of semantic and ontological tools for mapping [310], mediation, annotation and what else found needed for pursuing the most consensual and interoperable solution as possible. That means that ontological tools can support existing information in order to assist the knowledge construction process according to the desired format and organization of knowledge.

The next step is to converge to a pilot application, that implements the concept of i-Episodes, based on the above-presented background.

10.2.1. *The concept of i-Episodes*

In this work it is proposed two complementary definitions of what is an i-Episode. The first definition is the lower-level and the second the higher-level, being the first for the systems, or the developers, and the second for the people, the users.

Definition 1 (lower-level): An *i-Episode is a cluster of information, related to one person, in a given time, which captures all the sensory, physiological and environmental information about a person*.

That would be the systems' definition of an i-Episode, which means a lower level conceptualization that can be used to implement the capture and handling of i-Episodes on an information system.

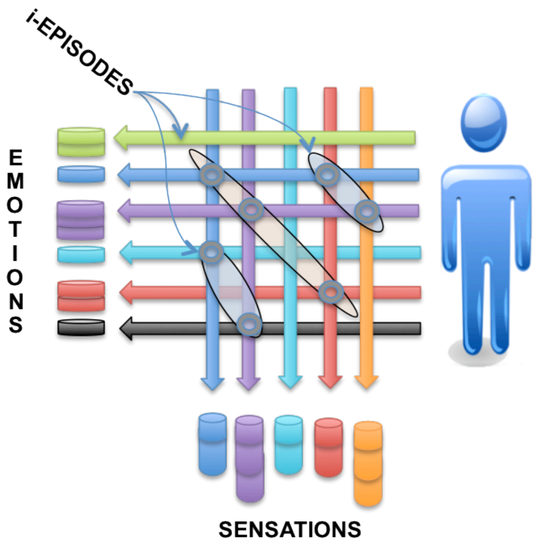
Definition 2 (higher-level): *An i-Episode is a record of one event of live, about a person in a given time, that includes all sensorial information available along with emotional tagging of that same person.*

In the same manner a movie is a sequence of slides passed with a frequency so that the eyes view the scenes with movement. We can think on the same approach for the usage of sequences of i-Episodes. That leads us to the next definition.

Definition 3 (lower-level): An *i-PhysEMOvie is a sequence of i-Episodes, related to one person (or more), along a period of time, which includes all the sensory, physiological and environmental information about that person(s)*.

Definition 4 (higher-level): *An i-PhysEMOvie is a record of events, about a person (or more) along a period of time, that includes all sensorial information available along with emotional tagging of that same person or persons.*

The proposed concept of i-PhysEMOvie is not explored in this Dissertation. As for the i-Episodes, in Figure 10.25 is depicted an i-Episode as a result from the proposed modelling approach. It consists of information centred in an individual and that can be supported by both a databank of emotions and a databank of sensations, with correlations that can be associated as episodes of a person's experience in life. Those data banks can be populated by known sensations and emotions but can permanently be updated with user's contributions that can be used by them or by others. When performing a query it is possible to find our own episodes but also other's episodes if available publicly. The resulting queries, if validated by users can increase the bonds between objects and associated emotions or perceptions.



Horizontal Lines *– Emotions resulting from self-expression or inferred from Physiology.*
Vertical Lines *– Sensorial information, captured by devices, related with the sensations experienced by a persons' sensorial organs.*
Donuts *– Elements of sensation tagged by emotions.*
Elliptic Lines *– Clusters of emotional tagged sensations composing an i-Episode*
Cylinders *– databanks with sensorial objects (horizontal) and emotional classifiers (vertical).*

Figure 10.25 - A person's Emotions and Sensations collected and clustered as i-Episodes

As an example of what could be an i-Episode, surfers may associate a beach with good waves along with good sensations and smooth sea odour. In terms of the system being used for diverse persons attending the same beach (or others) the occurrence of more associated results will reinforce such associations, making them easier to find by any search engine algorithm. As represented in the picture, three clusters result in a person's set of i-Episodes. Those episodes encompass selected emotions and perceptions for the person's episode's description. Both emotions and perceptions are stored in specific databases, which use existing content or the user's description, or measurements, as new content. The expected result in terms of contents is a new form of modelling information allowing richer sensorial descriptions and empowering existing knowledge. In terms of functionality, new services can be deployed, making use of sensorial and emotional information, providing more ubiquitously searching and finding of information.

Comparing to existing solutions, this pilot proposes a restriction of the whole framework that supports: 1) a new data model (c.f. 9.1.5) including sensorial an emotional information along with 'traditional' data, 2) a new approach to search methods on the Internet by allowing new specific fields with the proposed data model 3) a modelling approach that supports correlations between sensations and emotions. As a result we want to change the established paradigm of Internet object description, allowing new methods for knowledge management.

The first stage consists in using the proposed data model (c.f. 9.1.5) that support sensorial and emotional information starting its filling process with an annotation sequence that is supported by an ontology [311]. The second stage consists in using the proposed Framework (c.f. 9.1.4) to capture, store, and manage generated information and knowledge for usage in a seamless and standardized operating mode. Finally the objective is to establish a methodology for the association process of sensorial and emotional information in order to promote the existence of i-Episodes, which can be achieved by an instantiation of the conceptual Framework. The final result will be a permanently growing knowledge base of emotions, sensations and i-Episodes. As an instantiation of what is described, imagine that a person stores diverse i-Episodes in life. These episodes can include sport events, music concerts and other events where the person describes sensations and emotions. If a person opts by sharing those e-Episodes, with such rich variety of information it is possible that another person attending the same events will be able to find them on the Internet even with some disability, (e.g. a blind can find the environment of a rock concert by searching the music or the food served at that precise event). People can share memories, enriched with sensorial information, with others, as an extension to the conventional movie or picture album. It is also possible to compile a person's recordings by linking with other person's recordings case the databanks are made public, widely or to a selected group, as it happens in social networks. In this perspective, by sharing sensorial and emotional information, it is possible to build enriched i-Episodes for us using, or not, public recordings or contribute to other's i-Episodes.

We can also use emotional labels, or physiological measurements, to tag sensation's intensity and make it a personal mark that embodies our record of sensations in a personalized fashion.

The next challenge for this scenario application of the Framework would be to capture emotional information in real-time in anyplace. It can be with carried devices or using available information; if a person is in a place and there are accessible webcams authorized services will be able to take images from there and join it to a persons photos or films. Another example would be the usage of data from existing quality of air measurements, if accessible. It is a service that municipalities could provide to users or tourists that would enhance information for the i-Episode. In this case they would have an importance in personal healthcare management, especially for persons with respiratory system fragilities. In general, this scenario presents an opportunity to improve interoperability between computer systems and persons. The usage by computer systems of information about humans (e.g. physiological measurements) and widening to all kinds of sensory data makes possible for those systems to have the information that humans receive from the outside (e.g. sensorial stimuli) and produce the same kind of output that humans produce (e.g. physiological activity). That means computers will get closer to humans on how to use methods for retrieving and handling information. Either for personal usage, with ensured privacy or for sharing with others (e.g. those attending the same party, same event, etc.) an enriched contents, i-episode, would contain more than just image and sound, it would extend to all available sensorial experience and physiological measurements.

Advantages of the usage of i-Episodes

- Enlarged information sets, modelled in a human perspective and systematically clustered.
- The widest content of personal information will be retrieved and stored with privacy concerns.
- Information about people's "features" will be available pervasively via Internet in a secure manner, undisclosed until further instructions.
- A transduction of human physiology to computer systems will be made available with ensured privacy rules.
- Context awareness will be improved and available for that person or for Decision Support Systems.
- Service discovery will promote gathering of environmental information for a person's benefit.

In conclusion of the i-Episodes Scenario, published in Doceis 2012 International conference, presents many advantages to this conceptualization of information that is supported by the data model developed in this dissertation.

10.3. Learning Challenges – Other Application Scenario

Teachers and educators have the mission of transmitting the best of their knowledge using the most from available resources and following established programmatic guidelines. The continuous evolution of technology, proposing new tools and apparatus for knowledge representation and transmission, has offered innumerous options for the mission of teaching. However, more then providing a wide set of experimental setups, or multimedia contents, would be important to determine the best content for each student. Most probably it will not possible to catch all the students attention but, at least, would be important for a teacher to know what is the current status of a class and if any student, or group of students, is somehow lost in the class.

Hypothetically, the best content would be defined as the most suited to promote a seamless transmission of knowledge, according to the student status and his readiness to receive those concepts. Human Computer Interfaces can promote a better interoperability between those who teach and those who learn and can better adapt contents and transmission methods to the needs and abilities of each student in class. For that we would consider that existing contents and devices could be used in innovative ways so that they become facilitators of the teaching process. In that direction we should be able to adopt the qualities and methods of good teachers to the usage of a growing number of technological tools. For that we need to attend to high-level qualities of those teachers. It starts by considering that relationships between people (e.g. students and teachers) can have better moments and that some duplets of persons interacting have better understanding and thus enhances the teaching process, both in quality and gratification. It is likely that, people (e.g. teachers) have the ability to sense how others are receiving the message and identifying the peaks of interaction. If other persons are bored or restless, it is within teacher’s perceptional capacities to identify those states and react accordingly in order to re-establish the learning process (e.g. change attitude, change message or even pause interaction). These observations illustrate the powerful role that emotions and feelings can play in otherwise ordinary learning experiences. Dominant views of this relationship suggest that emotions are important in adult education because they can either impede or motivate learning [312].

The existing technology can support detection of emotional states and current mood of students in a class thus helping teacher’s assessment. On the other side, technological materials, such as video, websites or other computer-based information can be requested and deployed according to teacher’s guidance. Then the methodology would be; to provide teachers with means of assessment of student’s emotional state, in real-time, and to provide teachers with tools and devices to, accordingly to that assessment, select and guide the flow of the contents to be deployed.

The integration of such concepts results in a framework that has the ultimate objective of supporting contents adjustment to students' emotional status. In remote environments, those contents can be tailored for each student and selected according to feedback received at teaching institution. In a classroom, they can be shifted for better results of the group dynamics or to overcome identified problems with students' motivation. With different levels of maturity and degrees of depth, the pursue of a better HCI is a permanent goal that is now stepping to a new level, the evaluation and adaptation to emotional status on the human side of the equation. This research drives two directions, on one side to promote the representation of objects on Internet bases information systems with emotional information and wider sensorial information, supported by specific ontologies [313]. The other direction is to monitor emotion as part of the learning process, using that information to establish a personalized class contents.

Based on the proposed generalist framework it is possible to establish a restriction of that holistic view, with an architecture targeting the proposed goals for the teaching environment as depicted in the next figure.

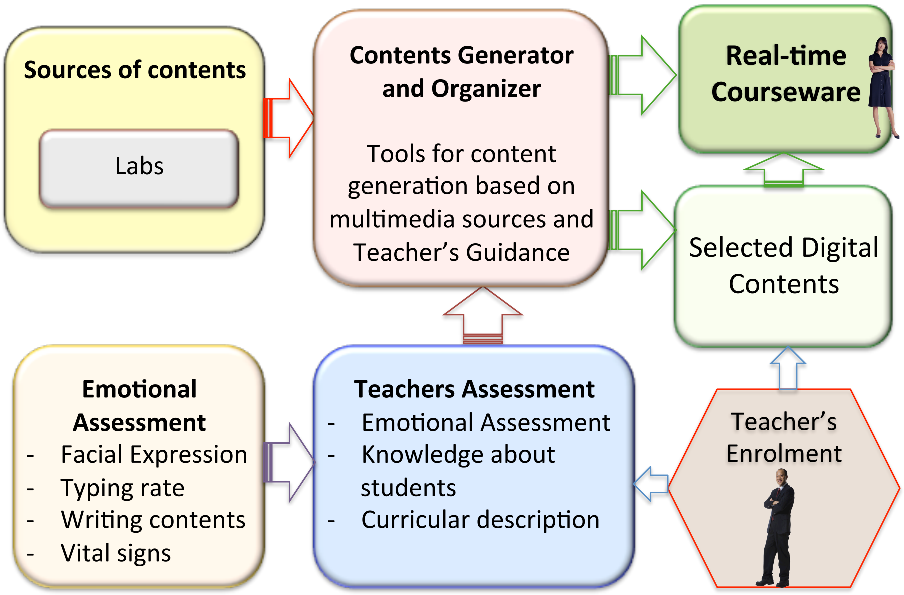


Figure 10.26 – Architecture of an instantiation of the Framework for content generation based on emotional assessment

The source courseware material includes all different types of available contents for that course. It can range from traditional class contents to more elaborated multimedia setups, and include labs or remote lab installations [314].

The innovation in the present work relies in the possibility of making an assessment in real-time of emotion related readings from students. In Figure 10.25 an emotional assessment is organized using several options as available for a given course. Some of those are more likely to be measured in classroom others can be captured remotely with a recommended set of devices. If the student is using a computer with camera, either locally or remotely, facial expression can be used to assess his emotional state [315]. Recently, there has been considerable interest in the automated recognition of affect from written and spoken language [316]. In that sense, if the student is typing, that can be used to give clues about emotional state, either by speed rates or by the nature of contents if available for assessment. In regard to physiological readings, including heartbeat, they are becoming more accessible to get by the usage of mobile phone specific applications, even if they remain less practical than would be desirable [317]. Teachers become able to guide lessons based on what is the established curriculum but also taking in account emotional information from devices, weighted with their knowledge about each student. As an example a History teacher can evoke some travel he made to an historic place when he feels like he is loosing attention, and present some slides or some recorded video.

The core of the proposed framework is the contents generator and organizer that can assume diverse technological aspects depending on remote or local setup and a previous selection of adequate contents. It can work as a planning tool for the teacher allowing an organization of the teaching materials and preparing several options to react to students' feedback in real-time. The course is adjusted in real-time providing multimedia content as needed by activation from the contents generator and organizer, serving teacher's options for the class deployment. This framework can be created in a sophisticated environment with real-time multimedia orchestration with multimodal assessment of student's emotions but can also be downsized to the available technological means available. The best solution would be an elaborated assessment of emotions but that is not possible unless using sophisticated equipment like MRI of fMRI [318]. Those are pieces of equipment not suitable to have in a classroom; an elaborated measurement as described above or a simple face-reading algorithm would mean an opportunity of obtaining emotional and attention clues.

Whatever the human computer interaction is being established, the current research aims to increase the interoperability between students and teachers using emotional assessment to facilitate the learning process. The research work developed and presented in this scenario relies on the premise that knowledge transmission can be adapted based on monitoring of students' feedback and, in particular, evaluating emotional evidence from students' assessment. That evaluation could be made by text mining, morphologic analysis of the face and by physiological measurements, like the heartbeat monitoring or face reading assessment.

Another perspective for the presented work puts an emphasis in the real-time evaluation and the possibility of immediately reacting and adjusting contents. There are many options for evaluating course effectiveness and the quality and substance of knowledge transmitted in teaching environments but an identifiable omission on real-time assessment is explored in current research work.

On the other hand, the concepts of interoperability are mostly applied to systems. IEEE defines Interoperability as the ability of two or more systems or components to exchange information and to use the information that has been exchanged[319]. In the proposed approach, lessons learned from interoperability of systems can be adapted to HCI in particular regarding the learning process. The proposed framework has diverse types of possible usage, depending on the channels used and the users addressed. In response to that diversity, some deployments where made for establishing learning environments either in Industrial context [60] or in scholar environment [314]. This on-going work has a main direction in the possibility of adapting contents for universal usage independently of cultural or linguistic differences. This perspective has been developed in the scope of our research group participation in Alter-Nativa[23] project with different types of learners from diverse cultures. The main contribution of this scenario is the technological empowerment of teachers for better managing the progression of the teaching class, by utilizing a framework that is growing from a programmatic scope to the emotional assessment of students, envisaging real-time assessment and adaptation of the classroom environment.

The proposed Framework would be suitable for the present scenario with the following advantages:

- The Framework will support a real-time adaptive classroom environment by systematically assessment of students' attention and emotional feedback.
- Teachers and trainers will have tools to assess in real-time the individual or overall status of the class in what regards to their feelings and moods variation along the class
- Teachers will be able to shift on-going class works towards better knowledge transmission towards students success in learning
- Teacher's assessment and experience will be augmented with decision support systems empowered by the available technological features.

[23] http://titanic.udg.edu:8000/www_alternativa/

- It will enable the establishment of correlations between student's emotional status and their success in class promoting better learning methods towards success of the learning process.

A stated by Hascher, teaching is facilitated or hampered by different strategies of learning. Emotions are, on the one hand, interrelated with the processes of learning and instruction, and, on the other hand, with cognition. Additionally to direct influences, the impact of cognition and emotion can be mediated. Basically, emotions have to be differentiated in terms of form and quality and to be analysed with regard to their multiple components. Crucial sources of cognition and emotion are the learners themselves, other protagonists of the learning situation like teachers and peers, as well as learning tasks.

In Conclusion, along with the above-mentioned advantages, specialists' words are a strong support to promote the usage of the Framework instantiated by this scenario in real classroom circumstances. This scenario was presented at International Conference HCII 2014 and it was clear that the theme is a motive of interest by members of the scientific community in the area of Human Computer Interaction.

10.4. BRAIN INSPIRED IDENTIFICATION – OTHER APPLICATION SCENARIO

This scenario aims at demonstrating the usage of lessons learned from the brain, in this case how an object can be identified using the strategies that humans follow.

The objective is that using multiple sensor input where some are still to be fully developed (e.g. smell and taste) will have a tentative approach to identify what is the object once one sensorial input (e.g. vision) is not enough to identify the object. In the example presented we start by developing what could be done, in trying to identify a presented round object with resource to the other senses.

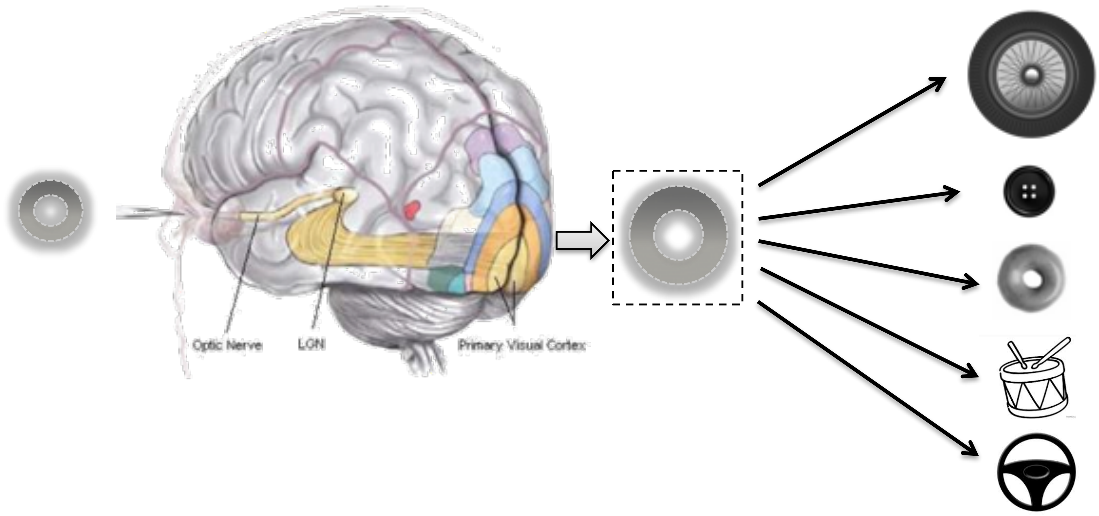


Figure 10.27 – Image of a round object and possible interpretations

The presented image, on the left of Figure 10.27, is captured by the eyes and flows through the optic nerve to the primary virtual cortex. What happens next is how the structures of the brain proceed in trying to identify the objects. In here we follow the inspiration from the two-stream hypothesis in an attempt to identify what is the object and where it is placed. If follows that, as the obtained image is not so clear, a process of comparison with known objects is executed. From this process, and without an unequivocal answer, a matching probability tree is developed towards each resembling known object.

This is in fact, what is advocated by the two-stream hypothesis, what the brain does in trying to evaluate sample objects. It is also based in the principle that the brain always tries to identify an object, or a situation, from existing knowledge.

The evaluation will be performed in trying to match what the vision is capturing with existing knowledge, recurring to other sensorial experiences. From our daily experience it is possible to recall some characteristic examples. For example, when we ear a sound we recognize a car or a person's voice, when we smell an essence we can identify a flower or the smell of gasoline and when we touch a surface we know that it is sand or a rock or a silk tissue. We know, by experience, that those examples result like that. But if the brain solves those identification problems so well, we may look for methods to replicate the identification process as the brain does, perhaps by using other senses when available. Next in Figure 10.28 a methodology is presented on how the identification process can be performed, tentatively, towards a positive match or an indication of the degree of certainty in matching the object.

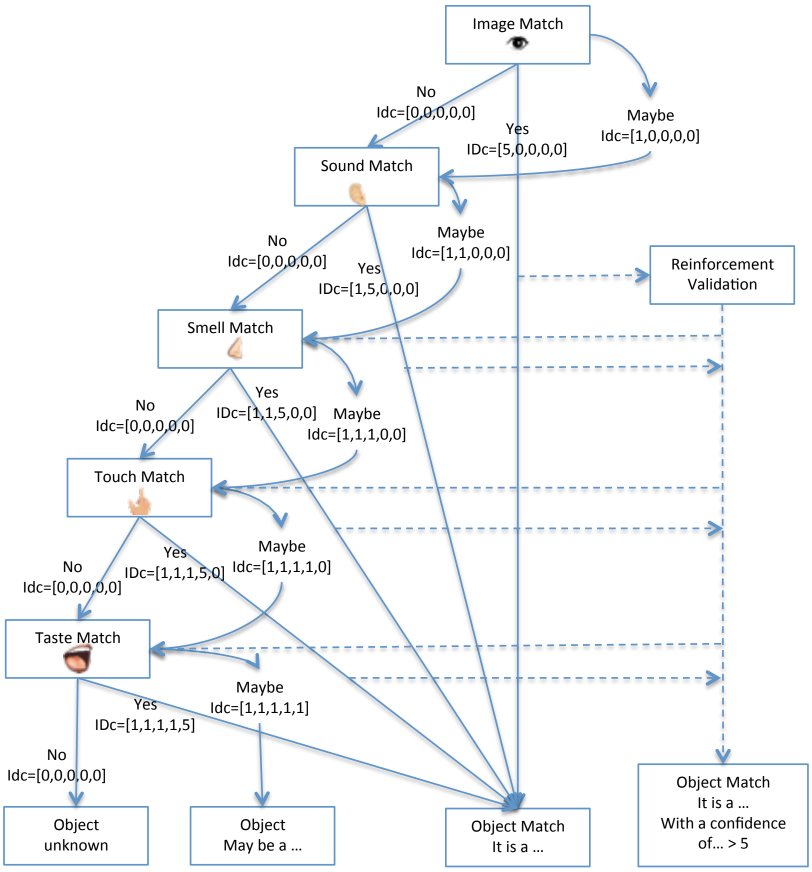


Figure 10.28 – Probabilistic model of identification

In the schematic example, we can observe a cascade of identification steps, each of which could be enough to finalize the identification process. The breakdown in all the sensory aspects would be performed as would append with a human subject, in trying to use all his sensing capabilities to identify what is the nature of the object. In Figure 10.28 we notice that the first step in trying to get a match is performed by the visual input, as it usually happens in humans. If at this point we clearly know what it is, the vertical arrow takes us to the object match and the process ends. Then if we don't identify, at all, what it is "No" we follow to the next level; the sound match, otherwise we establish a probability according to our confidence that this is probably a given object and proceed to the sound match. This is the "Maybe" stage. Then the same process occurs for the sound; if we get a perfect match then proceed to finalize, but if not, or we have no clue "No" and proceed to the smell or we suspect that it is the sound of something and we proceed to the smell with a given sound probability, a "Maybe".

The same procedure is done for the touch and smell. At the end we have an "unknown object" or we have a probable match "Maybe" the object is a (…). At bottom left we notice that we can say that the object is (…) with a degree of confidence of (…). This value results from what we call the "Reinforcement Validation" that is an accumulated of all "Maybe" results. That is to say that each time the system has a strong believe that the object matches some known object, the probability to correctly identify this object is increased. This is in accordance to what happens in human nature as a reinforce is defined as anything that increases the probability of a response [320].

This example fits directly in the proposed framework and would be instantiated by retrieving object's properties in the Data Acquisition Layer classifying it in the Data Classification layer and, after organizing information in the Data Processing layer it would be clustered and stored in the Data Storage layer. Finally the reasoning as described in the schema of Figure 10.28 would be executed by the reasoning, Learning & Assessment layer producing the assessment of what the object is, probabilistically, and providing that outcome in the Data Access Interface so that it becomes available to Applications in the Real World. The example could be associated with robotics or with people with some sensorial impairment. This shows what can be an approach for a system, a robot or a set of sensors, to perform an analytic examination of available sensorial data in order to identify an object or a situation.

Advantages of the proposed approach:

- This framework configuration allows better identification of objects and events, by computational devices, thus improving data retrieval, decision support and knowledge management.
- A systematic usage of diverse available sensor devices will allow a better identification of objects with impact in object identification by devices (e.g. robotics)
- Device detection capabilities will augment personal sensorial awareness using available technological devices (e.g. smartphones, Google-glasses, etc.)
- New tools can be developed using the framework for better evaluation of objects and goods (e.g. food and wine quality evaluation and tagging, better identification of items in industrial environments, etc.)

10.5. IoT for eHealth Supported by the Cloud – Other Application Scenario

This section is divided in two case studies, both establish the vision of the Framework needed for the goals that are proposed to achieve. The first case uses the services of the European Platform Fi-Ware to instantiate the proposed Framework. The second case makes an instantiation of the Framework and has a simulated validation with a set of values for this scenario.

Case 1: The usage of Fi-Ware European Platform [321]

Services for mobile health information making use of the sensorial perspective will most importantly require the integration of services for capturing environmental variables and users' health conditions. At the same time ubiquitous computing technologies are necessary to be integrated for storing data into the "cloud", allowing stakeholders – patients, providers, and relatives – to access the right information at the right time from anywhere in the world. Based on these requirements this case study proposes a strategy for integrated services to be used with mobile devices, at the same time leveraging IoT and Cloud technologies.

In Figure 10.29 it is represented the global view of the platform that is basically divided into three modules viz. IoT Infrastructures, Services Integration Platform and eHealth Analysis Platform. In addition the whole of the ecosystem is supported by mobile platforms to keep track of the real-time health status of the user.

IoT infrastructure comprises of sensorial network that will be used to capture environmental variables that surround the person. The White paper on Smart Cities as Innovation Ecosystems [322] presents work on set-up of smart cities making use of sensorial networks, which can act as the basic infrastructure for this research work. This layer also includes smart phones, capable of keeping track of physiological behaviours of the user, which is important to obtain real-time health condition of the person.

Services integration platform is the central hub, which not only provides various services, but also maintains the orchestration between the various services and their interactions. The lowest layer of this platform in IoT service Enablers which interacts with the IoT infrastructures with well defined interfaces and services for acquisition of the real-time environmental and physiological parameters. One important EU project that provides IoT Service enablers is FI-WARE [323] which forms the basic backbone for handling IoT Services in the context of this research work. The next layer makes use of processes for enhancement of the EHR reports of the users, by combining the real-time perception of the user to obtain extended EHR (xEHR) reports. The top layer comprises of cloud computing services that leverages the benefits of the cloud.

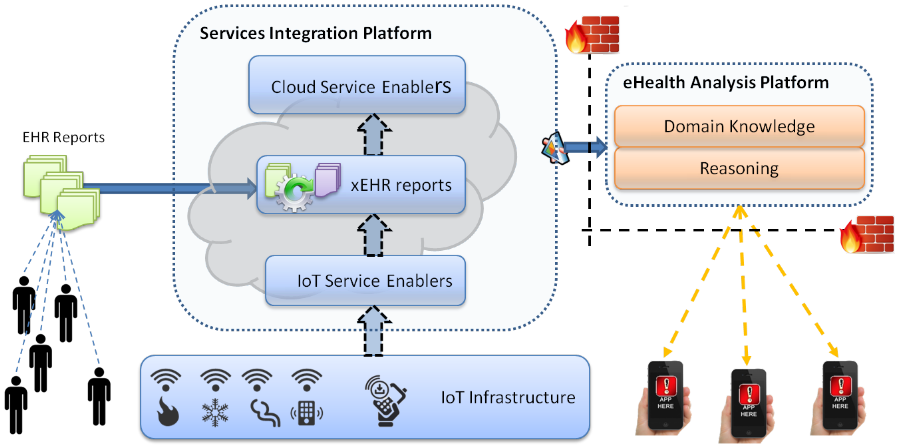


Figure 10.29 - Global view of the platform for eHealth supported by the Cloud

eHealth Analysis platform makes use of the information generated from various sources, to obtain useful knowledge and help in decision making for better health services for the user. According to Coiera et al [324] there is a clear consensus that the use of Decision Support Systems (DSS) can improve patient outcomes and make clinical services more effective. This research work takes DSS a step ahead by making use of semantic technologies. Widely available health related ontologies and environmental ontologies would be leveraged to generated enhanced knowledge, which is passed to the user and related stakeholders as alerts at the time of risks or as periodic reports. Note that this platform will be maintained within a secured environment to prevent unwanted access of useful personal information by intruders.

The whole of the system interacts with smart phones, which are not only the recipients of alerts but also keep track of the personal physiological conditions. Mobile application keeps track of the physical condition of the user and provides alerts in case of fatal conditions obtained with simple threshold calculations. At the same time these data are pushed to the service integration platform whenever connection is detected. Thus obtained data are used by the overall system to monitor the complex health condition of the user.

Advantages

- The framework will support the elaboration of a personal health book adding non-medical information to a person's data repository, with real-time personal health assessment.

- It will support the collection of health related information in a pervasive way as decided by the person.
- It will allow real-time reasoning that can provide clues about health threats, particularly for identified risk conditions.
- Secure and authorized sharing of information will allow discovery of environmental threats.
- Authorized information sharing will promote better management of catastrophes and crisis scenarios.

Case 2: The usage of the proposed Framework

A person living in modern societies is surrounded by an ever-growing number of technological devices [325]. The pervasiveness of computing and sensing devices offers different types of services that, ultimately, represent a source of data that can be used for the most different objectives and applications. As a person makes daily family or work activities, he/she is permanently exposed to an environment with which is necessary to properly interact and get valuable output for his/her life.

With the emerging developments of mobile devices and the Internet of Things becoming a reality, the offering of information provided by sensors or integrated services is growing fast. It would be desirable that a citizen could benefit from the best performance of all those systems, being supported by accurate context awareness thus improving quality of life, and security. In that direction, the information that devices and systems either portable or installed in surrounding environment (e.g. car, house, city, etc.) [326].

Most of animals have surveillance mechanisms, in which mammals stand out by the complexity of their sensorial organs and brain functions. Humans have, a sensorial capacity and processing at brain that detect and identify dangerous (e.g. fire in the surroundings) or risky situations (e.g. if you step there you may fall). In fact much of these mechanisms rely on how the brain makes assessment of the environment and what are the present dangers and the risk of following actions. In the current environment, of applications in portable devices, (e.g. smartphones) such equipment should be empowered to identify the situations surrounding us and, eventually, warning us about identified risks in the proximities. That strategy is pursued by the emerging research area on context awareness [327]. Current research, alike the brain, tries to identify our current physiological situation (e.g. temperature and heartbeat) and that of the surrounding environment (e.g. temperature, humidity) in order to evaluate our current health status and potential risks.

In the next section, the perspective of personal health monitoring powered by cloud with real-time data collection is explored. Section 3 provides research questions and hypothesis in close relation with the on-going doctoral studies. Section 4 contains a discussion on methodology and concepts proposed by this research work and finally, section 5 presents conclusions and future work.

10.5.1.1. *Personal Health Information Management using the Cloud*

Sensors and sensor networks are in expansion with the need to obtain data from persons or from the environment. Devices with the ability to capture data can have different capabilities; they can be standalone (e.g. RFID tags) or be part of a larger setup (e.g. data from meteorological stations). That range of devices includes devices that need to be small and cheaper so that they can be installed in many places (e.g. clothes) but also devices that must operate alone for long periods of time (e.g. car identifiers). That means the need to make those devices as simple as possible with low consumption with consequent constraints in their capabilities. The need for additional computational resources is an identified problem for small sensors and similar devices as they have small or inexistent computational power, they also may be passive, and must have low energy consumption.

The usage of small (and cheaper) low consumption devices, with limited or inexistent computational power, can be empowered by the usage of external resources. For that, the cloud can be a differentiating factor to overcome the limitation of small devices, either sensors or actuators, by providing storage capacity and computational power. The cloud can be used to ensure that sensors can generate data that is stored remotely at the cloud and processed remotely where computational power is available. In what refers to personal health information management, the usage of services at the cloud can provide reasoning over knowledge bases to evaluate a person's health and to generate evaluation reports in real-time [321]. For a person doing normal life, wearable or local sensors can permanently monitor generic activities or a specific exercise (e.g. jogging, playing sports). Data being permanently sent to the cloud can be remotely analysed and, if dangerous events are identified, the adequate warnings will be issued and, eventually, request medical assistance.

The observation of the current fitness and eHealth oriented devices and how they are operating makes us to question about its potential usefulness, for users, and how it can be improved. The problems of real-time evaluation of a person and her circumstances lead to the following question.

This scenario comes from the question on how to adopt lessons learned from the brain and neurophysiology to computing devices in order to monitor, inform and assist users for self-help when necessary. And for that we propose, by hypothesis, that if we monitor bodily functions along with environmental condition, it will be possible to establish an overview of a person’s health status and warn about potential risks by utilizing computation in cloud.

BODY MONITORING FROM THE BRAIN TO THE USAGE OF DEVICES

The brain and the nervous system permanently monitor a person’s body. Information is acquired by our sensorial organs, is perceived and interpreted by the brain using existing knowledge, gained by learning and experience. The reasoning is based on a combination of different inputs, acquired by sensorial organs [328], which generate better assessment (e.g. I felt a spike on my feet, the sand is red so i have a cut and I am bleeding). Thus the brain uses multiple inputs to assess if there is danger for the person or if we only need to take care, avoiding multiple attendances to a doctor.

People use many devices that have computational power and embedded sensorial capacities. Smartphones have processing capacities, usually are equipped with a GPS, have a camera and can capture sound. They also have schedulers and planners where people can shape their foreseen activities for the day. Fitness devices provide information about physiological measurements (e.g. heartbeat) and are also capable of determining at what pace you are walking or running and in general the amount of calories being spent [94][95]. Based on all those capabilities, it is possible these days to determine if you are jogging (e.g. reading your electronic scheduler) and measuring your pace, or determine that you are in a work meeting. In those cases, an elevated heartbeat has different interpretations; in one case it is normal that you have higher heart frequency as you are running as in the other case you can be facing some disturbance, as a work meeting is not going as you would like. Using all this information it is possible to make an assessment on the health status of a person and, eventually, warn her to slow exercise or to control their reaction to a meeting.

In summary, with the existing devices and services, it is possible to monitor health status according to the context, and trigger events to inform or warn actions to be executed.

AN APPROACH BASED ON INSTANTIATING THE PROPOSED FRAMEWORK

In this section we will first address the data processing flow to be followed in the proposed system, which starts with data acquisition from the real world until the actions to be performed in the real world.

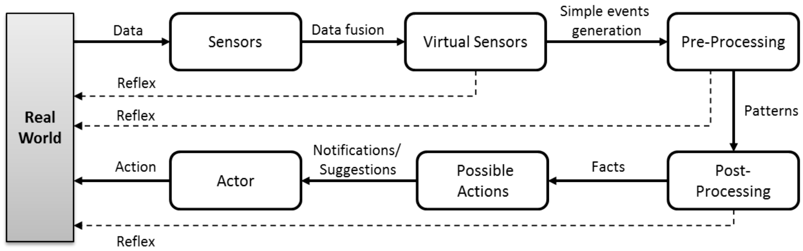


Figure 10.30 - Data processing flow based on the Conceptual Architecture

Figure 10.30 shows the data processing flow, which is a view of the proposed Framework for the IoT for eHealth scenario. In the first step data is captured from the real world by various types of sensors or from other service providers. Thus collected data act as measurement of the parameter under consideration like temperature, humidity etc. In the next step, data infusion is performed leading towards more meaningful state like the temperature and humidity of an object at a particular instant, which leads to the generation of virtual sensors (VS). VSs will have data infusion rules such as if the temperature > x and humidity < y then activate VS. These are useful for generating simple instances of events, with multiple parameters, thus allowing more understanding of the real world and may lead to reflex-like reactions as appends in the human body. The next step termed "Pre-Processing" is used for pattern extraction and will remove the unwanted data from the collected samples of instances thus providing filter over useful data. The patterns detected in this phase are passed to for post-processing, where domain knowledge and rules, are applied over the collected samples to generate facts. Interpretation of facts leads to generation of actions to be taken, over which actors can decide the follow-up procedures.

In the processing flow diagram, we also see that in each stage actions are generated, which we term as "reflex"- immediate response to the state of the real world. In order to act over the reflexes users should use their own knowledge and understanding of the overall scenario. The final actions are suggested based on wider processing of the scenario thus allowing users to respond with lower level of understanding. It is important to define some important concepts for further understanding of the methodology.

Sensor: Sensors are devices that are capable of reading physical and physiological parameters. A sensor *S* can be defined by a tuple $<D, C>$ where *D* represents data-stream and *C* the context of the sensor. *D* will have a data-type and an ordered set of readings obtained at various time which can be represented as $D=<DataType, \{R_1,\ldots,R_n\}>$. *C* is used for understanding the contextual use of the sensor and can have an URI to an external Sensor Networks Ontology[24] or can also be linked with other instances of metadata resources.

Virtual Sensor (VS): VS are termed virtual because they don't have physical occurrence but are formed by logical infusion of various sensors. So, a VS can be defined by a relation $\odot$ s.t. VS= $S_x \odot S_y$, where S_x and S_y are sensors as defined previously. The relation $\odot$ can have different syntax and semantics as needed based on the type of data infusion that should be established between sensors. For instance if VS is used for taking into consideration humidity and temperature of a body part (e.g. arm, armpit) at the same time then a one to one union over the reading of the sensors for humidity and temperature will give an ordered set of reading for this new VS. And if the operator is to find the difference of the reading of two sensors (e.g. environment and body temperature) then the ordered difference between each element of the reading of two sensors will give the dataset for the VS. Note that the context of the VS can always be obtained by the union of the individual contexts of the sensors forming the VS.

Complex-Event Processing (CEP): CEP is a widely accepted term, which is used to combine data from multiple sources (e.g. sensors or virtual) to infer events by observing specific patterns over observed data. This is important to identify meaningful events or threats by observing a series of patterns and an application of possible rules. For instance if it is observed that a person is having heartbeat above a given threshold and the difference between the outside and body temperature crossed a defined limit, then by comparing to similar patterns recorded as dangerous for that person, a warning is issue signalling that some immediate action has to be taken. Also note that based on the concept of adding context to the sensors and propagated to VS will be determinant for CEP to take into consideration the context of the environment. Same patterns can raise different scenarios in different contexts thus adding more value to the CEP.

For further understanding of the concepts of sensors and VSs, let us consider a simplified scenario in which body temperature, heartbeat and Scheduler is regularly monitored to detect critical situations. Table 1 shows a snapshot of some of the situations.

[24] http://www.w3.org/2005/Incubator/ssn/ssnx/ssn

Time [H]	9h00	9h30	10h00	10h30	11h00
T_body [º]	36	36.5	37	36.2	36.5
Heartbeat [BPM]	70	110	80	70	90
Scheduler	Jogging	Jogging	Showering	Work	Work
Result	OK	OK	OK	OK	Warning

Table 1 – Data generated by the sensors and analysed by the framework

The data are read by individual sensor, which is infused to produce warnings by considering situations that can arise at a particular instance. This can be modelled with the definitions of sensors and VSs given before. Note that context of sensors (which can be position, data type, personal identity etc.) is not considered for simple understanding of the modelling process.

Sensors are:

S_{T_body}={36,36.5,37,36.2,36.5},
$S_{HeartBeat}$={70,110,80,70,90},
S_{Time}= {9, 9.30, 10, 10.30, 11},
$S_{Scheduler}$= {(9, Jogging), (9.30, Jogging), (10, Showering), (10.30, Work), (11, Work)}.
Now VS can be modelled as follows:

$VS_{T\_BodyAndHeartBeat}=S_{T\_body} \odot S_{HeartBeat}$, $\odot$ is s.t. for i=1...n $VS_{T\_BodyAndHeartBeat}=\{(x_i,y_i)\}$ where $x_i \in S_{T\_body}$ and $y_i \in S_{HeartBeat}$

In this example: $VS_{T\_BodyAndHeartBeat}$ ={(36,70),(36.5,110),(37,80),(36.2,70),(36.5,90)}

$VS_{TimeAndScheduler} = S_{Time} \odot S_{Scheduler}$, $\odot$ is s.t. for i=1...n $VS_{TimeAndScheduler} = \{(z_i)\}$ where $x_i \in S_{Time}$, $(y_i, z_i) \in S_{Scheduler}$ and $x_i=y_i$

So we have: $VS_{TimeAndScheduler}$ = {Jogging, Jogging, Showering, Work, Work}

We define: $VS_{Warning} = VS_{T\_BodyAndHeartBeat} \odot VS_{TimeAndScheduler}$, $\odot$ is s.t. for i=1...n $VS_{Warning} = \{(x_i, y_i, z_i)\}$ where $(x_i, y_i) \in VS_{T\_BodyAndHeartBeat}$ and $z_i \in VS_{TimeAndScheduler}$ and $x_i>36$, $y_i>80$ and z_i=work or $y_i>150$

Which gives us $VS_{Warning}$= {(36.5, 90, work)}

This model shows the fusion of data from sensors and VS to detect warning. The $VS_{Warning}$ thus detects the situation that the person is at work, has body temperature above 36 and heartbeat above 80 or if the heartbeat is above 150. In the scenario as shown in Table 1, this VS issues a warning for the last column, as expected.

CONCEPTUAL ARCHITECTURE AND TECHNOLOGY ADOPTION

This section will present the conceptual architecture that is being followed for the realization of the system. The system should have layered architecture with well-defined interfaces and clear distinction between the independent components to be implemented at each stage of data processing flow. Figure 10.31 shows the conceptual architecture with distinct layers divided, with components designated for specific functionality, and a clear demarcation on the cloud and private deployments.

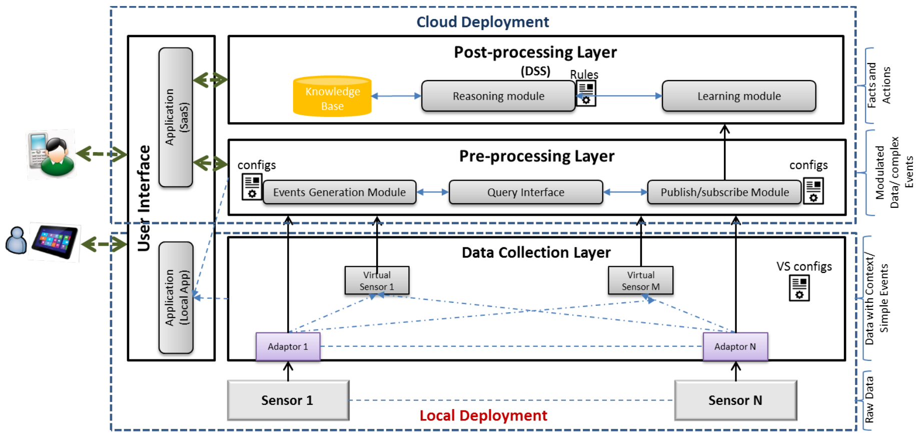


Figure 10.31 - Instantiation of the Conceptual Architecture

Data Collection Layer: This layer is responsible for the collection of data via different sensors deployed in real world. Sensors interact with this layer through the adaptors. Adaptors are sensor specific implementations that act as sink for sensors, the output of which is data streams. The context of the sensor can be registered through admin configuration. This configuration will also define the adaptor for the particular type of sensor. This methodology allows easy integration of the sensor into the system with minimal changes for the new type of sensor. This layer also consists of VSs, which collect data from the outputs of the adaptors. The operation to be performed on the data for generation of outputs for virtual sensors is defined in the configuration details assigned to the virtual sensor. *VS configs* are the configuration files (XMLs), which will generate a new set of outputs by selecting parameters from other sensors or VSs. Since VS can also be specified with constraints, some simple events (or reflexes) will be generated and notified to the user through local application within the reach of user even in the offline mode.

Pre-Processing Layers: This layer implements CEP functionality and provides a module for publication and subscription to data. It also provides interface to query over data, patters and events that have been generated by this or lower layers. Events Generation Module is an implementation of CEP and is used for sampling and filtering of data, the rules for which are defined in the configuration file (configs). Publish/Subscribe module acts as a subscriber of events from the data collection layer and publisher for Post-Processing Layer. This module pulls data from the lower layer, passes it to modules for processing and pushes the pre-processed data towards post-processing layer for further treatment. The query interface is utilized by the application for providing notifications and statistics to the user.

Post-Processing layer: This is a heavy-duty layer of the overall system, where critical processing of the data is performed such as reasoning and learning. This layer makes use of domain knowledge created by experts and reasoning algorithms based on logical reasoning, and/or probabilistic reasoning, to extract new facts for understanding of the overall situation. This layer also implements a learning mechanism to keep the knowledge base updated with new facts generated by automated reasoning. This layer thus acts like a decision support system (DSS) to help the responsible person to have better insight of the real-world scenario.

User-Interface: This layer is used for interaction with the users supported by local applications and applications deployed as SaaS. Local applications are for immediate response and notification of reflexes upon detected events. Other applications are provided as SaaS, in the cloud, and deliver detailed analysis of the scenario, historical data and suggested actions to be taken. The 'admin' functionality allows configuration changes of the sensors and virtual sensors. The applications can be configured to trigger alarms to the user, case an emergency situation is detected.

Technology Adoption

For the purpose of system implementation this research work adopts services and enablers, being developed by projects, under the European FI-PP program like FI-WARE[25] and FITMAN[26], which provide enablers for data acquisition from the physical world, complex event processing, context aware data handling, data analysis etc. Shop-floor Data Collection[27] (SFDC) is the implementation for data collection from various sensor networks (protocol agnostic methodology), and also for integration of tagged objects into the system. SFDC implements

[25] http://www.fi-ware.org/

[26] http://www.fitman-fi.eu/

[27] http://catalogue.fitman.atosresearch.eu/enablers/shopfloor-data-collection

creation and configuration of the VSs and provides adaptors for some standard sensors with easy integration of new types of sensors. VSs are created by writing XML with defined schema. Complex Event Processing (CEP)[28] and Publish/Subscribe Context Broker[29] are configured and used in the data pre-processing layer. Both of these enablers are the important components, which are adapted for the realization of events generation and publish/subscribe modules respectively. In the implementation of post-processing layer it is very important to consider knowledge extraction over real time data, which we have adopted from some current research work as described in [329] and [330]. This module also makes use of ANN with semantics for implementing probabilistic learning algorithm, which have been inspired by some works as described in [331] and [332].

CONCLUDING REMARKS FOR THE SCENARIO

Research presented in this scenario has potential impact in many societal and business aspects. New business models can be deployed to support real-time monitoring as proposed and, from the human side, a citizen can be monitored and assisted while performing a normal life. As by the usage of the proposed Framework, those objectives can be achieved by building computational methodology to integrate sensorial data and their interpretation, generating advice or asking for support as needed. This research work uses the framework for raw data collection from real world and multi-stage processing of data leading towards automated understanding of the surrounding. Proposed methodology will leverage cloud computing to utilize open linked data in the domain of health and big data processing for more reliable self-help health monitoring services.

[28] http://catalogue.fi-ware.org/enablers/complex-event-processing-cep-ibm-proactive-technology-online

[29] http://catalogue.fi-ware.org/enablers/publishsubscribe-context-broker-orion-context-broker

SECTION IV – CLOSING & FUTURE PERSPECTIVES

This section presents the conclusions and the lessons learned from the research work developed taking in consideration what were the Research Questions and validation of the presented Hypothesis into Thesis. It presents also the insights on what can be future exploitations of the present research work, either for technological applications or for continuing the research work in other doctoral studies. It finishes with the scientific publications both as conference papers and articles in scientific journals.

11. CONCLUSIONS & RATIONAL ON RESEARCH RESULTS

The proposed research has an ambitious scope as it can be applied to many situations in real-life. That happens because research work walks in borderlines of areas that are not often considered as adjacent research areas as they belong to Computer Science, Social Sciences and Medical areas. Those are, perhaps, less then probable coexistences. In order to promote the understanding of such confluence of ideas and research areas, section 1.4 has the overall concepts involved and how the identified gaps can be addressed in current research. Those areas are decomposed and analysed in Chapter 3, where those diverse research are succinctly presented, highlighting the aspects that matter for the on-going research. Those areas are as different as knowledge management, the targeted subject but also include, neurophysiology, and neuropsychology derivate areas that aim, by one side to provide models and knowledge on how humans manage from stimuli to knowledge but also to support the development of better interaction between humans and computing devices in an Internet based environment. The presented areas were considered necessary to establish knowledge background for the development of the proposed framework for knowledge management based on brain models. Thus the brain models are the corollary of the complex flow and management of information from external objects to the complex knowledge management that occurs at the brain. All that information from humans, and some higher-level mammals, serves as inspiration for innovative architectures, and consequently, to deploy technical solutions for a person's benefit promoting better services in computer based devices that are becoming pervasive in our lives.

As an overview, the present thesis identifies a problem; the lack of human oriented knowledge at the Internet and the potential of changing that status towards human specific characteristics. Then it proposes biologically driven examples from our sensorial organs to the theories about human brain, to propose new data models and new IT architectures to improve human-driven knowledge management. Proposed scenarios present some of the possible solutions to be elaborated based on usage of the proposed framework and data models. Demonstration and validation was performed by scientific acceptance of 14 publications by peers and development of the validation with human people about the potential usage of physiological readings to infer emotional states.

11.1. FROM A RESEARCH QUESTION TO VALIDATION

Research work departed from the question on the possibility of improving Information Systems based on lessons learned from the human body in particular attending for neuropsychology and brain models. That question was then decomposed in three sub-questions that refer to three aspects of human body that could be questioned on its value for improving Information Systems. Those are the usage of sensorial and physiological information that in this case refer to the input information. Then the inference of emotional states from physiology measurements it taken as the second aspect to be questioned once we know, from bibliography that emotions influence the way we collect and classify information (c.f. Section 1.4.3). This second question as a reflection not only in the information system's ability to manage information but also in its capacity in providing useful information about subjects. Finally, the third question takes a well-accepted theory, the two-stream hypothesis as an arguably model for the management of information in the same way that, by hypothesis, the brain does, with one stream of information to classify input to provide information on what it is (ventral stream) and another one that puts in context the object, locating it in the scene and helping on its identification (dorsal stream) (c.f. Section 4.1.1).

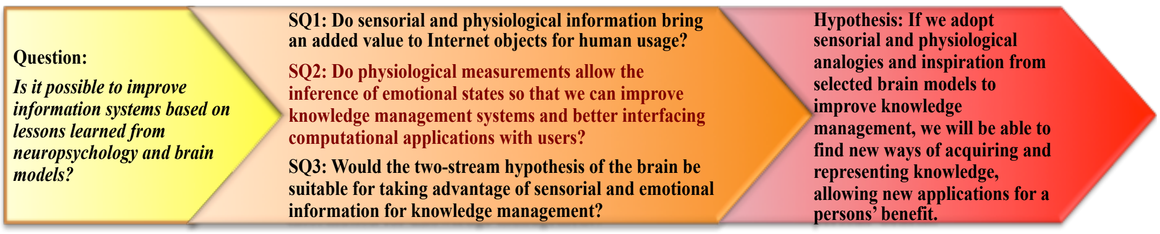


Figure 11.1 - Question, Sub-questions and Hypothesis

This sequence presented in Figure 11.1 closes with the Hypothesis that if we adopt sensorial and physiological analogies and inspiration from selected brain models then, by hypothesis, we would be able to acquire information by other means and also be able to represent knowledge in new ways, finding new applications that will be useful for people.

It is also to mention that the Validation Scenario (10.1) was published in two papers accepted published and presented in to International Conferences, IWEI 2015[30] and ICE 2015[31]. Those publications aimed at explaining the contribution of the present research work for the interoperability domain and for the Health domain.

[30] http://iwei2015.mines-ales.fr/

[31] http://www.ice-conference.org/

The research developed in the scope of the presented work adopts sensorial and physiological analogies with the human body in diverse aspects to know, the way the sensorial organs capture information from the outside and how they are processed and related was developed in the framework. The way the brain relates information in memory with new acquired information and the two-stream hypothesis are two main examples on how inspiration from selected brain models are used to improve knowledge management, as is the case of the resulting framework the resulting data model and the developed concept of i-Episodes. Finally, the proposed establishment of relationships between self-assessment and physiological measurements will allow new applications for a person's benefit. Tangible benefits are the extended data model where a person can collect his/her own i-Episodes for diverse motives (e.g. health applications, biographical records, social applications). Also to mention that a person can benefit from a better context assessment so that applications, or people, using that information can better address and support a persons wills and desires (e.g. not to be disturbed, needing emotional or medical support).

Table 11.1 – Outcomes related with the Research Questions and Sub-Questions

ID	Question	Development & Outcomes
SQ1	**Do sensorial and physiological information bring an added value to Internet objects for human usage?**	A) A new data model was developed to include sensorial and physiological information (c.f. 9.2). B) The proposed Framework includes storage of clusters physiological-sensorial information (c.f. 9.3). C) Physiological information was used in the pilot and proved to be useful to generate emotional information. (c.f. 10.1), thus: - From A), B) and C) it is proven that using physiological along with sensory information the objects will have an added value, an emotion driven tagging.
SQ2	**Do physiological measurements allow the inference of emotional states so that we can improve knowledge management systems and better interfacing computational applications with users?**	A) The trial revealed significant relationship between Heart rate and Self-Assessment of emotions (c.f. 10.1.10). B) The trial revealed significant relationship between Galvanic Skin Response and Self-Assessment of emotion (c.f. 10.1.10). - From A) and B) it is possible to improve knowledge management systems by emotional tagging events and objects. - From A) and B) it is possible to develop better interface with users once it is possible to get emotional information about them.
SQ3	**Would the Two-stream Hypothesis of the brain be suitable for taking advantage of sensorial and emotional information for Knowledge Management?**	A) A new Data Model was developed based on the Two-Stream Hypothesis (c.f. 9.2) B) The Framework is able to evaluate position and feature following a Two-Stream logic. (c.f. 9.3) - From A) and B), by assessing features and position, it is possible to assess the impact of places and activities with emotional information. - From A) and B) we can use emotional information to tag sensorial samples so that they have a meaning for the user, the same as results from brain models as in the case, the Two-stream Hypothesis.

11.2. DEVELOPMENTS ACHIEVED TOWARDS THE FORESEEN CONTRIBUTIONS

In Section 1.4, with the identification of a series of gaps in each of the main areas, there was a foreseen contribution for each of the areas. In the next table we put the developments achieved towards the foreseen contributions as presented in section 1.4.

Table 11.2 – Development Achieved for the Foreseen Contribution on main Research Areas

Area	Foreseen Contribution	Development Achieved
Knowledge Management	**To address the need for proper knowledge management of human sensorial data, and to make contents more interoperable with human cognition processes. In overall, to improve knowledge management towards human needs by providing support for human related contents (e.g. by the inclusion of environmental, physiological and emotional information and promoting the emergence of relevant correlations).**	The work developed provides tools and methods to make possible a human centred knowledge management. The data model includes human related contents such as physiological an emotional data. The interoperability with humans is ensured by the Framework in allowing an evaluation of the emotional state thus allowing applications to interact more respectful to the emotional state of the person. The only aspect that was not validated was the inclusion of environmental data, which was not used because it was not in the scope of the pilot. Expected 90% success.
Neurophysiology, Brain Models and Physiology	**The present work seeks for inspiration from selected conceptualizations about the brain to apply it on knowledge management. It is of particular importance to observe the way external stimuli are received by the brain and apply it towards context awareness and situation awareness (e.g. using the two-stream hypothesis as inspiration for the handling of incoming input from sensorial organs, relating that information with physiological activity).**	Several inspirations from the brain were used in the research work developed: the two-stream hypothesis, the episodic memory analogy and the neurophysiologic processing of physiological data towards emotional assessment. The pilot validation successfully demonstrated that it is possible from physiological measurements to infer about a person's emotional state. The Two-stream hypothesis was used to create de data model but also to establish the requirements for the proposed Framework. Expected 100% success.
Neuropsychology, Sensations, Perceptions and Emotions	**Taking the importance of sensing and perceiving the world for human cognition processes, it is relevant for the present work, to take in account the role of emotions in ranking input for knowledge acquisition and knowledge management purposes. For that, it is within the scope of the present work the inclusion of physiological and emotional data in new data models, allowing related research work to be developed. (e.g. getting sensorial information from multiple devices from the external world and being able to associate an emotional classification of objects).**	The work developed was based on the sensing of the world in diverse aspects. In the pilot application it was used stimuli from the real world (IAPS database photos) and it was acquired physiological information along with the emotional assessment from the person. The data model fully copes with the need to store emotional and physiological information. The work developed opens a path to many other developments, as identified in the next session. What was made with the pilot experience was to associate two types of emotional classification to the objects (pictures) displayed; it was the physiological measurements and the self-assessment. Expected 100% success.

In the next section it is made an overview about the results achieved and the importance they have in different contexts.

11.3. THESIS OUTCOMES

The major outcome of the research work developed is that it was proven that it is possible to improve information systems based on lessons learned from neuropsychology and brain systems.

In this section are a list of questions raised in section 2.3 that were addressed by the present research work, followed by the presentation of the scientific outcomes.

PROBLEMS RAISED EARLY IN THE DOCUMENT AND HOW THEY WERE ADDRESSED

Problem: Information is growing at a fast pace and there is an overload of information available that is not optimized for a person's usage. There is a limited offer in terms of human sensory information, disregarding some or our sensory aptitudes (e.g. smell, taste, touch).

The proposed Framework addresses this problem by:

a) Establishing methodologies to reason over physiological information so that it becomes possible to associate objects, events and people with emotional information. That way information becomes more optimized for a person's usage, as presented in section as results from section 10.1.

b) Allowing an aggregation of information, the i-episodes, that represent coherent large spectrum human information including all sensorial information available. Ultimately it can become a movie format with emotional and sensorial information, the i-PhysEMovie as presented in section 10.2.1.

Problem: Technological devices are able to collect human related data (e.g. physiological from wearable devices) which are used for immediate purposes and lack in consistency with data models thus are limited in its potential use (e.g. relating physiology and emotions).

The research work addresses this problem by:

c) Establishing methodologies to reason over physiological data so that it becomes relevant for emotional assessment and also able to be used for health related purposes as presented in sections 10.1 and 10.5

d) Supporting an emotional tagging of information, either automatic or manually, thus making physiological data useful to classify information as results from a usage of the inference methodology developed in section 10.1.

Problem: Individuals are using devices that are becoming more proficient in capturing sensory and physiological information with little usefulness to them.

The Framework addressed this problem by:

e) Establishing that, as in the two-stream hypothesis, information is captured with a *what* enhanced description (e.g. extending sensorial information) and a *where* logic that allows a permanent association of location and event or measurement along with the time of occurrence, as in the clustering provided by the i-episodes in section 10.2.1.

f) Data (what) captured with a location identification (where) can become useful to correlate places with human features (e.g. illnesses, emotional evaluation) as in the health scenario in section 10.5.

WHAT ARE THE SCIENTIFIC OUTCOMES OF THE WORK DEVELOPED?

Question: Can we learn from brain models and physiology to improve information systems?

This question comes directly from the title of the Dissertation and aims at presenting the lessons learned from the brain with similarities as those adopted in the present work are:

g) The adoption of the two-stream hypothesis is a changer in how we look for information and in particular to how we use the feature-location logic of the brain to improve data storage with an immediate impact information systems.

h) The clustering of information in i-Episodes uses the same approach, as does the Episodic Buffer that aggregates different types of sensorial and physiological information (c.f. section 6.2).

i) The emotional relevance that the brain coins to information, that influences memory and attention, is produced by structures as the amygdala, pons and hippocampus. That same approach can be used to tag information with emotional weighting that can be inferred from physiological measurements as resulted from the pilot application (section 10.1.9).

j) The brain uses Central Nervous System (CNS) to process involuntary information as the Peripheral Nervous System (PNS) to process involuntary information. In the Framework, as was executed in the pilot application, we use the processing of physiological data to generate information independently of the user's reasoning (as in the

CNS) and we use self-assessment reporting where users express they voluntarily express their own assessment (as in the PNS).

Question: What are the scientific results from the work developed?

A Data Model, developed in section 9.2, that:

k) Support features, such as images, sound and others with associated time and position features.

l) Supports physiological information as the case of that generated by wearable or portable devices

m) Encompasses all kinds of sensorial information as that of devices in early stages of development such as the electronic tongue and electronic nose.

A Framework, developed in section 9.3, that:

n) Can have the intervention of humans or electronic components in its different levels

o) Can use data from sensors, devices and available services.

p) Clusters information in the form of i-Episodes.

q) Can issue events about pre-established parameter limits.

r) Can make assessment of emotions from physiological parameters

s) Can produce results to be used in Support Decision Systems and to support Context Awareness and Situation Awareness

Question: What is the advance from State of art from the work developed?

t) A Data Model that can handle physiological data, sensorial data, and data from services as described from k) to m).

u) The Framework for Knowledge Management based on Brain Models and Human Physiology as described from n) to s).

v) The human centric management of information as result from the i-Episodes and the proposed Data Model

w) The analysis of results, from a human trial, between the next physiological parameters: heart rate, Galvanic Skin Response, eye tracking (gaze), pupil dilation and self-assessment based in SAM scale (Self-Assessment Manikin) (sections10.1.11 to 10.1.14).

11.3.1. *Convergence between the Framework, Brain Models and Human physiology.*

The initial research challenge was to find interesting and useful lessons from how the brain captures and subsequently processes and stores information, e.g. how the brain manages knowledge. For that purpose, another request seemed to be obvious, the kind of information to be handle needed to be human centric and that would mean to consider the human sensorial apparatus but also to consider physiological data that could provide information about affect and emotional status.

From the initial research, the Two-Stream Hypothesis seemed to be an important reference, not only because it is gaining adepts in the scientific community but, especially, because it gives insights on how sensorial information flows in the brain and how the brain processes that information. This is quite relevant for the vision, once we saw something we try to identify what it is, by the ventral-stream and to place it in context, by the dorsal stream. This seemed to be inspiring enough to apply in computational support, at the internet, we need to represent an object as best as we can and we would identify its position which would be easy with positioning technology that is broadly used (e.g. GPS, wireless networks, etc.).

In some surprising ways, the developments being made in this direction found parallel in the human “systems”, that is the case of the i-episode concept. The initial idea was to cluster different sensorial data collected in the same moment so that it would be referenced, in a two-stream point of view, to the same subject in the same location. In terms of elementary sensorial capturing there was no evidence in that direction but once we started studying theories on how brain handles memory there was a curios overturn as the brain also clusters input and also has the concept of episodes; the so called episodic buffer.

Another aspect, that makes part of the early selection of aspects to be addressed, was the tagging of emotions. We considered that, especially for personal information, e.g. information collected by a person in a place, it would be relevant, in terms of knowledge management, to consider what was the emotional state of that person. The trend was like this; if a person wants to have the information organized in terms of her personal experience, it would be relevant to know what is the emotional state he/she was experiencing. That would be an important tag so that information would be selectively located but also a relevant tagging for the person as emotions are that important in human's life. The study on how that happens in the human brain led to another relevant question in neuroscience; what is the importance of emotion in the cognition process? The answer is that it is very relevant the emotional state on how the collected information is handled and stored. Emotion is in fact an important classifier for knowledge management in humans.

As the validation process demonstrates, it is possible to obtain that emotional information by inference from collected physiological data.

The framework can be instantiated in multiple configurations that fit diverse goals as stated in the objectives.

11.3.2. *Added value from State of Art*

State of art in technology and knowledge management processes revealed two major weaknesses in the scope of present research work; technology is being developed in a proprietary way, sometimes with open-source software but always in a manufacturer's perspective, e.g. a company makes a fitness band and uses data for their own purposes without regarding any consensual data model. We pursued in this thesis a data model that could be widely used and, because of that, appealing to be adopted by manufacturers. The proposed framework aims at a new type of living registry, that technology is not yet capable to properly address, that would use all kinds of sensorial information as humans are capable of perceive and not constrained to wearable devices but also from devices in the surrounding environment. In this point the framework meets the IoT design for the near future which will allow the usage of devices in daily life or while working, which could open new horizon in research areas such as Human to Human Interaction or Human Computer Interaction (c.f. section 8.2.2) which contribute to the new paths in Enterprise Interoperability by considering humans as a key element on the Enterprise ecosystem.

Following that line of thought, in what regards to knowledge management (KM), research widely addresses KM for the companies addressing humans as a valuable resource for KM inside the company but missing the human-centric approach of a person. In this sense the human is one of the assets for the company disregarding on how the company can contribute for a person's well-being and disregarding how a person's symbiotic interaction with the company can be a benefit for both individual and company successful growth and progress. That is why the present research work, published at IWEI 2015[32] with the title "Humans in Enterprise Interoperability" [333] was considered, by reviewers "**subject is interesting and perhaps it can open a new research area inside interoperability**" and "**makes an interesting initial contribution to a new frontier to EI engineering through psychological measurements of human emotion in experiments**."

New perspectives for human computer interaction based on emotional assessment. New challenges can be addressed from decision support systems, for application deployment, in computers, smartphones and in other type of computational devices (e.g. vehicles, healthcare devices and home automation). Core features to be adopted would benefit all those applications in identifying emotional states from physiological readings and enabling human-centric context awareness. As validated in this research work, it is possible to infer emotional states from selected physiological readings (e.g. galvanic skin response, ECG, pupil dilation).

11.4. INTEGRATION WITH OTHER RESEARCH ACTIVITIES

The research work was started under the scope of FP7 Crescendo IP, Collaborative and Robust Engineering using Simulation Capability Enabling Next Design Optimisation. Grant agreement no.: *234344 (http://www.crescendo-fp7.eu) a*nd the FITMAN project EC 7th Framework Programme, Future Internet Technologies for MANufacturing industries, under grant agreement n° FITMAN 604674 (http://www.fitman-fi.eu)

Rational

The research performed under CRESCENDO's grant aimed, partly, in establishing technological support for collaboration between companies participating in aerospace consortia. In that sense several problems were identified and several questions were addressed. Key points that enforced the current thesis are:

- Aerospace business addresses person's needs, to travel and to feel safe and comfortable, thus reliable analysis on physiology and emotions should be an important issue for airplane design and successful operation. During the scope of CRESCENDO it was noticeable that those issues are hardly considered during planning and conception of aerial vehicles (e.g. helicopters, airplanes).

[32] http://iwei2015.mines-ales.fr/

- Travelling by plane is a rich sensorial experience that is not analysed and for that there are little has no support strategy in terms of identifying emotional and sensorial aspects. That kind of interaction between companies and travellers could benefit both sides; travellers would feel more confortable and companies could provide a better service. For instance, by monitoring emotional experience in passengers, the companies could setup different light schemas in different airplanes and assess what generate better well-being for passengers. Similar trials could be essayed with resource of planted odours or even essaying different tastes for food served on board. More easy would be to determine which melodies in the environment sound would better relax passengers.

- As for the technical aspects, Crescendo aimed at improving business collaboration between partners involved in an aircraft design and construction. By evaluating the emotions expressed in communications, either synchronous; by voice, or videoconference, or by email or other asynchronous means, it would be possible to assess what relationships needed to be observed which needed to be improved. Those methodologies if developed could be translated to other business scenarios.

The research developed at European project aimed to develop the Factories of the Future and business in Europe by using the Fi-Ware core platform of services.

- The FI-WARE platform provides services for European companies to perform a wide range of IT operations. Within the scope of FITMAN project existing services are being used for business support. Those services can be used for personal use, either in mobile or other applications and would be able to constitute instantiations of the proposed Framework.

- FITMAN uses generic and specific enablers for deployment of service. IoT services and other generic services can be used for development of human centric applications.

The proposed Framework will propose an extension of the FI-WARE capabilities, towards human needs, making a new case study as is the ambition of the FITMAN and other projects in the area of Factories of the Future (FoF).

12. FUTURE WORK

The technologies being developed allow explorations to be foreseen for the presented job. Scientific developments and their potential exploitation for personal use, or business, can be envisaged either by development of different configurations of the framework or by the reengineering of the proposed modules.

Future Work for the developments so far have immense possibilities as the new devices are coming to market with new sensing and detection capabilities, enriching the range of sensorial and physiological data to be collected seamlessly. Another important aspect to consider in future work is the usage of such approach for better understanding physiological processes in the human body, their implications in neurophysiology and neuropsychology.

The diverse proposed scenarios, all published in International Conferences, provide motive to pursue the execution of pilot tests that can provide scientific data and new opportunities for further developments. The usage of newly developed devices, for tracking, fitness and other physiological setups can be used for proposed applications like those related with health or for learning environment.

For instance it seems easy to determine if a person is physiologically affected related to external stimulus, with Galvanic Skin Response measurement as it was seen in section 10.1.9.5. Case we use a wearable device able to measure our GSR and as people usually have positional information from cell phone networks or from GPS devices, it is possible to design an application that tracks our physiological changes associated with position. We can have a map of places that most affect us, positively or negatively. If shared we can have a count on frequency of occurrences relating places with physiological arousal.

The emergence of new types of 'things', some related with IoT applications, can provide useful opportunities to foster wider usages of the platform towards a rich sensorial capture of information or a rich sensorial experience of full and immersive sensorial experiences.

In what concerns to future applications in the area of health, telemedicine can provide less expensive medical care including deliverance of care to people in isolated or remote areas. However there are several identified problems that limited the application of telemedicine in general by its application limitations and in particular to the specific requisites to medical intervention areas. An interesting question rises from the detachment between patient and doctors in medical practice that happens when using telemedicine. A study from Stephen Fairclough concludes that certain populations can benefit from treatment delivered via tele-psychiatry, but, although it may not be suitable for treatment in all areas of mental health due to the problems assessing non-verbal communication [103]. It is possible to address such problems by the implementation of the proposed framework in obtaining and transmitting a wider range of sensorial information, but also, by the possibility of transmitting other non-verbal information as in the case of sending physiological measurements. New opportunities will empower telemedicine consultation by promoting and approach of remote consultation to live attendance in medical practice.

Also the protection of people, especially those that require most concentration or those who may put humans at risk probably could have some kind of monitoring (even for self evaluation). The present scenario opens ground for that kind of assessment from physiology with the concern of attending ethical and privacy concerns. The continuous update of the working model deployed in this setup can ensure the validity and adequacy to different persons in different circumstances.

Another interesting feature would be to perform the measurements while people are interacting with computers or other “smart” devices. Would be interesting to verify in which degree a person’s emotional change is affected by the interaction with computers, as Affective Computing studies (c.f. section 8.1). Future work should advance in the direction of the measurements to be performed with available fitness devices as stated before. The unnoticed use of devices would allow it to be used seamlessly within the daily life, working or performing other tasks thus allowing a wider range of collected data. Also future work could include other types of measurements that did not fit in the scope of this paper but that can be coupled with the presented measurements in order to obtain more rigorous correspondences between physiology and emotional assessment (e.g. blood pressure).

Another potential usage for the framework, as previously mentioned and published, is their application for a better assessment of context and situation awareness [334]. The role of the framework, in such scenario, is to support, organize and store a wider range of sensorial information, detailing the scenes and thus enriching context but also by including a better characterization of the person by the retrieval of physiological information. That will enhance context information with a special relevance to human centred context awareness and establishing new paradigms for better situational awareness assessment.

In Summary, the future will provide many opportunities for the proposed Framework to be deployed and to be used more and more widely. Ultimately, with full experience it can give a remote user the sensorial experience of being there, as in the futuristic movies like Avatar[33] and Surrogates[34]

The research work developed and reported within this PhD Thesis leaves many open opportunities for the Future that hopefully will be pursued, by us and by others, and that will improve knowledge management and, if possible, will improve existing knowledge about the human brain.

[33] http://www.avatarmovie.com/index.html

[34] http://www.chooseyoursurrogate.com/

13. Publications

The research work published in conference papers or journals addresses several areas that can benefit from the proposed framework. In the next table those areas are presented and the papers related to those areas are listed according to their fit to the same areas.

Emotional Assessment	• Framework for Knowledge Management Towards Human Centric Internet of Things and Sentiment Analysis [337] • A Behavioral Framework for capturing Emotional Information in an Internet of Things Environment [326] • Framework for Management of Internet Objects in their relation with Human Sensations and Emotions [313]
Health	• Internet of Things for eHealth in a Physiologic and Sensorial perspective supported by the Cloud [339] • Brain inspired health monitoring supported by the cloud [334] • Towards Human-Centric Healthcare supported by Emotional Assessment [340]
Knowledge Transmission & Learning	• Learning Challenges: Remote labs powered by the five senses [314] • Framework for Adaptive Knowledge Transmission Supported by HCI and Interoperability Concepts [338]
Framework & Data Model	• Modeling of Things on the Internet for the search by the Human Brain [117] • Internet of Persons and Things inspired on Brain Models and Neurophysiology [253] • Framework for Knowledge Management based in the Two-Stream Hypothesis [341] • Towards self-evolutionary Cyber Physical Systems [244] • Internet of Things based Situational Awareness Framework for Real-Time Project Management [342]
Humans in Enterprise Interoperability	• Humans in Enterprise Interoperability Ecosystem [333] • On the formal definition of the systems' interoperability capability: an anthropomorphic approach [343] • Towards Self-Evolutionary Cyber Physical Systems [244]

Table 13.1 – Publications within each related research area

During the scope of the thesis, the author also published a book: Programação em AutoCAD com AutoLISP e VisualLISP [335] which has the first edition sold out and second edition is in preparation. This book follows a previous one from 2002 with the title Programação em AutoCAD – Curso Completo [336]. Both books were edited by FCA, Editora de Informática, Lda.

A communication was made at Feb 22th 2013 in the 3rd Bioengineering Meeting[35] at Universidade do Minho as Keynote speaker with the title: "Learning Challenges, engineering the interoperability between brain and the Internet".

[35] http://www.uminho.pt/uploads/eventos/EV_6508/20130219542246416250.pdf

In the next table is presented the formal list of publications, by year, including those four made before the doctoral program.

Table 13.2 Publications by year

i	Luis-Ferreira F., Malo P., Ifeachor E., and Jardim-Goncalves R., "Towards Bioprofile a New Concept of Electronic Health Records," in EACDA 2005 - Conference on Emergent Aspects of Clinical Data Analysis. 2005.	*2005*
ii	H. Vieira, F. Ferreira, J. Kennedy, and R. Jardim-Gonçalves, "Evaluation and Testing as support for a consistent Architecture development." 12-Oct-2008.	*2008*
iii	A. Dogac, G. Laleci, J. Kennedy, S. Drissi, M. Sesana, R. Jardim-Goncalves, and A. Canepa, "ISURF: RFID Enabled Collaborative Supply Chain Planning Environment," MCIS 2009 Proceedings. 2009.	*2009*
iv	Luis-Ferreira F. and Jardim-Goncalves R., "Framework for Knowledge Management Based in the Two-Stream Hypothesis," in IFIP Advances in Information and Communication Technology, 2012, vol. 372, pp. 69–76. 2012.	*2012*
v	Fernando Luis-Ferreira, Programação em AutoCAD com AutoLISP e VisualLISP. FCA Editora de Informatica, ISBN: 978-972-722-714-3, 396 pages, 2012.	
vi	Luis-Ferreira F. and Jardim-Goncalves R., "Internet of Persons and Things inspired on Brain Models and Neurophysiology," Computational Methods in Social Sciences, vol. 1, no. 1, pp. 45–55, Jan. 2013.	*2013*
vii	Luis-Ferreira F. and Jardim-Gonçalves R., "Modelling of Things on the Internet for the Search by the Human Brain," in IFIP Advances in Information and Communication Technology, 2013, vol. 394, pp. 71–79. 2013.	
viii	Luis-Ferreira F. and Jardim-Goncalves R., "A behavioral framework for capturing emotional information in an internet of things environment," in 11TH INTERNATIONAL CONFERENCE OF NUMERICAL ANALYSIS AND APPLIED MATHEMATICS 2013: ICNAAM 2013, 2013, vol. 1558, no. 1, pp. 1368–1371. 2013.	
ix	C. P. Leao, F. L. Luis-Ferreira, and R. Jardim-Goncalves, "Learning challenges: Remote labs powered by the five senses," in 2013 International Conference on Interactive Collaborative Learning (ICL), 2013, pp. 696–699. 2013.	
x	Luis-Ferreira F., Sarraipa L., Marques-Lucena C., and Jardim-Goncalves R., "Framework for Management of Internet Objects in Their Relation with Human Sensations and Emotions," in IMECE, 2013.	
xi	Luis-Ferreira F., Sarraipa L., and Jardim-Goncalves R., "Framework for Adaptive Knowledge Transmission Supported by HCI and Interoperability Concepts," in Universal Access in Human-Computer Interaction. Universal Access to Information and Knowledge SE - 34, vol. 8514, C. Stephanidis and M. Antona, Eds. Springer International Publishing, 2014, pp. 370–377. Rhodes, Greece. 2014.	2014
xii	Luis-Ferreira F., Ghimire S., and Jardim-Gonçalves R., "Internet of Things for eHealth in a Physiologic and Sensorial Perspective Supported by the Cloud," in Advances in Transdisciplinary Engineering, 2014, pp. 790–795. CE 2014, Beijing, China. 2014.	
xiii	Ghimire, S., Luis-Ferreira, et al "Towards Self-evolutionary Cyber Physical Systems," in Moving Integrated Product Development to Service Clouds in the Global Economy, Advances in Transdisciplinary Engineering, 2014, p. 821. CE 2014, Beijing, China, 2014.	
xiv	Luis-Ferreira, Fernando; Ghimire, Sudeep; Zdravkovic, Milan; Jardim-Goncalves, Ricardo, "Framework for knowledge management towards human centric internet of things and sentiment analysis" *Volume 2B: Advanced Manufacturing* p. V02BT02A029, ISBN: 978-0-7918-4644-5, IMECE 2014, 2014.	
xv	Luis-Ferreira F., Ghimire S., and Jardim-Goncalves R., "Brain Inspired health monitoring supported by the cloud" in Doceis'15, 2015.	2015
xvi	Luis-Ferreira F., Panetto H., and Jardim-Goncalves R., "Humans in Enterprise Interoperability Ecosystem" Sixth International IFIP Working Conference on Enterprise Interoperability, IWEI 2015, 2015.	

xvii	Luis-Ferreira F., Ghimire S., and Jardim-Gonçalves R., "Towards Human-Centric Healthcare supported by Emotional Assessment", ICE 2015, 2015
xviii	P. Oliveira, J. Lima, F. Ferreira, J. Sarraipa, "A Knowledge-Based Approach for Supporting Aquaculture Data Analysis Proficiency", IMECE 2015, 2015 (submitted)
xix	Sudeep Ghimire, Fernando Luis-Ferreira, Tahereh Nodehi and Ricardo Jardim-Goncalves, "Internet of Things based Situational Awareness Framework for Real-Time Project Management", International Journal of Computer Integrated Manufacturing
xx	Zdravkovic M., Luis-Ferreira, F., Jardim-Gonçalves R., "On the formal definition of the systems' interoperability capability: an anthropomorphic approach", Journal of Enterprise Information Systems May 2015. DOI: 10.1080/17517575.2015.1057236

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