Cognitive-Emotional User Correction for Multimedia Interactions Using Visual Attention and Psychophysiological Signals

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A thesis submitted for the Degree of Master of Philosophy

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Declaration

The Thesis is my original work and has not been submitted previously for a degree at this or any other university/institute. To the best of my knowledge it does not contain any material published or written by another person, except as acknowledge in the text.

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This is to certify that this thesis is based on the work of Mr./Mrs./Ms .... under my/our supervision. The thesis has been prepared according to the format stipulated and is of acceptable standard.

Certify by

Supervisor 1	Name	....	Date	....
	Signature	....		
Supervisor 2	Name	....	Date	....
	Signature	....		

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Abstract

Today, the multimedia interaction domain is a developed area not only focusing on the presentation of information to the human user, but also get the human involved in computer modeled real-world scenarios, such as computer games and e-learning. In this relation, the computer can only process symbolic information and the knowledge is representation oriented. However, humans are biological creations having basically three different aspects: brain activation, cognitive behavior and emotional reaction. Currently, under human computer interactions, only the cognitive behavior of the human is recognized by the computer. As a result, humans do not show the same involvement when they are attached to real world activities and when the activities are decided by the computer. In multimedia computing, this problem is termed as perception-semantic gap, arguing the main reason for this problem is the semantic incompatibility between the knowledge representation of the computer and the internal representation of the human user. However, modern cognitive science explains that human behavior can not be described without considering the emotional reaction revealing many relationships between cognition and emotion. Therefore, researchers are trying to recognize emotions using facial expressions of the human user. However, this approach does not provide a correct relationship, because the facial muscles are under conscious control of the subject, so the expressions can easily be faked. Psychophysiological explanations of emotional reaction describes better relationships between a person's true psychological behavior and his/her bodily (physiological) changes. Therefore, the work of this research tries to capture these bodily signals to determine the emotional involvement of the subject.

Humans exist in a world with unlimited knowledge dynamics. Therefore, selective attention helps humans to filter out unwanted information from their senses. The visual attention plays an important role in this effort, because it gives a directional focus to the attended information in the outside world. Therefore, the research tries to capture the visual attention using biopotentials generated as a result of eye movement activity of the subject, which is a low-cost solution compared to sophisticated and expensive techniques used today that returns the actual spacial coordinates of the eye focus.

The attention and most other cognitive aspects of the human are controlled by a mental phenomenon called the consciousness. Yet, the consciousness is beyond any scientific explanation and can only be linked with cognitive emotional aspects using philosophical models. Therefore, the study also includes a proposal of a coherent model of human psyche which is then used to develop a psychophysiological evaluation framework that can be used to determine discrete levels of involvement of a subject to a multimedia interaction. Results of the experiments show the validity of the framework.

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Acronyms

ACT Adaptive control of thought

ANS Autonomic nervous system

CAD Computer aided design

CAT Computed axial tomography

CBR Content-based retrieval

CNS Central nervous system

CT Computed tomography

DOM Document object model

DRL Driven right leg

ECG Electrocardiogram

EDF European data format

EDR Electrodermal response

EEG Electroencephalography

EMG Electromyogram

ENMGEP Electromyography and evoked potential

EOG Electro-oculogram

ERG Electroretinogram

ERP Event-related potential

fMRI Functional magnetic resonance imaging

GIS Geographical information systems

GSR Galvanic skin response

HAL Hemispherical activation level detector

LTM Long-term memory

MMDBMS Multimedia database management systems

MPEG Moving picture experts group

MRI Magnetic resonance imaging

NS Nervous system

PET Positron emission tomography

PGR Psychogalvanic response

PNS	Peripheral nervous system
PSG	Polysomnography
RAS	Reticular activation system
scEEG	Soundcard EEG
SCR	Skin-conductance response
SNS	Somatic nervous system
STM	Short-term memory
TCP	Transmission Control Protocol
UCSC	University of Colombo School of Computing
USD	United States dollar

Chapter 1 - Introduction

In early days, the interactions were basically limited to human-human interactions, whereas today human-computer interactions are becoming popular. Few examples for these human-computer interactions are e-learning, computer games, and virtual reality. In the future, it can be expected that human-robot interactions also will change this domain.

The modern human-computer interactions are different from some of the other interactions, such as reading a paper, because human-computer interactions involves modeling the real world scenarios. For instance, e-learning is the computer realization of real-world class-based teaching and learning scenario. In the real-world, human behaviors are influenced by cognitive, emotional, and social factors. However, in front of a computer, humans have to behave differently, because still the computers are capable only to obtain inputs from symbolic modalities from human users and to process those inputs only as symbolic percepts. Under this computational framework, a larger scale of interaction dynamics are ignored. Figure 1.1 depicts a human involvement in a multimedia interaction with visual attention.

Figure 1.1: Human involvement in a multimedia interaction

In recent years, researchers have identified the limitations in current human-computer interactions and started to provide solutions in different dimensions. Some of the researchers in the e-learning domain try to solve this problem by capturing learning patterns of the learner while the learner is engaged in an e-learning session. Image processing techniques are also used to capture the facial expressions to recognize emotions to profile learner's preferred learning paths. Researchers in the multimedia domain termed this as the perception-semantic gap (Panchanathan, et al., 2003) and argued the main reason for this problem as the semantic incompatibility between the human and the computer. Therefore, researchers have proposed and developed a number of knowledge organizing structures similar to human knowledge structures to bridge this perception-semantic gap.

Meanwhile, another group of researchers (Davcev, et al., 1993) approach this problem while being inline with findings of modern cognitive science framework. Recent developments (Galotti, 2004; Thagard, 2005) in the cognitive psychology has revealed in depth explanations on how humans acquire, process, and store information internally and which factors have influence on this model. However, these experiments are conducted under very expensive and sophisticated hardware and software platforms with very specialized researchers from different domains. Therefore, much of the findings of modern cognitive psychology are limited to clinical environments to treat brain disorders and diseases.

For centuries, the study of emotions had been ignored under cognitive science framework seeing it as a side issue to the more central cognition of a human. However, according to modern cognitive science, human emotions play a major role in the human decision making process. Therefore, some research attempts can be found focusing on integrating emotion considerations to computational framework to improve the computer side with more human-like behaviors. Literature shows (Thagard, 2005) the modeling of emotions is not easy or impossible at all because of the facts that the complicated structure of the emotions and the computers are capable of processing only symbolic information. Therefore, current research attempts are limited to emotional judgment considerations, i.e. categorizing emotions as angry, fear, happy, etc., with corresponding intensity levels and use these quantities in the computations. The emotions for these purposes are recognized either from image processing of human facial expressions or from other externally observable means, which can be easily faked by the subject.

The work reported on this thesis tries to bridge these two domains by developing a hardware/software framework that can recognize different classes of involvement of the human in a human-computer interaction, so that the computer will be able to recognize the cognitive-emotional needs of the human and personalize its presentation improving the human-computer relationship. Currently, there is no universally agreed model to explain the existence of the mind with the body and how cognitive and emotional aspects fits on with these considerations. Therefore, our research is aimed at proposing a model for the human psyche to explain the relationships between high mental aspects, such as consciousness, the cognitive-emotional aspects, and the physiological aspects. We then use this model as the base to develop a psychophysiological evaluation framework that can be used to predict discrete levels of involvement of a human to a multimedia interaction. The work is also unique with the methods it uses where the visual attention is used to determine the cognitive behavior and the skin resistance is considered to recognize the emotional activity of the subject.

1.1 The Scope and Objectives of the Research

The research is based on the following hypothesis:

The psychological involvement of a human user in a computer-based multimedia interaction can be quantitatively determined from the psychophysiological signals, and this quantified readings can be used to determine the human's acceptable range of involvement to the interaction from other distractions.

Considering the subjective nature of the hypothesis, the following primary objectives have been derived from the hypothesis to guide the experimentation process of the research:

- Investigate the relationship of brain's cognitive-emotional activity and the affect signals, and possibility of recognizing these psychophysiological behavior from the changes in the skin resistance (GSR).
- Investigate the relationship of the brain's cognitive activity and the visual attention, and the possibility of recognizing the visual attention using the biopotentials generated at the human eyes.
- Formulate a framework using combined relationships between skin resistance activity and eye activity to recognize discrete classes of involvement of the human to a multimedia interaction, so that, this framework can be used to evaluate the multimedia content or to improve the human's involvement to the multimedia interaction.

In addition to the above primary objectives, the following describes the supportive objectives of the research:

- Use low cost hardware devices to capture the affect signals of the human,
- Requirements for the safety of human subjects from the artifacts of capturing devices,
- Use comfortable electrode placement arrangements for the human,
- Properly justify the need for the consideration of cognitive and emotional aspects in multimedia interactions, and
- Propose a conceptual framework to encompass internal information processing of human.

1.2 Methodology

The human is a biological creation and their interactions are comprised of cognitive, emotional, and social aspects. On the contrary, the computer is a machine which can only recognize and process information in a symbolic nature using electrical current. Therefore, bridging the perception-semantic gap between these two sides in a human-computer interaction is essential to improve their interrelation.

Literature is unable to present a unified explanation for human emotions and its role is mainly discussed under the aspects of bodily reaction and cognitive judgment. The bodily reaction is centralized around the limbic system (Best, 1990) of the human brain and its role as the preparation of the body for protecting the human from external threats and alerting the brain is mostly recognized. The human cognition is the identity of a particular human in his/her conscious decisions in their day-to-day activities, which is based on symbolic information. The literature is unable to give an extensive explanation about how cognitive-emotional activities are interrelated, and therefore, the thesis extends its discussion basically towards this aspect. Since, it is very difficult to explain high mental explanations, such as consciousness and existence of the mind with the body, the work also includes a revision of few religious and philosophical explanations to find any mechanism that can link these aspects. Finally, the work ends up while proposing a model for the human psyche. Later, this model is used to develop a psychophysiological evaluation framework for discrete levels of psychological involvement of a human in an human-computer interaction. However, this work does not include some other variables, such as gender differences, age, and brain disorders.

Most signals resulting from the bodily reaction of an emotional response, for instance changes in the heart rate, are able to capture using external electronics. However, these reactions are influenced by various functional units of the brain at different time periods since the stimuli and have a complex relationship to the cognitive-emotional behavior of the human. Again, very sophisticated and expensive electronics are needed to capture some of these biological signals because of the low amplitude, noise and other artifacts. Out of those affect signals, the change of skin resistance, also called GSR, has a very good relationship basically to the emotional activity of the human. The skin resistance also can be measured using low cost hardware. Therefore, after considering these factors and the availability of the hardware, the work uses the changes in the skin resistance to recognize the brain's emotional activity against incoming stimuli.

Studies about the brain's cognitive activity show that it is affected by the emotional activity and vice versa. The attention is considered as a high level cognitive activity and the visual attention is the most important aspect of the attention. Therefore, this study tries to use this aspect to understand the cognitive activity of the brain.

During a human-computer interaction, it is expected that a person's visual attention develop towards the computer screen. Most researches focusing on this aspect uses high cost hardware/software to capture the spatial location of the current focus of the eyes. However, this research will attempt to use biopotentials generated at the eyes as a result of eye movement activity to determine the quality of visual attention.

Although there are software tools to analyze affect signals, almost all those tools are designed to read signals from specific hardware devices. Therefore, a new software tool is implemented to read real-time signals from the GSR reading device and the eye potentials reading device at the same time with real-time graphing, recording and analyzing capabilities.

Finally, few experiments are conducted using human users engaged in computer-based multimedia interactions to evaluate the proposed psychophysiological framework. The experiments are conducted in two steps. The initial experiments are designed to identify any unpredicted variables that may have influence on the expected results and to adjust the experimentation process as necessary. Later, based on the results from the previous experiments, more experiments are conducted using more individuals to evaluate the framework for individual differences.

1.3 The Outline of the Thesis

The following summarizes each chapter's scope and flow of this dissertation.

The chapter 2 starts by retrieving the problem of perception-cognition gap from the multimedia computing domain where it describes why the user correction is required for multimedia interactions. Since this problem needs a greater understanding of human cognitive and emotional functions, the chapter constructs its content addressing how far the literature has developed over the years under philosophical, scientific, and technological fronts. This review is constructed in such a way by connecting subjective and objective aspects of humans, for instance form the point of stimulus, how it captures by the brain, how cognition and emotion are triggered, how it changes the physiology of the body, and how these changes can be measured and interpreted using available technological possibilities.

Next, the chapter 3 constructs a conceptual framework for human psyche combining the knowledge grained from the literature to explain the levels of internal information processing of humans. This framework is then used to setup a psychophysiological framework for the evaluation of human involvement to multimedia interactions.

The chapter 4 elaborates the development of BioMedia software framework to capture, integrate, and visualize human affect signals and media events while the subject is involved with a multimedia interaction. It also describes hardware devices and their design issues.

The chapter 5 gives the details of the experiments conducted to test the hypothesis and its primary objectives. The discussion of experiments is organized into two sections: pilot and hypothesis test experiments. The pilot experiment has been conducted to verify the strength of the proposed hardware and software framework in conducting tests and the hypothesis test experiments give descriptions of more focused experiments to prove the hypothesis.

Finally, the chapter 6 summarizes the work with the important findings. It also gives directions for future similar work. Selected implementations of the source code and design details are included under appendices.

Chapter 2 - Developments in Literature

2.1 Perception-Cognition Gap in Multimedia Computing

Traditionally, the computing was mainly limited to manipulating numerical and textual data. However, with the advancement of digital systems, digitalized representation of images, audio, and video data was introduced and these heterogeneous media types enabled vast number of application domains to be emerged. Today video on demand, home shopping, geographical information systems (GIS), computer aided design (CAD), photographic libraries, art galleries and museum management, educational systems are all get benefited from multimedia computing.

The heterogeneity of multimedia data, higher storage, processing and communicating requirements require specialized systems to be developed to manipulate data. Today multimedia database management systems (MMDBMS) and video servers have evolved to meet such requirements (Kosch and Doller, 2005; Kosch, 2002). However, it is identified that the traditional keyword-based search proposed by those systems is not sufficient in retrieving materials. Therefore, the content-based retrieval (CBR) is proposed (Kosch, 2002; Yoshitaka, 1999).

CBR requires that the content is indexed before it stored in the database. Currently, the indexing is done at two abstraction levels. The low-level abstraction corresponds to the low level properties of the multimedia document where the indexing is done based on features, such as color, texture, and object segments. The retrieval of this level is based on similarity tests. The following is an example for a feature-based query:

"Give all the images where tabletops are similar to image I"

The high-level abstraction corresponds to the view in which the contents of the multimedia document are seen by the end uses. The indexing of such systems requires spatial-temporal semantic relationships to be considered (Donderler, 2002; Kosch, 2002; Yoshitaka, 1999).

The spatial relations consider directional (e.g. west, south, south-west), topological (e.g. cover, equal, inside, disjoint, touch, and overlap), and 3D (e.g. infrontof and samelevel) relationships while temporal relations are derived from interval operations (e.g. equal, meet, during, starts, finishes and before). The following are two examples for spatial-temporal queries possible in BilVideo video database management system (Donderler, 2002):

“Give the number of shots to the goalkeeper of the opponent team for each player of Arsenal.”

“Find the migration paths of bird O over region R in a given video clip.”

The indexing and deriving of these relationships require authoring of multimedia materials using authoring tools. The BioVideo is an example for a video annotation tool (Donderler, 2002). After annotating, these objects and their relationships have to be modeled in a unified data structure to provide efficient storage, retrieval, and transport services for end users and applications. The Flash MX JSFL DOM (Watson, 2004), MPEG-7 and MPEG-21 (Moving Picture Experts Group, 2008), and KMeD model (Dionisio and Cardenas, 1998) are examples for data models developed to capture richer semantics.

Recently, the notion of informatics changed dramatically and according to modern informatics the information is defined as any aspect of the natural world that can be abstracted, digitally represented, and mentally processed (Wang, 2002). Under this viewpoint, the knowledge modeling in a semantic network is referred as ontology modeling. Research work can be found from literature that attempts to customize knowledge for different applications under semantic networks (Yang and Zhuang, 2002).

To address the mental processing of information by different users cognitive informatics has been defined with the aim to study the internal information processing of humans using an interdisciplinary approach called cognitive science [section 2.2.1]. The ultimate objective of this mission is to give the computers the ability to interpret percepts and concepts similar to how humans interpret sensory inputs. Researchers have tried different approaches to address this problem. Some attempts are to develop human-machine interaction models (Panchanathan, et al., 2003). Another approach is to organize the knowledge in a model similar to how humans organize their knowledge calling it a cognitive network (Davcev, et al., 1993). The e-learning discipline approaches this issue calling it personalization or adaptive e-learning (Hewagamage and Lekamarachchi, 2003; Dolog, et al., 2004; Brusilovsky, 2004). The MPEG-21 tries to address this issue by introducing the concept called "digital item", where it is a multiple representation of data for different users (Kosch and Doller, 2005). However, yet this perception-cognition gap is an unsolved issue.

2.2 Cognition and Attention

Cognition is a high-level mental process mainly centralized around humans giving them the ability of judging, reasoning, and memory. The attention is a supportive mental process for cognition allowing humans to interact with the outer world in a more focused and specialized manner. This section of the chapter elaborates cognition and attention discussing its scientific nature and its relevance to human-machine interactions.

2.2.1 Why Cognitive Science? Motivation, Evolution, and Revolution

Cognitive science is the interdisciplinary study of mind and intelligence. Neisser, in 1967, described its scope as the study of how people acquire, store, transform, use, and communicate information (Galotti, 2004). Understanding the nature of mind is important in many aspects (Thagard, 2005): teachers can better focus their instructions to mental requirements of students, engineers and designers can design their products for the needs of the users, computers can be made more intelligent, and mental disorders can be better described and treated.

The studying of mind is not easy, because it requires a recursive mental power to explore the brain by the brain. The attempts to understand the mind date back to ancient Greeks, when at that time psychology was a branch of philosophy. Plato (428-347 B.C.) believed that knowledge comes from the virtue that people know innately (Thagard, 2005). Aristotle (394-322 B.C.) perceived psychology as the study of the soul, "the form of a natural body having life potentially within it" (Wang and Wang, 2002). His explanations about knowledge concerned with "learn from experience". Even later philosophers, such as Descartes (1596-1650) and Leibniz (1646-1716), believed that knowledge can be gained just by thinking and reasoning, a position known as rationalism. This philosophical position was defended by

Locke (1632-1704), Hume (1711-1776), and other philosophers setting out the principles of empiricism, a view that the knowledge depends on sense experience. However, in the 18th century, Kant (1724-1804) attempted to combine rationalism and empiricism by arguing that human knowledge depends on both sense experience and innate capacities of the mind (Thagard, 2005).

While the western philosophical position developing in such a way to explain the human knowledge, Lord Buddha (563-483 B.C.), an Indian philosopher and the founder of Buddhism, was teaching mental conditions that conduces to awakening and comprehend pain. The essential framework upon which Buddha's teachings were based on is the framework consisting of four noble truths (Thanissaro, 2008): the truth of stress and suffering, the truth of the origination of stress, the truth of the cessation of stress, and the truth of the path to the cessation of stress. Because of the ignorance of these noble truths and the inexperience in framing the world in their terms, our existence remains bounded to the samsara, the wearisome cycle of birth, aging, illness, death, and rebirth.

When exploring Buddhist teachings, especially suttas, a deep psychological review encompassing each step contributing to cognition and other mental processes can be revealed. One such explanation is the existence of five aggregates (Thanissaro, 2008; Wikipedia, 2008): the form or matter (rūpa), the sensation or feeling (vedanā), the perception (saññā), the fabrication or formation (sankhāra), and the consciousness or cognize (viññāna). The form encompasses external (physical world) or internal (body organs) matter. The feelings can be pleasant, painful, or neutral. The perception is the recognizing of objects and concepts, for instance, yellow color or sound of a bell. The formation can be intention oriented (aimed at sights, sounds, aromas, tastes, tactile sensations, and ideas) or based on feelings (ripening in pleasure, pain, or formless). According to this explanation, for instance, the breathing is explained as a bodily fabrication because it is bounded up with the body. The consciousness is classified simply by the condition in dependence on which it arises, i.e. eye, ear, nose, tongue, body, or intellect. Although, Buddha has explained these five aggregates as unseparable, it can be seen that these five aggregates are somewhat compatible with commonly agreed levels in modern psychology: matter, sensation, perception, semantics, and cognition. According to Buddha's teachings, the origination of stress continues as long as cling to these five aggregates.

Literature (Thagard, 2005; Galotti, 2004; Wang and Wang, 2002) points out the founding of the actual field of psychology dates back to 1879, when Wilhelm Wundt (1832-1920) employed more systematic laboratory based experiments to study the aspects of the mind giving birth to the experimental psychology. Wundt wanted to identify the simplest essential units of the mind and to determine how these units combine to produce complex mental phenomena, a stance known as structuralism. Opposing Wundt's stand of structuralism, William James (1842-1910) tried to uncover mental functions, a stand known as functionalism. In 1913, J.B. Watson (1878-1958) rejected unobservable subjective mental states and processes, such as consciousness and mental representations, and argued that psychology should restrict itself to observable stimuli and behavioral responses. This view that virtually denies the existence of the mind is known as behaviorism and it dominated especially in North America. In addition, several other psychological views can be found in the literature, such as Gestalt psychology and genetic epistemology (Galotti, 2004).

Another philosophical stand of psychology became apparent as soon as Sigmund Freud presented the iceberg metaphor (Figure 2.1) to the scientific community in 1932 (Kazlev, 2004; Freud, 1932). He believed that behavior is determined by the unconscious mind, a repository of repressed impulses and desires, of which the waking mind is completely unaware, but determine the way one thinks, feels, and acts. According to Freud, all behavior is motivated by the desire to feel pleasure and it is the basic psychic energy (libido). His explanation of various parts of the psyche included economical (the hydraulics of unpleasure avoidance through pleasure), the dynamic (libido movements through id, ego, and superego), and the topographic (psyche as structured into conscious, preconscious, and unconscious layers) interactions. Both Buddhist teachings and Freud's conceptions are compatible to some level in explaining behaviors by their motivation or desire to feel pleasure but are not always completely controllable unless radically analyzed.

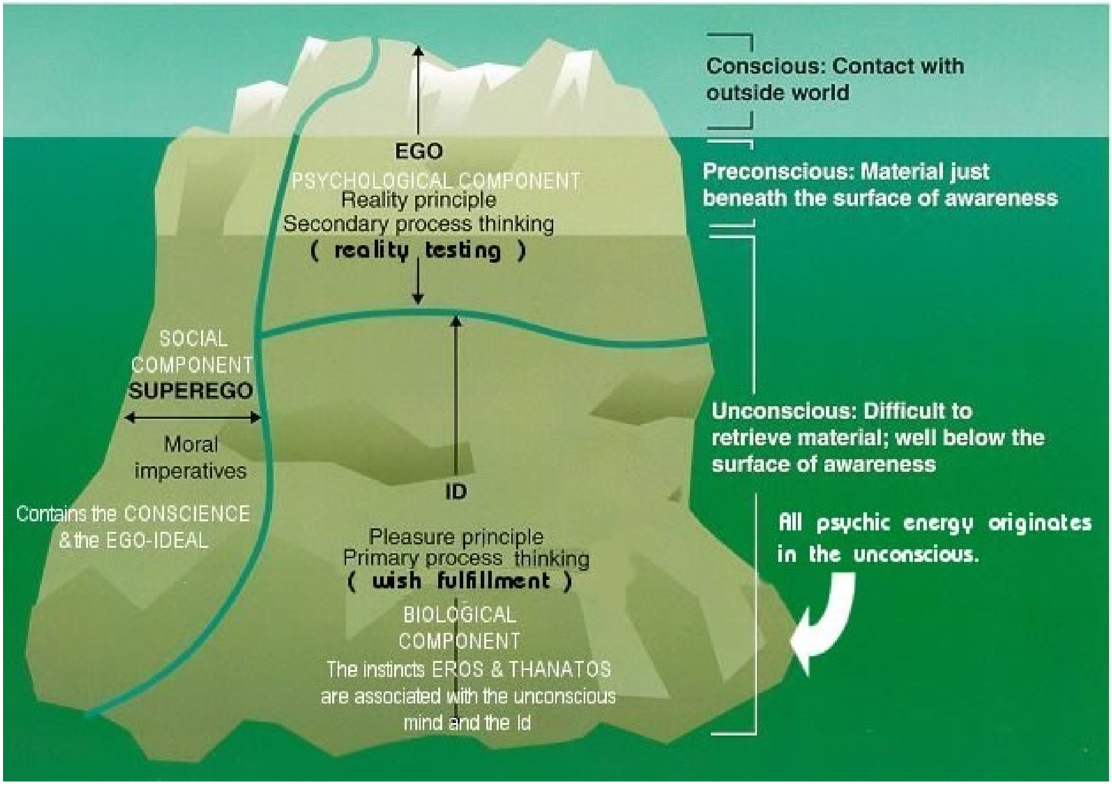


Figure 2.1: Freud's model of personality structure

Source: http://www.kheper.net/topics/psychology/Freud.html

Around 1956, George Miller showed that the human thinking is constrained by the capacity of short-term memory which is around seven elements, i.e. words, digits or letters (Thagard, 2005). He further proposed that this limitation can be overcome by recording information into chunks, mental representations that require mental procedures for encoding and decoding information. At this time, the primitive computers had been around for only a few years and John McCarthy, Mervin Minsky, Allen Newell, and Herbert Simon were founding the field of artificial intelligence which demands the need of knowledge representation. With these findings, the behaviorist ideas started to change dramatically.

Meanwhile, another group of researchers were analyzing the human brain to reveal its structure and function. The first important method for studying the brain was dissection (Thagard, 2005), in which brains were carefully cut apart to reveal their anatomical structure. However, this method did not reveal much about how it function (its physiology).

The next major step of insight into the physiology of the brain comes by the method of studying lesions (Thagard, 2005), which are injuries to specific parts of the brain, which can occur naturally or produced by cutting or burning. In 1875, Richard Caton reported the existence of electric current in the brain that varies with different stimuli presented. This helped researchers to develop machines to record brain's electrical activity and explain the physiology of the brain without making injuries.

The artificial intelligence research took a different path in achieving its main objective of human like decision making with the central assumption that intelligence is memory based. For more than several decades it analyzed the power of different approaches to knowledge representation (Thagard, 2005), such as rules (1960s), frames (1970s), schemas and scripts, mental images, code-base reasoning (1980s), and connectionist approaches. Out of the proposed approaches, the connectionist approach seemed to be different from other representations, because it was a computational modeling of neuronal structure of the brain. The main contribution of artificial intelligence can be found from the robotics literature (Murphy, 2000).

Until late 1980s, the prevalent approach in achieving intelligence in robots was the hierarchical paradigm. This method was heavily dependent on planning the actions simulating how humans plan a task before making any action. However, soon researchers realized that natural intelligence is too far from hierarchical intelligence approaches after exploring the biological sciences, such as behaviors of insects. As a result, around 1986, Brooks (1991) presented a technique called "subsumption architecture" for implementing intelligence for robot creatures without mental representation. Soon, robotics researchers tried to combine both of these concepts in a hybrid manner to get a better outcome from robots (Murphy, 2000).

The modeling of the abstract word comes under the scope of computing. The information under classical informatics (during 1940s) is a probabilistic measure of the quantity of messages that can be obtained from a message source via a transmission channel encompassing the domain of communication and coding theories (Wang, 2002). According to this definition, the quantity of information is dependent on the receiver's subjective judgment and if the content of a message is already known, there is no information. Again, the same message may have information for some people, and no information for others.

In the last three decades, the domain of information theories has been influenced by the developments of computer science and information technology. Rather than probabilistic measurements of messages, contemporary informatics tended to regard information as entities of messages. As a result, information in modern informatics is defined as any aspect of the natural world that can be abstracted, digitally represented, and mentally processed (digital bit vs. information bit).

During 1990s, the intellectual landscape started to change again. The technologies for recording and scanning the brain were maturing enough to identify activity in large brain regions and in single neuron cells with higher temporal and spatial resolutions (Thagard, 2005). Out of the technologies, EEG (Electroencephalograph) and fMRI (Functional magnetic resonance imaging) helped to identify the specific brain regions involved in various kinds of thinking.

Soon, researchers in many other fields realized that their collective effort is more effective than individually working towards specialized paths, realizing one of Newell's dreams (Anderson and Lebiere, 1998). The result of this effort was the reestablishment of cognitive science unifying the efforts of psychology (study of the minds of humans and other animals), philosophy (abstract and general questions such as the nature of representation and relation of mind and body), artificial intelligence, neuroscience (concerned directly with the nature of the brain), linguists (identify grammatical principles that provide the basic structure of human languages) and anthropology (expands the examination of human thinking to consider how thought works in different cultural settings). With this change, informatics theories rephrased and information under cognitive informatics focused on internal information processing mechanisms and processes of natural intelligence (Wang, 2002).

The field of cognitive modeling evolved to simulate human problem solving and mental task processes in a computerized model. These models are useful to simulate and predict human behavior or performance of tasks similar to the ones modeled. Examples for cognitive modeling architectures are ACT-R (by Anderson, 1993), SOAR (by Newell, 1991), 3CAPS (by Just & Carpenter, 1992), and EPIC (by Meyer & Kieras, 1997) (Anderson and Lebiere, 1998). Figure 2.2 shows that model prediction is very close to actual human data for the task of total time to complete dialing a mobile phone in different ways.

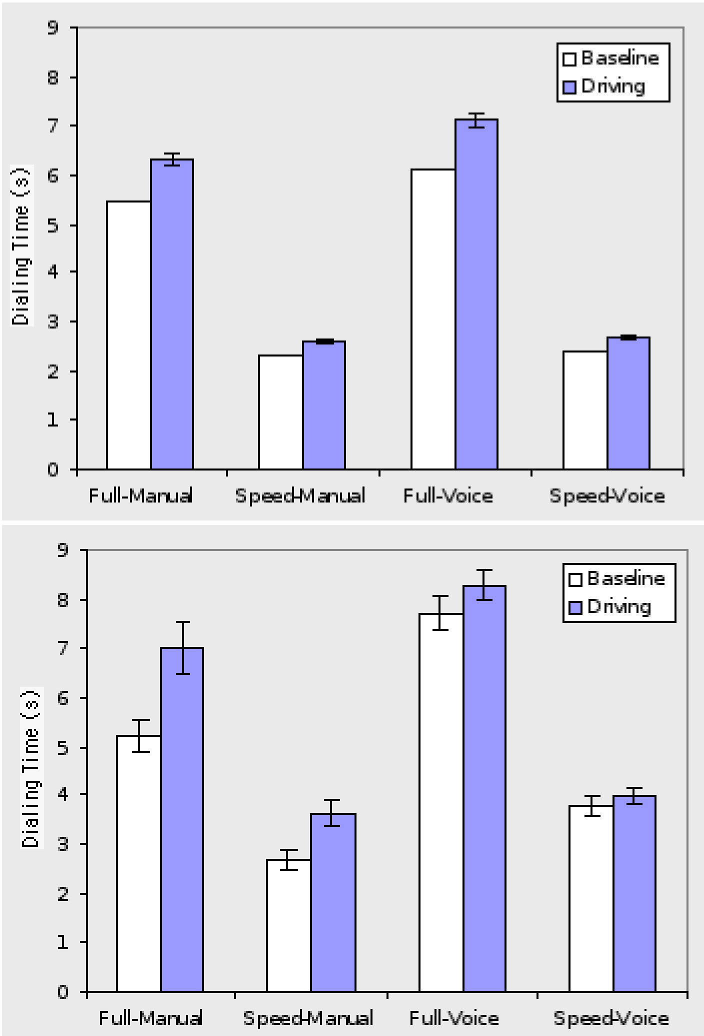


Figure 2.2: Evaluating ACT-R performance (top) against human data (bottom) for time to complete dialing of a mobile phone

Source: Introduction to ACT-R 5 Tutorial, Available at: http://act-r.psy.cmu.edu/

For more than half a century, machine learning in artificial intelligence focused on finding a rule set that efficiently characterizes a concept. Cognitive modeling differs from artificial intelligence approaches in that the focus is also on errors and speed, so the cognitive model also has to make the same errors people do, and show the same increase in performance due to practice (Taatgen, 2000). Chris Forsythe made the following comment in his regard,

"…the problem was that early models followed logical processes that humans don't always adhere to, and failed to take into account variables that affect human cognition, such as fatigue, emotion, stress, and distraction (TechTarget, 2006)."

Until recently, studying of emotions has been largely ignored under the cognitive science, seeing it as a side issue to the more central study of cognition (Thagard, 2005). The emotional studies have been conducted under Affective Computing (Affective Computing Group, 2006) which focus on computing that relates to, arises from, or deliberately influences emotions. A more detailed discussion of how emotions contribute to human cognition is discussed under the section 2.3.1.

2.2.2 Neuropsychology of Human Brain and Its Cognitive Functions

Based on Best, 1990; Gilbert, 2008; SEER, 2008; Bird, 2005; Chudler, 2008; Morris and Maisto, 2002; Chip, 2006, neurophysiology of human brain can be conceived as follows.

The brain is considered as the control center for every activity necessary for the survival of humans and other animals. The human brain is made up of approximately 100 billion neurons and trillions of other cells (glial cells). It weights around 1.4 kg, and it is the largest natural brain on the earth. The brain is part of the central nervous system (CNS) where the other part is the spinal chord (Figure 2.3). Although the brain and the spinal chord are considered two separate organs, both are connected in continuous sense.

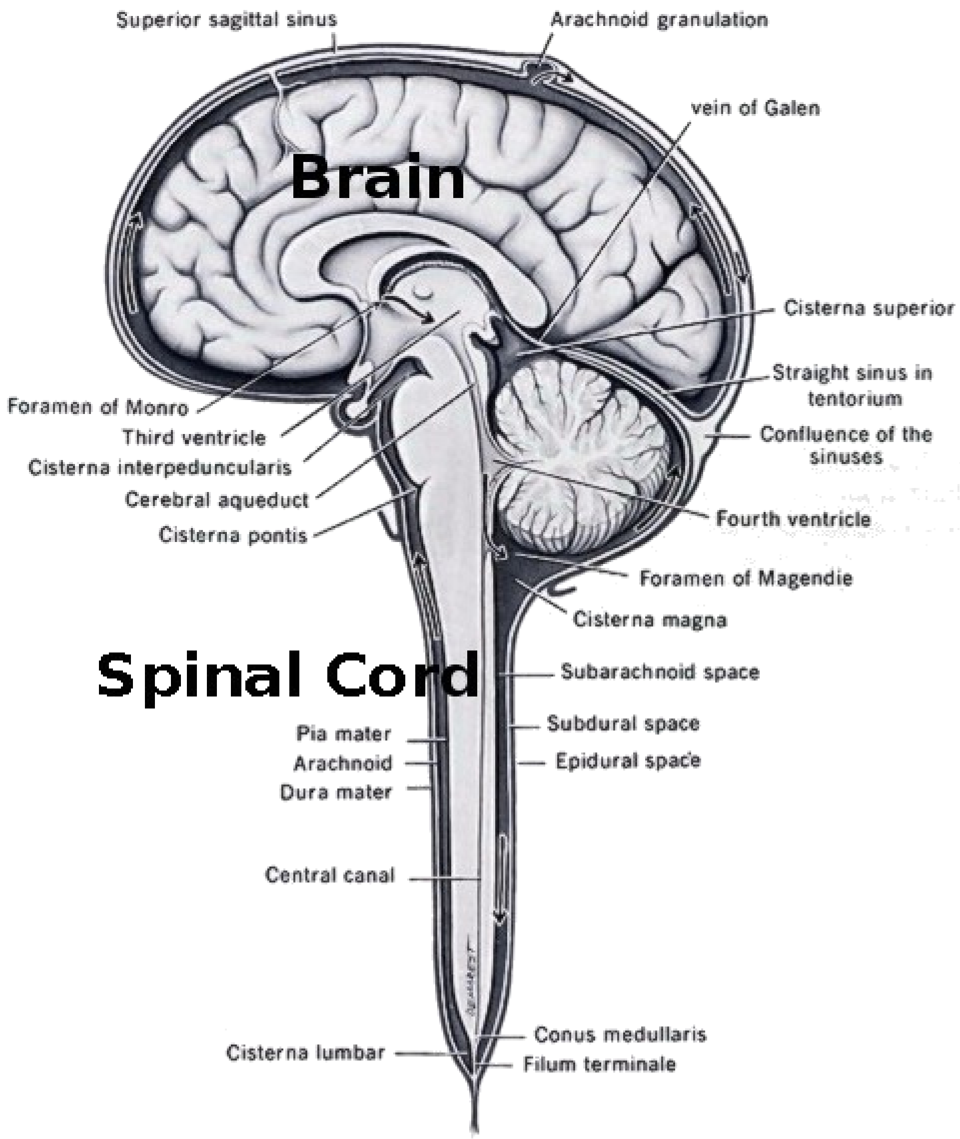


Figure 2.3: The parts of the central nervous system

Source: http://www.burtonreport.com/infspine/AdhesArachAnatomy.htm

The nervous system (NS) is a specialized network within animals responsible for receiving stimuli, transmitting nerve impulses, and activating muscles. The NS is composed of nerve cells, or neurons, where these neurons are interconnected to each other in complex arrangements, and conducts information to each other using electrochemical signals. Each neuron has a cell body (or soma) and the structures called dendrites and axons (Figure 2.4). The dendrites are involved in the neuron's reception of stimuli and conducting the information to the cell body. The nerve cell body is the primary site for maintaining the life of the nerve cell and sending received information out through the axon. The axon is a single long extension (can be up to 4 meters in length) involved in conducting nerve impulses away from the nerve cell to the axon terminals. A group of axons bundled together makes up a nerve.

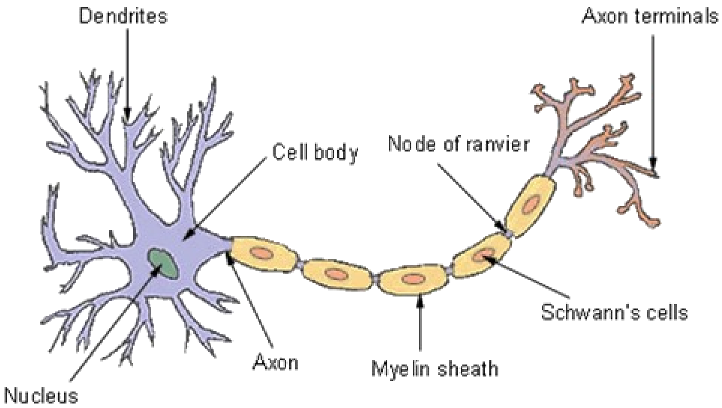


Figure 2.4: The structure of a typical neuron

Source: http://www.web-books.com/elibrary/medicine/Physiology/Nervous/Nervous.htm

Three different types of nerve cells exist for specialized, but overlapping, functions: sensory, motor, and intergrative (Figure 2.5). The sensory (afferent) neurons exist outside the CNS where the primary function is to detect changes, called stimuli, which occur outside and inside the body, such as temperature, light, sound, pH value, and CO_2 concentration, and transmits to the CNS. The interneurons (association) exist within the entire CNS, with many interconnections, connecting sensory neurons and motor neurons as well as producing thought, memory, and other cognitive functions. The motor (efferent) neurons transmit motor impulses from the CNS to effectors, such as muscles and glands.

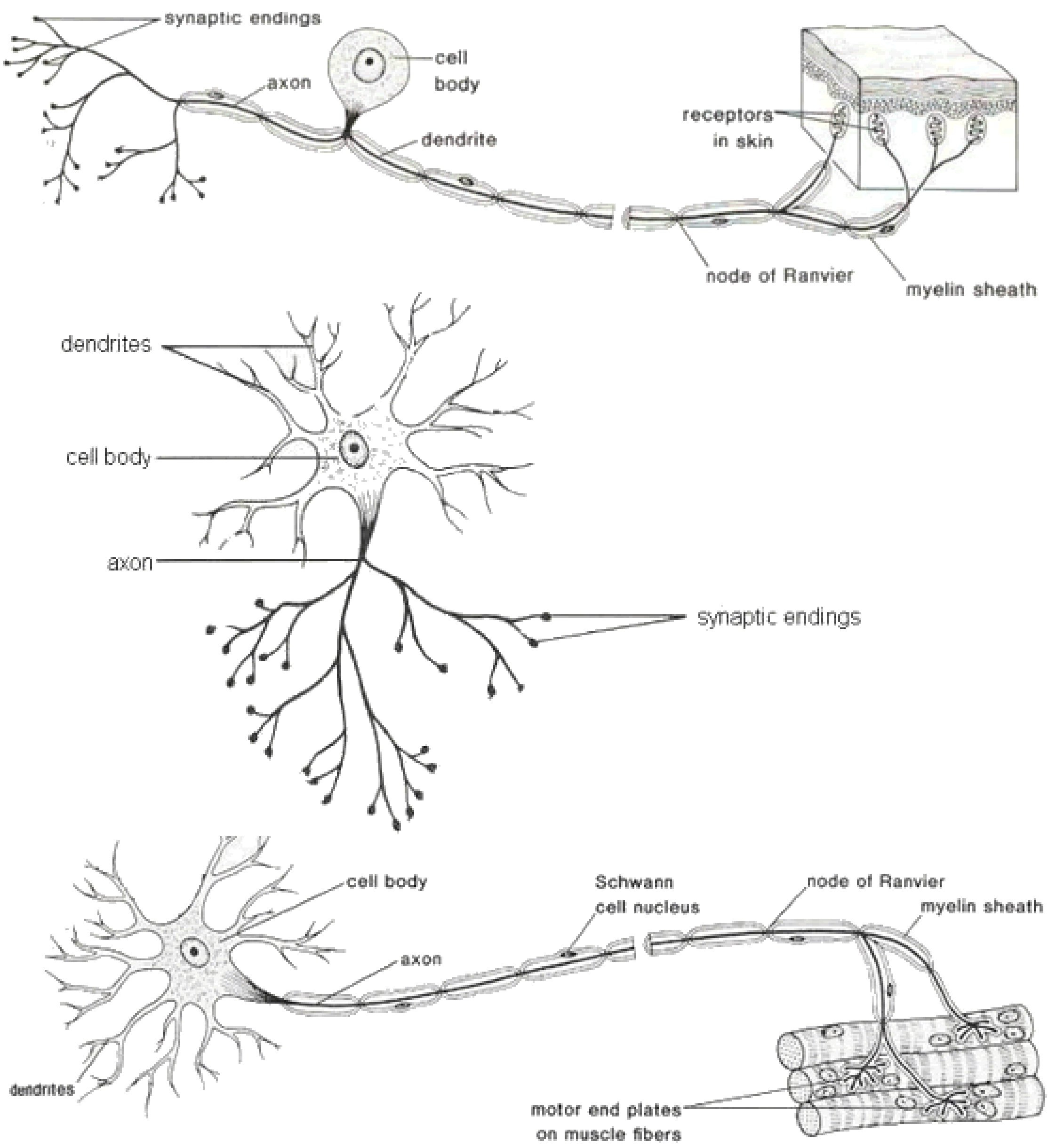


Figure 2.5: The three types of neurons: a sensory neuron (top), an interneuron (middle), and a motor neuron (bottom)

Source: http://www.biologymad.com/NervousSystem/nervoussystemintro.htm

The nerve impulse can be passed from the axon of one neuron to the dendron of another neuron at a specialized junction called synapse using neurotransmitters and enzymes (Figure 2.6). The synapse operates as an on/off switch and as a filter for information flow.

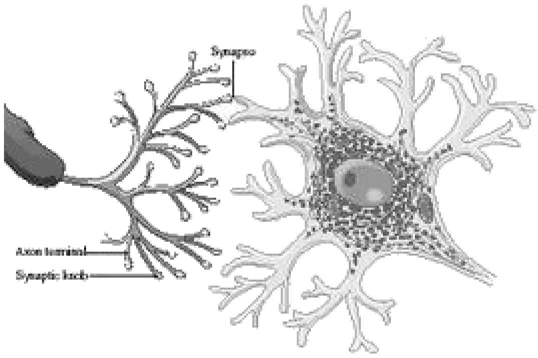


Figure 2.6: A synapse junction

Source: http://www.faqs.org/health/Body-by-Design-V2/The-Nervous-System.html

When a neuron is at rest, a slightly higher concentration of negative ions exists inside the membrane, surrounded by the cell body, than outside resulting a negative potential relative to the outside (called resting potential or resting membrane voltage; Figure 2.7). When an incoming message is strong enough, an action potential is generated, and the neuron is depolarized (Figure 2.8). If the potential exceeds the minimum threshold of excitation, the neuron will fire.

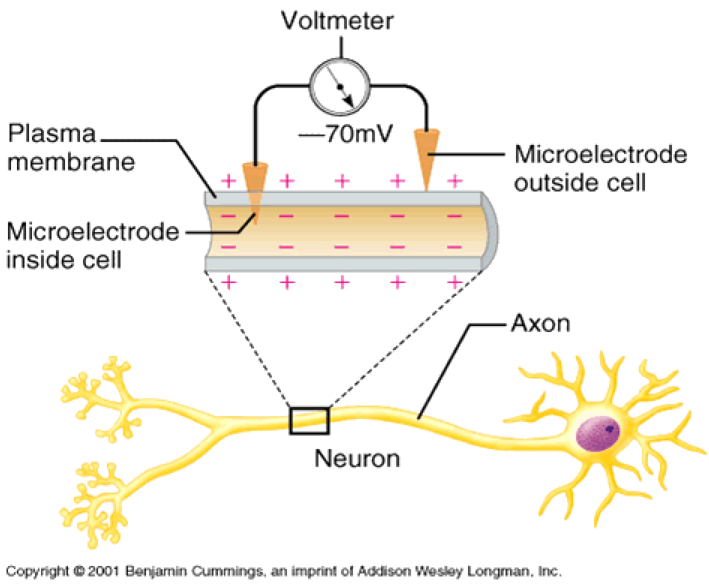


Figure 2.7: The resting potential of a neuron

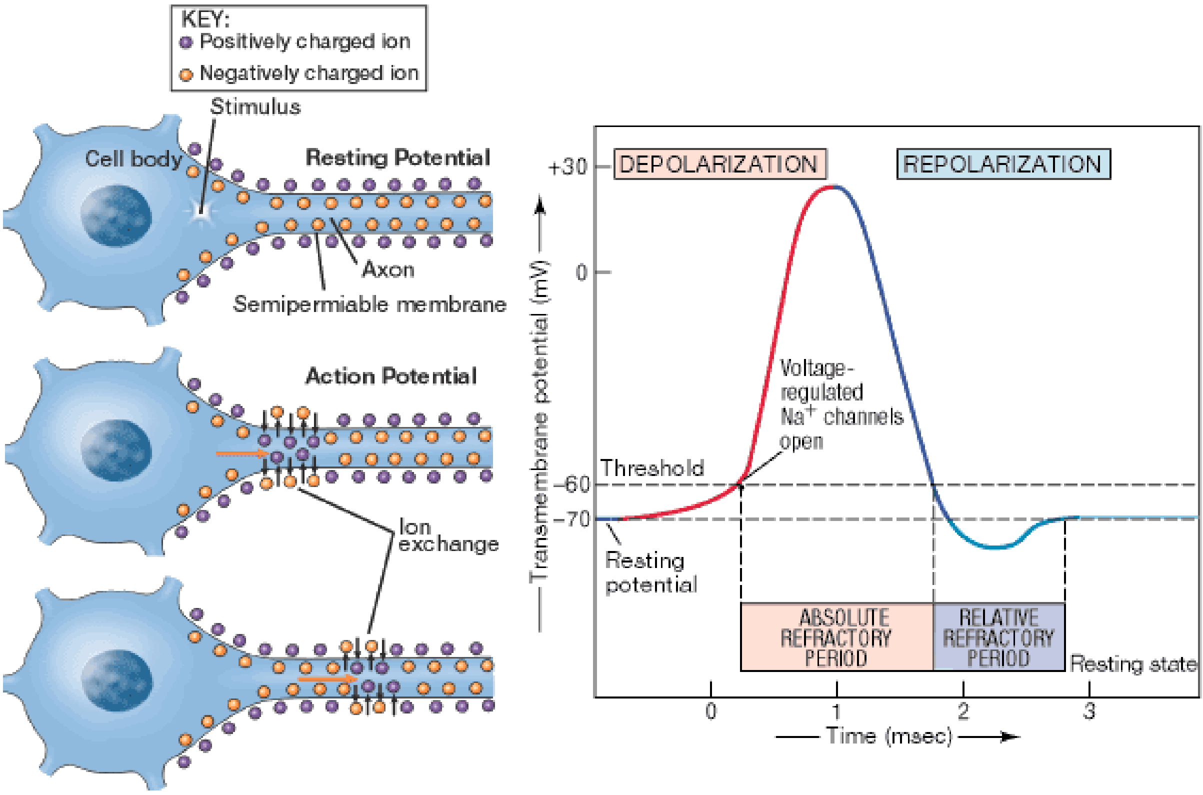


Figure 2.8: The action potential propagation (left) and the electric charge during neuron fire (right)

Source: http://cwx.prenhall.com/bookbind/pubbooks/morris5/chapter2/custom1/deluxe-content.html

The firing of a neuron causes the releasing of neurotransmitter molecules contained in the synaptic vesicles of axon terminals of that neuron. These molecules enter into the synaptic space and then into the dendrite of the receiving neuron and latch on to a receptor site (similar to a key fits into a lock; Figure 2.9).

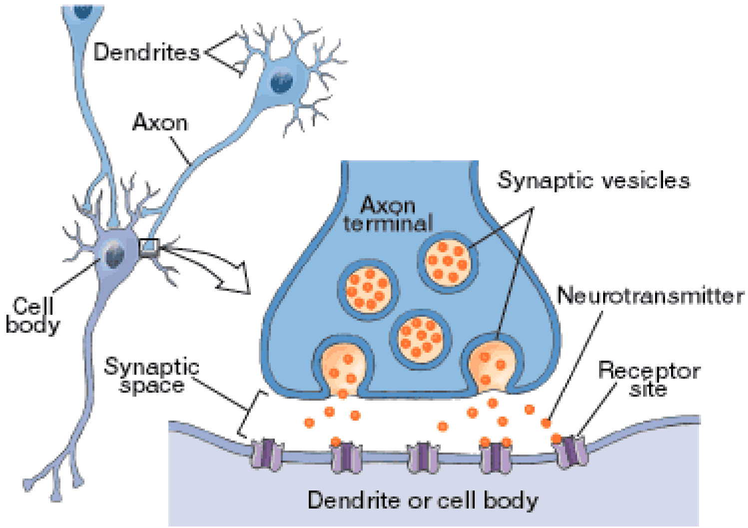


Figure 2.9: The synaptic transmission

Source: http://cwx.prenhall.com/bookbind/pubbooks/morris5/chapter2/custom1/deluxe-content.html

The firing may cause excitatory or inhibitatory effects on receiving neurons. The excitatory effects are initiated by excitatory neurotransmitters, such as acetylcholine, which encourages the receiving neuron to emit an action potential. The inhibitatory effects are initiated by inhibitatory neurotransmitters, such as gamma amino-butyric acid, which discourages the receiving neuron from emitting an action potential. A typical neuron may fire hundreds of times per second.

The spike train of a neuron is its pattern of firing or not firing over a period of time, for instance the pattern 1100010110 at a firing rate of 3 fires per second is such a pattern. It is believed that the representational and computational power of neurons is contained at groups of neurons representing concepts and their relations and the spike trains which transmit information (Thagard, 2005).

The nervous system (NS) of humans is organized into two parts: the central nervous system (CNS), which consists of the brain and the spinal chord, and the peripheral nervous system (PNS), which connects the CNS to the rest of the body. The organization of the NS is shown in Figure 2.10.

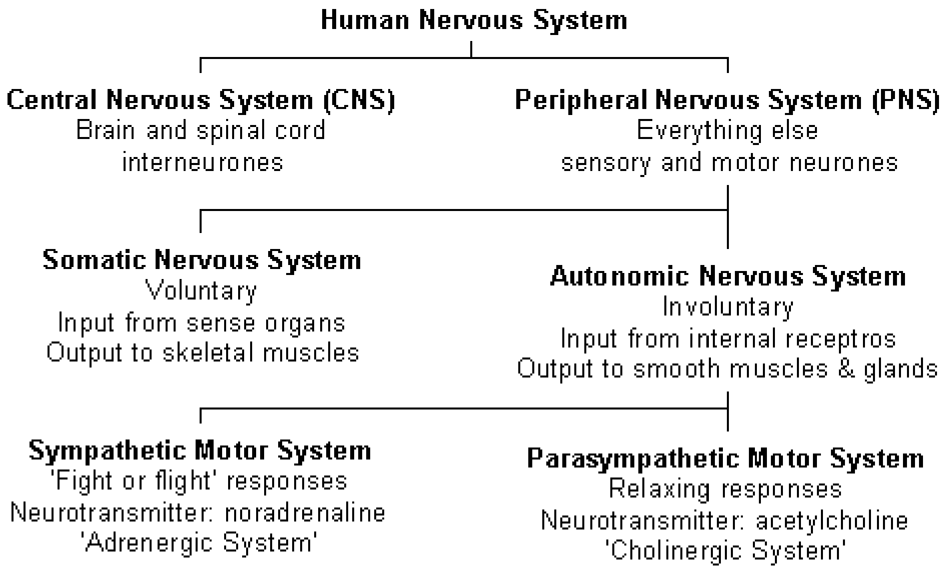


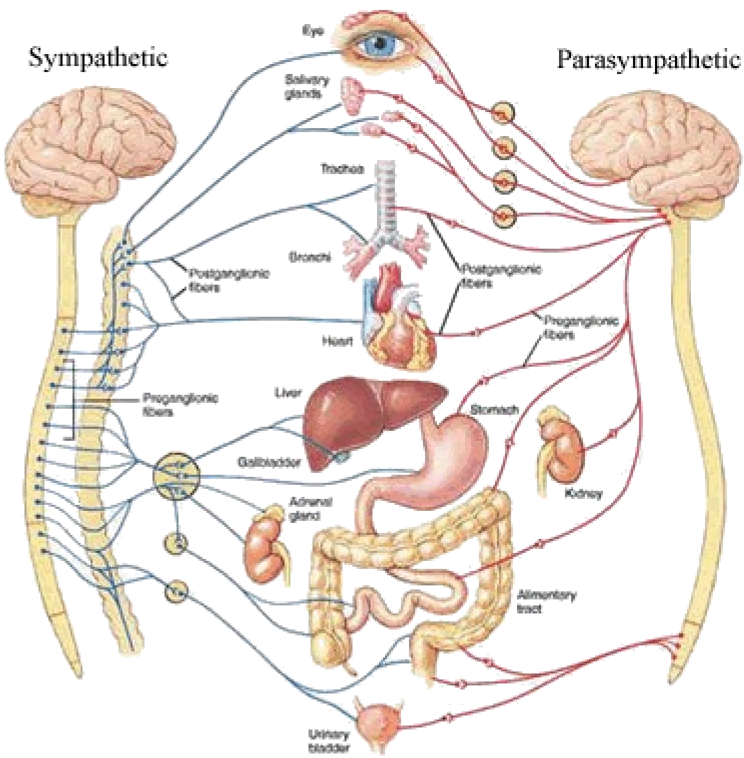
Figure 2.10: The organization of the human nervous system

Source: http://www.biologymad.com/NervousSystem/nervoussystemintro.htm

The PNS consists of the nerves branches out from the brain and the spinal chord. The PNS is further subdivided into somatic nervous system (SNS) and autonomic nervous system (ANS). The SNS consists of nerves that go to the skin and muscles and is involved in conscious (voluntary) activities. The ANS consists of nerves that connect the CNS to the visceral organs such as the heart, stomach, and intestines mediating unconscious (involuntary) activities.

The ANS has two parts, the sympathetic division and the parasympathetic division. Most body organs are innervated by motor neurons from the sympathetic ANS and parasympathetic ANS. The neurons from the sympathetic division stimulate the “fight or flight” responses (arouse the body) in threatening situations, for instance speeds up the heart rate, and the neurons from the parasympathetic division inhibit the sympathetic behaviors (relaxes the body). Figure 2.11 summarizes the ANS responses to body organs.

The CNS is the coordinator of all the behaviors of a living creature. The simplest behavior of the CNS is observed when three types of neurons, a sensory neuron, an interneuron, and a motor neuron, arranged in a circuit forming a reflex arc, such as the knee jerk. Figure 2.12 shows the nerve arrangement of its process.



Organ	Sympathetic System	Parasympathetic System
Eye	Dilates pupil	Constricts pupil
Tear glands	No effect	Stimulates tear secretion
Salivary glands	Inhibits saliva production	Stimulates saliva production
Lungs	Dilates bronchi	Constricts bronchi
Heart	Speeds up heart rate	Slows down heart rate
Gut	Inhibits peristalsis	Stimulates peristalsis
Liver	Stimulates glucose production	Stimulates bile production
Bladder	Inhibits urination	Stimulates urination

Figure 2.11: The sympathetic and parasympathetic effects for body organs

Source: http://www.biologymad.com/NervousSystem/nervoussystemintro.htm

The most important component of the CNS is the brain and it contains more than 90% of the body's neurons. The brain has three distinct areas: the hindbrain, the midbrain, and the forebrain. The hindbrain is found in even the most primitive vertebrates and it is made up of the cerebellum, the pons, and the medulla oblongata. All the ascending (sensory) and descending (motor) nerve fibers connecting the brain and the spinal cord pass through the medulla. In addition, it is the point at which many of the nerves from the left part of the body cross to the right side of the brain and vice versa. The medulla is also responsible for controlling involuntary functions such as breathing, blood pressure, coughing, and heart rate.

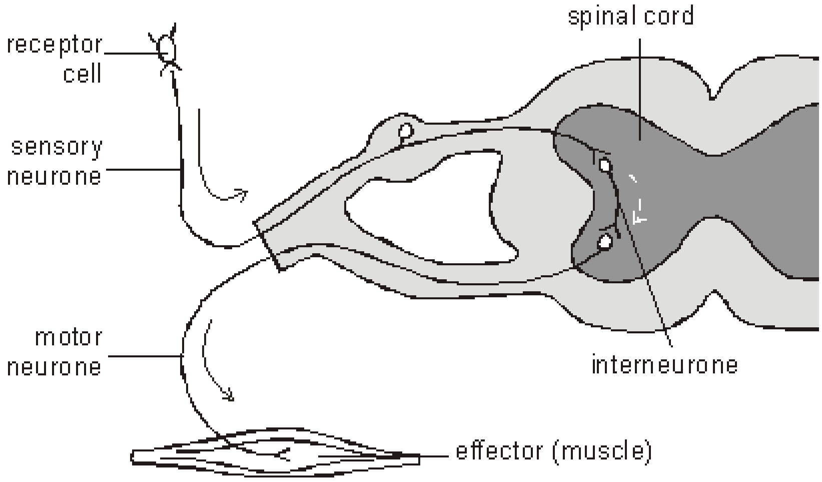


Figure 2.12: The neuron arrangements of a reflex arc

Source: http://www.biologymad.com/NervousSystem/nervoussystemintro.htm

The pons, located just above the medulla, connects nerve fibers from the top of the brain (cerebral cortex) to the cerebellum. It also helps to maintain the sleep-awake cycle of animals. The cerebellum has two hemispheres and it is primarily responsible for maintaining the balance of the body, coordinating voluntary muscle movements, and fine tuning motor skills. The midbrain lies between the hindbrain and the forebrain and is crucial for hearing and sight. The midbrain, pons, and the medulla are all parts of the brain stem (Figure 2.13).

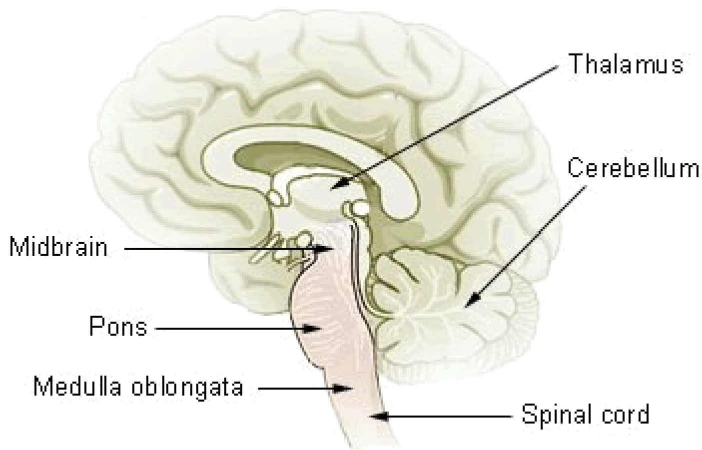


Figure 2.13: The parts of the brain stem

Source: http://www.web-books.com/elibrary/medicine/Physiology/Nervous/Nervous.htm

The forebrain is supported by the brainstem and consists of the thalamus, the hypothalamus, and the cerebral cortex. The thalamus is the switching station for sensory inputs (excepts smell) and it relays these information to the cerebral cortex for further processing. The hypothalamus is a small region is the brain and it is responsible for maintaining homeostasis of the body, for instance, if the person feels too hot, the hypothalamus detects this and then sends a signal to expand the blood capillaries in the skin. The thalamus, the hypothalamus, and another organ called the epithalamus are all parts of the diencephalons (Figure 2.14). The epithalamus is a small gland involved with the onset of puberty and rhythmic cycles in the body (like a biological clock).

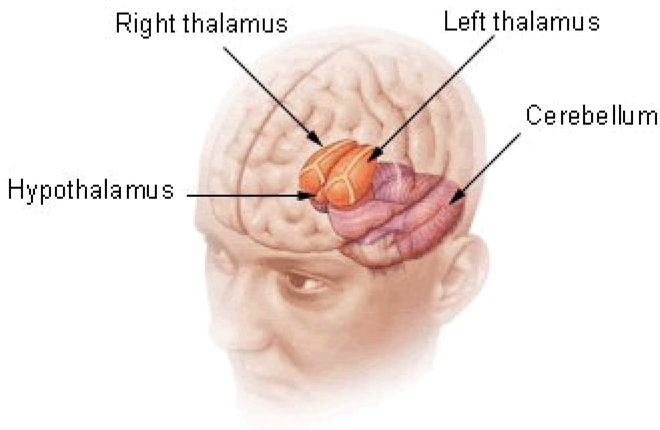


Figure 2.14: The parts of the diencephalon

Source: http://www.web-books.com/elibrary/medicine/Physiology/Nervous/Nervous.htm

The cerebral cortex (cerebrum) is the most recently evolved and most complex part of the brain. It is where the intelligence emerges, all the cognitive functions (learning and judgment) happen, and all the conscious (voluntary) activities are controlled. It owes 85% of the weight of the brain.

The cerebral cortex is divided by a deep longitudinal fissure into two cerebral hemispheres: left and right. These two hemispheres are connected by an arching band of white fibers, called the corpus callosum that provides a communication pathway between the two halves. Each cerebral hemisphere is divided into four lobes: the frontal lobe, the parietal lobe, the occipital lobe, and the temporal lobe (Figure 2.15).

The occipital lobe is located at the back of the brain and processes visual information. The parietal lobe contains the primary sensory cortex through which sensations, such as touch and pressure are felt, and figures in spatial abilities are received. The temporal lobe is where auditory perception and sense of smell is originated. It also processes complex visual tasks and memory, such as recognizing faces. The frontal lobe is the part which is responsible for voluntary movements and attention as well as goal-directed behavior. Figure 2.16 shows these divisions and their specialized functions.

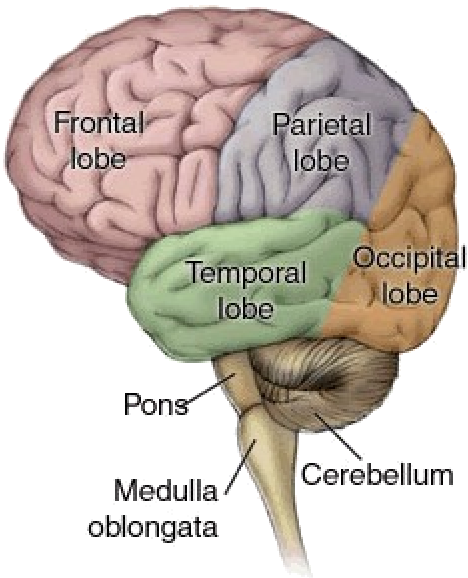


Figure 2.15: The lobes of the cerebral cortex

Source: http://www.ahaf.org/alzdis/about/AnatomyBrain.htm

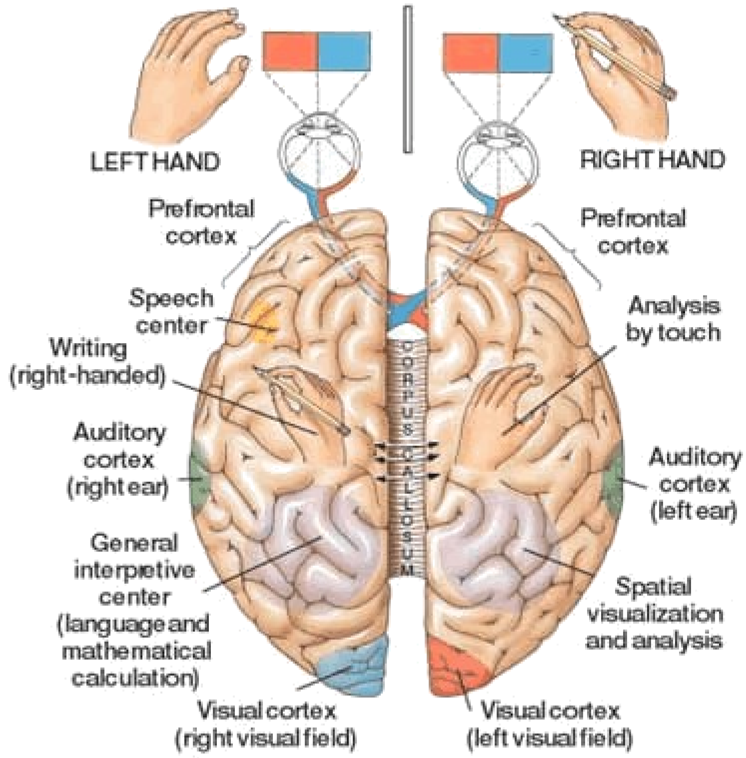


Figure 2.16: The left and right hemispheric functions

Source: http://cwx.prenhall.com/bookbind/pubbooks/morris5/chapter2/custom1/deluxe-content.html

The memory and learning are regarded as most essential supportive processes for cognitive functions. The modal model of memory, proposed in 1960s, distinguishes kinds of memory according to the length of time information is stored, how the information is received, processed, and stored (Galotti, 2004). The information is first received to the sensory memory where the unattended information is held only briefly. The attended information is held in the short-term memory (STM) for periods of up to 20 to 30 minutes. The information needed for longer periods of time is transferred to the long-term memory (LTM). Figure 2.17 depicts the modal view of memory.

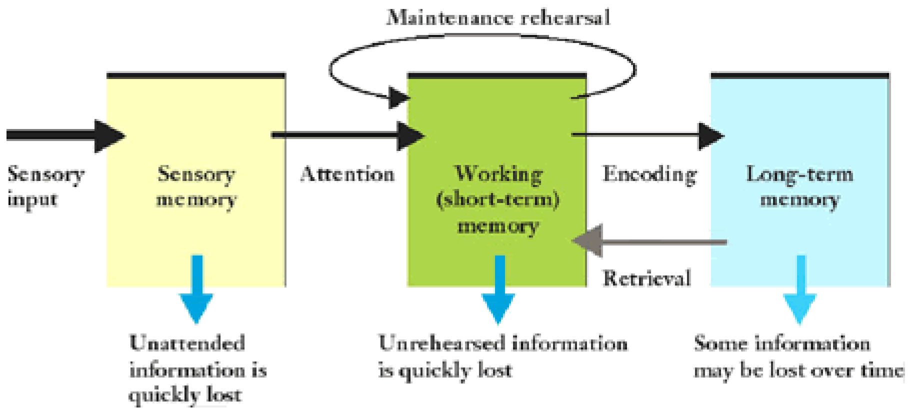


Figure 2.17: The modal view of memory

Source: http://www.usu.edu/psycho101/lectures/chp9memory/memory.htm

Many cognitive psychologists believe that separate sensory memories exist for each sensory modality: visual, auditory, olfactory, gustatory, and tactile. Different sensory memories store their received sensory information differently. For example the sensory memory for a visual material is referred as an icon, and the icon is held at the visual sensory memory for up to about 150 to 200 milliseconds. The echo is the sensory memory for an auditory material.

The short-term memory holds limited amount of information for a period of minute or two. However, this period can be extended up to a day. George Miller in 1956 reviewed evidence demonstrating that if a person is presented a string of random digits (or any kind of unrelated pieces of information), that person will be able to recall them only if the string contains about five to nine digits. This limitation can be overcome through the technique known as chunking, which requires some knowledge about the pieces of information and how they relate.

Forgetting of information is explained through decay and interference. The decaying of memory starts as soon as the person stops rehearsal of information held at the STM for more than 20 seconds. The interference is the displacement of materials already held at the STM with newer materials.

A newer conception of STM, proposed by Alan Baddeley in 1990, is called working memory. The working memory is thought to consist of a central executive, concerned with coordinating and controlling incoming information; a phonological loop, acting as an inner “ear”; and a visuospatial sketch pad, used as an inner “eye” (Figure 2.18). Researchers think the phonological loop plays an important role in tasks, such as learning to read, comprehending language, and acquiring a vocabulary. The visuospatial sketch pad involves the creation and use of mental images.

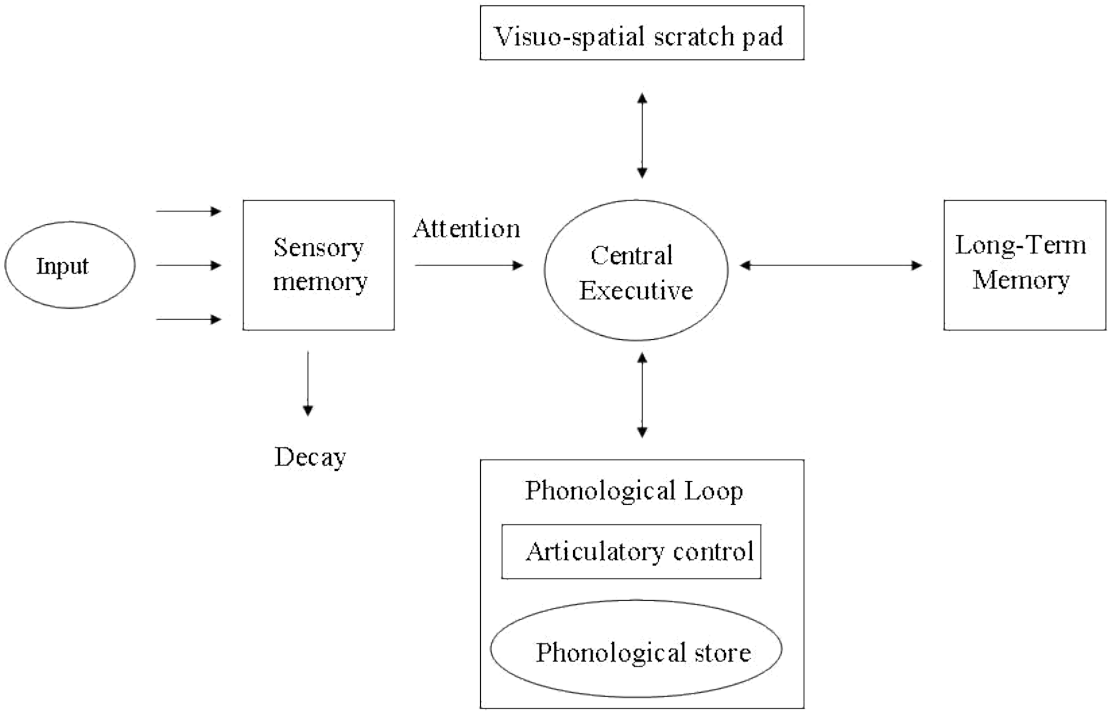


Figure 2.18: The Baddeley’s model of working memory

Source: http://www.simplypsychology.pwp.blueyonder.co.uk/working%20memory.html

Recent psychological studies conducted by Eagle (Galotti, 2004) suggests that working memory capacity is a powerful variable, relating to the ability to resist distraction and distortion, to reason with abstract or concrete premises, and to maintain control of attention more generally. Neuropsychological studies of memory processes identify hippocampus and medial temporal cortex areas as main components involved in memory formation. Again, different activation patterns have been reported for verbal working memory (in the left frontal and left parietal lobes) and for spatial working memory (in the right parietal, temporal, and frontal lobes).

The formation of long-term memory is explained through the mechanisms called Hebb rule and long-term potentiation. The Hubb rule states that if a synapse between two neurons is repeatedly activated at about the same time the postsynaptic neuron fires, and the structure or the chemistry of the synapse changes. The long-term potentiation is that the neural circuits in the hippocampus that are subjected to repeated and intense electrical stimulation develop hippocampal cells that become more sensitive to stimuli.

Literature discusses different types of long-term memories, such as autobiographical memory, flashbulb memory, and eyewitness memory (Galotti, 2004). Among them, flashbulb and eyewitness memories are formed under intense emotional events.

2.2.3 Theoretical Aspects of Attention

Most people know how hard their first driving experience was. However, after some time, they become somewhat automatic with the driving task and try to do lot of other tasks while driving, such as, listening to a radio or talk with others (Figure 2.19).

Figure 2.19: The attention when driving a car

Source: http://www.edmunds.com/reviews/list/top10/117028/article.html

Cognitive psychologists were studying how people are paying attention for more than half a century. These studies primarily concerned with cognitive resources and their limitations (Galotti, 2004). At any given time, they believe, people have only a certain amount of mental energy to devote to all the possible tasks and all the incoming information confronting them. If they devote some portion of those resources to one task, less is available for others. The more complex and unfamiliar the task, the more mental resources must be allocated to that task to perform it successfully.

More conscious attempt of attention is known as selective attention, where it refers to one's attempt to focus the attention on one or few tasks or events rather than on many. A well known experimental setup for studying the selective attention is the dichotic listening task (Figure 2.20). In this experiment, a participant is presented two different messages to hear simultaneously for opposite ears and asked to repeat one of the messages (this becomes the attended message). The following list summarizes the important findings of that experiment:

- People can shadow the attended message, but they can not recall the content or language of the unattended message. However, they could report whether it is a speech or noise and, if speech, whether the voice was that of a man or a women (reported by Cherry in 1953).
- When the two messages contained little information, or presented information slowly, people could process both messages simultaneously (reported by Broadbent in 1958).
- Shadowing performance is disrupted when one's own name is embedded in either the attended message or unattended message, referred to as "cocktail party effect" (reported by Moray in 1959).
- If the content of the two messages switched the ears in the middle of the session, participants repeated few words from the unattended ear (reported by Treisman in 1960).

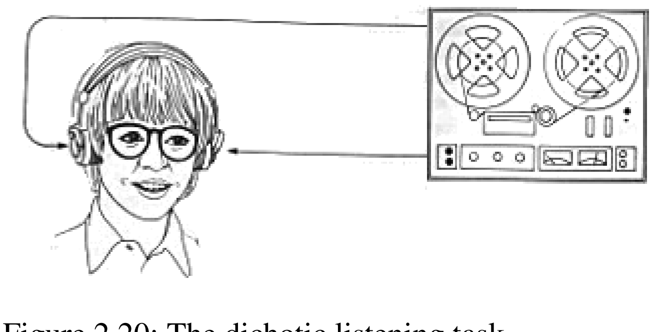


Figure 2.20: The dichotic listening task

Source: http://penta.ufrgs.br/edu/telelab/2/lec2.htm

To explain the above findings, initially, Broadbent (in 1958) proposed the filter theory of attention. Filter theory states that there are limits on how much information a person can attend to at any given time. Therefore, if the amount of information available at any given time exceeds capacity, the person uses an attentional filter to let some information through and to block the rest (Figure 2.21).

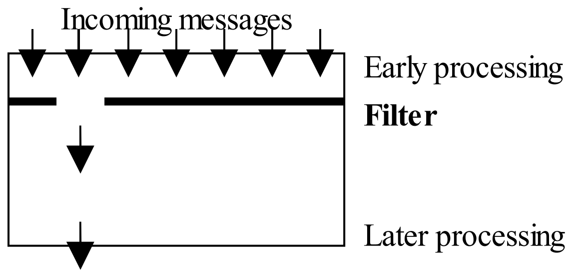


Figure 2.21: The filter model of attention

According to Broadbent's filter theory, the meaning of the unattended message is not processed. However, this idea was contradictory to the "cocktail party effect" and later it was explained after discovering that one's attention occasionally lapses and shifts to the unattended message. After Treisman's finding, the latter explanation modified and proposed that participants must be basing their selection of which message to attend to at least in part on the meaning of the message, referred as the late-selection theory. Later, in 1995, Wood and Cowan reported that the shift of attention to the unattended message is unintentional and completed without conscious awareness.

Some investigators, such as Johnson and Dark, compare attention to a spotlight that highlights whatever information the system is currently focused (Galotti, 2004). According to this spotlight metaphor, shift of attention requires a mental effort. In ACT-R production system theory, the shift of visual attention is controlled by explicit firings of production rules, simulating the mental effort required (Anderson, et al., 1995). However, spotlight metaphor has many shortcomings (Galotti, 2004); for example, it assumes that the attention is always directed at a specific location, which may not be the case.

Few other studies focused on how stimulus features, such as color and size, affect the performance in visual attention. These findings suggest that search in a visual field is not aided by attending to a particular stimulus feature, rather, items that possess the attended features results in the prioritization of those items in that visual field (Moore and Egeth, 1998).

Kahneman, in 1973, presented somewhat complex and more process oriented model for attention and mental effort as shown in Figure 2.22 (Galotti, 2004). He viewed attention as a set of cognitive processes for categorizing and recognizing stimuli. The more complex the stimulus, the harder the processing, and therefore more resources are engaged.

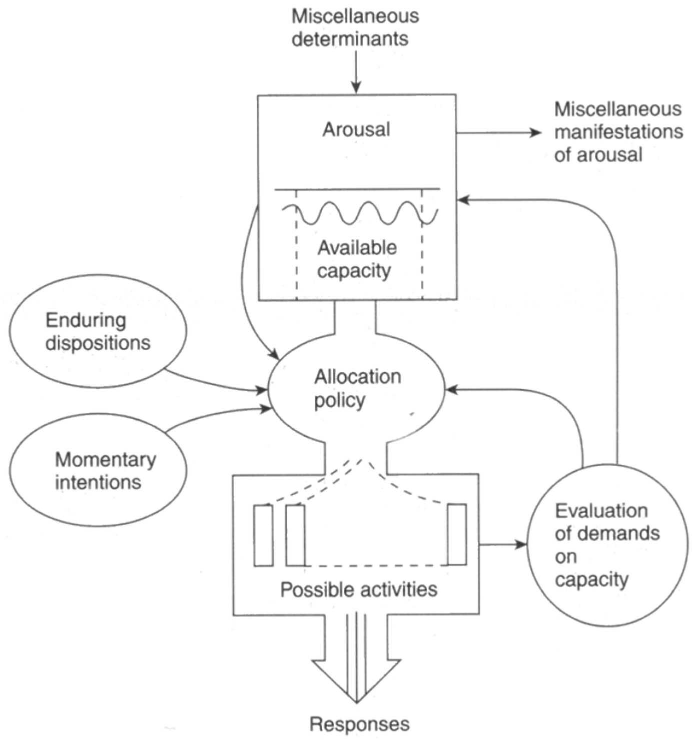


Figure 2.22: Kahneman's model of attention and effort

Source: http://www2.fhs.usyd.edu.au/ess/odwyer/Human Motor Learning and Control/Lectures/Week 5/Attending_to_Information.htm

The availability of mental resources in the Kahneman's model is affected by the overall level of arousal. If the arousal is too high or too low, a smaller amount of capacity is available than if it is at the optimal level of arousal. On the other hand, the level of arousal also depends on a task's difficulty (a paradox!). A detailed discussion of arousal and its affect is presented in the section 2.3.2. The allocation of available mental resources to cognitive tasks depends on many factors and it is labeled "allocation policy" in the model. This policy is affected by the following factors:

- Basic rules for involuntary attention known as enduring depositions, e.g. a loud noise or hearing one's own name at a crowed party.
- Selective attention to specific aspects of a situation named momentary intensions, e.g.

a mother wants to find his child in a party, before doing anything else.

- Evaluation of demands on one's capacity or the knowledge that a task one need to do right now will require a certain amount of one's attention.

Studies focused on recording brains electrical activity, such as EEG, have reported the existence of event-related potential (ERP) after presentation of a stimulus (Galotti, 2004; Rice, 2008). Figure 2.23 shows an ERP recording.

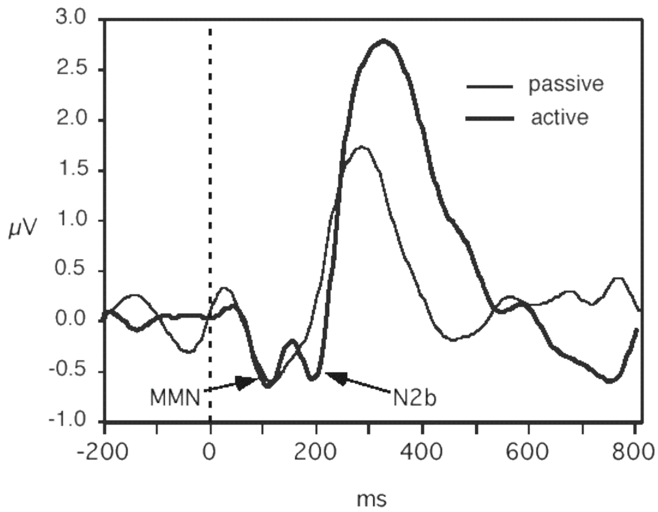


Figure 2.23: ERP waveforms from the scalp over auditory cortex areas

Source: http://psych.rice.edu/mmtbn/attention/attention/attention.html

Such ERP waveforms comprised of different peaks at different times relative to the stimulus. Depending on the polarity and the latency, these peaks represent different stages in the process. Thus, the first positive peak (called P1 or P100) in the visual ERP occurs at about 100 ms after the stimulus, the first negative peak (called N1 or N180) at about 180 ms after the stimulus, and so on. Early components in the waveform represent low-level perceptual processes while the signal traveling from sensory receptors to the brain areas, and later components (usually after 80 ms from the stimulus) represent higher-level cognitive operations at the cerebral hemispheres.

The model view of memory (refer section 2.2.2 for a detailed discussion) suggests that unattended information presented quickly is stored only briefly in the sensory memory while attended information is held in working memory for longer periods. In the Baddeley's model the central executive plays a major role concerned to attention. It is also thought to coordinate information coming from the current environment with the retrieval of information about the past. Baddeley has equated this coordination with conscious awareness.

Gibbs and Habeshaw (1992) describe how attention varies against time when people carryout a passive task for a very long period (Figure 2.24). When a person is involved in a passive task for a longer period, for instance a student involved in learning session, the tendency is that the person loses his/her attention on the task. In learning, the active participation of the student is regained through introducing lecture breaks at the end of each 10-20 minutes duration of a passive task.

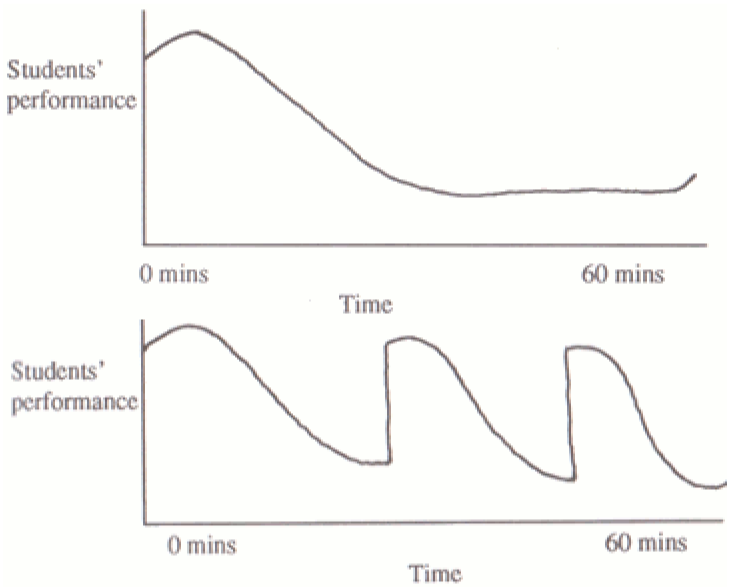


Figure 2.24: Learner's attention respect to passive learning (top) and active learning (bottom)

2.3 Studies of Emotion

Emotion is a more complex processing mechanism exist within highly developed biological creatures. The role of emotion varies from protecting those creatures from external threats to supporting cognitive functions. This section of the chapter elaborates discussions concerning the role of emotion, how they are processed in biology, and attempts to computationally model the mechanism.

2.3.1 Why Emotions are Studied and What are Emotions?

Until recently, studying of emotions has been largely ignored by the cognitive science communities thinking it as a minor side issue to cognitive studies. However, as the contributions of emotions to rational decision making has been revealed, now emotions are considered as an integral component in cognition. Currently, emotions are being largely studied in behavioral programming after seeing its plausibility of achieving autonomy in cognitive agents. Thagard (2005) and Davis (2000) review a large literature on emotional studies.

Emotional concepts date back to Plato where he has viewed emotion as a distraction or impediment to effective thought. Merleau-Ponty supposed humans are moved to actions by disequilibria between the self and the world. In this effort, emotion is a prime source of motivation, and plays a large role in initiating and providing descriptors for these disequilibria.

All humans are aware of emotions from their feelings and other observable changes of their bodies, such as facial expressions and tone of voice. Literature suggests that the nature of emotions is falling into two categories; cognitive judgments about one's general state and bodily reactions. The nature of judgment in emotions is contributions to the cognitive functions including motivations to goal accomplishment, memory processing, deliberative reasoning, and learning. Among those, valencing of thoughts related to emerging problems, tasks, and challenges, for example directing attention to aspects of internal and external environments that relate to current and important motivational interests, is mostly appreciated. Empathy is also a judgment where someone develops a mapping between someone else's situation to get the same emotional experience.

Wollheim (Davis, 2000) describes emotions as preconscious mental dispositions which cannot be directly experienced. What can be consciously experienced is feelings (mental states) associated with mental dispositions. A mental state, such as impulses, drives, and perceptions, is a short-lived state of the mind temporally local to its initiating event or transit. Mental dispositions are temporally global and more long-lived with histories. Beliefs, knowledge, memories, abilities, phobias, and obsessions are examples for mental dispositions. Both can be casually interrelated and affects each other.

Bodily reactions of emotions are of two forms; expressions and physiological signals. Expressions are recognizable to the outside agents as expressions of face, tone of voice, and gesture. However, these expressions are more or less controllable to the agent and can easily be faked. Physiological signals caused by emotions are spontaneous changes in the body and less controllable to the agent. These signals can be divided into two categories: those originating from peripheral nervous system (e.g. skin conductivity, heart rate, blood volume pressure, and electromyogram) and those coming from central nervous system (e.g. electroencephalogram) (Davis, 2000; Chanel, et al., 2006; Niemic, 2004). Arousal corresponds to more increased physiological changes of body. A more in-depth discussion is included under the section "psychophysiology of emotions".

All the emotions felt in an instant can be combined to describe an emotional state of a biological agent. Literature suggests that valence (i.e. pleasant or unpleasant), arousal (i.e. aroused or unaroused), and appraisal (cognitive reflection of the valence) are used as the primary basis for describing an emotional state (Davis, 2000; Chanel, et al., 2006; Thagard, 2005). The valence is subjected to events (pleased vs. displeased), actions of agents (approving vs. disapproving), and objects (liking vs. disliking) (Bécheiraz and Thalmann, 1998; Davis, 2000). The following are the currently agreed semantically distinct basic emotions resembling the appraisal manifest of cognitive judgment (Davis, 2000):

- Fear defined as the physical and social threat to self, or a valued role or goal.
- Anger defined as the blocking or frustrations of a role or goal through the perceived actions of another agent.
- Disgust defined as the elimination or distancing from person, object, or idea repulsive

to self and to valued roles and goals.

- Sadness defined as the loss or failure of a valued role or goal.
- Happiness defined as the successful move towards or completion of a valued role or goal.

The above basic emotions provide ingredients for more complex emotions, such as guilt, pride, shame, and jealousy (Hudlicka, 2004). Emotions are rather continuous phenomena having its final intensity determined by personality factors openness, conscientiousness, extraversion, agreeableness, and neuroticism (Chittaro and Serra, 2004; Thurstone, 1934). Most studies of behavioral programming focus on how emotions and personality factors affect individual differences and autonomy of agents (Chittaro and Serra, 2004, Bécheiraz and Thalmann, 1998; Davis, 2000).

2.3.2 Psychophysiology of Emotions

The explanation of psychophysiology of emotions is too complex and there is no universally agreed explanation for this. This review will focus on amygdala (unconscious emotional responses), reticular activating system (cortical arousal), cortex (conscious responses), and septal area (pleasure center) to construct its explanation.

The amygdala is the executive of memory and processing of emotional reactions. It exists within the brain's limbic system (Figure 2.25), which process emotion, behavior, and long-term memory with the help of few other structures including hypothalamus, thalamus, hippocampus, fornix, and cingulate gyrus (Best, 1990; Wikipedia, 2008). A summary of the function of those structures are given below (refer section 2.2.2 for details):

- Hippocampus: Formation of long-term memory and learning.
- Cingulate gyrus: Autonomic functions regulating heart rate, blood pressure and cognitive and attentional processing.
- Fornix: Carries signals from the hippocampus to the mammillary bodies and septal nuclei.
- Hypothalamus: Regulates the autonomic nervous system via hormone production and release. Affects and regulates blood pressure, heart rate, hunger, thirst, sexual arousal, and the sleep/wake cycle.

- Thalamus: Switching station for sensory input except smell.

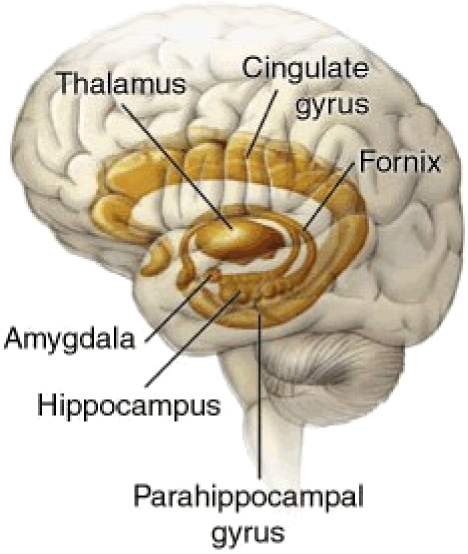


Figure 2.25: The parts of the limbic system

Source: http://www.ahaf.org/alzdis/about/AnatomyBrain.htm

The explanation of why people react for situations that are emotionally significant without thinking much is coupled with the emotional response of the body and Figure 2.26 summarizes the flow.

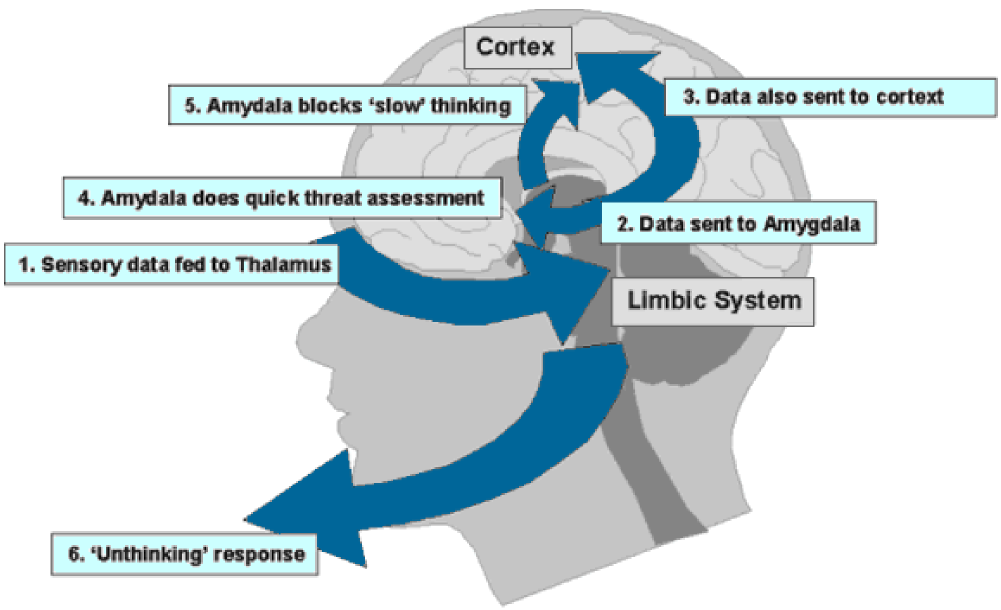


Figure 2.26: The Amygdala Bypass System

Source: http://changingminds.org/explanations/brain/amygdala_bypass.htm

Original reference: Carter, Rita (2000), Mapping the Mind, University of California Press

Sensory data first come to the thalamus, the relay station of the brain, and it sends these data to the specific areas of the cerebrum (prefrontal cortex) for further processing and also to the amygdala. As soon as sensory data comes under the attention of the cortex we start thinking about the situation.

The amygdala has a large database of stimulus-response kind of behaviors of past experiences stamped within the brain as being dangerous or emotionally significant. The amygdala does a quick assessment by matching the incoming stimuli with the stamped past experiences to detect any danger associated with the situation. Depending on the level of danger, the amygdala alerts other structures and systems, including hypothalamus to activate the sympathetic nerves system (increased blood pressure, metabolic rate, etc.) and endocrine system (release of hormones), nuclei of the trigeminal nerve and facial nerve (expression of fear), nucleus of reticularis pontis caudalis to increase startle reflexes (causing quick involuntary movements), and ventral and dorsal pathways of reticular activating system to activate the cortex (Best, 1990; Wikipedia, 2008; Shepherd, 2006).

The sympathetic activation of autonomic nerves system and activation of endocrine system is described as the preparation of body for “fight or flight” behavior associated with the anger or fear (Best, 1990; Shepherd, 2006). The release of adrenaline causes the stimulation of heart action for increased blood pressure, metabolic rate, and blood glucose concentration to supply energy for the action about to be taken by the subject. Meanwhile, through startle reflexes, the body initiates involuntary movements supported by the autonomic nerves system.

The reticular activation system (RAS) is the center of attention and motivation of the brain (OMH, 2006; Mayer, 2001; Amdahta, 2004). It is the center of balance for the other systems involved in learning, self-control or inhibition, and motivation. When it functions normally, it provides the neural connections that are needed for the processing and learning of information, and the ability to pay attention to the correct task. However, if is over excited, it distract the individual through excessive startle response, hyper-vigilant, touching everything, talking too much, restless and hyperactive. Figure 2.27 shows the components of the RAS and Figure 2.28 shows the interaction of attention and arousal.

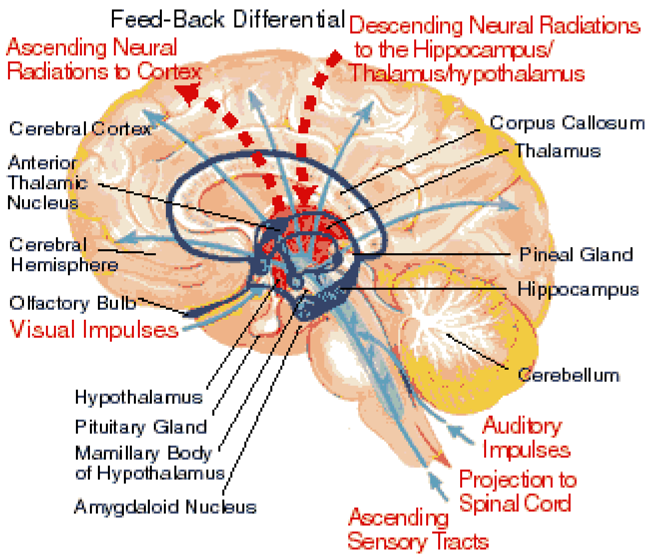


Figure 2.27: The reticular activation system

Source: http://www.deficitdeatencion.org/reticular.htm

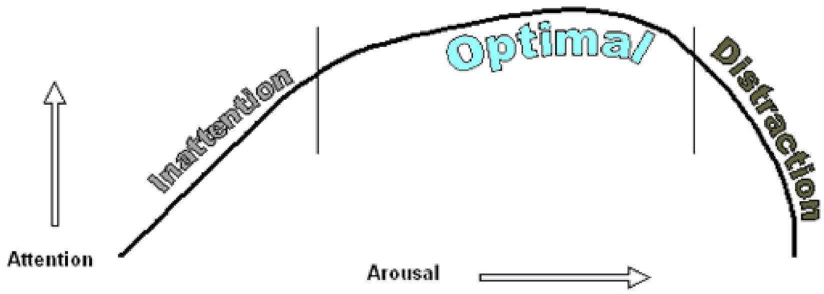


Figure 2.28: The interaction of attention and arousal

Source: http://www.omh.state.ny.us/omhweb/EBP/Family_psychoEducation.htm

The amygdala over excites the RAS by flooding the neurotransmitters dopamine, norepinephrine, and acetylcholine through ventral tegmental area, locus ceruleus, and dorsal lateral tegmental nucleus (Best, 1990). In turn, RAS activates the cortex through ventral (reticulo-hypothalamic-cortical pathway) and dorsal (reticulo-thalamic-cortical pathway) pathways (Dubuc, 2002). This over activation of cortex distracts the individual from being taking a conscious response and makes the amygdala's unconscious response wins the race (Syque, 2007). This is when the cognitive judgment about individual's state and bodily reaction are all come under the conscious attention of the individual. As the inhibitatory functions take over, the neurotransmitter concentration gradually drops down into normal levels and conscious thinking could be now taken over for conscious responses. Figure 2.29 shows the two activation strategies of the brain.

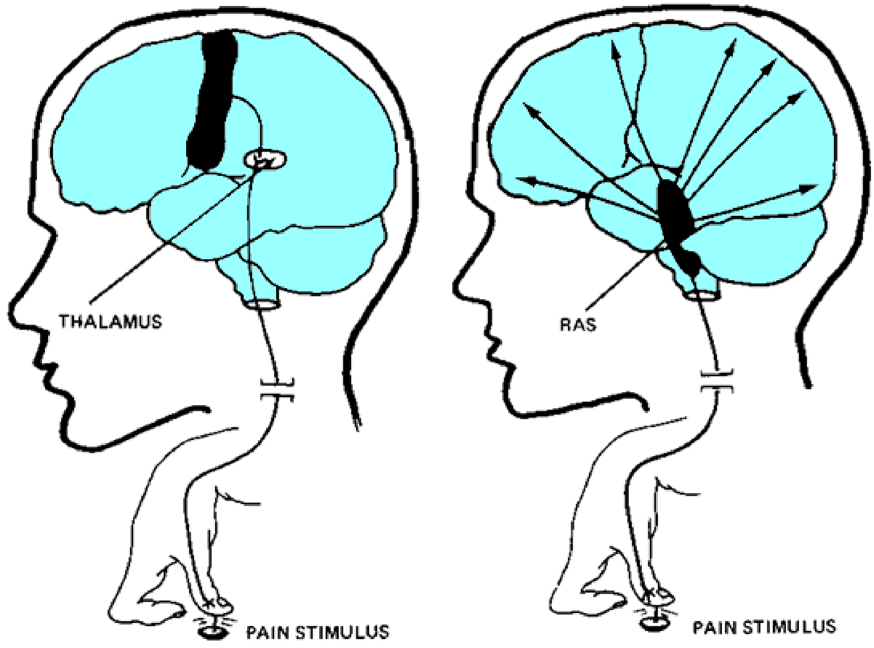


Figure 2.29: Comparison of thalamus and RAS responses to a pain stimulus

Source: http://online.sfsu.edu/~psych200/unit5/56.htm

The septal area is the pleasure center of the brain, which has connections with the cortex through fornix, has inputs from the amygdala, and has connections with the hippothalamus. Stimulation of septal area has an inhibitory effect on the autonomic nervous system, including cardiac deceleration. These connections enable pleasure obtained from bodily stimulus as well as from cortical processes, such as by solving a mathematical problem (Best, 1990; Wikipedia, 2008).

Literature points out many other factors having impact on emotional responses of humans and some are listed below (Pease and Pease, 2001; OMH, 2006; Niemic, 2004):

- Genetically transmitted characteristics from the ancestors
- Cultural and regional aspects
- Abnormalities in the RAS
- Asymmetries between cerebral hemispheres
- Gender differences
- Age and hormone activity

2.3.3 Emotion Assessment and Modeling

The above sections discussed how emotions are described with respect to valence (i.e. pleasant or unpleasant), arousal (i.e. aroused or unaroused), and appraisal manifest (cognitive reflection of the valence) of an emotion stimulating event. Thagard (2005) presents a chart which summarizes the discussed dimensions in a 2-D structure (Figure 2.30).

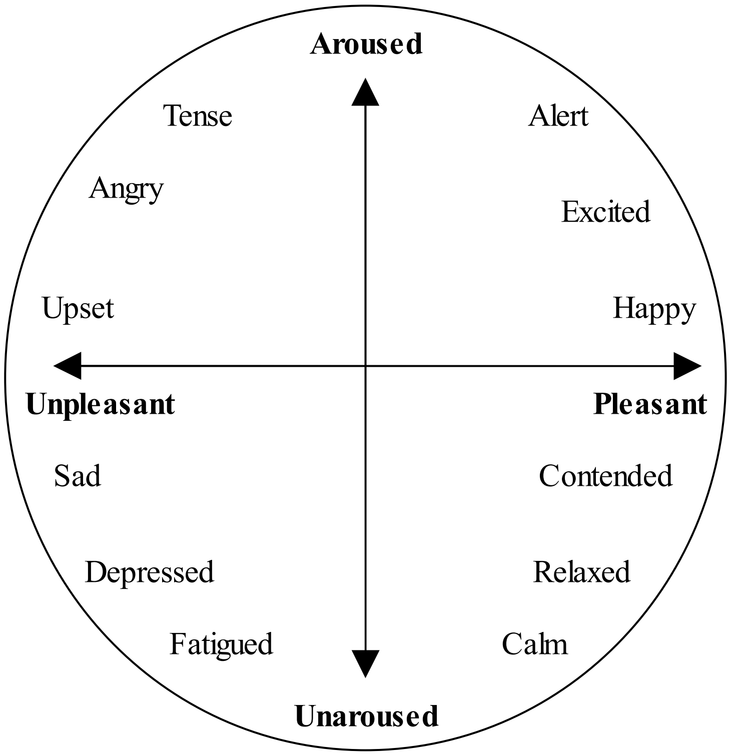


Figure 2.30: The structure of emotions with respect to pleasantness and intensity

The emotion assessment is the process of recognizing an individual's emotional state using the signals from physiological sources. The following summarizes three such sources one can employ when assessing emotions:

- Facial expression or speech
- Signals from peripheral nervous system
- Signals from central nervous system

Studies focusing on the analysis of facial expressions of emotions or speech are more popular than any other method in recognizing emotions (Song, at al., 2006). However, the problem with that approach is those signals are unreliable due to the controllability to be faked by individuals (Chanel, et al., 2006).

In contrast, the sympathetic activation of autonomic nervous system and the activation of endocrine system introduce changes to heart rate, skin conductivity, blood volume pressure, respiration, and many other sympathetic organs. Using these signals to recognize emotions provide more accurate results (Healey and Picard, 1998).

The third option is to use signals from central nervous system to recognize emotions. For that the preferred method is by using noninvasive EEG signals from the brain (Chanel, et al., 2006). However, EEG alone seems not supporting accurate emotion assessment rather arousal recognition. For a robust outcome, the fusion of peripheral signals with EEG is used.

The computational modeling of emotions is far the most unsolved problem in research community. Thagard in his book (Thagard, 2005) doubt that computers and robots will ever have emotions at all like humans. The current approaches in emotion representation and modeling can be organized in to three levels (Hudlicka, 2004; Thagard, 2005):

- Shallow emotion models
- Middle emotion models
- Deep emotion models

In shallow models, the appraisal manifest and/or valence is considered. Those models represent emotions using prepositions, concepts, rules, analogies, images, or local connectionist approaches. For example, a pattern such as “If user exhibits behavior xxx, then s/he is likely experiencing emotion yyy” might be a possible way of modeling emotion in such a model. Becheirz et al. (Bécheiraz and Thalmann, 1998) models emotions integrating them into behaviors. In their approach, the emotions are generated in reaction to person’s emotive perception. The emotions are computed in two steps: an emotion potential is computed from the group of elements contributing to the emotion, and if the potential crosses a given threshold, then its value is used to compute the emotion intensity. The values of the potential, the threshold, and the intensity ranges between 0 and 1. The following is an example of emotion description for such autonomous character:

Emotion name : liking

Emotion range : 0.2 0.9

Object category : object.toy.puppet

Gesture : applause

Similar attempts can be found from literature and in some models individual differences are induced using personality traits (Chittaro and Serra, 2004). Other shallow emotion models are used when developing computer programs that can understand stories (Mueller, 2002).

The middle emotional models, such as MAMID (Hudlicka, 2004), assume that certain structures and processes are necessary to adequately model emotions. In MAMID, the architecture is capable of deriving an affective state via an appraisal process and representing the effects of affective state on processing.

Finally, the deep models try to accurately model human-like emotion models with similar physiological and cognitive aspects. Thagard et al.'s GAGE neurocomputational model of emotional decision making (Thagard, 2005) is an example for a deep model where it considers the divisions of brain's functional areas and their distributed representations (Figure 2.31).

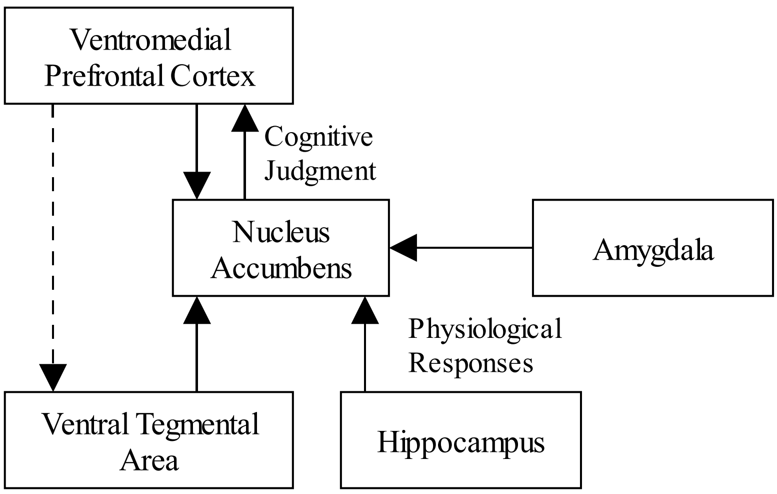


Figure 2.31: The GATE model of emotional decision making

Davis's model proposes a layered architecture (Davis, 2000) encompassing four distinct processing layers (Figure 2.32):

- A reflexive layer that is analogous to the autonomic system activity,
- A reactive (preconscious) layer representing the arousal processes,
- A deliberative layer representing the appraisal processes, and
- A reflective layer monitoring the deliberative appraisal processes and attentional processes

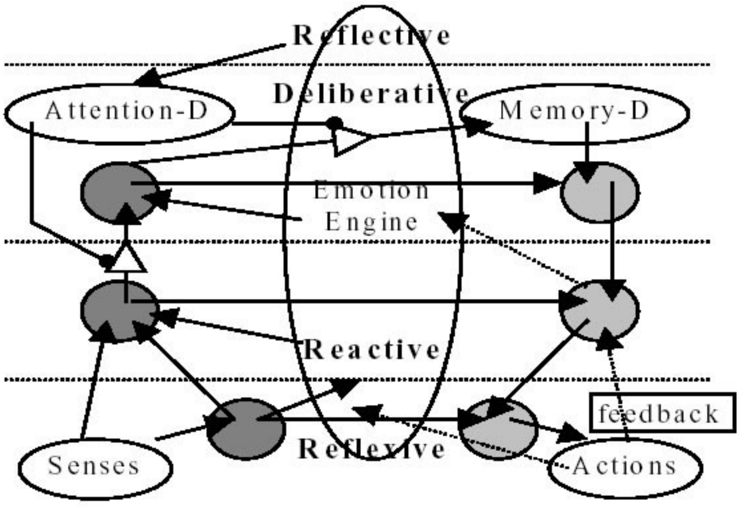


Figure 2.32: Davis's four-layered architecture with emotion core

However, the model is yet incomplete and does not follow the distributed representation of the brain. In contrast, the ACT-R production system theory investigates sub-symbolic processing mechanisms to incorporate emotional information to cognitive models (Anderson and Lebiere, 1998).

2.4 Biomedical Instrumentation

2.4.1 Brain Scans Technologies

This review attempts to list few most popular brain scans (neuroimaging) technologies used today (Murray, 2004; Evolution Channel, 2008; Wikipedia, 2008).

The Computed Tomography (CT) or Computed Axial Tomography (CAT) is a brain scan technology introduced in 1970s, and it uses a series of x-rays of the head taken from many different directions to image the brain (Figure 2.33). The major downfall of using x-rays is that x-rays can cause damages to tissue cells.

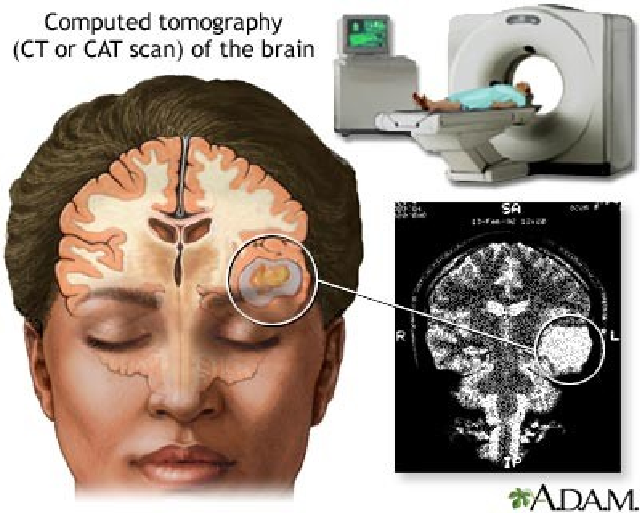


Figure 2.33: CT scan of a brain

Source: http://www.nlm.nih.gov/medlineplus/ency/imagepages/19237.htm

In Positron Emission Tomography (PET) the subject is first injected with a radioactive material that spreads through the bloodstream. The PET scanner can now detect increases in radioactivity due to an increase in blood flow in most active areas, for example, when the subject is given a picture to look at, the PET scan will show increased blood flow to the primary visual cortex located at the back of the brain (Figure 2.34). Some limitations of this technique are the use of radioactive material and inability to localize activity to regions smaller than a cubic centimeter. PET scan was introduced in early 1980s.

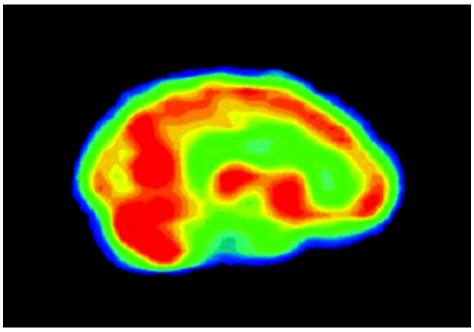


Figure 2.34: PET scan of a brain

Source: http://www.physics.utoronto.ca/~key/PHY138/

In Magnetic Resonance Imaging (MRI), introduced in early 1980s, the subject is exposed to a large magnetic field that generates signals from the hydrogen nuclei of water molecules in the body. The MRI machine detects these signals and uses computers to distinguish physical structure (2D or 3D) at the time of imaging (Figure 2.35). The MRI scan provides only structural information of the brain.

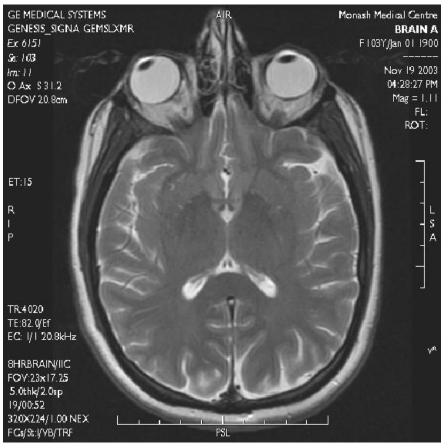


Figure 2.35: MRI scan of a brain

Source: http://www.southernhealth.org.au/imaging/mri_mmc.htm

Since its introduction in 1990s, the Functional Magnetic Resonance Imaging (fMRI) has become the dominance brain scanning technology which has revolutionized the field of cognitive psychology. In fMRI, specific magnetic pulses are generated to enable the detection of changes in blood flow in a person performing a mental task. The images of the brain can be produced in a few seconds with a spatial resolution of few millimeters. This has made fMRI crucial for identifying the specific brain regions involved in various kinds of thinking (Figure 2.36). The major limitation of fMRI is it has no temporal resolution as in EEG.

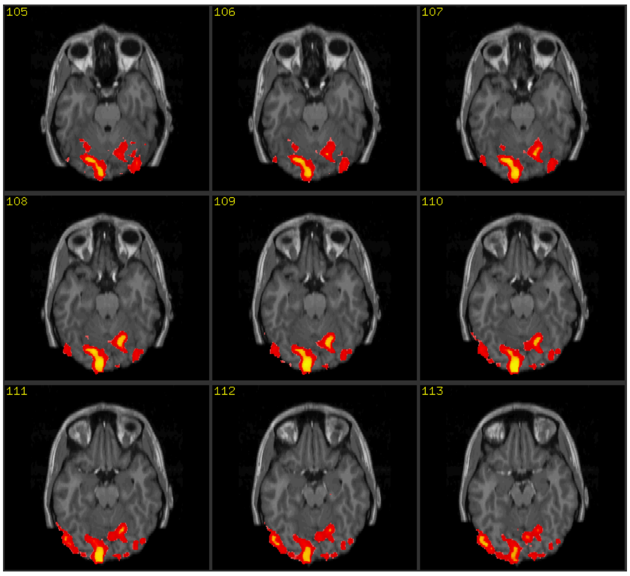


Figure 2.36: fMRI scan of a brain

Source: http://www.csulb.edu/~cwallis/482/fmri/fmri.html

2.4.2 Electroencephalography (EEG)

EEG (Thagard, 2005) is the measurement of the electrical activity of the brain by recording from electrodes placed on the scalp (Figure 2.37). It is one of the few techniques available that has high temporal resolution. Limitations of EEG are that scalp electrodes are not sensitive enough to pickup individual action potentials nor identify the electric unit of the brain and it does not provide details of the electrical activity as it is releasing inhibitory, excitatory or modulatory neurotransmitters.

Figure 2.37: EEG recording using an electrode-cap

Source: http://ieng9.ucsd.edu/~phammon/

The international 10-20 system of electrode placement (BrainMaster, 2006) is one of the internationally recognized and widely used methods of placing electrodes on the scalp. It is based on the relationship between the location of an electrode and the underlying area of cerebral cortex. Each site has a letter (to identify the lobe) and a number or another letter to identify the hemisphere location: "F"-Frontal lobe, "T"-Temporal lobe, "C"-Central lobe, "P"-Parietal lobe, "O"-Occipital lobe. Even numbers (2,4,6,8) refer to the right hemisphere and odd numbers (1,3,5,7) refer to the left hemisphere. Letter "Z" refers to an electrode placed on the midline. The smaller the number, the closer the position to the midline. Figure 2.38 shows the locations of 10-20 system.

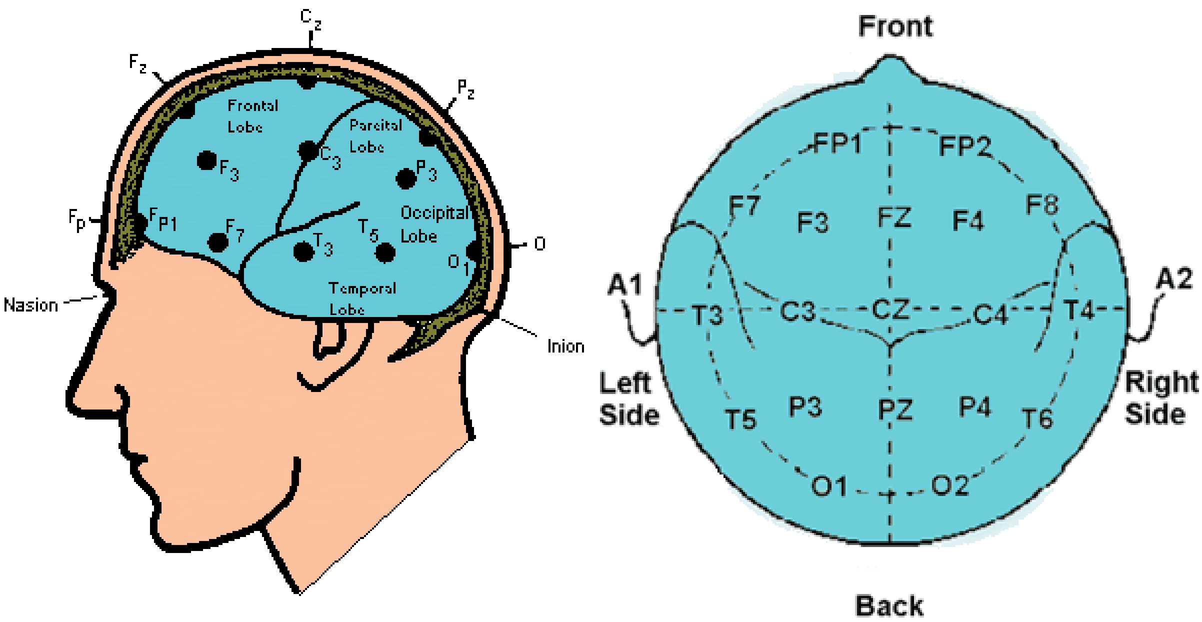


Figure 2.38: The scalp locations of international 10-20 system of electrode placement

Source: http://www.brainmaster.com/generalinfo/electrodeuse/eegbands/1020/1020.html

The label "Fp" stands for Front polar. "Nasion" is the point between the forehead and nose and "Inion" is the bump at the back of the skull.

10% and 20% refer to inter-electrode distance derived from three main measurements: nasion–inion, preauricular points and circumference of the head, and the units are measured in centimeters. Figure 2.39 shows a sample EEG waveform.

Figure 2.39: A recorded EEG waveform for an awaken state

Source: http://www.massgeneral.org/childhoodepilepsy/medical/diagnosis-popup_normal.htm

EEG waves are classified according to their rhythm (previously referred as brainwaves) and Figure 2.40 summarizes the classification.

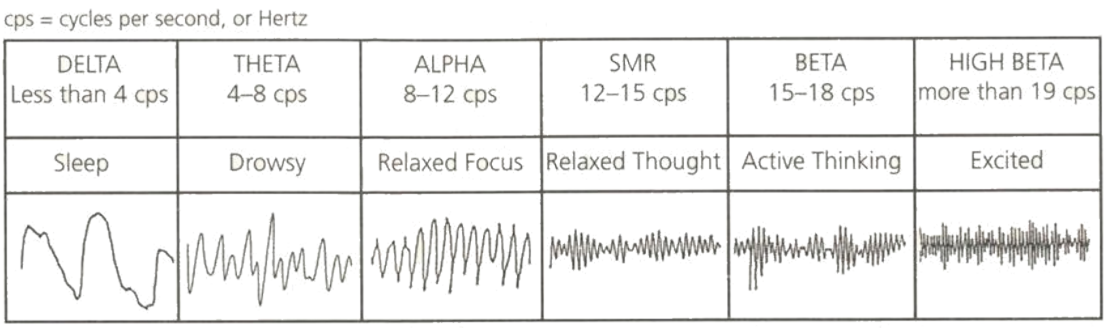


Figure 2.40: The range of brainwaves in the human brain

Source: http://www.drross.org/templates/System/details.asp?id=27439&PID=149311

Commercial EEG machines are very expensive and Figure 2.41 shows a commercial EEG machine where the cost is between $949 and $1349.

Figure 2.41: Commercial EEG devices: BrainMaster brainwave monitor

Source: http://www.dynamind.com/

2.4.3 Galvanic Skin Response (GSR)

GSR, also known as electrodermal response (EDR), psychogalvanic response (PGR), or skin-conductance response (SCR), is the method of measuring the electrical resistance of the skin. Skin conductance is known to have a linear correlation with the person's arousal level (Cornell, 2008), thus it is used as a method of quantifying a person's reaction to different stimulus presented. Figure 2.42 shows a modern commercial GSR recorder where the cost is $1350.

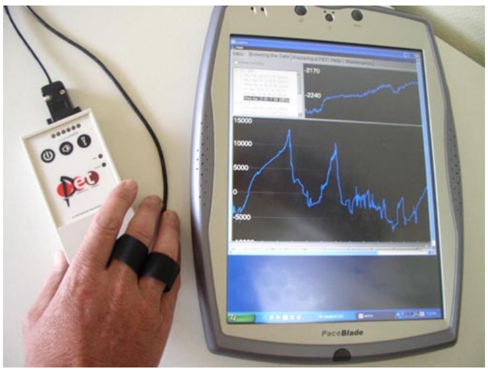


Figure 2.42: A modern commercial GSR recorder: PET GSR recorder

Source: http://www.biof.com/onlinestore/pet.asp

GSR experiments have a long history and the simple psycho-galvanometer wan one of the earliest tools of psychological research (Shepherd, 2006; Wikipedia, 2008). The first paper based on the psycho-galvanometer was written by Tarchanoff in 1890. Later, Carl Gustav Jung published a book entitled “Studies in Word Analysis” where he described a technique of connecting the subject via hand-electrodes to an instrument measuring changes in the skin resistance while the subject is presented emotionally charged words. However, his device had lots of difficulties in using until more sophisticated valve amplifier was integrated in 1930s.

Once the psycho-galvanometer became portable, the idea was picked up by criminologists and used as a “lie detector” (Figure 2.43). However, in 1970s, biofeedback research became popular and used the psycho-galvanometer to measure subject’s level of awareness connection with meditation and relaxation. The level of awareness directly relates with the cortical arousal (refer section 2.3.2).

- Low level of cortical arousal describes relaxation, hypnosis, and subjective experience of psyche states and unconscious manifestations.
- High level of cortical arousal describes increased power of reflection, focused concentration, increased reading speed, and increased capacity for long-term recall.

Figure 2.43: The first lie detector by John Larson in 1953

Source: http://www.umw.edu/hisa/resources/Student %20Projects/Singel/students.umw.edu/_ksing2os/polygraph/origin.html

The cortical arousal has a simple relationship to skin conductivity:

- When the arousal of the cortex increases, the conductivity of the skin also increases.

- When the arousal of the cortex decreases, the conductivity of the skin also decreases.

Although the relationship looks simple, literature suggests four causes that affects the electrical resistance of the skin:

- Tarchanoff response is a change in DC potential across neurons of the autonomic nervous system connected to the sensory-motor strip of the cortex. It has an immediate effect (0.2 to 0.5 seconds) on the subject's level of arousal and this effect can be detected using hand-held electrodes, because hands have a particularly large representation of nerve endings on the sensori-motor strip of the cortex.
- "Fight or flight" stress response of the autonomic nervous system comes into action as the arousal increases as a result of increased sweating due to release of adrenaline. This is a slow response compared to Tarchanoff response.
- Forebrain arousal is a complex physiological response, unique to man, affecting the resistance in thumb and forefinger.
- Changes in alpha rhythms cause blood capillaries to enlarge and ultimately this too affects the skin resistance.

Literature also presents somewhat challenging observations of GSR. Psychophysiological explanation of emotion (see section 2.3.2) encompasses amygdala's immediate reaction to stimulus as well as the deliberative activities of the cortex which is much slower. This causes an instant reaction in GSR reading originating from amygdala's quick response, and much slow and delayed response to cognitive thoughts originating from the cerebral hemispheres.

Another challenging observation reported under psychotherapy research and it refers as the Paradoxal Arousal which is first noted by Dr. Apter of Bristol University in his book "Reversal Theory". In a psychotherapy session, when a repressed material (associates with pain or guilt) is coming to the surface, the skin resistance rises and the client experiences feelings of tension. Then, when the repressed material reaches the surface and the negative emotion discharges, there is a sudden large drop in skin resistance and the client experiences relief. Apter findings are that the cortical arousal is unequal due to restimulation of heavy traumatic historical experiences of a person. Therefore, he explains that high arousal can be pleasant and exciting when a person is in the Paratelic (active) state, whereas high arousal is experienced as unpleasant in the Telic (thinking) state (Figure 2.44). To resolve the paradox, Shepherd suggests that it would be more effective to correlate high and low skin resistance with “withdrawal” and “involvement” respectively.

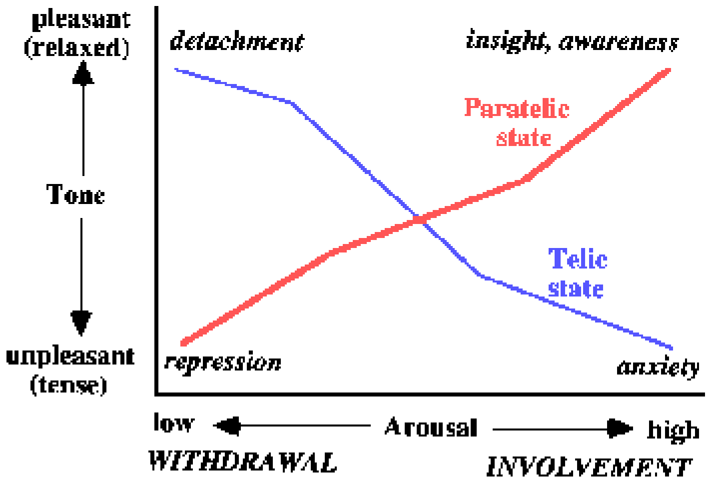


Figure 2.44: Involvement and withdrawal versus skin resistance

Source: http://www.trans4mind.com/psychotechnics/gsr.html

2.4.4 Eye Potentials

Eye is the light-sensitive organ of vision in animals. Electro-oculogram (EOG) and electroretinogram (ERG) are two popular recordings of electrical signals originating in the eye (Malmivuo and Plonsey, 1995; Kirtley, 2002; Polikar, 2006) used for clinical diagnostic purposes and various other applications.

Electro-oculogram (EOG) measures the resting potential of the retina. Bois Reymond, in 1848, discovered that the cornea of the eye is electrically positive relative to the back of the eye making a fixed dipole with a positive pole at the cornea and a negative pole at the retina (Figure 2.45). The magnitude of this corneoretinal potential is in the range 0.4 – 1.0 mV. The reason for this potential is the higher metabolic rate in the retina.

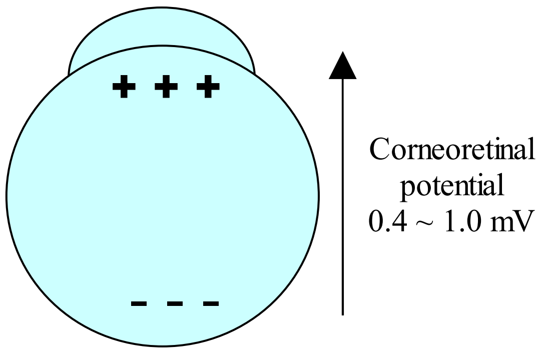


Figure 2.45: The corneoretinal potential generated at the eye

EOG signals are used to measure the degree of eye movement (Figure 2.46). In the measurement of horizontal eye movement, a pair of electrodes is mounted at the outside of the left and right eye (outer canthi). When the eyes are at rest, no potential is generated. If the rotation of the eyes is to the right, the electrode in the right canthi starts becoming positive relative to the left electrode. Opposite rotation results left electrode to become positive.

EOG experiments have reported accuracy up to ±2°, and maximum rotation ±70°. However, linearity drops beyond 30°. The signal magnitude is in the range 5-20 μV/°.

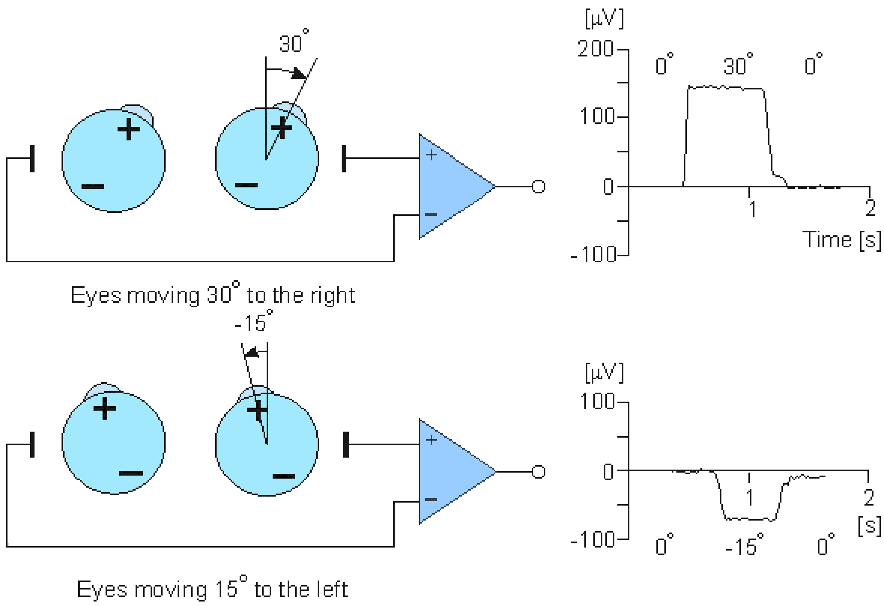


Figure 2.46: EOG signals generated by horizontal eye movements of the eye

Source: http://butler.cc.tut.fi/~malmivuo/bem/bembook/28/28.htm

EOG potentials can be used to control a mouse pointer in the computer screen (Kirtley, 2002; Connell, 2007b). For this application, a two channel instrumentation amplifier is needed with a gain of approximately 5000 times. The electrodes are placed in the forehead and towards the temples (Figure 2.47).

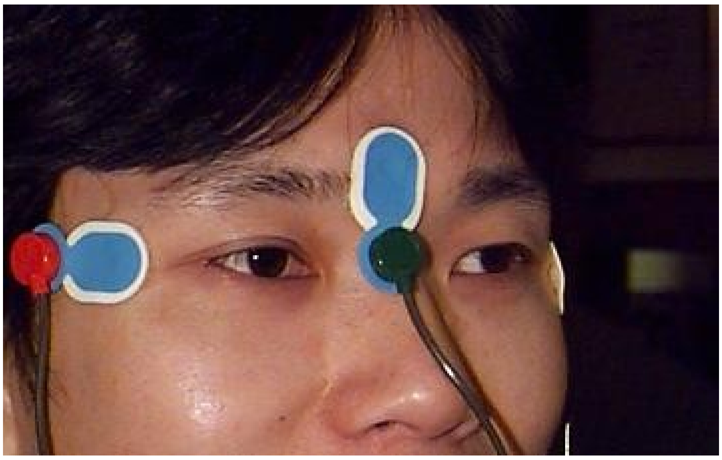


Figure 2.47: Electrode placement for the capturing of EOG potentials

Source: http://www.univie.ac.at/cga/courses/BE513/Projects/

Grant G. Connell's method of eye motion controlled mouse cursor uses low cost hardware and software setup (Connell, 2007b). Using his setup eye motion towards all four spatial directions (up, down, left, and right) as well as eye blinks can be captured. The visualization of eye potentials is shown in Figure 2.48.

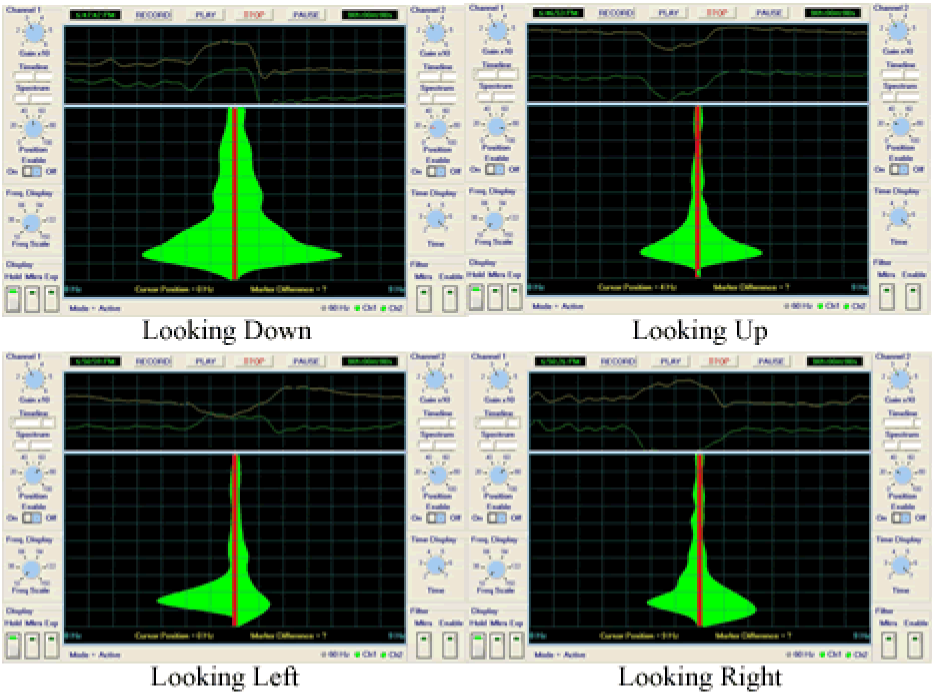


Figure 2.48: Grant's EOG project: eye potentials generated for the four movement directions

Source: http://www.hotamateurprograms.com/eeg.htm

Later, the corneoretinal potential has been found to slowly varying and to be affected by light, fatigue, muscle activities, and other qualities. This has put the requirement of frequent calibration of the measuring instruments. In contrast, the method is very effective in that it brings minimal discomfort to the subject and the recording with minimal interference with subject activities. Further, the recording can be done in the total darkness or eyes closed (no stimulus needed).

Electroretinogram (ERG) is the record of the retinal action currents produced by the retina in response to the light stimulus, first reported by Holmgren in 1865. To record ERG, a specially constructed contact lens is used in conjunction with reference electrode placed on the forehead, temple, or earlobe (Figure 2.49). The signal range is in 0 – 900 μV and the amplitude depends on the stimulating and physiological conditions.

Figure 2.49: Electrode placement for the capturing of ERG signals

Source: http://www.metrovision.fr/

ERG potentials are the results of electrical responses of the light-sensitive cells, such as rods and cones, to light stimulus. Figure 2.50 shows these potentials in response to a light stimulus.

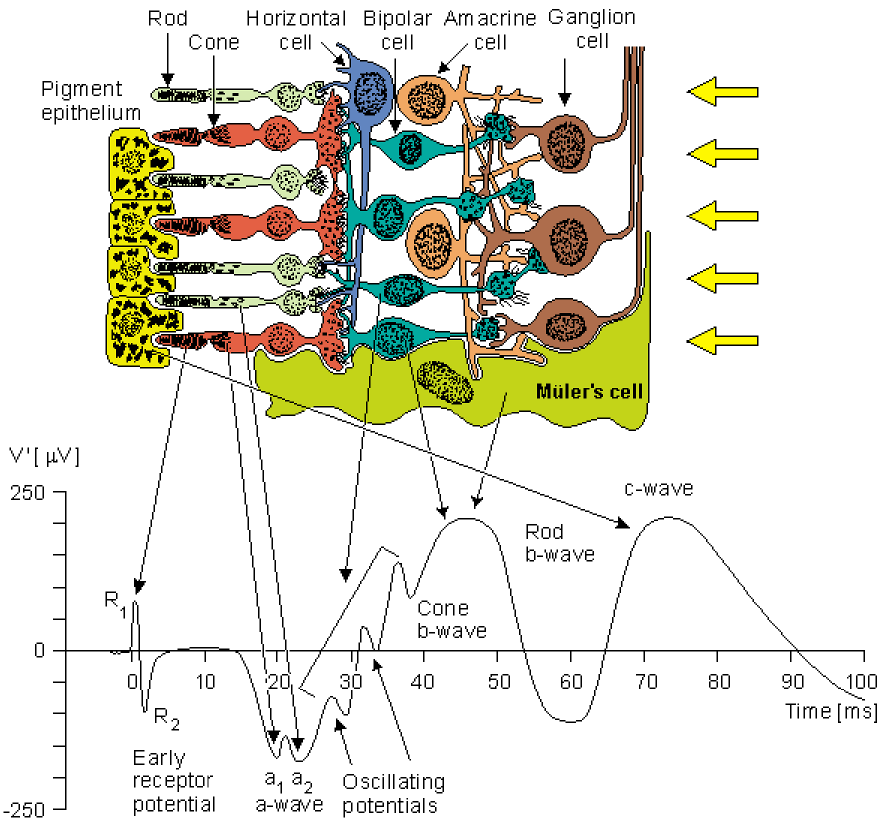


Figure 2.50: The cells of the retina and their response to a spot light flash

Source: http://butler.cc.tut.fi/~malmivuo/bem/bembook/28/28.htm

2.4.5 Standards and Requirements

The European Data Format (EDF) (Kemp, et al., 1992) is a standard file format for exchange and storage of multichannel biological and physical signals. It has been developed by few European medical engineers and published in 1992. Since then, EDF has become the de-facto standard for electroencephalography (EEG) and polysomnography (PSG) recordings.

An EDF data file consists of a variable-length header record followed by data records. The header record identifies the patient and specifies the technical characteristics of the recorded signals. The data records contain consecutive fixed-duration epochs of the polygraphic recording.

The EDF+ format has been published as an extension to EDF in 2003 (Kemp and Olivan, 2003). The main motivation behind EDF+ is that EDF specification specifies its recordings to be uninterruptible creating difficulties in recording discontinuous ElectroNeurography, ElectroMyoGraphy and Evoked Potential studies (ENMGEP) data. The EDF+ files can contain interrupted recordings, annotations, stimuli and events. It also can store any medical recording such as EMG, Evoked potentials, ECG, as well as automatic and manual analysis results such as deltaplots, QRS parameters and sleep stages (Figure 2.51). The EDF and EDF+ are open and non-proprietary formats and Java is a good programming language for creating EDF/EDF+ files and viewers (Palacios, 2003).

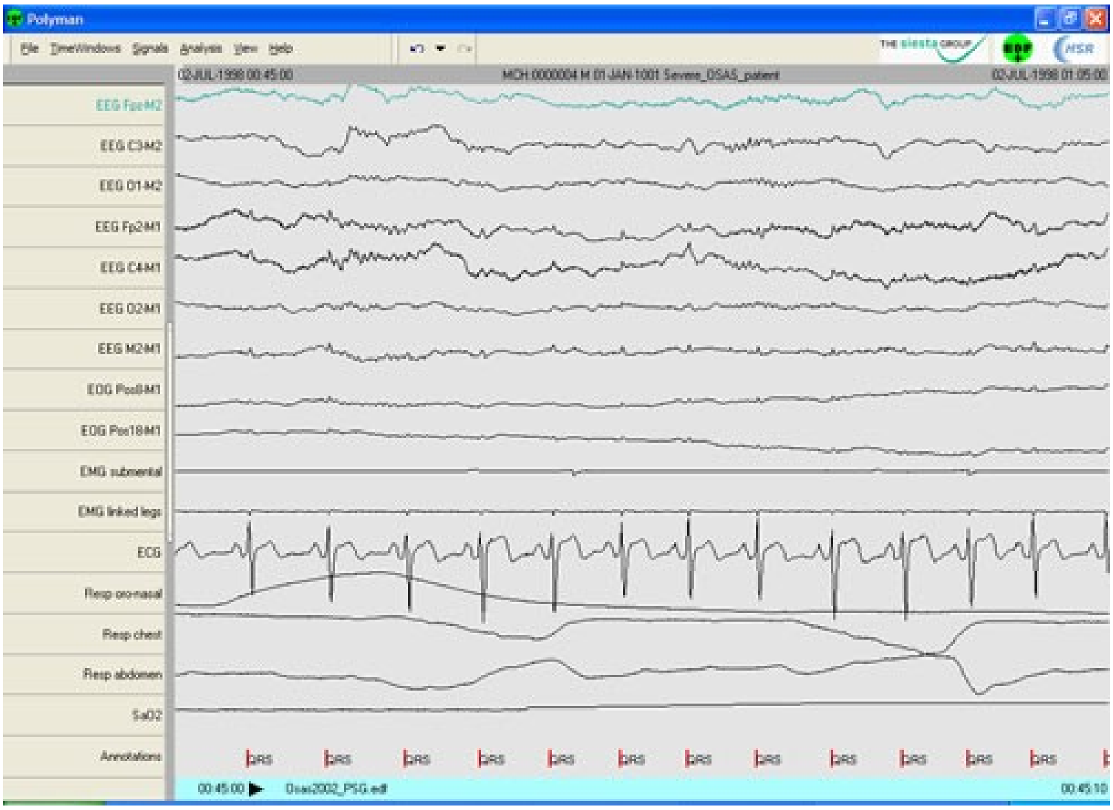


Figure 2.51: EDF+ file viewed using Polyman viewer

There are safety standards and design guidelines for medical devices designed to use on humans. The IEC 606 (601help, 2007) is such a standard which specifies the general requirements for safety in medical electrical devices. The following lists some of those requirements need to be considered in the design and usage of medical electrical equipments:

- Maintain an electrical isolation barrier between a user connected to a medical device, and the device (typically a computer) to which the medical device is connected.
- A medical device should never be used during a lightning, storm, or whenever the electrical power grid is unstable.
- Neurofeedback should not be used if is cause unpleasant side-effects on subjects, such as anxiety, mood changes, insomnia, and panic attacks.
- The electrode placement should never be opposite sides of the body (this would give small currents causing fibrillation in the heart).

2.4.6 Low-cost Neurofeedback Devices

This section of the dissertation focuses on few low-cost hardware designs for biopotential detection. The main problem behind low-cost hardware designs is that they are not certified for use in clinical purposes, because they are not designed to be safe enough under extreme electrical conditions and used with subjects having abnormalities.

The Hemispherical Activation Level Detector (HAL4, 1999) is a low-cost standalone four-channel EEG brainwave monitor (Figure 2.52). It is able to display the relative amounts of brainwave activity in each brain hemisphere. The hemispheric activity is used to determine different conscious states, for example, if a person is analytically debugging a program, HAL should show a predominance of left hemispheric activity. If the person is listening to music and daydreaming, the HAL should show a predominance of right hemispheric activity.

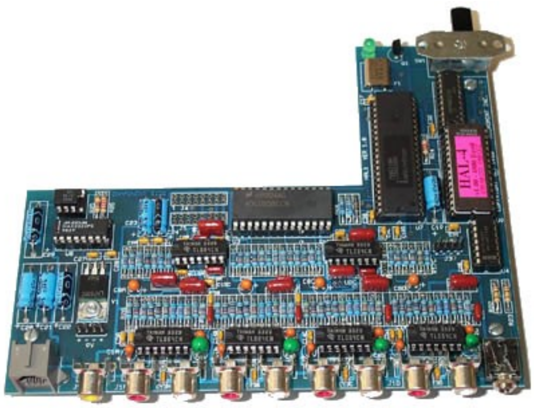


Figure 2.52: The HAL-4 PCB design

Source: http://www.cc-concepts.com/products/legacy/hal4/

The HAL-4 hardware circuitry consists of two sections: preamplifier/filter and digitizer/control. The preamps and filters (built around TL-084) acquire and boost the analog brainwave voltages, gathered from four sets of scalp contacts, to useful levels. The digitizer section (built around 80C31 microcontroller and ADC0808 converter) does the signal conditioning, analog to digital conversion, and sends through an optocoupler and RS-232 to the host computer for recording and analysis.

The HAL-4 is battery powered. The voltage gain is up to 82 dB (12,500 times) and the bandwidth of the analog section is approximately 16 Hz. It also capable of rejecting 60 Hz mains hum. However, as the more powerful designs are available, for instance ModularEEG, the HAL-4 is currently an outdated design.

The ModularEEG is the most active EEG hardware design (Figure 2.53) at the OpenEEG project (OpenEEG, 2006). The OpenEEG is a sourceforge project aimed at making EEG hardware designs and software freely available for experimenters and hobbyists. All the designs at OpenEEG can be implemented at low cost (200 to 400 USD).

More people have contributed to the design of ModularEEG, therefore, the design is more optimized for the purpose. Furthermore, there is plenty of online documentation and help available for the ModularEEG.

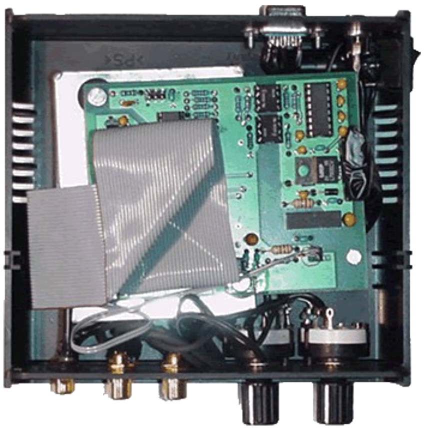


Figure 2.53: ModularEEG design

Source: http://openeeg.sourceforge.net/

The ModularEEG does not require commercial expensive electrodes to be used, but can be cheap silver, tin, or steel electrodes. The signal amplitude is only a few microvolts (usually less than 10 μV) and needs to be amplified several thousand times before it can be captured by the computer for analysis. However, this attempt can easily be compromised by the noise, particularity by the 50/60 Hz mains hum. The ModularEEG addresses these issues through its design. It first amplifies the signal using high quality instrumental amplifier, which measures the voltage difference between two locations at scalp. This attempt ensures that a large percentage of the mains hum never enters the system, because the level of the mains hum on those two locations is essentially the same.

Next, the signal is further amplified using normal amplifier stage, and passed through a low-pass filter which minimizes the signal distortion caused by aliasing. After the filtering, the signal is converted to digital by the analog-to-digital converter insider the microcontroller (AT90S4433). The signal is then transmitted to the computer through a standard serial cable (RS232). An optocoupler circuit is used as an electrical barrier between the ModularEEG device and the computer. Figure 2.54 shows the components of the ModularEEG design and their connectivity.

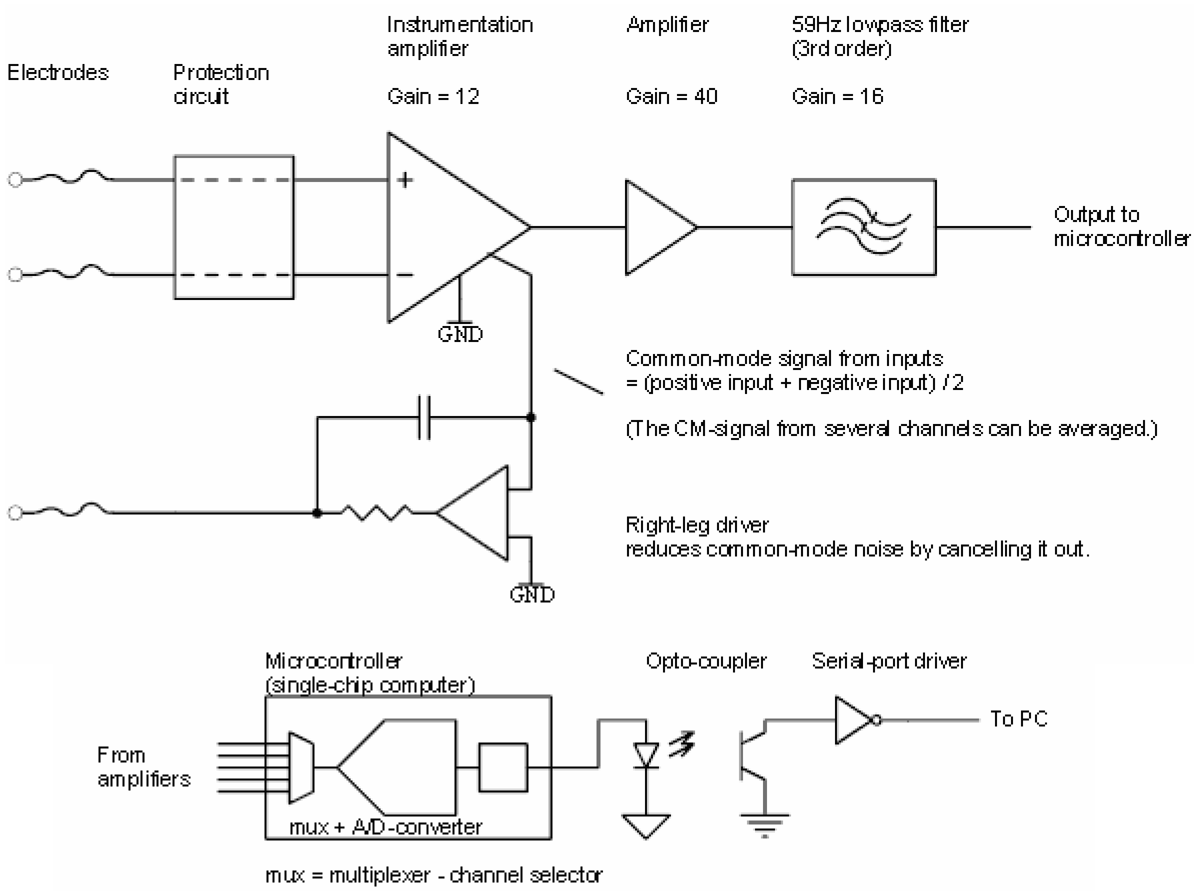


Figure 2.54: ModularEEG amplifier stage (top), microcontroller, opto-coupler, and RS232 interface

Source: http://openeeg.sourceforge.net/

Technical specification of the ModularEEG v0.06 design has specified the following information (Table 2.1):

Table 2.1: Technical specification of ModularEEG v0.06

Number of channels	2 – 6 (only 2 tested)
Resolution	four 10 bits, two 8 bits
Input Voltage Resolution	0.5 μV
Input Voltage Full Scale	±256 μV
Wideband noise	~ 1 μVp-p
Supply Current (5V or 9 - 12V supply)	70 mA (2 channels)
Isolation voltage	2500V (1 minute)
Continuous isolation voltage	480V

Source: http://openeeg.sourceforge.net/

The soundcard EEG (scEEG) is another EEG hardware design available under OpenEEG project (OpenEEG, 2006; Connell, 2007a). The main motivation behind scEEG is to use the computer's sound input as part of the hardware design, so that the device can be simplified and the cost can be further reduced. The soundcard serves as an amplifier as well as an analog-to-digital converter.

However, soundcards filter out input frequencies below 20 Hz. This limits the freedom in designing EEG hardware, because EEG spectrum of signals includes frequencies below 20 Hz. Grant Connell, the scEEG hardware designer, overcomes this problem in two ways: by employing frequency modulation (FM) or amplitude modulation (AM). In either case, a software demodulator is used to recover the original EEG signal.

The scEEG design is somewhat compatible to ModularEEG design. The same type of electrodes can be used for scEEG. The scEEG also uses high precision instrumental amplifiers (AD8221) for its pre-amplification stage. The design is highly scalable in adding more channels. The electrical isolation barrier between the device and the acquisition computer is established using an isolation transformer. The designs guarantee the following performance:

- AM sound card EEG design (Figure 2.55): spectrum management 500 Hz per channel, 70 dB dynamic range, current drain approximately 6.5 mA
- FM sound card EEG design: spectrum management 2 kHz per channel, 63 dB dynamic range, current drain approximately 10 mA

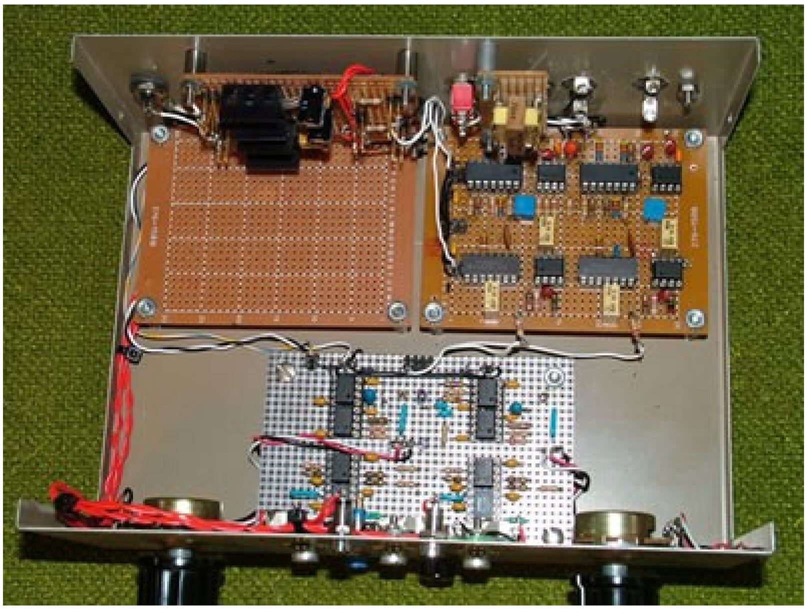


Figure 2.55: Soundcard EEG AM unit

Source: http://www.hotamateurprograms.com/eeg.htm

The electrodes are the ones which capture biopotentials from the contacting skin surface and send the signals to the capturing device for amplification. Since humans are involved, a great care should be made when selecting electrode materials. Further, an electric charge can accumulate on the surface of the electrode (polarization) resulting incorrect readings as biopotentials.

In biofeedback experiments, gold (Au), silver (Ag), or tin are used frequently as electrode material. An electrode gel is also applied between the electrode and the skin to improve the skin contact and to minimize the polarization effect. As a low cost solution, a silver/silver-chloride (Ag/AgCl) gives good performance. Saline electrodes (sponge full of salt water next to skin) are also a good alternative, but sometimes salt water gives bad feeling for the person. A preparation of the skin (can use pure alcohol) is also required before the placement of electrodes in order to minimize the artifacts (by sweating).

Each channel needs two electrodes named positive and negative input. A special electrode referred Driven Right Leg (DRL) acts as an active earth and suppresses mains hum. The electrodes can be normal rounded plate electrodes or needle electrodes. The electrode cables which carry signals from the electrode contact to the device needs to be shielded in order to reduce any capacitive loading. Long cables (usually more than 1 meter in length) are not recommended as electrode cabling. Figure 2.56 shows the utilities required for EEG experiments.

Figure 2.56: Electrodes and electrode utilities

Source: http://www.easycap.de/easycap/e/products/products.htm

Active electrodes come with inbuilt circuitry at the electrode. This circuitry amplifies the signal current and improves the signal quality received by the device. Active electrodes do not require skin preparation or conductive paste required by passive electrodes. Joe Street's active electrodes (OpenEEG, 2006) are more compatible with ModularEEG device (Figure 2.57).

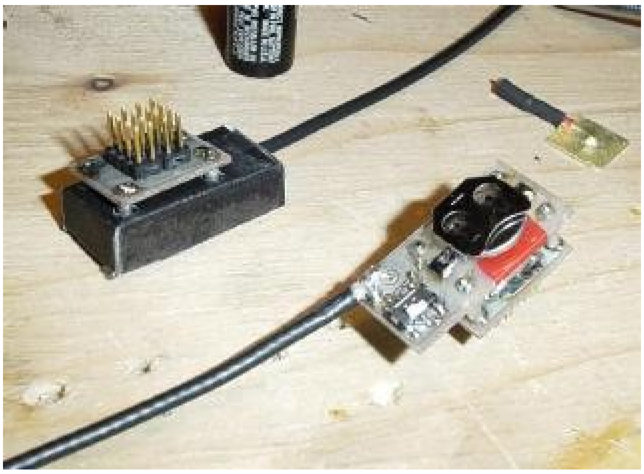


Figure 2.57: Joe Street's active electrodes

Source: http://openeeg.sourceforge.net/

2.4.7 Neurofeedback Signal Analysis Tools

Neurofeedback analysis tools are required to display, record, and analyze signals captured by various neurofeedback devices. Most of the available software tools for this purpose are either proprietary or can only be interfaced with commercial neurofeedback devices. Under OpenEEG project (OpenEEG, 2006) many have tried to develop open-source applications, such as BrainBay and BioEra, to overcome this limitation (Figure 2.58).

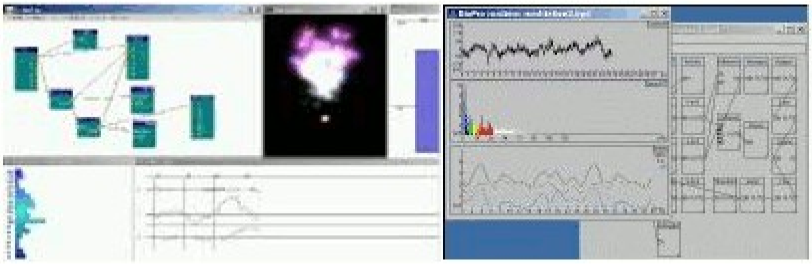


Figure 2.58: BrainBay (left) and BioEra (right) EEG analysis tools

Source: http://openeeg.sourceforge.net

The NeuroProbe (Connell, 2007a) is a closed-source application but freely available in the web (Figure 2.59). It has been designed by Grant Connell to interface with soundcard EEG devices.

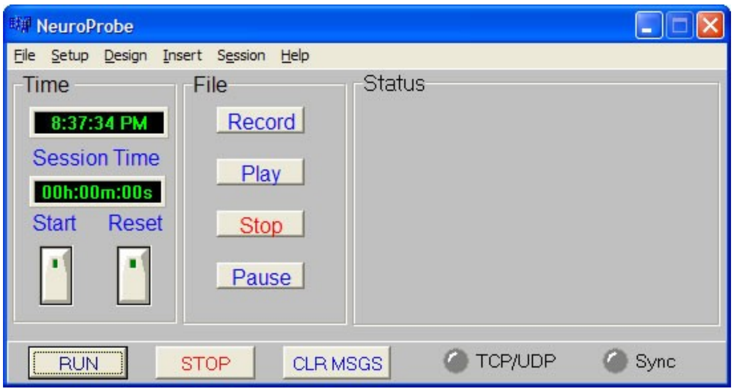


Figure 2.59: The NeuroProbe neurofeedback analysis tool

Source: http://www.hotamateurprograms.com/eeg.htm

2.5 Digital Signal Processing

The experimentation framework which is demonstrated by this thesis consults external data acquisition systems to measure biological signals and to read them as digital signals by the computer to further analyze and store in memory. This section of the thesis discusses some essential knowledge components one would require to understand the process of time-varying data acquisition and analysis (Lynn and Fuerst, 1989; MathWorks, 2003; Kästner, 2003).

A sensor converts the physical phenomena of interest, for instance the skin conductance, into an electrical signal. There are two types of sensors based on the output they produce: digital sensors and analog sensors. A digital sensor produces an output signal that is a digital representation of the measured physical phenomena where the magnitude has discrete values measured in discrete time intervals. This digital output can be read by the computer if the output logical levels are compatible with the computer input; otherwise an additional circuitry is required to convert them to compatible levels (for example, the usage of RS232 level converter).

An analog sensor differs from a digital sensor in that it produces an output signal that is directly proportional to the physical phenomena and it is continuous in both magnitude and in time. This analog signal cannot be read by a digital computer unless it is converted to digital form and to compatible logic levels.

The analog-to-digital (A/D) conversion of an analog signal involves sampling and quantization. The sampling is a process of taking snapshots of the analog signal at discrete time intervals. Next, this snapshot of the signal value is converted to a binary number that the computer can understand which is called quantization.

In digital systems, the sampling is performed by a sample and hold (S/H) circuit. If the system has more than one input channels, the sampling is performed for the channels either sequentially (S/H) or all at once (SS/H). In an S/H circuit, a time gap exists between consecutive sampled channels, which is called the channel skew (Figure 2.60). The sample period is the time between two sampling sessions.

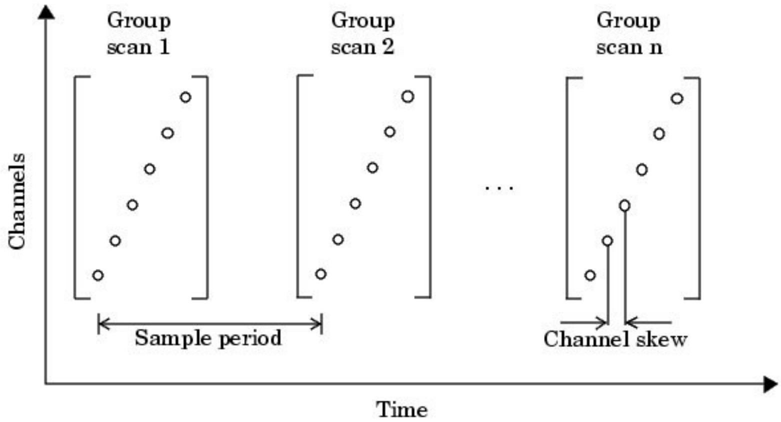


Figure 2.60: Sampling delays in a sampling and hold circuit

Source: MATLAB Data Acquisition Toolbox

The sampling rate is an important parameter which determines the amount of information acquired by the digital system. If the sampling rate is too slow, the analog signal is undersampled, and aliasing can occur. Meanwhile, an unnecessarily higher sampling rate is computationally expensive both in memory and resource usages.

The aliasing refers to the fact that higher frequencies incorrectly interpreted as lower ones (Figure 2.61). The rule to prevent aliasing is given by the Nyquist theorem, which states that the samples should be taken at equal time intervals and the sampling rate must be equal to or grater than twice the highest frequency component in the analog signal.

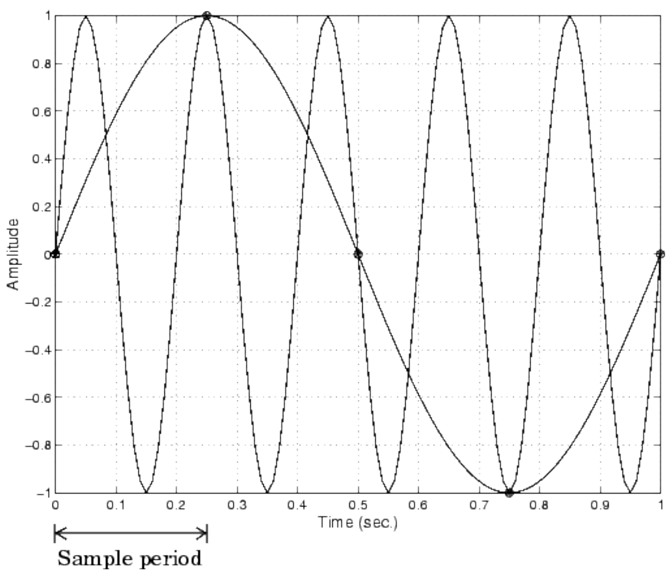


Figure 2.61: Aliasing in digital signal processing

Source: MATLAB Data Acquisition Toolbox

In practical situations, the analog signal is conditioned before sampling by filtering out higher frequency components greater than the maximum frequency component of interest using a low-pass filter. This will greatly reduces errors that would have introduced to the signal from noise. Sometimes, the sampling rate of the sampled signal is increased (upsample) or decreased (downsample) to suit the requirements. Usually, upsampling is performed to increase the resolution of an image, whereas the downsampling is performed to reduce the data rate. In either case, anti-aliasing filters are used to maintain the Nyquest sampling theorems for the resampled signals.

For the quantization, the A/D converter uses a finite number of evenly spaced values to represent the analog signal (Figure 2.62). This value is then represented as a binary number. The number of different values is determined by the number of bits used for the conversion, for instance a 3-bit A/D converter can give only 8 quantized values.

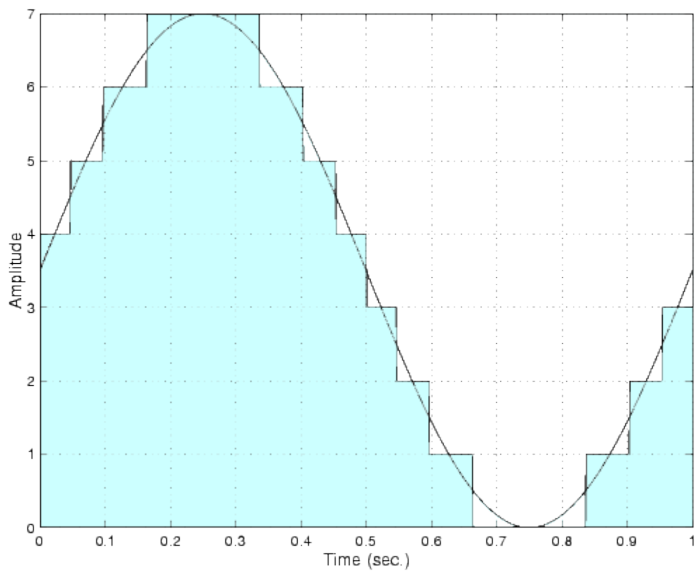


Figure 2.62: Quantization: 1 Hz sine wave quantized by a 3 bit A/D converter

Source: MATLAB Data Acquisition Toolbox

The accuracy and precision (resolution) are two important parameters which determine the quality of the measurement system. The accuracy determines how close the measurement comes to the true value, whereas, the precision determines how exactly the result is determined without reference to what the result means. In a digital measurement system, the accuracy is usually ±0.5 of the least significant bit (LSB), and the number of bits used to represent the analog signal determines the precision. For example, if the device is configured for a 10 volts range and uses 12 bits A/D converter, the precision is 10 volts/212, which gives the precision of 0.00244 volts.

Most neuropsychological signals, such as EEG and GSR, are limited to lower frequencies. Signal analysis systems often require these information signals to transmit in a communication medium to another point. Prior to transmission of an information signal, usually, it is combined with a carrier signals to overcome hardware limitations and to transmit multiple information signals in a one channel.

The modulation refers to the process of modulating the carrier signal to contain the information signal in it. Depending on the method, there are several types of modulation techniques and Figure 2.63 summarizes them. The demodulation is the process of recovering the original information signal from the modulated signal.

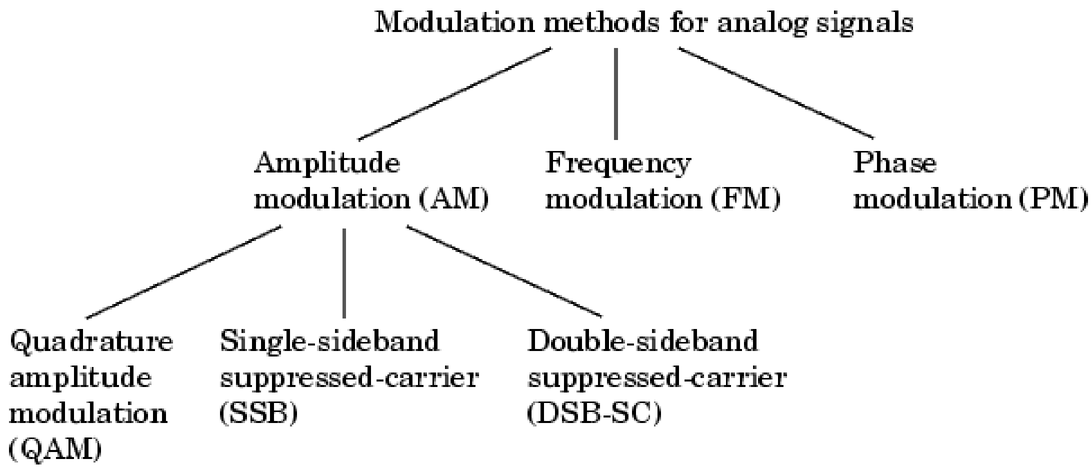


Figure 2.63: Analog modulation techniques
Source: MATLAB Data Acquisition Toolbox

In signal processing, the function of a filter is to remove unwanted frequency components of a signal, such as noise, and to extract the useful frequency components. Filters can be analog or digital. An analog filter is constructed using analog electronic circuits (Figure 2.64), whereas a digital filter uses a digital processor. In digital filters, the filtering effect is produced by performing numerical calculations on digitized sampled values. Analog filters are better than digital filters because the electronic components are cheap and can operate in real-time. In contrast, digital filters are programmable and the characteristics are predictable.

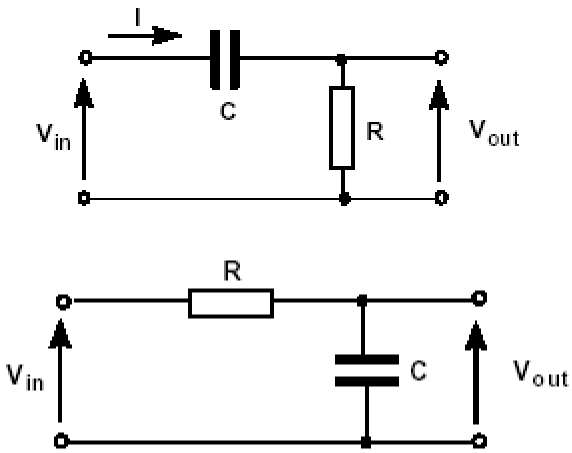


Figure 2.64: Analog high pass filter design (top) and low pass filter design (bottom)

A digital filter is characterized by its impulse response, step response, and frequency response (see Figure 2.65). The impulse response is the output sequence from the filter when a unit impulse is applied as its input. A unit impulse is an input sequence consisting of a single value of 1 at time t=0, followed by zeros at all subsequent sampling instants. The step response (transient response) is the output signal when a step input is applied. The frequency response is the filter's reaction to a sinusoidal input signal.

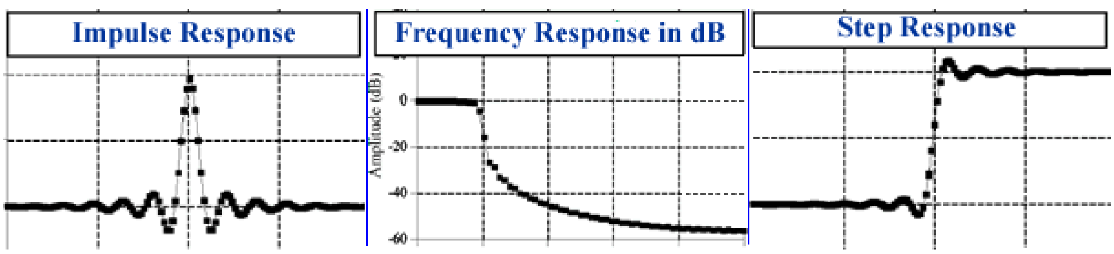


Figure 2.65: Impulse response, frequency response, and the step response of a digital filter

Digital filters are two types based on how the output is calculated from its input. In a non-recursive filter the output is calculated solely from the current and previous input values. However, in a recursive filter, the output is calculated from its input values as well as its previous output values. The order of a digital filter is the number of previous inputs used by the filter to calculate the current output. Since, recursive filters refer to its previous outputs, their orders are much lower then non-recursive filters. Therefore, recursive filters need low computer memory than non-recursive filters. However, since recursive filters depend on previous outputs, they are not stable as non-recursive filters. An alternative terminology for non-recursive filter is known as Finite Impulse Response (FIR) filter, and a recursive filter as an Infinite Impulse Response (IIR) filter. In an FIR filter the impulse response is of finite duration, whereas, in an IIR filter the response is theoretically infinite.

The step response parameters of a digital filter are its rise-time, overshot, and linear phase. In a signal, to detect events, the step response duration (the rise-time) of the filter must be shorter than the spacing of those events in the input signal. The overshot of the filter must be minimized or eliminated; otherwise it can change the amplitude of the output signal. The linear phase refers to the requirement that the filter's response must be symmetrical for rising and falling edges.

Depending on the frequency response, filters are of four types (Figure 2.66): low-pass (LP), high-pass (HP), band-pass (BP), and band-stop (BS):

- A LP filter attenuates frequencies above the cut-off frequency letting frequencies below cut-off through,
- A HP filter passes high frequencies through and stops low frequencies,
- A BP filter passes only frequencies in a certain range, and
- A BS filter passes all the frequencies except the frequencies in a certain range.

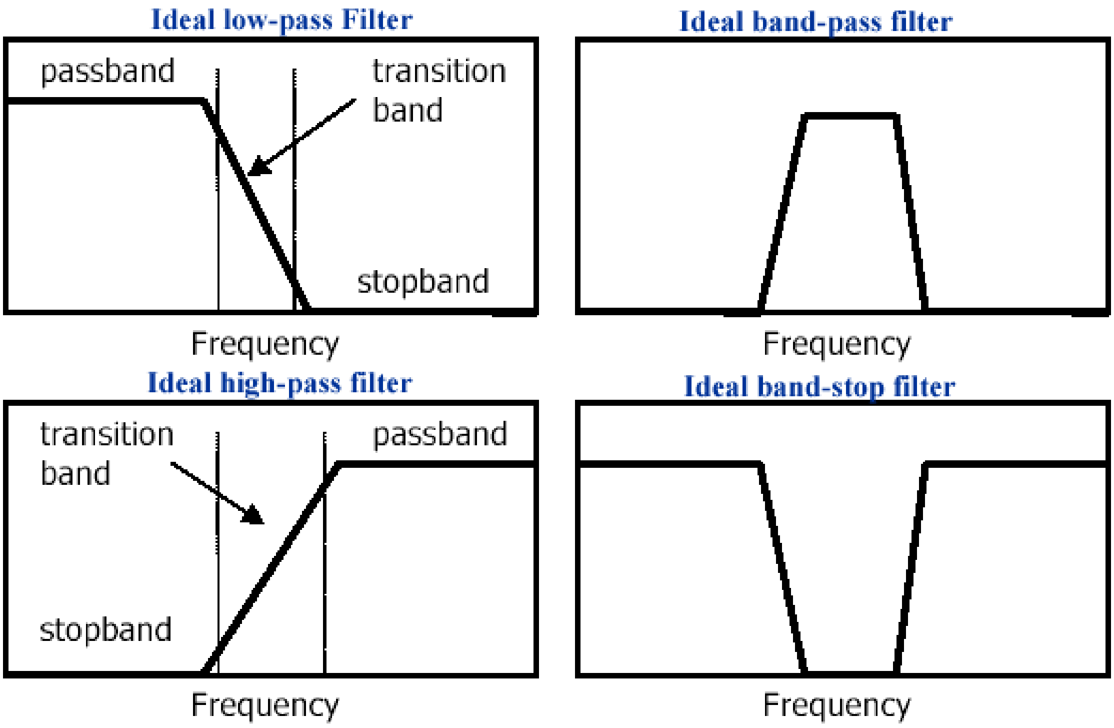


Figure 2.66: Ideal filter designs

However, the real filters are different from ideal filter designs. A good filter should have a fast roll-off, no pass-band ripple, and good stop-band attenuation (Figure 2.67).

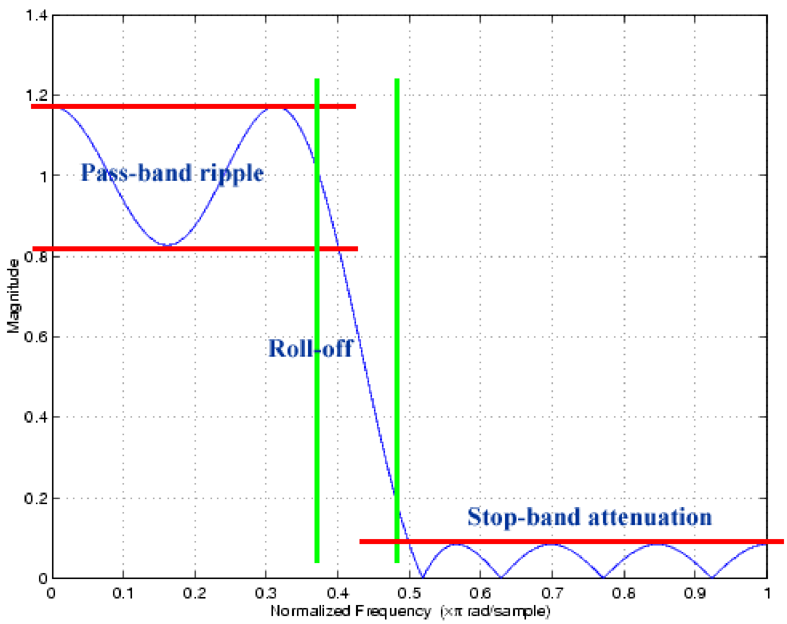


Figure 2.67: Parameters of a real low-pass filter

Chapter 3 - Cognitive-Emotional User Correction for Multimedia Interactions

3.1 Conception of Human Psyche

The sections 2.2 and 2.3 have discussed how cognitive emotional aspects, such as memory, attention, and arousal, affects human decision making. After conceptualizing the relationships, the informative and energy view model of human psyche (Figure 3.1) was proposed to better describe the external interactions and internal information processing of humans. It is an expanded and refined model of cognitive architecture proposed by Ekanayake et al. (2006a; 2006b).

The sensation is the resulting neural excitation when visual, auditory, or haptic sensory systems constantly stimulated by a stream of events from the physical environment. These neural excitations can produce symbolic and sub-symbolic perception. The symbolic perception results when a continuous sensory stream is transformed into discrete percepts of visual, auditory, or haptic. The neural excitations also produce sub-symbolic percepts where it refers to continuously varying quantities of sensation.

The externally recognized symbolic and sub-symbolic percepts interact with the semantic space where they get associated with existing memory networks to expand the meaning and to activate the links. Beneath of this layer reflexive behaviors are handled, for instance knee jerk.

The Kahneman's model explains the relationship between arousal, attention and mental effort. If the arousal is too high or too low, a smaller amount of capacity is available than if it is at the optimal level of arousal. Over arousal can distract the individual, and lower or no arousal can make the individual inattentional (physical mental energy is not enough).

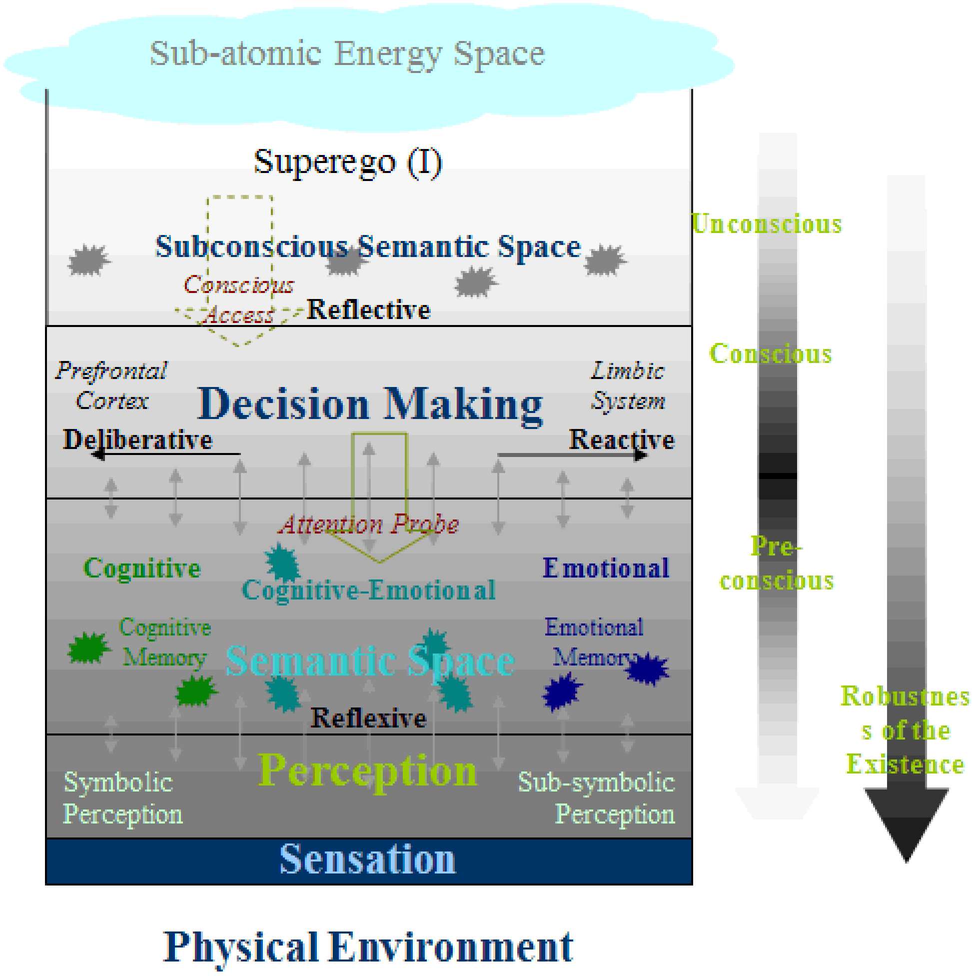


Figure 3.1: The informative and energy view model of human psyche

The semantic space of the model has all these realities. If the activation in the emotional space is higher (activity of the amygdala), it results increased arousal. On the other hand, if the activation in the cognitive space is higher (activity of the prefrontal cortex), it results reduced or no arousal. The optimal arousal occurs at the middle of the semantic space. Again, only at the middle the balanced cognitive-emotional memory networks are get activated and usage is utilized.

The attention probe is a slider that moves left or right depending on the level of arousal (Figure 3.2). If the arousal is high, the attention probe moves right. If the arousal is low, it moves left. Again, the level of attention is dependant on the level of arousal. The optimal attention can be gained when the arousal is at middle levels.

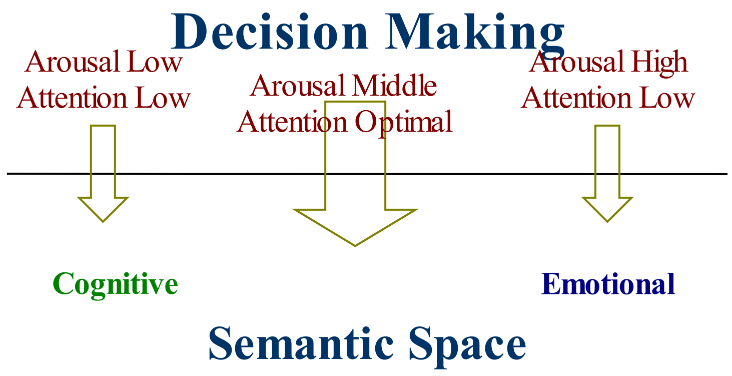


Figure 3.2: The relationship between attention and arousal

At the level of decision making, the cognitive agent tries to make atomic steps to minimize the disequilibria between self and the world. The world to the decision making level is the immediate underneath semantic space. It receives information in both symbolic and sub-symbolic quantities. The self for the decision making level relies at the upper subconscious semantic spaces. The personality is one aspect enforced by that subconscious semantic space.

Higher levels to the subconscious semantic space forms superego and beyond that the conception opens to the antimatter energetic space. The discussions about these layers are beyond the scope of scientific studies.

The proposed model has compatibility with Freud's conception of the human psyche (the iceberg metaphor), Davis's layered architecture with emotion core, and the five aggregate model in Buddhism. The lower layers to decision making layer forms preconscious space where the individual is able to dig into details of that space through attention. The individual can gain the awareness of its own decision making as a result of conscious access through the subconscious semantic space. Receiving more emotional quantities to the decision making later can make the atomic steps more reactive, while receiving more symbolic quantities can make the decisions more deliberative. The balance of the two quantities helps to make rational decisions. The neural circuits can make reflexive, i.e. stimulus-response, reactions at lower semantic levels when the agent's biology needs immediate actions to its survival.

The model consumes both energy from the physical environment (metabolic) and antimatter energy (only an assumption). Going into lower levels of the model confirms the individual's worldly existence, or robustness, where the functional units of those layers are made up of physical matter. However, the upper most layers are freer from physical matter and made up of antimatter (cosmic energy).

3.2 Perception-Cognition Gap or Cognitive-Emotional User Correction?

The section 2.1 has highlighted the need for addressing the perception-cognition gap in multimedia interactions. This issue was raised based on the assumption that human cognition is solely dependent on symbolic information processing. Under that assumption, the individual differences exist on the way each individual represents perceived symbolic information in their internal semantic networks.

However, according to modern cognitive science framework, the human cognition also depends on sub-symbolic information processing. In this continuum, emotions play a major role in defining an individual's identity. Therefore, the individual differences exist both in symbolic and sub-symbolic levels. So, what is needed when defining individual differences in processing multimedia interactions is from the understanding of cognitive-emotional constraints of each individual.

The average explanation for defining one's cognitive-emotional space is from the relation between attention and arousal. The attention describes the quality of cognitive functions and the arousal describes the quality of emotional functions of an individual. Figure 3.2 showed the relation between attention and arousal and its correspondence to the proposed informative and energy view model of human psyche.

According the model, an individual's most effective cognitive-emotional processing range is found when the arousal is at middle. Only within this range we can assume that the individuals are sufficiently responding to external interactions and taking the maximum benefit from them (learning, retention, enjoying, etc.). The effort of my research is to detect these quantities using sensing instruments and identify the patterns which can be used to describe an individual's optimal interaction to multimedia content.

3.3 The Psychophysiological Evaluation Framework

In my study, I have considered the GSR activity and eye activity of a user to determine his/her psychological involvement to a multimedia interaction. The eye activity can be used to determine the visual attention, while the GSR activity can be used to determine the level of arousal (discussed under section 2.4.3).

The visual attention is considered assuming that the multimedia interaction is computer based. Since the computer screen has limited dimensions, the user's visual space should be limited to the space defined by that computer screen in order to consider that the user actually responding to the events of computer interaction (Figure 3.3).

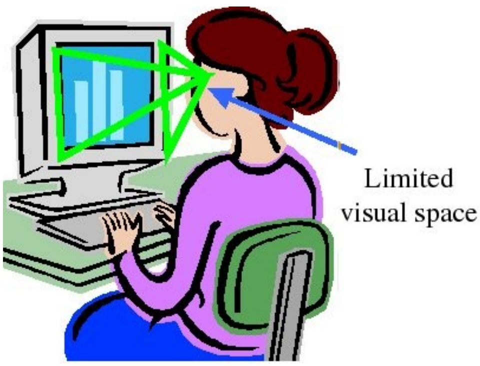


Figure 3.3: Subject's limited visual field bounded by screen dimensions

The visual attention is determined by analyzing the EOG signals generated at the eye (see section 2.4.4). The assumption is that once the user focused his/her attention towards the computer screen, the amplitude of EOG signals should be within the limits of a certain range. The variations out of the range are an indication that the user looking outside the boundaries of the computer screen (Figure 3.4).

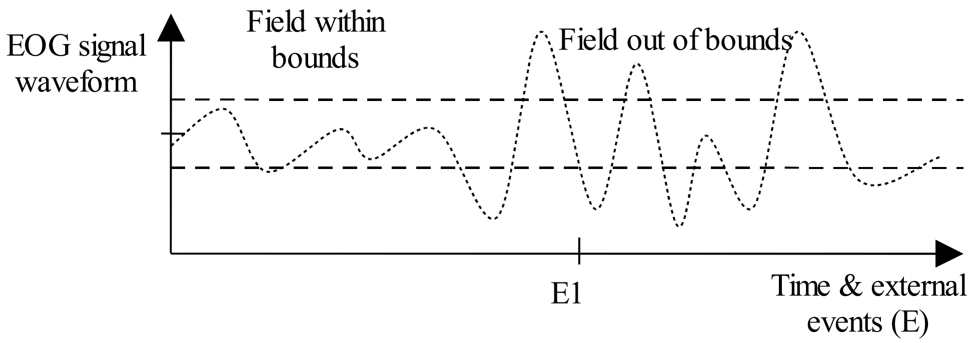


Figure 3.4: EOG signal variance for within bounds and out-of-bounds visual attention

The important advantage of this method is that the hardware required to capture the signals are low in cost compared to hardware required to capture the exact special location of attention of a person. Refer section 4.2.2 for a detailed discussion of the hardware configuration.

The GSR activity is recorded to determine the temporal psychophysiological reaction to the external stimuli. For this measurement also I have employed a low cost hardware arrangement (see section 2.4.6). The GSR is an efficient and popular technique in determining one's arousal level (see section 2.4.3). The section 2.3.2 has discussed the rationale behind optimal arousal respect to optimal psychological performance. Based on this theoretical understanding of arousal respect to one's emotional reaction to external stimuli (discussed under sections 2.3.1 and 2.3.2) and its correlation to GSR behavior (discussed under section 2.4.3) three classes of GSR waveforms can be expected as given below:

- GSR pattern corresponds to less arousal and no involvement,
- GSR pattern corresponds to optimal arousal and active involvement, and
- GSR pattern corresponds to internal or external distraction and no involvement.

The expected waveforms for the above three classes of GSR patterns are depicted in Figures 3.5, 3.6, and 3.7.

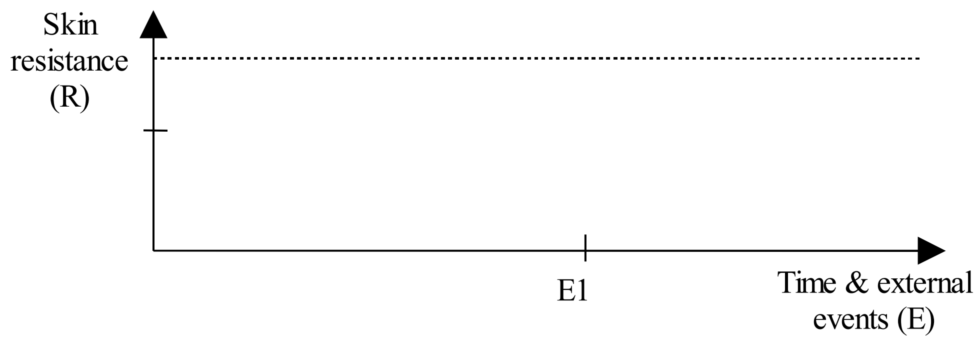


Figure 3.5: GSR pattern for no or low arousal of individual

Figure 3.5 shows the GSR pattern when no or low arousal of individual. The pattern's characteristics are higher skin resistance (R), a steady waveform and no or less response to external events.

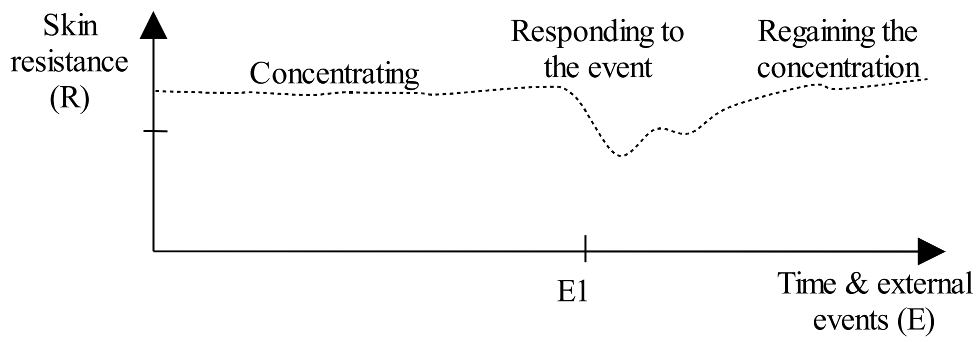


Figure 3.6: GSR pattern for optimal arousal of individual

Figure 3.6 shows the GSR pattern for the optimal arousal of an individual. The pattern's characteristics are average skin resistance, approximately steady waveform when concentrating, and fall and recover waveform when responding to external events.

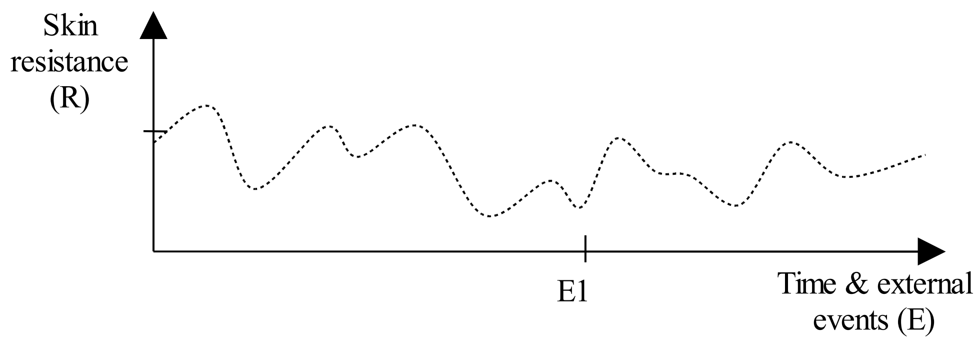


Figure 3.7: GSR pattern for higher arousal of individual

Figure 3.7 shows the GSR pattern for higher arousal of an individual. The pattern's characteristics are low average skin resistance and higher variations in waveform. The cause for higher arousal is either the individual is involved with an interesting activity or facing an emotional situation.

Out of the arousal classes, the optimal arousal gives the optimal psychological performance for the individual. The optimal psychological performance relates with optimal memory processing and other cognitive functions. Therefore, the task is to maintain the individual at that arousal level respect to the multimedia content to consider that the involvement of the individual is at optimal.

The higher arousal of an individual relates with higher emotional situation of an individual, such as frightened and anger (see section 2.3.2). However, respect to a multimedia interaction, the user can be in such situation depending on the content of that multimedia, for instance a horror film. Therefore, this emotion evoking multimedia also should be considered respect to involvement. This involvement can be filtered from internal emotional situations, such as stress and depression, or external out of focus attention to the environment by visual attention and analyzing how the individual responding to media events.

Although, the optimal arousal relates with increased concentration, in practice, both concentration and inattention states give similar GSR patterns, for instance when the subject is consciously attending a video lecture and getting into inattention state after some time. To differentiate the inattention situation from a concentration state I have used the eye blink rate, which can be derived from the EOG waveforms. The general observation is that, when an individual is drowsy, his/her eye blink rate increases and the pattern of the EOG signal changes with respect to an active situation (see section 4.2.1).

Table 3.1 summarizes the psychophysiological evaluation framework constructed from theoretical understanding to determine an individual's involvement to a multimedia interaction. This framework is evaluated under the section 5.2.

Table 3.1: The psychophysiological evaluation framework

Psychophysiological sensing modality	Inattention (bored)	Cognitive concentration	Cognitive-emotional involvement	Internally distracted	Externally distracted
GSR activity	Steady waveform; low variance; weak/no response to media events	Steady waveform; low variance; strongly responding to media events	Higher fluctuations in the waveform; higher variance; responding to media events	Higher fluctuations in the waveform; higher variance; weak/no response to media events	Higher fluctuations in the waveform; higher variance; weak/no response to media events
Eye movement activity	Within bounds	Within bounds	Within bounds	Within bounds	Out of bounds
Eye activity rate (blink rate)	High	Low	Low	Low	High or Low

Chapter 4 - BioMedia: Affect Integration and Visualization System for Multimedia Interactions

4.1 Overall System Architecture

For the evaluations of multimedia psychophysiological framework proposed under the section 3.3, it is required to analyze individual's affect activities, for instance EOG and GSR signals, against multimedia interactions (Figure 4.1). This brings the need for a tool where integration of multiple affect streams and media streams is possible with recording and analysis facilities. Almost all the tools available in the web (see section 2.4.7) can only be interfaced with predefined devices having fixed sample rates. Moreover, no tool is found that can capture media events.

Figure 4.1: Affect monitoring of a human while involved with a multimedia interaction

To overcome this barrier, an affect integration and visualization system for multimedia interactions is proposed naming it BioMedia system. The high-level architecture of the BioMedia system is depicted in Figure 4.2.

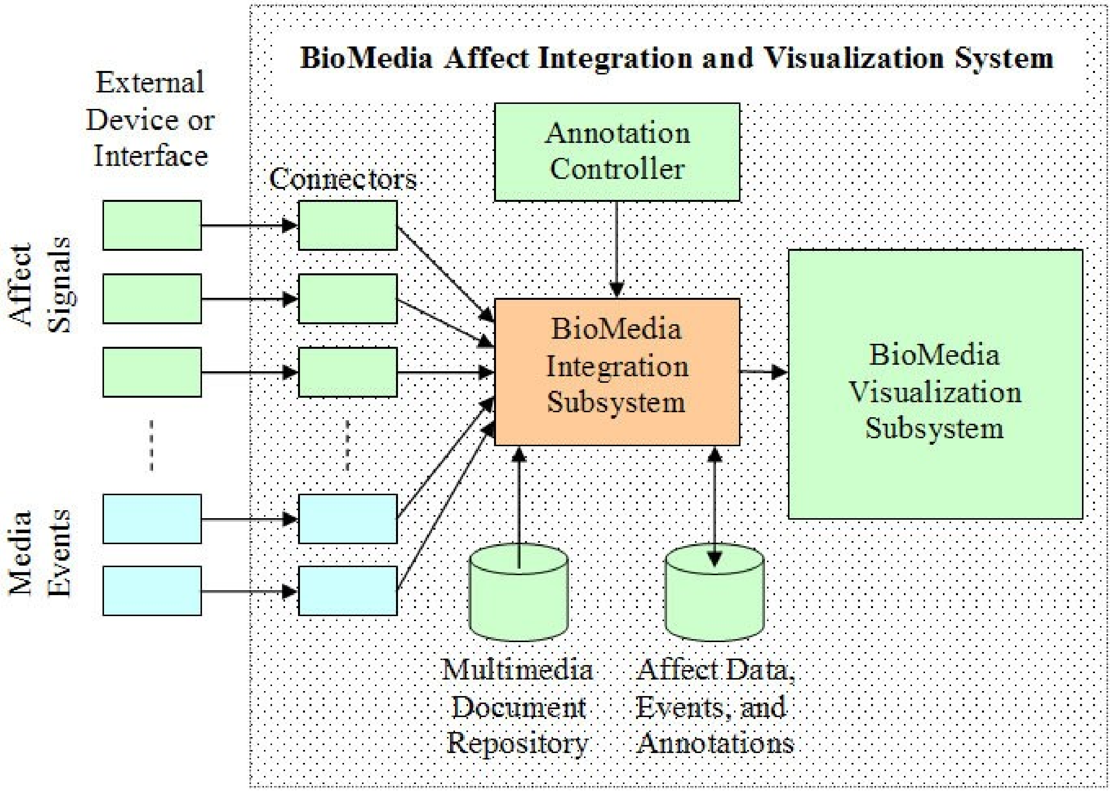


Figure 4.2: The high-level architecture of BioMedia system

The core of the BioMedia system is its integration subsystem. It receives affect stream data through affect connectors and media events through media connectors. A connector is an interface for external capturing device or external interface. These connectors have internal buffers, so that they can match sampling rates between external signal sources and BioMedia system. The sections 4.2.2 and 4.3.2 discusses implementation details of the NeuroProbe connector for EOG data and the LEGO GSR connector respectively.

A media event can be start of interaction, end of interaction, or internal transition respect to multimedia document. The corresponding documents are found under multimedia document repository. However, current implementation of BioMedia does not communicate with the multimedia document repository.

Since the hardware devices I have employed for the capturing of neurofeedback signals do not guarantee stable sampling rates (compromised under low-cost), it seemed difficult to use standard file formats, such as EDF, for the recording of affect signals and media events. As a solution, a file format was used where the integration subsystem channels stream data into one file organizing data and events in chronological order of occurrence (Figure 4.3). This indirectly enforces real-time constraints to the system. It uses the following definition of records:

GSR&M <GSR value> <Media event id>
S&TIME <Sequence number> <Timestamp>
EOGLR <EOG left channel value> <EOG right channel value>

```
GSR&M 854 0
S&TIME 0 1216162214734
GSR&M 854 0
S&TIME 1 1216162214843
GSR&M 855 0
S&TIME 2 1216162215062
EOGLR -78 68
EOGLR -45 86
EOGLR -23 88
EOGLR -10 76
GSR&M 852 0
S&TIME 3 1216162215500
EOGLR 81 19
EOGLR 122 101
EOGLR -6 53
```

Figure 4.3: Example of file format used by BioMedia

Figure 4.4 gives the simplified algorithm used by the BioMedia integration system. The actual implementations of most essential functions are included under appendix.

Affect signals and media events are graphed by the visualization subsystem. Since there are multiple streams with different sampling rates, the streams are organized under two rates: fast and slow. In the interface, fast signals are displayed in the top and slow signals in the bottom (Figure 4.5). Since, the current BioMedia system has interfaces to EOG, GSR, and media event streams, the visualization subsystem can interface with these signals only. The EOG signals are captured at a higher sampling rate (256 samples/second) and GSR signals are at a lower rate (2-4 samples/second). Therefore, these signals cannot be displayed in the same graph with their correct resolution. To resolve this problem, EOG signals are displayed under the fast signals section of the graph while displaying GSR and media event data in the slow signals section.

```
If PLAY or RECORD
      Check readiness of connectors
      Initialize the graphs
      If RECORD
            Prepare the data file for recording
While PLAY or RECORD
      While data not ready in the GSR buffer
            Read next data record from EOG connector
            Send the data to the fast graph
            If RECORD
                  Write data record to the file
      Repaint fast graph
      If data ready in the GSR buffer
            Read the GSR data record
            Read media data record
            Send the GSR and media data records to the slow
graph
            Repaint the slow graph
            If RECORD
                  Write GSR and media data records to the file
                  Write timestamp to the file
      Sleep for n milliseconds
```

Figure 4.4: Algorithm for play and record

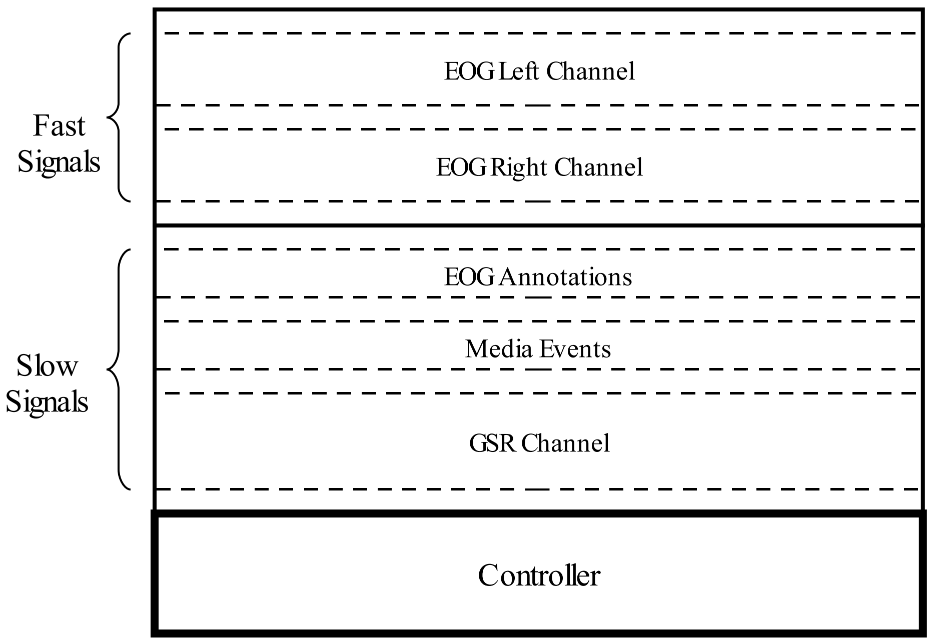


Figure 4.5: Graphing of signals

At the time of analysis, it is required to collectively analyze EOG signals and GSR signals against media interaction events. This prompts the need to graph all these signals in a single graph. The BioMedia system resolves this issue by allowing annotations for EOG signals. An EOG annotation can be defined respect to discrete classes, for instance eye blink, look up, look down, look left, or look right. Once annotations are added, they will get displayed under slow signals section, so that all signals can be analyzed under one graph. Figure 4.6 shows the BioMedia user interface of the actual implementation.

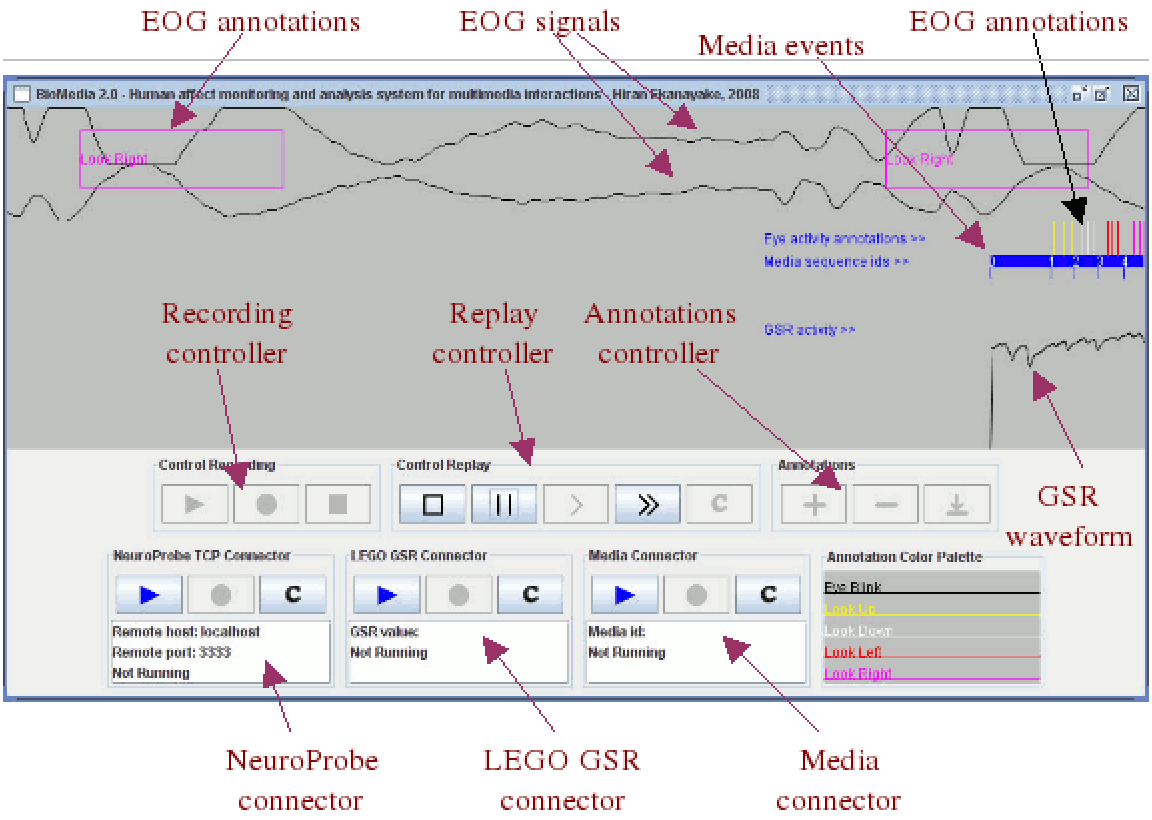


Figure 4.6: BioMedia GUI

While implementing the graph interface, it was observed that Java is very weak in displaying real-time graphs. Most available graph packages have been optimized either for static graph designs or show time varying graph designs. The BioMedia visualization system has been able overcome this limitation by using moving image and append graph technique (Figure 4.7). The implementation of the technique is given in the appendix.

The controller section provides controlling facilities for recording, replaying, annotations, and changing parameters. Figure 4.8 shows the dialog box appears when inserting an EOG annotation. To insert these annotations, the operator has to monitor the EOG panel and detect EOG waveform patterns for different eye movements, similar EOG responses depicted in

Figure 2.48, and select appropriate label.

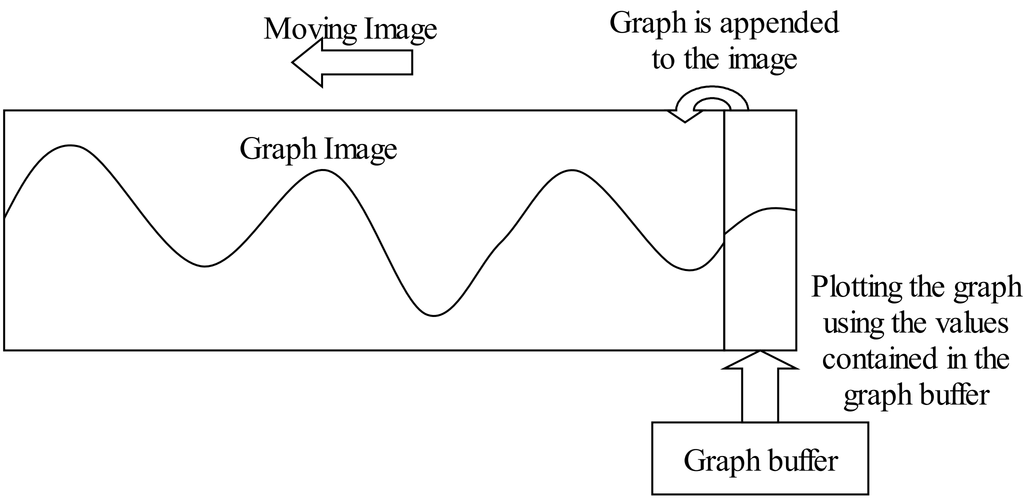


Figure 4.7: Graphing technique used by BioMedia

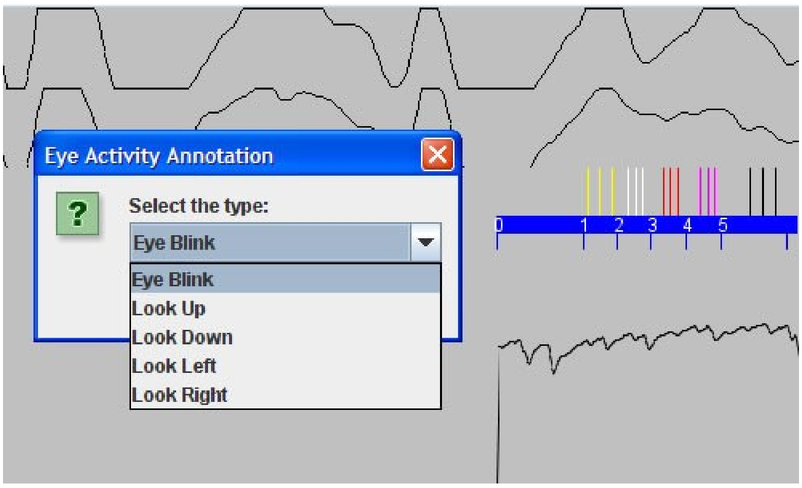


Figure 4.8: Insert EOG annotation

4.2 Eye Activity and Visual Attention

4.2.1 Eye Activity to Determine Visual Attention

In EOG, the resting potential of the retina is measured in relative to eye movements (see section 2.4.4). The signal magnitude of the corneoretinal potential is in the range 0.4 – 1.0 mV. However, in neurofeedback research this corneoretinal potential is measured by placing electrodes at the forehead and two temples. Although, the measurable potential with this arrangement drops into the range 10 – 100 µV, hardware arrangement using instrumentation amplifiers with sufficient gain of amplification allows amplifying these signals to detectable range. The section 4.2.2 discusses hardware arrangement for this purpose.

The section 3.3 discussed the rational behind using eye movement activity in determining visual attention towards an onscreen multimedia interaction.

4.2.2 BioMedia's EOG Interface

The hardware of this experiment was constructed based on low-cost low-power soundcard EEG dual channel AM unit, proposed by Grant Connell in 2005 (see section 2.4.6). The first time development cost of the unit is around USD 150, but the unit can be reproduced for a cost less than USD 100. Figure 4.9 shows the constructed EOG capturing device.

Figure 4.9: The EOG capturing device

Figure 4.10 shows the hardware components of the EOG capturing device. The schematic of the circuitry is included in the appendix.

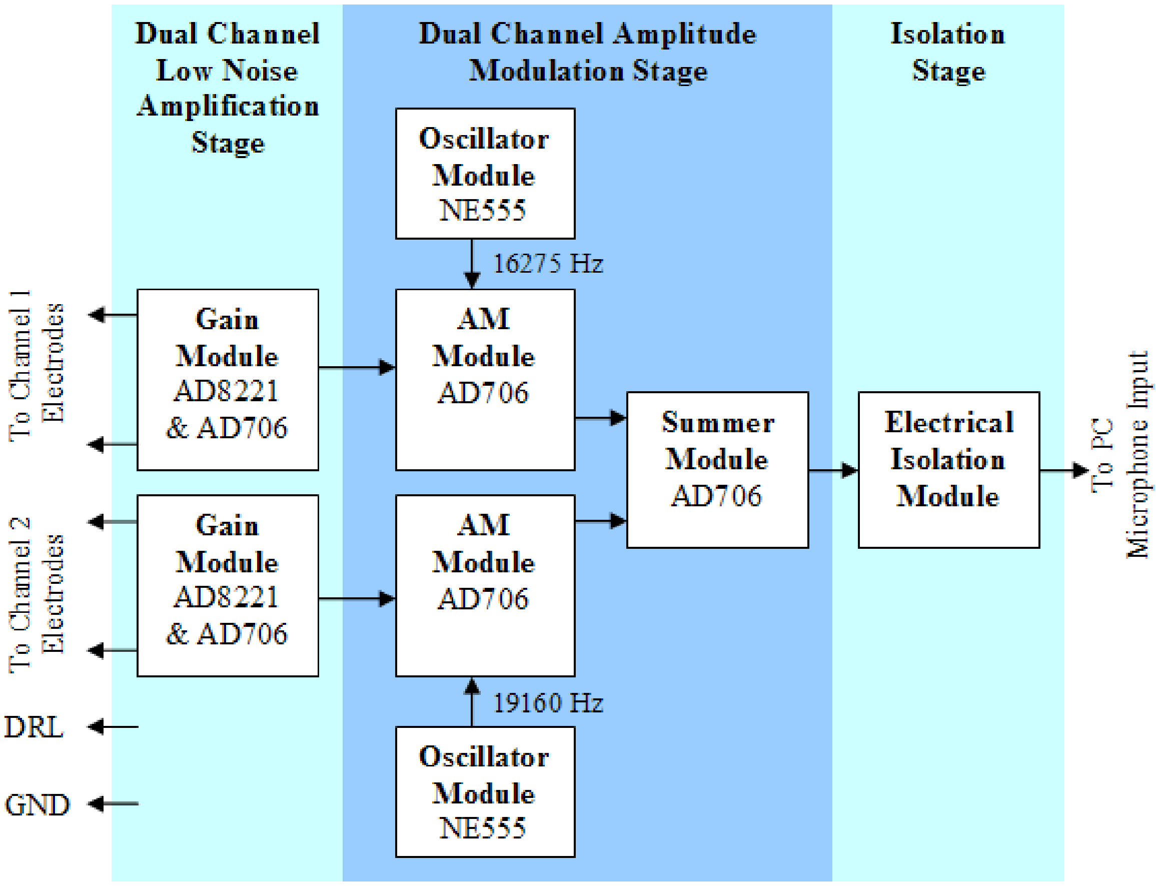


Figure 4.10: The components of EOG hardware unit

The electrodes are passive electrodes constructed using silver (Ag) plates. For this research I have developed a home-made headband mounting the electrodes to touch the skin at middle of the forehead and two temples (Figure 4.11). To make a good skin contact, I have used Spectra 360 electrode gel.

Figure 4.11: EOG headband

Once the modulated signal is fed in to the soundcard, a software demodulation stage is needed to recover the original EOG signals. The processing chain of the software demodulation is something like shown in Figure 4.12.

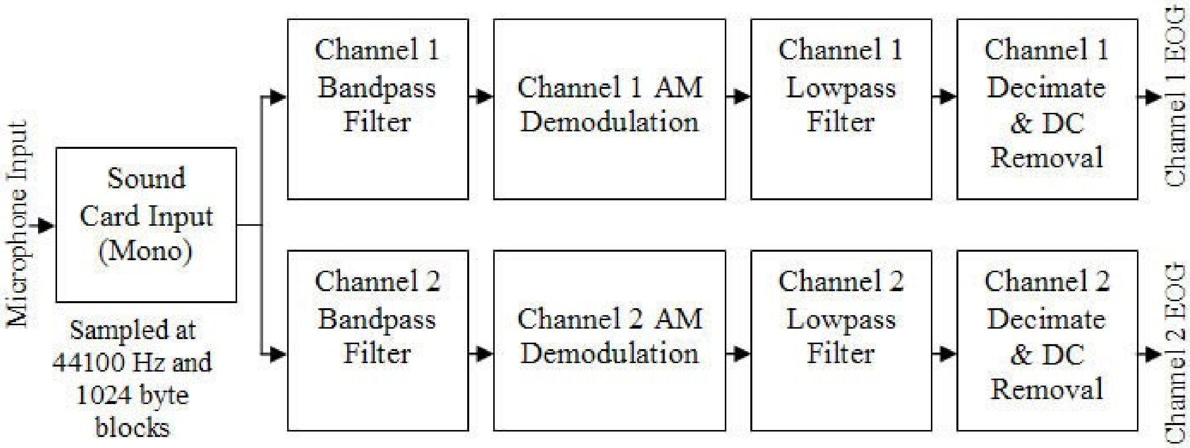


Figure 4.12: Software demodulation of EOG unit

The chain has been verified using MATLAB 6.5.1 and Figure 4.13 lists the code of that function.

```
    % ********************************** %
    % Demodulate and Prepare Channel Data %
    % ********************************** %
function [ch1, ch2] = filtersig(x)
      fs = 44100; % Sampling frequency
      fc1 = 16275;
      fc2 = 19160;
      bs = 1024; % block size

      % Apply bandpass filters
      [b1, a1] = cheby1(4, 0.5, [fc1-250 fc1+250]/(fs/2));
      [b2, a2] = cheby1(4, 0.5, [fc2-250 fc2+250]/(fs/2));
      x1 = filter(b1, a1, x);
      x2 = filter(b2, a2, x);

      % Demodulate signals
      o = ones(1,bs)';
      hx = hilbert(x1);
      r = real(hx);
      i = imag(hx);
      y1 = sqrt(r.*r.*o + i.*i.*o);
      hx = hilbert(x2);
      r = real(hx);
      i = imag(hx);
      y2 = sqrt(r.*r.*o + i.*i.*o);

      % Low pass filtering (remove 50Hz mains hum also)
      [b, a] = cheby1(3, 0.5, 15/(fs/2));
      ch1 = filter(b, a, y1);
      ch2 = filter(b, a, y2);

      % Decimate
      ch1 = decimate(ch1, 10);
      ch2 = decimate(ch2, 10);

      % DC removal
      ch1 = ch1 - mean(ch1);
      ch2 = ch2 - mean(ch2);
```

Figure 4.13: Software demodulation implemented in Matlab

The MATLAB function only process data of collected samples. However, for real-time recording more sophisticated processing chain is required. This has been achieved using the NeuroProbe's AM module. The refined signals are transmitted to BioMedia's NeuroProbe connector thru TCP at a sampling rate 256 Hz. The NeuroProbe's connectivity diagram is shown in Figure 4.14. The bandpass filter is to limit the pass band range to 0.5 – 20 Hz.

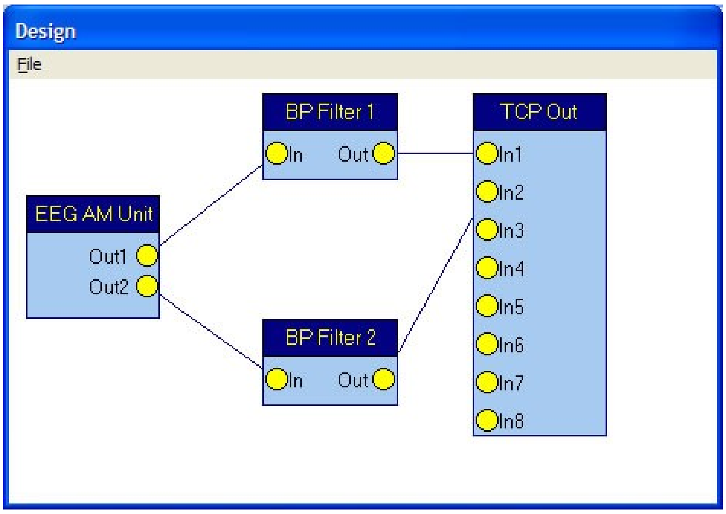


Figure 4.14: NeuroProbe's connectivity

The BioMedia's NeuroProbe connector is a process written in java and it simply acts as a data buffering module for the data transmission from NeuroProbe to BioMedia's streams integration and visualization subsystems (Figure 4.15). The reason for buffering the data is to match the sampling rates of different affect and multimedia.

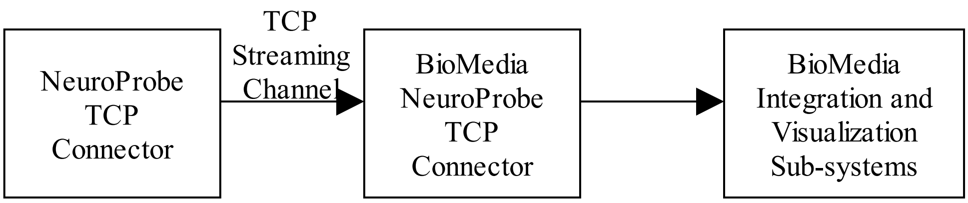


Figure 4.15: NeuroProbe BioMedia connectivity

The buffering process is implemented using a two channel cyclic queue. The NeuroProbe TCP (Transmission Control Protocol) connector writes data to the buffer while BioMedia's streams integration and visualization subsystems read data from it. Figure 4.16 depicts the process.

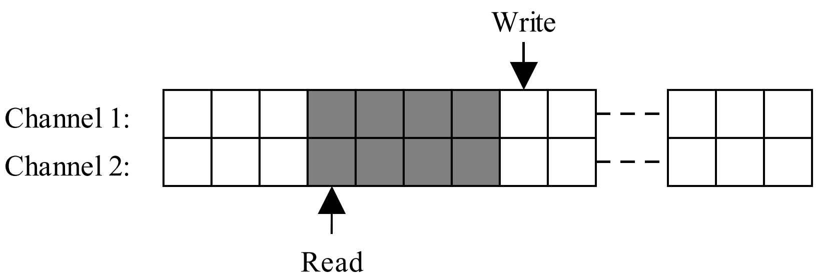


Figure 4.16: BioMedia's NeuroProbe TCP connector buffer

When reading: if read = = write, then “data not ready”

When writing: if read = = write, then “buffer overflow”

The data reaches the BioMedia’s NeuroProbe TCP connector in a TCP streaming channel. The format of the data line is very close to the European Data Format (EDF) (see section 2.4.5) and its fields are given in Figure 4.17.

```
typedef struct
{
     unsigned char MessageHeader[16];
     int source_type;
     int fltr_pts;
     float sample_rate;
     int channel_mode;
     int modulation_type;
     int sample_rate_position;
     int packet_number;
     int data_index;
     float chanA_data[64];
     float chanB_data[64];
} EEG_datastream;
```

Figure 4.17: NeuroProbe's output data format

The data captured at 560 bytes blocks from the TCP channel and processed to recover the original data values. These values are written to the data buffer unless the buffer is filled. This process is shown in Figure 4.18.

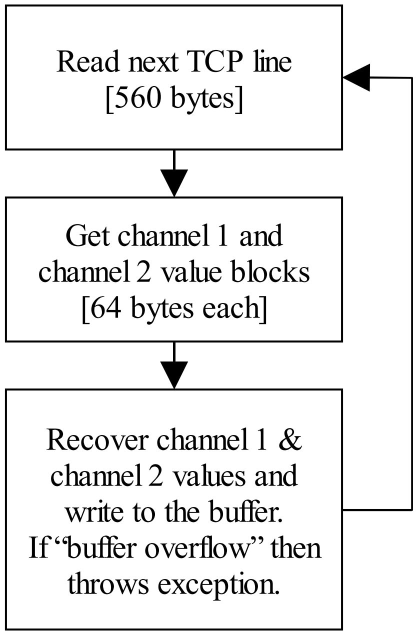


Figure 4.18: Buffer reading process of BioMedia EOG interface

The java code listing of the BioMedia's NeuroProbe TCP connector is included in the appendix.

4.3 GSR Activity and Arousal

4.3.1 GSR to Capture the Level of Arousal

The skin conductance of a person is dependant on skin conductance level (SCL) and skin conductance response (SCR) (Cornell, 2008). The SCL is a slow varying skin conductance value changing over the course of minutes. The SCR is a fast varying skin conductance value and it reflects person's mental response to different stimulus presented. The SCR rides on top of SCL and the change is over the course of seconds.

A SCR waveform has several statistics that are useful for psychological analysis (Figure 4.19),

- Latency is the amount of time between the stimulus and the rise of the wave.
- Rise time is the amount of time it take the skin conductance to reach its peak.
- Amplitude is the height of the SCR.
- Half recovery time is the amount of time it takes for the wave to fall back to half of its amplitude.

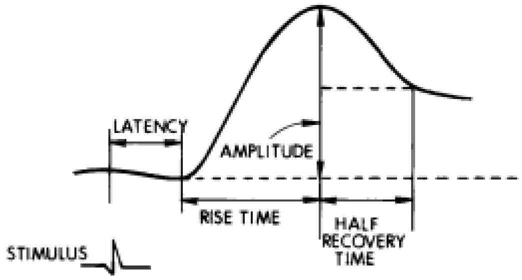


Figure 4.19: Skin conductance response to a stimulus

Source:
http://instruct1.cit.cornell.edu/courses/ee476/FinalProjects/s2006/hmm32_pjw32/index.html

The latency can be used to determine the amount of attention placed on the stimulus by the individual. The amplitude is the strength of the reaction of the user to the stimulus and the half-recovery time is how fast the individual recovers from the stimulus. These relations are directly correlates with "involvement" and "withdrawal" suggested by Shepherd (see section 2.4.3).

In emotion research, the reaction within a window of 1 to 10 second is analyzed (Healey and Picard, 1998). Practical observations have reported that the skin resistance varies in the range 5 – 25 kilo ohms (Shepherd, 2006). Below or above that range the person is less able to address any issue objectively (refer section 2.3.2).

4.3.2 BioMedia's GSR Interface

For the recording GSR activity, I have employed a LEGO Mindstorms RCX based GSR reader (Figure 4.20), an idea triggered after reading Gasperi's GSR sensor poject (Gasperi, 2008). This hardware setup is effective in that it separates the subject from the computer, so there will be no connection from the human to the main power grid. All data transmissions happen through an infrared channel.

Figure 4.20: LEGO GSR sensor

Source: http://www.extremenxt.com/gsr.htm

The electrodes are constructed using silver (Ag) plates and Spectra 360 electrode gel was applied to improve the skin contact. The GSR reading program was written using LeJOS. At each iteration, this program records 7 GSR readings in 40ms durations and at the end of the 7th reading it applies the Gaussian smoother to focus at the 4th reading. The smoothing operator is given below,

val = (2*gsrBuf[0] + 16*gsrBuf[1] + 61*gsrBuf[2] + 97*gsrBuf[3] + 61*gsrBuf[4] + 16*gsrBuf[5] + 2*gsrBuf[6])/255;

The Gaussian smoothing is necessary to remove noise and to breakup the discretized data due to insufficient skin conductance resolution (Cornell, 2008). Finally, it transmits the value where it takes approximately 300ms to reach and read by the computer program. This gives the total latency of approximately 583ms from the real-time recording (Figure 4.21). The actual transmission latency depends on many factors, such as the distance, battery power level of the RCX, and light disturbances. Practically, the maximum achievable sampling rate of this hardware setup is about 2 Hz which is not sufficient to observe a clear SCR waveform. However, it is sufficient to record slowly varying physiological reactions of the subject.

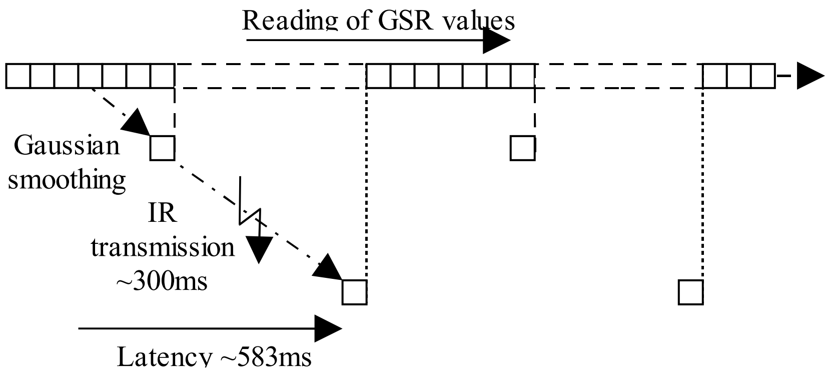


Figure 4.21: GSR data transmission and latency

At the computer, the values are captured by the BioMedia's LEGO GSR connector program. The program allows BioMedia's streams integration and visualization subsystems to get the latest GSR reading of the subject. The code listing of the BioMedia's LEGO GSR connector is included in the appendix.

Chapter 5 - Experiments, Results, and Evaluation

5.1 The Pilot Experiment

The idea of pilot experiment was to test the hypothesis set out in section 1.1 and to evaluate the strength of hardware and software platform and also to uncover factors which could affect the performance of experimentation process.

5.1.1 The Experiment Parameters and Constraints

For the experiment, an air conditioned computer laboratory was selected. The inside temperature was below 26° C and the laboratory was free from outside noise. The subject's visual field was covered from outside distractions. Three computers were used to setup the computational framework considering remote operation and affect monitoring: the interaction renderer, video monitoring and interaction controller, and the BioMedia affect monitoring and integration system. The EOG electrodes were mounted on subject's forehead and GSR electrodes were wrapped around the subject's index and middle fingers of his left hand. Figure 5.1 shows the recording environment and setup of the experiment.

For the experiment five interaction sessions were planned:

- Interaction session 01, July 15, 11:40 am, Gihan, IRQUE Lab: Eye blink | Eye blink | Look up | Look up | Look down | Look down | Look left | Look left | Look right | Look right | Eye blink | Eye blink | Video (China demonstration) | Song (Anantayata, 5:17) | Song (Ricky Martin, 4:27)
- Interaction session 02, July 15, 12:00 pm, Gihan, IRQUE Lab: Question (Maths) | Music (Yanni, Almost a Wisper, 3:06) | Video (Animal attack, 5:07) | Question 2 (Maths) | Video Lecture (Brain Scan, 4:04)
- Interaction session 03, July 15, 12:45 pm, Gihan, IRQUE Lab: Video Lecture (Brain Scan, 4:04) | Question 3 (Brain scan) | Question 4 (Brain scan)
- Interaction session 04, July 15, 1:03 pm, Gihan, IRQUE Lab: Video Lecture (TED talk, brains, 20:12)
- Interaction session 05, July 15, 3:40 pm, Gihan, IRQUE Lab: Question (general) |

Picture (worry) | Video (Racing car accidents, 4:27) | Video (animal killing, 2:13) | Picture (frustrated) | Video (water bed, 3:40)

Figure 5.1: Recording of pilot experiment

5.1.2 Results and Discussion

The GSR waveform shown in Figure 5.2 clearly differentiates the subject's active state at the beginning and then developing the concentration. When the subject concentrates on the multimedia interaction, the GSR waveform stabilizes and the skin resistance gradually increases. Between the end of first song and start of second song (media transition), the waveform shows a drop in skin resistance and then a recovery pattern. This is an indication of the subject psychologically responding to media events. Therefore, it can be concluded that the subject's attention has been towards the media during the period. Again from the low EOG activity, it can be concluded that the subject's visual attention is towards the computer screen and the interaction is not boring.

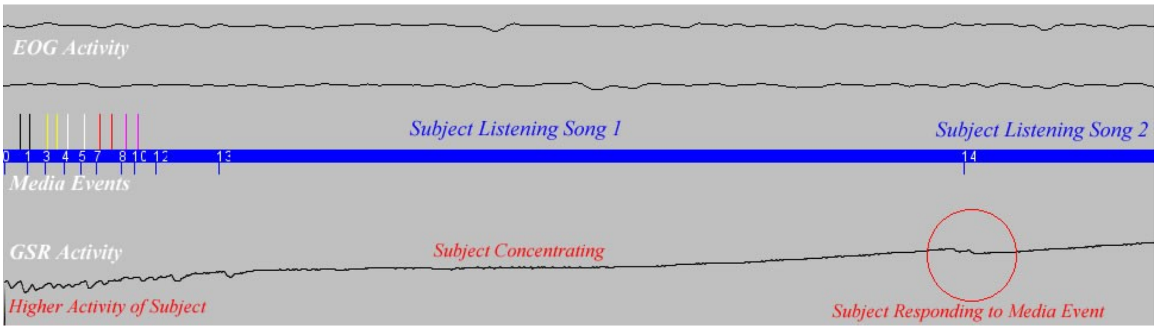


Figure 5.2: Part of recoded GSR waveform of interaction session 01

The first part of GSR waveform shown in Figure 5.3 shows the change of skin resistance when the subject is solving a mathematical equation. Higher variation in the GSR is an indication that the subject is actively involved with the interaction. After the activity, the subject is listening to a song and it is followed by a video. The waveform shows how the subject responded to media events during transitions and then redeveloped the concentration. The psychological responses to transitions are higher than session 01 interactions. The reason for this may be the different media types: activity, non-visual song, and video.

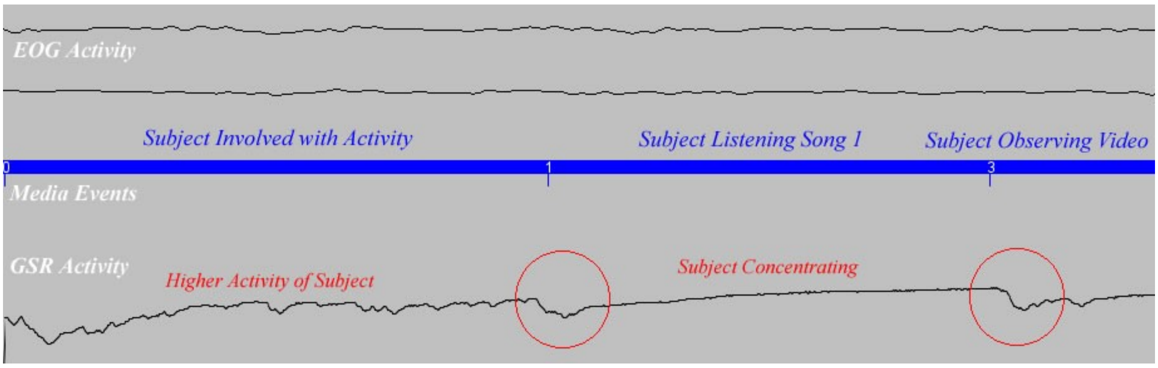


Figure 5.3: Part of recoded GSR waveform of interaction session 02

Figure 5.4 shows affect waveforms recorded to understand subject's interaction towards a long education video of over 20 minutes duration. During the interaction, the subject lost the concentration and finally became drowsy. The GSR waveform is consistent with the observed behavior of the subject. The EOG waveform showed higher eye blink rate from the pattern of left and right eye potentials and their intensities.

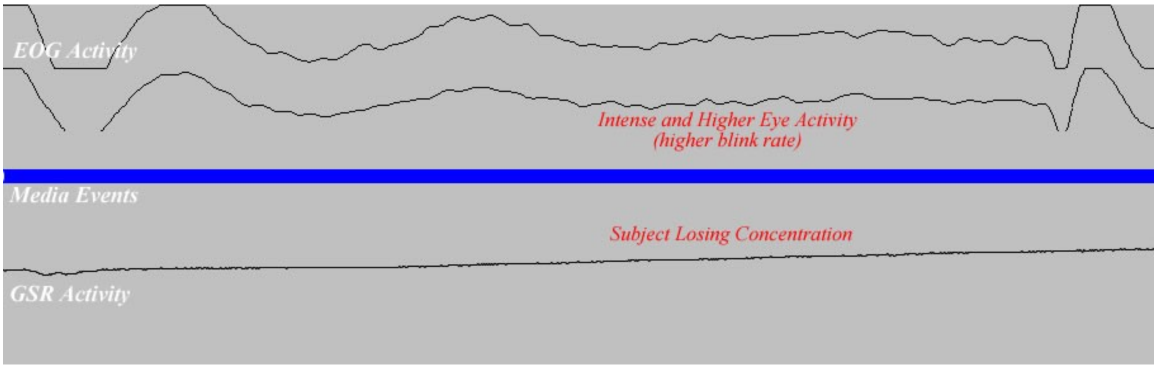


Figure 5.4: Part of recoded GSR waveform of interaction session 04

Figure 5.5 shows the subject's affect activity while he was observing an emotional video (killing an animal), a picture, again a video (funny), and finally withdraw his attention from the computer screen and looking outside. The GSR patterns during media transitions are an indication that the subject has been consciously involved with those interactions. However, during the transition between emotional picture and video, there is no clear psychological response from the subject. The reason may be, after observing the picture for some period, the subject has lost his visual attention.

During the funny video, the GSR waveform shows a higher fluctuation. This indicates the emotional involvement of the subject to the interaction. The EOG waveform shows subject's eye activity after he has withdrawn his attention from the computer screen. The higher fluctuations of the EOG waveform are results of rapid eye movements between long distance locations of the environment.

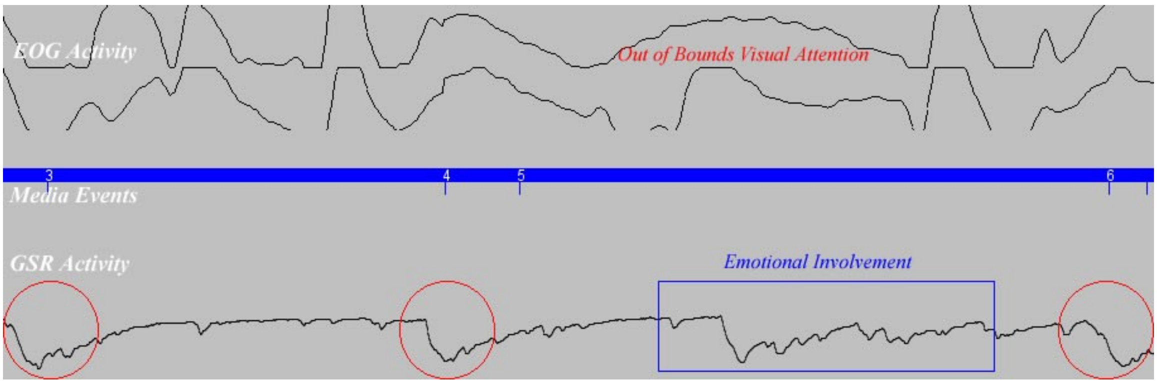


Figure 5.5: Part of recoded GSR waveform of interaction session 05

During the experiment it was observed the following:

- Different individuals have different head dimensions, so the headband electrode set designed based on my head dimensions was not appropriate for others.
- Since BioMedia system does not display time information, it was difficult to analyze waveforms against an exact timeline. Moreover, since BioMedia is not capable of comparing waveforms of different individuals or interactions, the data needed to be exported to MatLab for analysis.
- During the recording, it was observed that battery life of the batteries used by devices has a direct impact on the quality of the readings. Therefore, it was decided to use new batteries for each recording session to minimize low battery impacts on readings.
- All the recordings accompanied video recording of facial expressions, especially eye activity, of individuals. This helped to cross check the results against actual behaviors of individuals.
- It was also observed that currently the BioMedia system is not up to professional standards for recording because there are streams synchronization latencies and real-time bottlenecks.
- The EOG waveforms for left and right eyes followed similar patterns in increase or decrease of eye activity rate. Therefore, for the comparing of eye activity, it seemed sufficient to consider activity of one eye.

5.2 The Hypothesis Test Experiment

The hypothesis testing experiments were planned after considering the observations and results of pilot experiment. The idea was to check whether similar results can be obtained for sufficient number of different individuals, so that the conclusions can be generalized. Additionally, I wanted to uncover other relations that would help me to prove my objectives objectively. The following sections give the description of the experiment and discussion of its results.

5.2.1 Final Experiment

For the experiment, an air conditioned computer laboratory was selected. The inside temperature was below 26° C and the laboratory was free from outside noise. Each subject's seating was arranged so that his/her visual field is not disturbed by outside visual noise. Five computers were used to setup the computational framework considering remote operation affect and video monitoring: the interaction renderer, the interaction controller, video monitoring client, video monitoring controller, and the BioMedia affect monitoring and integration system. The EOG electrodes were mounted on subject's forehead and GSR electrodes were wrapped around the subject's index and middle fingers of his/her left hand.

For the experiment six individuals were selected. Table 5.1 summarizes some of their biological and psychological details. Figure 5.6 shows how they faced the experiment.

Table 5.1: Biological and psychological details of the individuals participated to the experiment

Individual	Gender	Age range	Observable characteristics
A	Male	Between 25-30	Organized, critical
B	Female	Between 25-30	Curious, relaxed
C	Male	Between 25-30	Critical, analytical, social, relaxed
D	Male	Between 25-30	Sympathetic, private
E	Male	Between 25-30	Sympathetic, private
F	Male	Between 30-35	Traditional, relaxed

The multimedia interaction session was planned using different types of multimedia and Table 5.2 summarizes their details.

Table 5.2: The details of the multimedia interactions

Interaction ID	Interaction Type	Description
I00	Activity	Eye movement activity
I01	Song (177 sec)	Relaxation
I02	Picture	Scare snake
I03	Movie (119 sec)	Meditation to scare ghost
I04	Movie (53 sec)	Seeking love with baby pandas
I05	Movie (311 sec)	Lecture about cognitive science
I06	Movie (311 sec)	Repeating I05
I07	Picture	Scare snake
I08	Movie (16 sec)	Relaxation to scare ghost
I09	Activity	Play the game Minesweeper
I10	Movie (133 sec)	Magically breaking a women into two parts
I11	Movie (533 sec)	Cartoon
I12	Movie (177 sec)	A real story about a ghost
I13	Activity	Talking with the subject pretending that the session is over

The interaction session starts with a small eye activity exercise. During this interaction, the subject is asked to move his/her eyes in all four directions followed by blinks to profile signal intensities for that particular individual. Another objective of this attempt is to get the focus of the subject into the screen area by helping him/her to flush the visual sensory memory contents.

Next, the individual listens to a song that does not have a visual. This will charge the individual's phonological loop of the working memory and gradually the subject should increase his/her concentration to the song. Immediately after the song a picture of a snake is presented to see whether there is a change in visual attention. The picture interaction is followed by an emotional video. For this interaction, the individual's visual attention is needed and the emotional events within the video content should charge individual's emotional involvement.

Next, an educational video is presented which again demands increased cognitive concentration of the individual. This video can become bored to the subject. To see how the subject reacts to a repetitive interaction, the same education video is presented again. During this interaction, the subject would lose his/her attention, because it has already observed.

Immediately after the video, another snake picture is presented. If it does not make the subject scare, it should give the subject a small break to reconsider the visual concentration. This picture is followed by another emotional video that would make the subject excited by a ghost appearing suddenly.

A game interaction is attached to regain the attention of the subject. This interaction needs higher cognitive and emotional involvement of the individual. After the activity, another few videos are presented to check the subject's emotional and cognitive involvement.

Finally, an out of the screen conversation is planned to see how the affect streams respond when the subject is out of his/her involvement to computer based interaction.

Figure 5.6: The individuals facing the multimedia interactions and affect recording

5.2.2 Results and Discussion

This section evaluates each of the primary objectives using the results of the experiment to see how strongly they support the hypothesis.

Objective 1:

The recorded GSR waveforms for each subject for the interactions I03 and I08 are shown in Figure 5.7 and Figure 5.8 respectively. Each figure highlights the change of GSR waveforms when a media event occurs within the interaction.

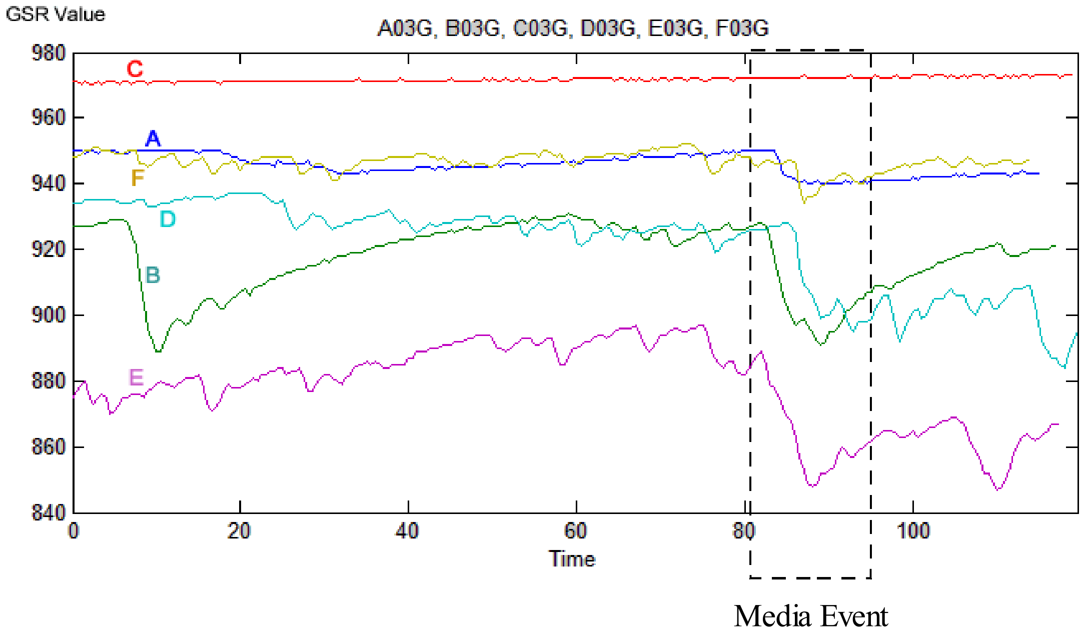


Figure 5.7: GSR waveforms for each subject (A to F) for the interaction I03

During the interaction I03 the media event is caused by a scare ghost appearing after the 90th second from the start of the interaction. Figure 5.7 shows the subjects A, B, D, E, and F responding to this incident at different variance levels. However, the chart does not show the subject C responding to this incident or all the other subjects responding exactly at the 90th second. The reason for the latter may be that the recording framework of the experiment. During the experiment it was noted that there is a start and end of interaction latency in recording. In addition, the timeline depicted in the chart does not exactly correspond to the interaction timeline because of unstable sampling rate of GSR capturing device (see section 4.3.2).

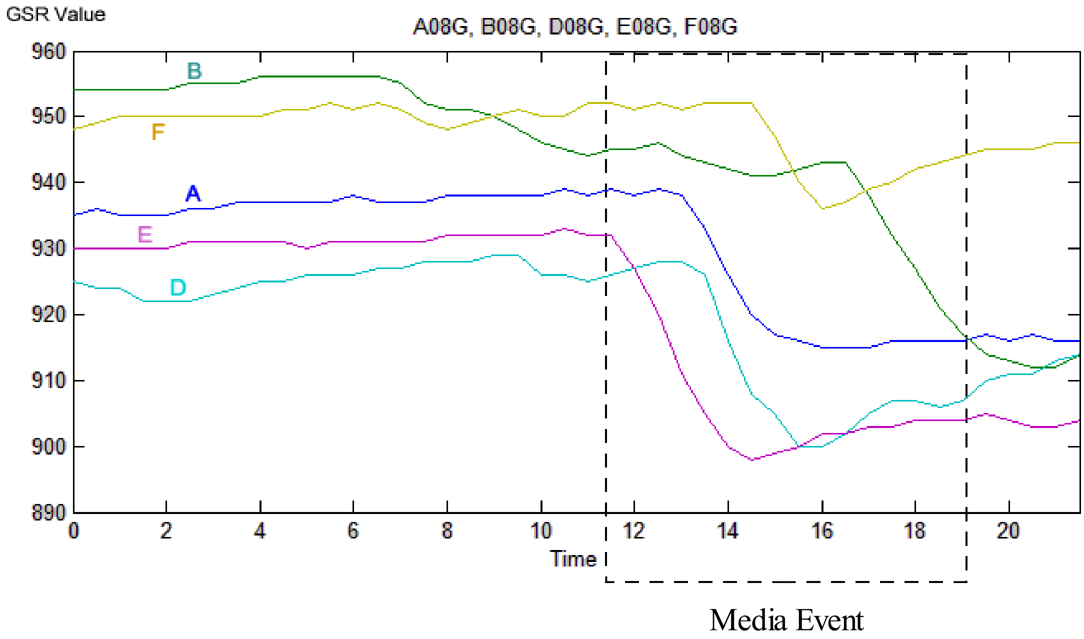


Figure 5.8: GSR waveforms for each subject (A,B,D,E and F) for the interaction I08

Figure 5.8 shows the GSR waveforms for the interaction I08. During this interaction also a scare ghost is appearing after the 14th second from the start of the interaction. The figure shows each subject's psychological reaction to this incident. However, in this chart also there is a variance in the reaction time because of the problems in the recording framework.

Table 5.3 shows each subject's GSR variance in responding to emotional incidents and Figure 5.9 plots the variance values:

Table 5.3: GSR variances for the interactions I03 and I08

Subject	Interaction I03	Interaction I08
A	10	24
B	37	30
C	0	0
D	33	28
E	42	35
F	13	16

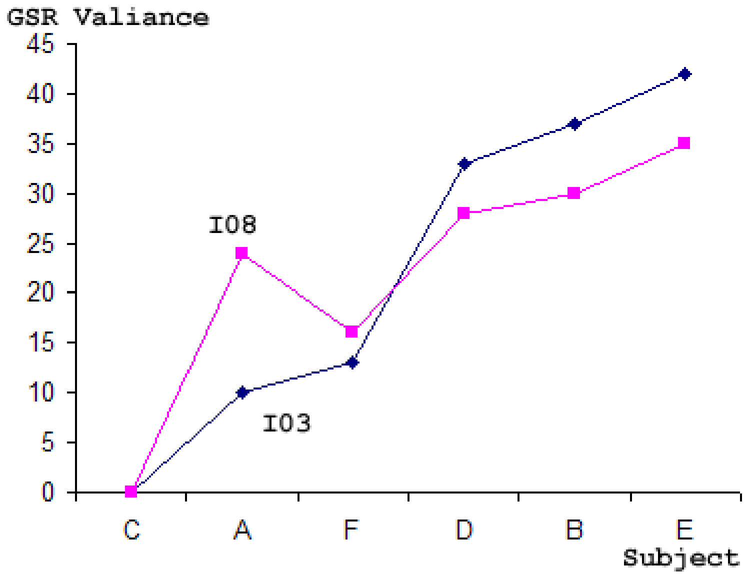


Figure 5.9: Graphing the GSR variance for the interactions I03 and I08

Figure 5.9 shows the relationship between GSR variance for each subject over two different interactions. From the plot it can be seen that each subject's GSR response is approximately profilable. Another interpretation will be that individuals can be organized into a GSR variance spectrum, so that each individual will belong to a certain level of that spectrum (Figure 5.10).

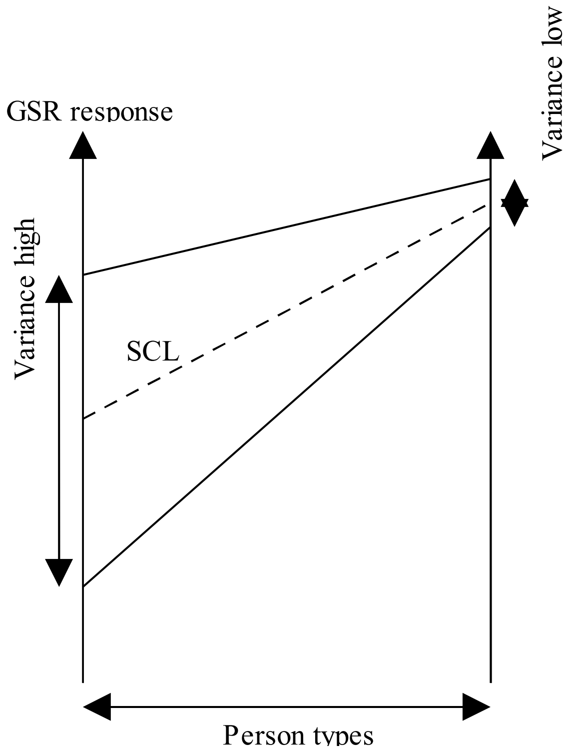


Figure 5.10: GSR variance spectrum for different individuals

The above results show that there is a clear relationship between media events and GSR response for each subject. Therefore, it can be concluded that there is a relationship between one's psychological involvement to a multimedia interaction and his/her GSR response.

Objective 2:

Figure 5.11 and Figure 5.12 show the EOG waveforms reflecting left eye (similar right eye) movement activity for the interactions I03 and I13 respectively. The interaction I03 is an onscreen video interaction while I13 is an off-screen conversation. During the onscreen interaction, subject's eye movement is limited to a frame with limited dimensions. Therefore, the eye potentials generated as a result of eye movement is within a certain range. While the subject is involved with the off-screen conversation, the range of eye movements increases and the eye potentials become increased in magnitude. Figure 5.11 and Figure 5.12 clearly differentiate EOG potentials for onscreen and off-screen visual fields for each subject.

Another differentiation is how clearly discrete eye movement or blink activities can be identified from EOG signals. Figure 5.11 waveforms clearly differentiate eye activity waveform regions and still eye waveform regions. However, Figure 5.12 waveforms do not differentiate these regions.

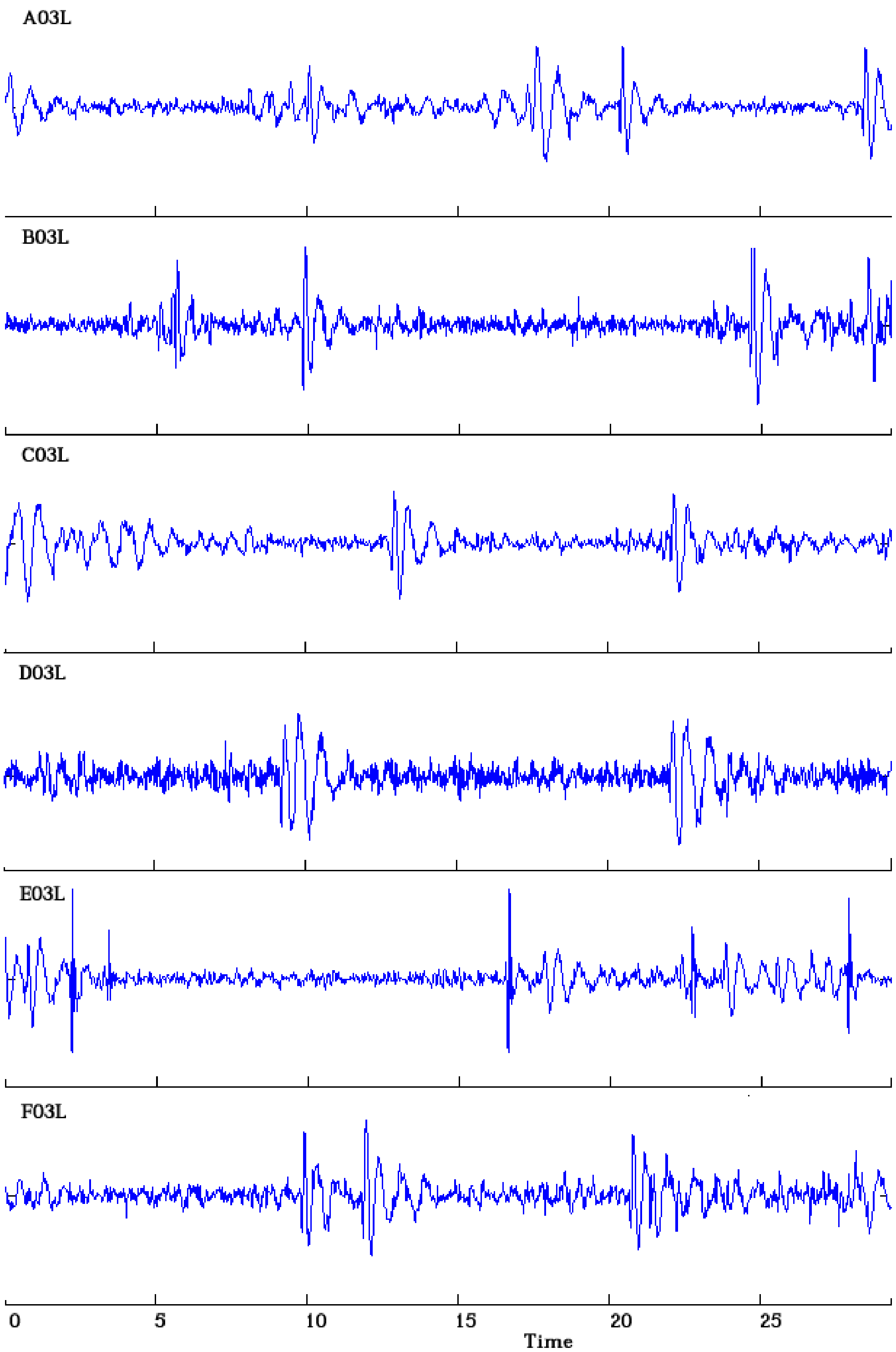


Figure 5.11: EOG left eye (L) waveforms for each subject (A to F) for the interaction I03

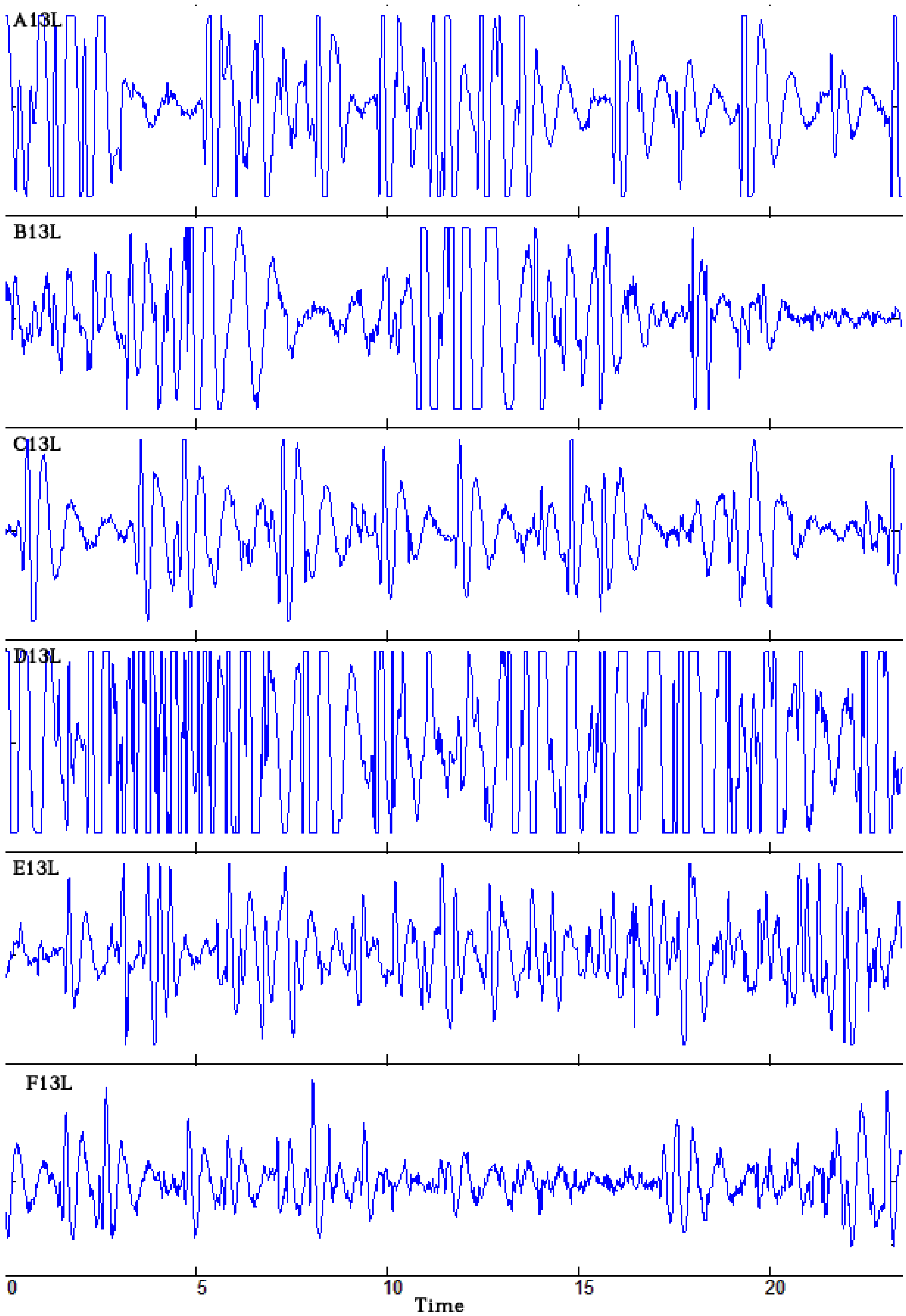


Figure 5.12: EOG left eye (L) waveforms for each subject (A to F) for the interaction I13

Table 5.4 summarizes the standard deviations of EOG signal magnitudes for each subject for the interactions I03 and I13. It also presents the increase in signal strengths for both interactions.

Table 5.4: Standard deviations of EOG signal magnitudes for onscreen and off-screen interactions

Subject	Standards deviation for the interaction I03	Standards deviation for the interaction I13	Increase in signal magnitude
A	803	2651	330%
B	1122	2163	192%
C	608	1542	253%
D	551	1732	314%
E	851	1787	209%
F	411	833	203%

From Table 5.4 it can be seen that for each subject the standard deviation of EOG signal magnitude when the subject is visually distracted has increased than when the subject's visual attention is framed within the onscreen multimedia interaction.

Therefore, it can be concluded that there is a clear relationship between one's visual attention to the visual field of multimedia content and eye movement activity.

Objective 3:

Under section 3.3 five psychologically distinct classes of involvement have been identified:

- Inattention state
- Cognitive concentration state
- Cognitive-emotional attentive state
- Externally distracted state
- Internally distracted state

Figure 5.13 and Figure 5.14 show the GSR response for each subject during the interactions I01 and I05 respectively.

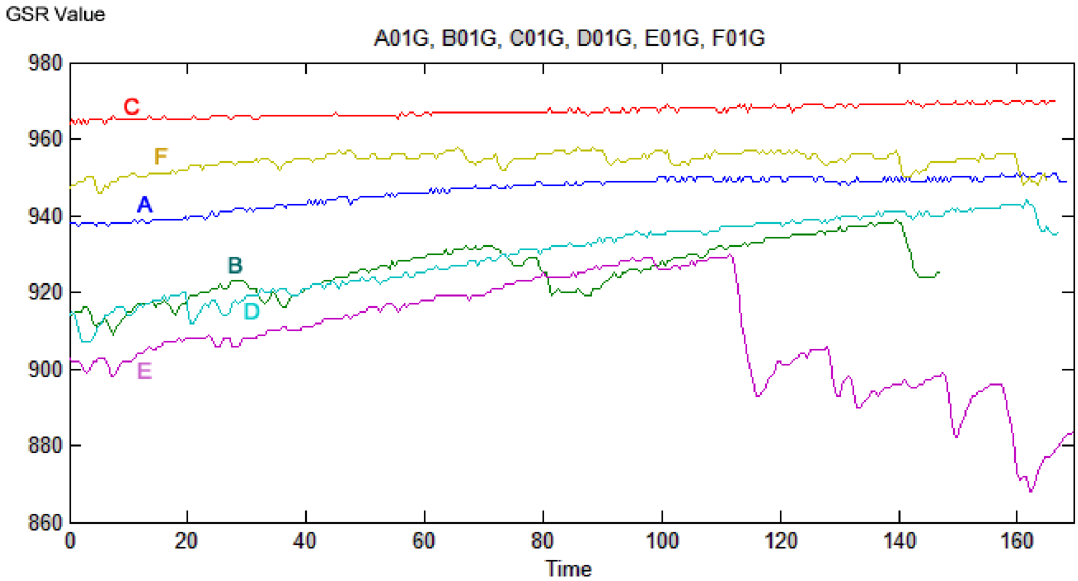


Figure 5.13: GSR waveforms for each subject (A to F) for the interaction I01

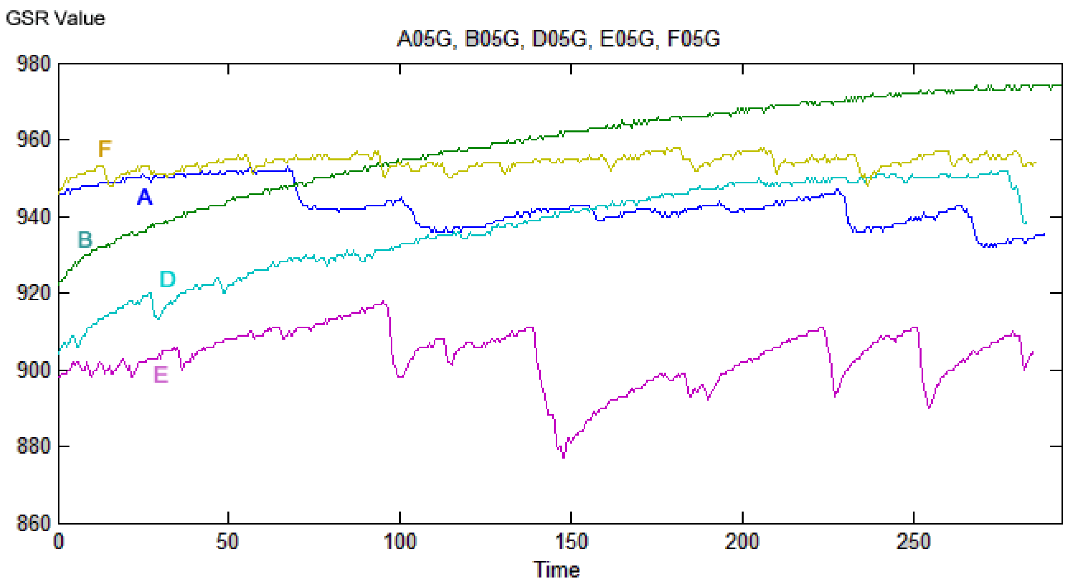


Figure 5.14: GSR waveforms for each subject (A to F) for the interaction I05

According to Figure 5.13 and Figure 5.14, for majority of individuals the GSR level is gradually increasing during the course of interaction. This is the characteristic of increased involvement (refer 2.4.3) and indication that the subject is in the cognitive concentration state.

However, among those individuals, it also observed that some are getting drowsy as the interaction getting bored for those individuals. This is the inattention state and the GSR characteristic of this state is similar to the cognitive concentration state. To distinguish a subject in cognitive concentration state and inattention state the characteristics of EOG signals are analyzed. Figure 5.15 and Figure 5.17 show GSR waveforms for two subjects for the interactions I05 and I06. The interaction I05 is a recorded lecture and I06 is the repeat of that same lecture. Therefore, it is expected that the interaction I06 is bored for the subject.

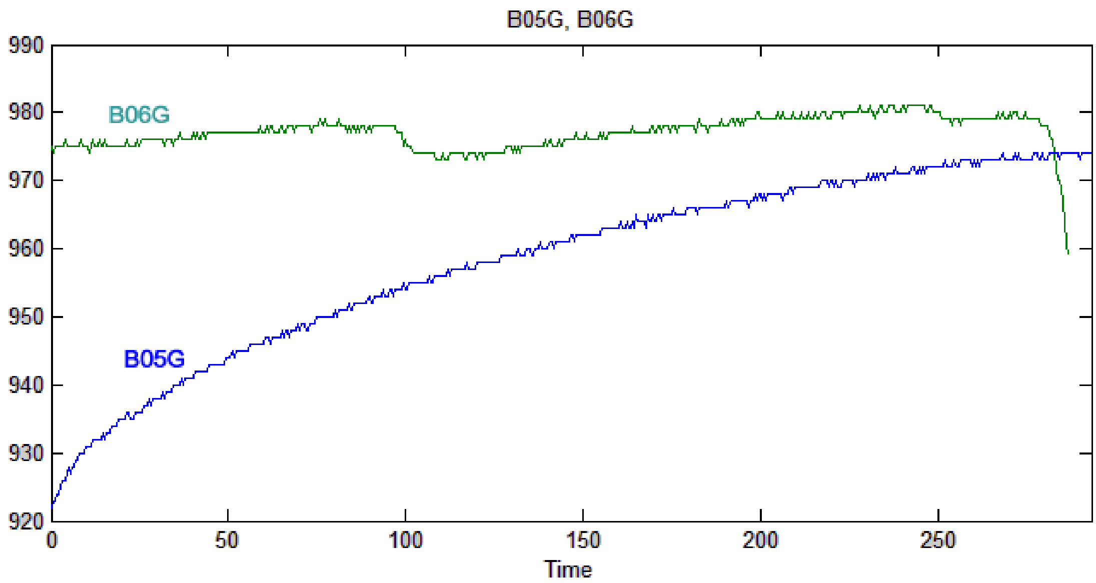


Figure 5.15: GSR waveforms for the subject B for the interactions I05 and I06

The GSR waveforms for the subject B in Figure 5.15 shows that he/she is concentrating on the lecture and continues the concentration during the repeat of the same lecture as well. However, it is not clear that the subject is losing the concentration and shifting to inattention state. To distinguish the states, the EOG signals are analyzed during both interactions (Figure 5.16).

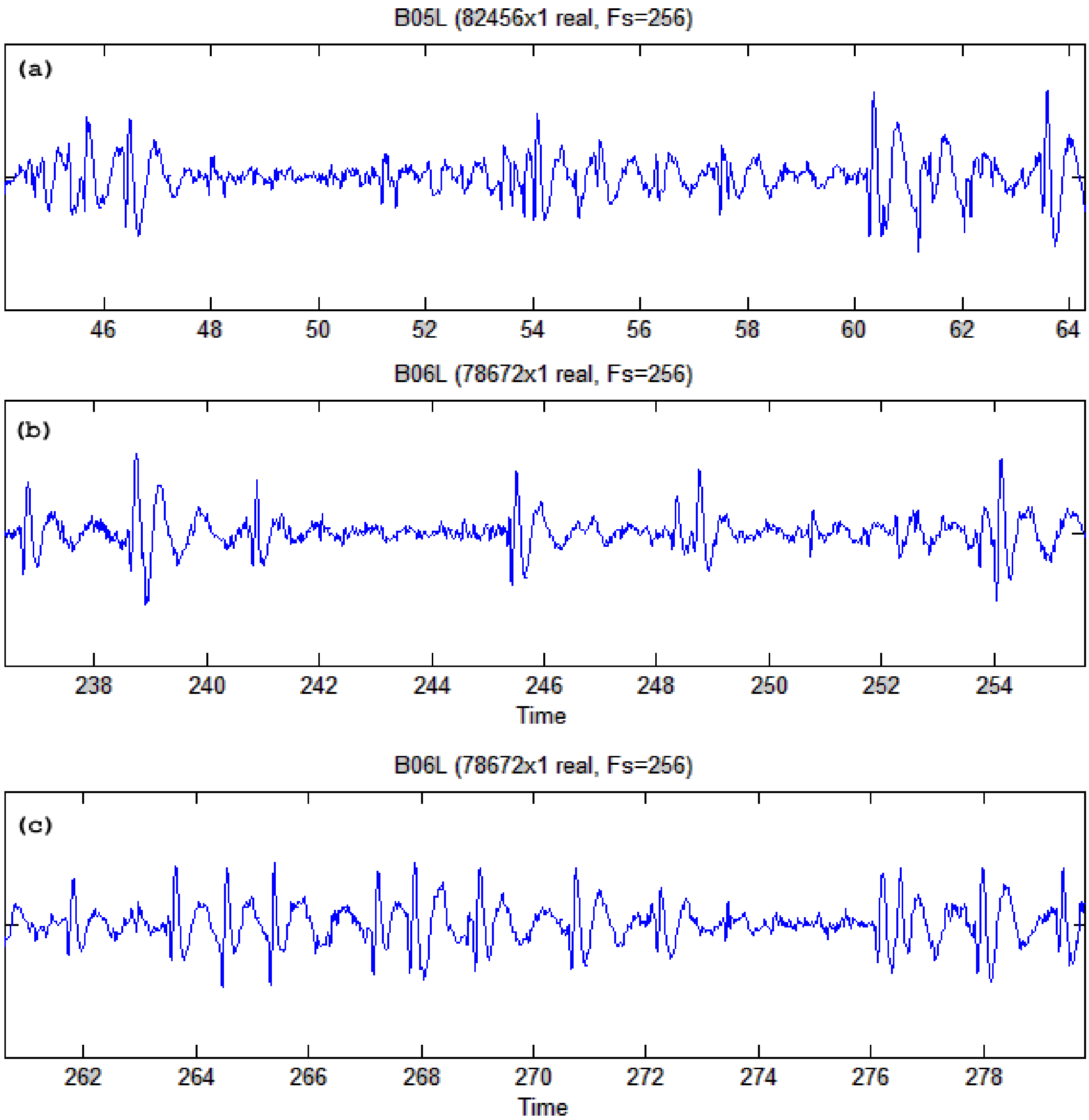


Figure 5.16: EOG left eye (L) waveform instances of the subject B for interactions I05 and I06

Figure 5.16 shows EOG waveforms at three instances: one during the interaction I05 and two others during the interaction I06. The waveforms show that the eye activity has been increased during the interaction I06. This increase of EOG activity at higher GSR level is an indication that the subject's psychological involvement is shifting to the inattention state.

Figure 5.17 shows the GSR waveforms for the subject D for the interactions I05 and I06.

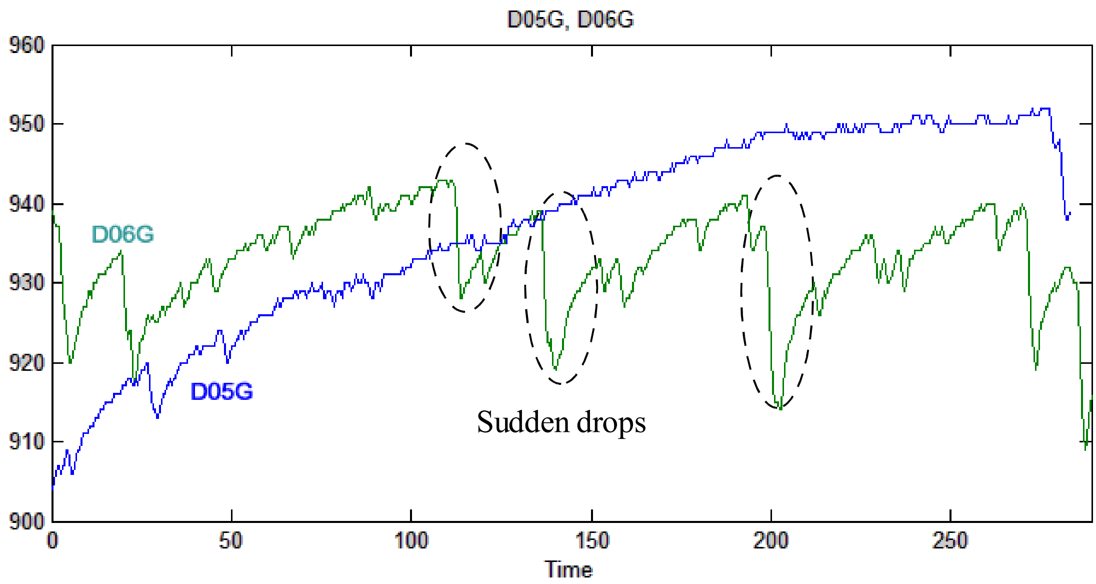


Figure 5.17: GSR waveforms for the subject D for the interactions I05 and I06

The GSR waveforms for the subject D shows that the subject's concentration increases during the interaction I05, but the concentration is subjected to disturbances during the interaction I06. The explanation for this behavior is realized after analyzing how the subject behaved during the interaction. It was observed that the subject is feeling discomfort and trying to correct the seating during the course of interaction I06. While the subject's body moves a sudden drop in GSR observed, but soon after the slope tried to recover (Figure 5.17). The EOG waveforms for the subject during the two interactions are depicted in Figure 5.18.

The EOG waveform shows same increase in discrete eye activities (blink rate) as of subject B during inattentive states. Therefore, it can be concluded that a sudden drop and a recovery of GSR waveform during a subject's concentration or inattentive state corresponds to an internally distracted state.

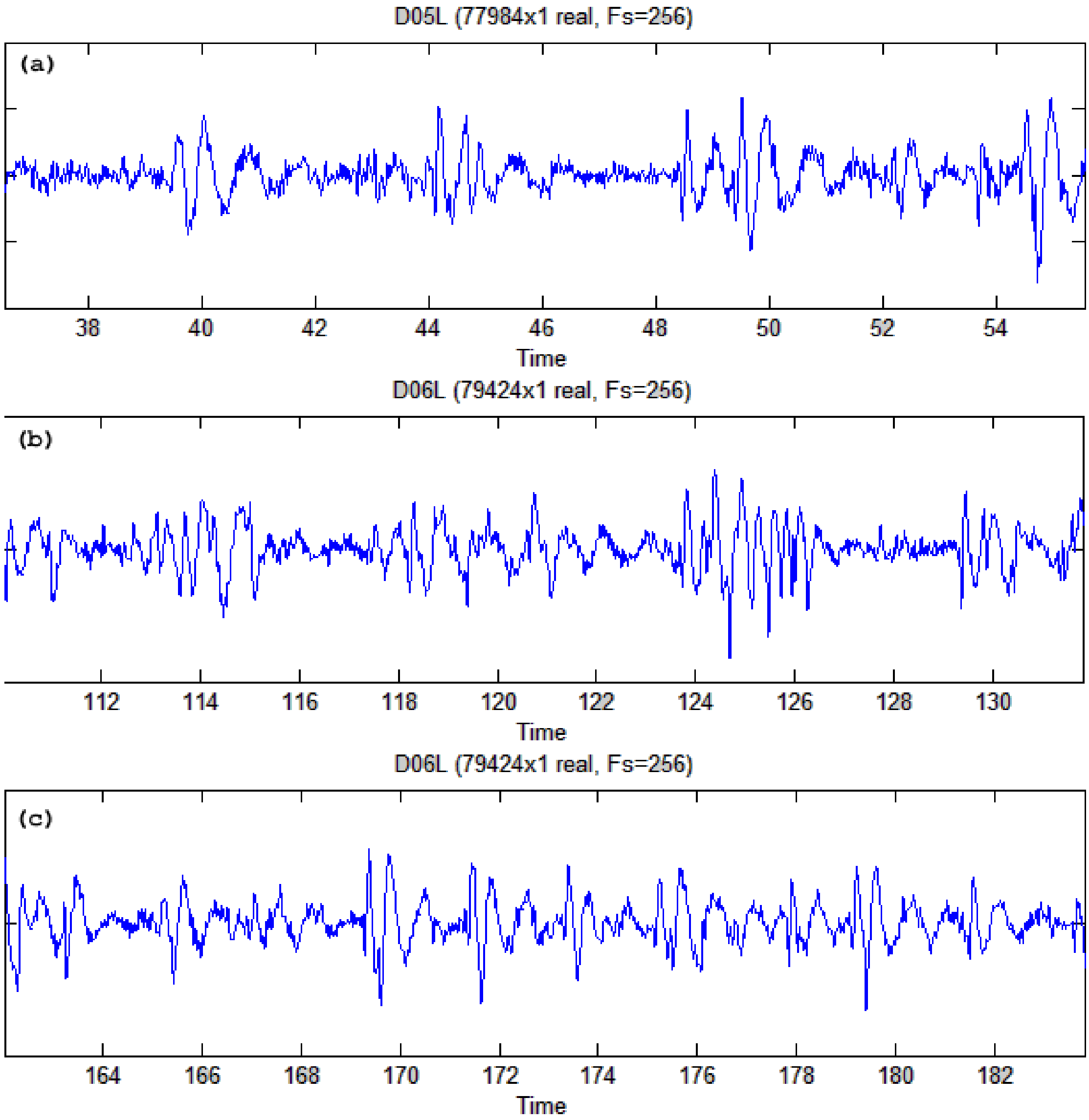


Figure 5.18: EOG left eye (L) waveform instances of the subject D for interactions I05 and I06

Figure 5.7, Figure 5.8, Figure 5.19, and Figure 5.20 all shows GSR waveforms when subject's active involvement to the interaction is demanded or observed. They all shows similar pattern of reacting to media events or waveform with higher fluctuation.

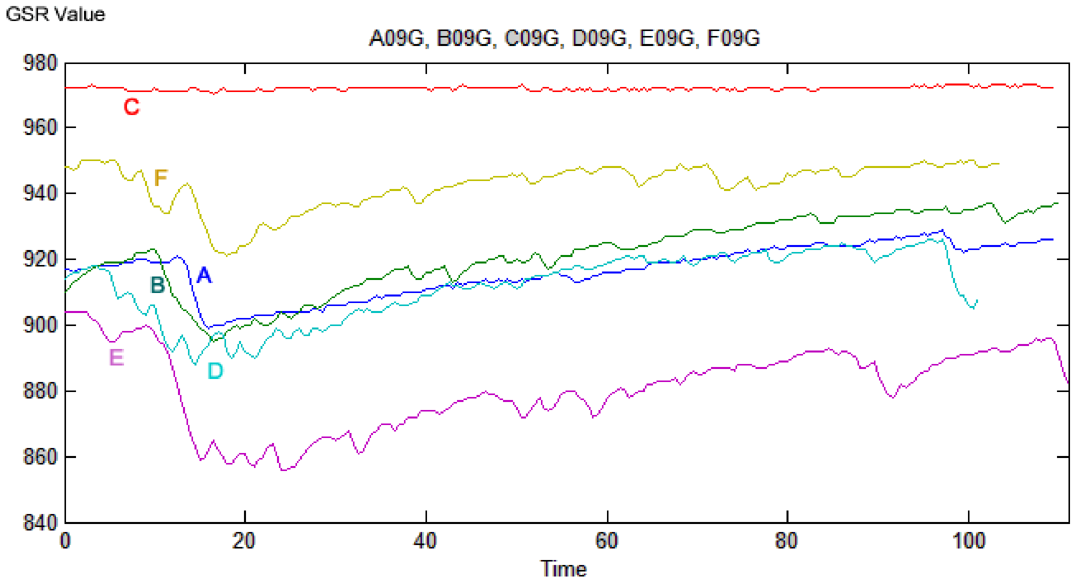


Figure 5.19: GSR waveforms for each subject (A to F) for the interaction I09

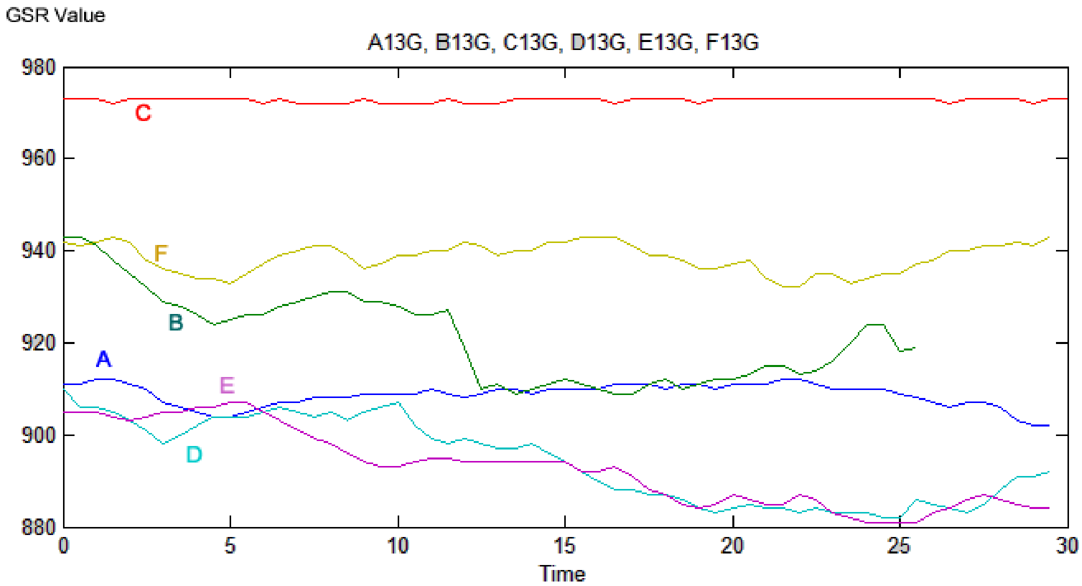


Figure 5.20: GSR waveforms for each subject (A to F) for the interaction I13

Out of the interactions, the interaction I13 is an out of the screen conversation with an external party. The GSR waveform for the interaction I13 shows that it is subjected to fluctuations at low GSR level (Figure 5.20). This is an indication that the subject is actively involved in the interaction. To distinguish active involvement to onscreen interaction and off-screen interaction, the EOG activity is analyzed (Figure 5.11 and Figure 5.12). Higher eye activity is reported when a subject is involved with an off-screen interaction.

Another GSR pattern is observed when a subject is involved with onscreen activity. Figure

5.19 shows GSR patterns for each subject when they involved with an onscreen game. These GSR patterns correspond to increased concentration. It can be seen that all the subjects start to concentrate on the game after some time regardless of internal or external psychological disturbances.

Therefore, the results clearly differentiate the identified psychological involvement class. Figure 5.21 conceptualizes the identified classes with their distinguishable physiological behaviors.

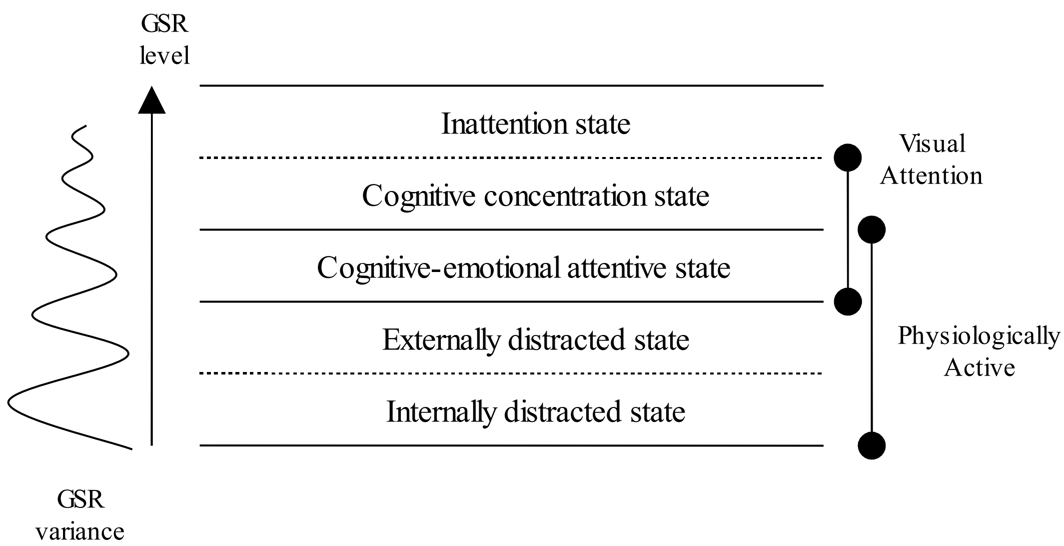


Figure 5.21: Conceptualized psychological involvement classes with their physiological behaviors

5.2.3 Summary of the Observations

- Different individuals respond to emotion invoking multimedia content at different GSR variance levels.
- For a particular individual, the GSR variance for different emotion invoking multimedia contents describes some psychophysiological identity of that individual.
- The GSR variance of different individuals for different multimedia content can be organized under a GSR variance spectrum, so that a particular individual can be easily identified within that spectrum.
- When an individual's visual attention is focused on a multimedia content, that person's

eye movement activity decreases causing the magnitude of eye potentials to drop.

- When the individual is attending outside content off the screen dimensions, the eye movement activity increases resulting rapid and higher magnitude eye potential waveform.
- Out of the proposed involvement classes, the inattention state can be recognized from its low variance GSR waveform at a higher GSR level and EOG activity with increased and periodic eye potentials. These observations correspond to low brain activation level and increased eye blink rate due to drowsiness.
- When a subject is cognitively concentrating towards a multimedia content, such as to a video lecture, a similar GSR pattern is observed to inattention state, but with a moderate EOG activity waveform. These observations correspond to a low brain activation level with mental resources utilized to the content currently attending with increased visual attention.
- If the multimedia content has emotion invoking events, the subject would move to cognitive-emotional attentive state. This state is distinguishable from a GSR waveform having higher magnitude fluctuations at a low GSR level synchronized to media events and EOG waveforms with moderate activity. These observations correspond to a higher brain activation level due to the involvement to the multimedia content with increased visual attention.
- Similar increased GSR activity to cognitive-emotional attentive state is observed when a subject is in externally distracted state, but with a low coupled synchronization to media events and with increased EOG activity. These observations correspond to a higher brain activation level, but disturbed due to external events, with increased visual attention for both multimedia content and outside content.
- Sometimes, while a subject describing waveforms similar to cognitive concentration state or cognitive-emotional attentive state, sudden disturbances are observed in the GSR waveform those are not resulted from concentration or emotion evoking media events. This state of the subject corresponds to internally distracted situation, where the involvement shifts between what the subject involved in the external multimedia content and stress responses in the subject's internal psyche.

Chapter 6 - Conclusions and Future Work

This research has addressed one of the prevailing problems in multimedia interactions domain. The section 3.2 argued that the perception-cognition gap does not give the correct idea when describing the semantic gap between the human and the computer, but the requirement for cognitive-emotional user correction. Based on this aspect, this research has elaborated on how cognitive and emotional aspects affect the internal information processing of human and how the physiological feedback can be used to determine the level of involvement of the human with respect to multimedia interactions.

Currently no universal human model has invented to predict behaviors of humans in all aspects. Therefore, the only way to predict human behaviors is by applying the problem to a human and analyzing the reactions. Literature suggested that most human functions are initiated and guided by emotions. However, it was seen that no proper modeling method has been discovered for this concern. The reason for this may be that the computer is still limited as a symbolic information processor. Therefore, this research has decided to observe real-time physiological signals from the subject while he/she is attending a multimedia interaction. These signals have been used to recognize the level of emotional and cognitive involvement.

For the capturing, low cost devices have been employed. The GSR capturing device has been built around a LEGO RCX brick. Among the advantages of using this solution, the separation of subject and computer by an IR link is recognized, though the IR latency has decreased the effective sampling rate. This requirement comes under one of the objectives of the research which signifies the need to safeguard the subject from the main power grid. However, the accuracy, precision and sampling rate of the readings provided by that solution have not achieved satisfactory levels to decide the immediate stimulus-response reaction of the subject for the change of visual content of an interaction. Again, it was observed that there is a considerable latency in transmitting the data between the brick and the computer. However, for long duration emotional research, the solution seemed appropriate.

The results showed a clear relationship between GSR and emotional involvement of a subject with respect to multimedia interactions. However, there were many artifacts preventing the expected outcome of the research, for instance startle body movements created unpredictable GSR noise.

The EOG signals capturing device has been built around Grant's EEG capturing device. This device is again a low cost device and it was a home-made device. At the initial stage of the research, this device has been used to check whether it can capture EEG potentials from the scalp. However, soon it was realized that EEG solution is not required for this research because of several reasons. Firstly, EEG needs placement of electrodes at the scalp of the subject after applying a conductive gel which seemed an annoying experience for the subject. Next, GSR has been identified as an alternative solution to EEG because GSR has a good relationship with the arousal activity of the brain. Therefore, instead of using the EEG device to capture EEG signals, it has been used to capture eye potentials of the user. This only applies gen on the temples, which is not as annoying as applying gel on the scalp.

The eye potentials are stronger than EEG signals. Therefore, EOG signals had good signal strengths to identify patterns. The findings showed a clear difference between the signal patterns when the subject was concentrating on a computer interaction and while he/she was looking beyond the screen dimensions. Finally, EOG patterns and GSR patterns were combined to verify the involvement classes and the results showed that these involvement classes can be identified from the signal patterns.

The integration of affect signals and media events happens under the BioMedia software framework. Although, the framework was capable of achieving its primary objectives, for the analysis of waveforms, the framework seemed inefficient. To make it a more sophisticated framework at least the synchronization of signals with the real-time constraints, stable sampling rates, video recording integration, navigation within the timeline of the waveforms, different types of annotations and accelerated graphics are required. The work also can be extended by introducing automatic annotation and feature recognition functions to affect signals. Next, these patterns can be classified according to different user profiles to predict the interaction behaviors of users.

The literature also pointed links to research that uses signals from other affect signal sources, for instance respiration and heart rate, for the recognition of emotional classes. If this research can be extended by using the signals from those sources, more accurate predictions can be made identifying exact emotion types triggered by media events in addition to the involvement.

For the experiments, mostly video based interactions were selected because from the initial experiments it was observed that pictures and non-visual media are not triggering sufficiently strength affect signals that can be captured by the devices used. However, for non-visual songs, emotional videos, educational videos and games the subjects showed distinguishable affect activities.

For the attention, the research considered only visual attention. However, attention also refers to filtering information from auditory, tactile and other sensor modalities of a human. For full immersive interactions, the attention to all these modalities is needed.

This research has considered only participants form the age group 25-35 and majority were male. The literature suggests that there are developmental psychological issues and gender differences in cognitive emotional aspects. Again for mentally disordered persons this solution can not be appropriate.

In addition to technological framework proposed by this research, it also proposes a conceptualized framework for human psyche. This framework is capable of explaining internal information processing of humans and how the concepts in cognitive science, such as consciousness, apply to multimedia domain. It also links philosophy, especially Buddhist explanations of the mind, to scientific framework. However, this framework needs verification with respect to different research approaches.

The research work of this project does not give guidelines for any application domain. As the application domains e-learning, mind-machine interfacing, computer games and cognitive robotics are predicted. Among these domains, the research has a direct impact to e-learning where the level of involvement of a learner can be decided to personalize the learning content or to evaluate the learning materials in providing good learning experience to the learner. Current hardware arrangements are such that the sensors are mounted on subject's body putting lot of constraints to the person's natural body movements and making them more discomfortable. However, in the future this problem will be solved as the introduction of ubiquitous hardware arrangements and remote monitoring systems making brain computer interfacing and affecting monitoring solutions more plausible for applications.

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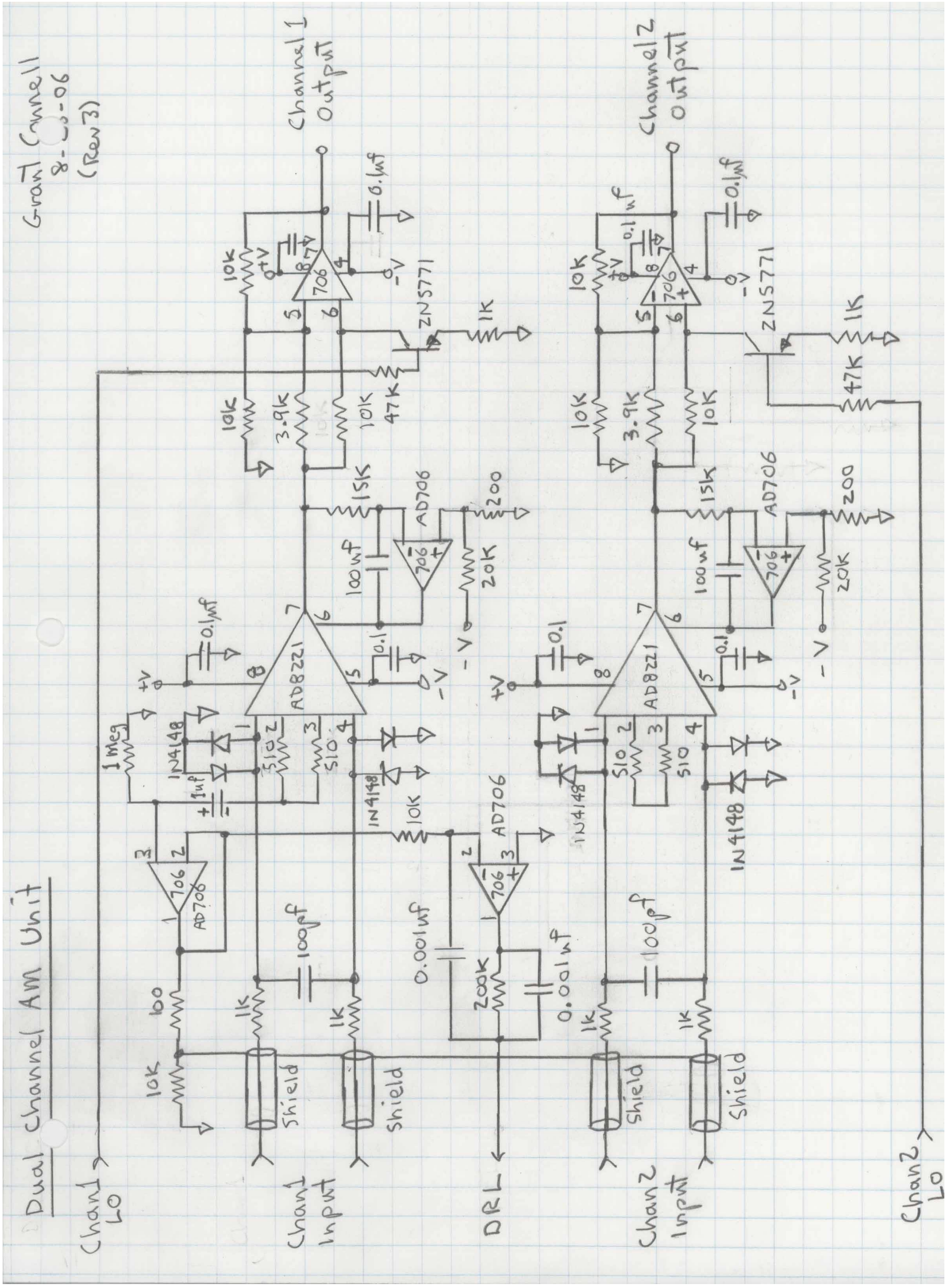
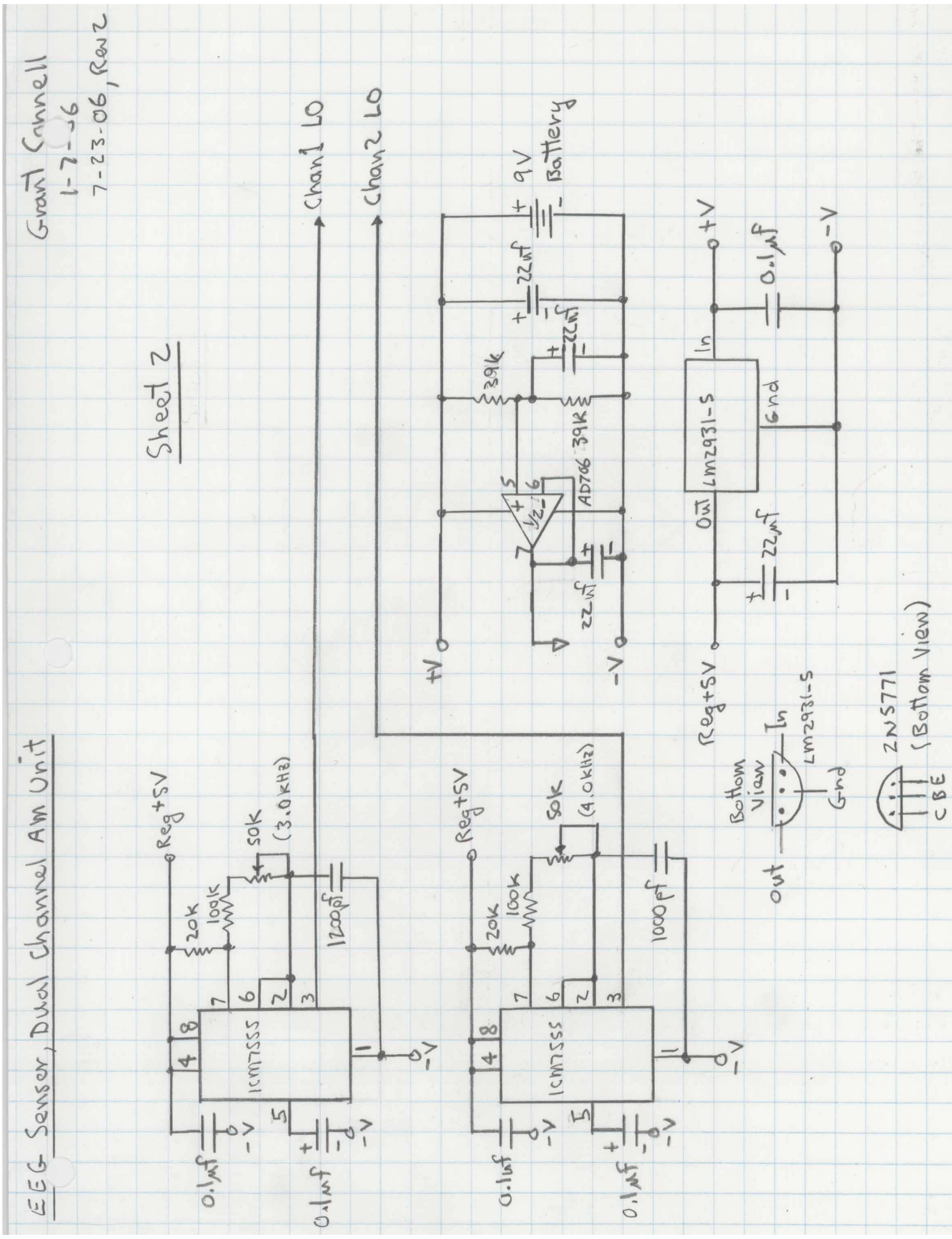
Appendix A: Schematic Diagrams



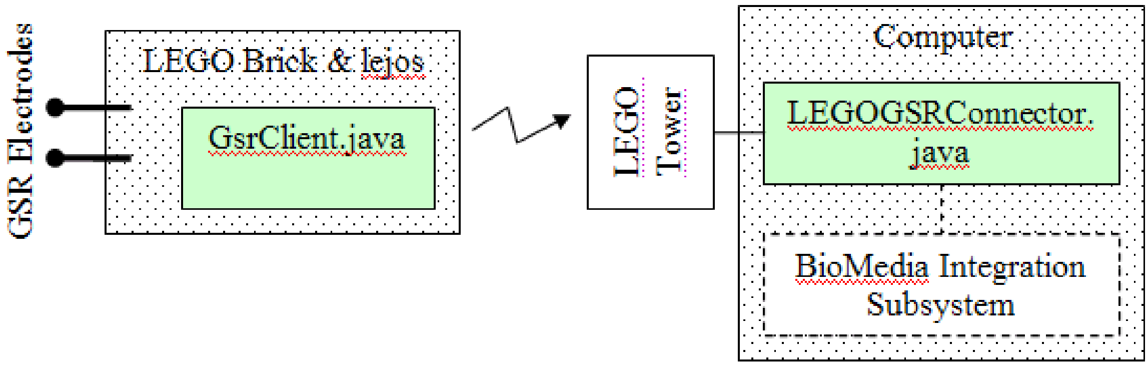
Dual channel AM Unit – Part 1



Dual channel AM Unit – Part 2

Appendix B: Selected Code Listing

GSR Interface



GsrClient.java

```
import java.io.*;
import josx.rcxcomm.*;
import josx.platform.rcx.*;

public class GsrClient {
	// Written by Hiran Ekanayake - April 15, 2008 - Smoothing
using Gaussian filter
	// Worked well. Fast enough to display real-time data (latency
< 1000ms)

	public static void main(String[] args) {
		RCXPort port = null;

		try {
			Sound.twoBeeps();
			port = new RCXPort();

			OutputStream os = port.getOutputStream();
			DataOutputStream dos = new DataOutputStream(os);

			TextLCD.print("OK");

			int val, pccommCount = 0, scCount = 0;
			int[] gsrBuf = {0, 0, 0, 0, 0, 0, 0};
			while (true) {
				for (int i=0; i<=5; i++) {
					gsrBuf[i] = gsrBuf[i+1];
				}
				gsrBuf[6] = Sensor.S1.readRawValue();
```

```
                    LCD.showNumber(gsrBuf[6]);

                    // Send the gaussian smoothed GSR value at
every 6th time tick
                    // i.e. 240ms intervals, so that pc has enough
time to capture the latest value
                    if (pccommCount >= 5) {
                         pccommCount = 0; // Reset the count
                         val = (2*gsrBuf[0] + 16*gsrBuf[1] +
61*gsrBuf[2] + 97*gsrBuf[3] + 61*gsrBuf[4] + 16*gsrBuf[5] +
2*gsrBuf[6])/255; // Apply gaussian filter for smoothing
                         dos.writeInt(val);
                         dos.flush();
                    } else {
                         pccommCount++;
                    }

                    if (gsrBuf[6] <= 10) {
                         Sound.beep(); // Beep when short
circuited
                         scCount++;
                         if (scCount>50) break;
                    } else {
                         scCount = 0;
                    }

                    Thread.sleep(40);
               }

          } catch (Exception ioE) {
               TextLCD.print("ERR");
          } finally {
               if(port!=null)
                    port.close();
               TextLCD.print("BYE");
               Sound.twoBeeps();
          }
     }
}
```

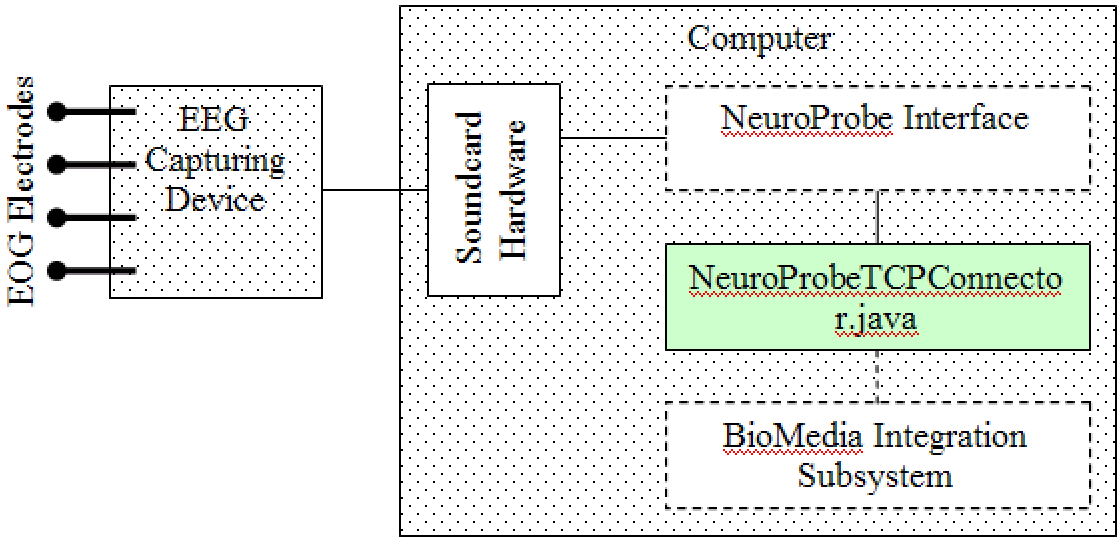
Selected code sections of LEGOGSRConnector.java

```
// Imported classes

public class LEGOGSRConnector extends JPanel implements
ActionListener {
     private RCXPort port;
     private boolean running = false; // To control the thread
     private DataInputStream dis;
     private int value;
     private boolean DATAREADY; // Data ready?
```

```
public LEGOGSRConnector() {
      DATAREADY = false;
      setUIComponent();
}

/********   PUBLIC FUNCTIONS *******/

public boolean isConnected() {
      return port!=null;
}

public boolean isDataReady() {
      return DATAREADY;
}

public int getNextData() throws Exception {
      if (DATAREADY) {
            DATAREADY = false;
      } else {
            // Data not ready
            new Exception("Data not ready!");
      }

      return value;
}

public void startReceiver() {
      Thread th = new Thread() {
            public void run() {
                  // First connect with the RCX
                  if (!isConnected()) {
                        running = connect();
                  }

                  // Read data from LEGO RCX
                  while (isConnected() && running) {
                        try {
                              value = dis.readInt();
                              DATAREADY = true; // Data now ready
                        } catch (IOException e) {
                        }
                  }

                  // Disconnect from NeuroProbe
                  disconnect();
            }
      };
      th.start();
}

public void stopReceiver() {
      running = false;
      disconnect();
```

```
	}

	/********   INTERNAL FUNCTIONS *******/

	private boolean connect() {
		try {
			port = new RCXPort("USB");
			dis = new DataInputStream(port.getInputStream());

			btnConnect.setEnabled(false);
			btnDisconnect.setEnabled(true);
			btnConfigure.setEnabled(false);
			return true;
		} catch (IOException e) {
		}
		return false;
	}

	private void disconnect() {
		try {
			btnConnect.setEnabled(true);
			btnDisconnect.setEnabled(false);
			btnConfigure.setEnabled(true);
			dis.close();
			port.close();
			port = null;

		} catch (Exception e) {
		}
	}

	private void setUIComponent() {
		// Code for GUI
	}

	public void actionPerformed(ActionEvent e) {
		if (e.getActionCommand().equals("Connect")) {
			startReceiver();
		} else if (e.getActionCommand().equals("Disconnect")) {
			stopReceiver();
		} else if (e.getActionCommand().equals("Configure")) {
			Support.message("Sorry, not implemented yet!");
		}
	}
}
```

EOG Connector



Selected code sections of NeuroProbeTCPConnector.java

```
// Imported classes

public class NeuroProbeTCPConnector extends JPanel implements
ActionListener {
	private final int TCP_PK_LEN = 560; // Length of TCP data
packet
	private final int TCP_PK_MODTYPE_OFFSET = 32; // Modulation
type: 1 for AM, 2 for FM
	private final int TCP_PK_SR_OFFSET = 36; // Sample rate
position: 1 for 256Hz...5 for 4096Hz
	private final int TCP_PK_CH1_OFFSET = 48; // Channel 1 bytes
position
	private final int TCP_PK_CH2_OFFSET = 304; // Channel 2 bytes
position
	private final int TCP_PK_CH_LEN = 64; // Length of channel's
bytes

	private String host = "localhost";
	private int port = 3333;
	private boolean running; // To control the thread

	private Socket socket = null;
	private InputStream in = null;
	private int buffSize;
	private int[][] chDataBuffer;
	private int w;
	private int r;
	private boolean OVERFLOW; // Data buffer overflow
```

```
	public NeuroProbeTCPConnector() {
		buffSize = 256*10;
		chDataBuffer = new int[2][buffSize];
		init();

		setUIComponent();
	}

	/********   PUBLIC FUNCTIONS *******/

	public void init() {
		w = 0; r = 0;
		OVERFLOW = false;
	}

	public boolean isConnected() {
		return (socket != null && socket.isConnected() &&
running);
	}

	public int[] getNextData() throws Exception {
		int[] data = new int[2];

		if (r != w || OVERFLOW) {
			data[0] = chDataBuffer[0][r];
			data[1] = chDataBuffer[1][r];
			r = ++r % buffSize;
			OVERFLOW = false;
		} else {
			// Data not ready
			new Exception("Data not ready!");
		}

		return data;
	}

	public int getBuffStatus() {
		if (w >= r) {
			return (100 * (w - r + 1)) / buffSize;
		} else {
			return (100 * (buffSize - (r - w) + 1)) / buffSize;
		}
	}

	public void startReceiver() {
		Thread th = new Thread() {
			public void run() {
				// First connect with the NeuroProbe
				if (!isConnected()) {
					running = connect();
				}

				// Read data from NeuroProbe
```

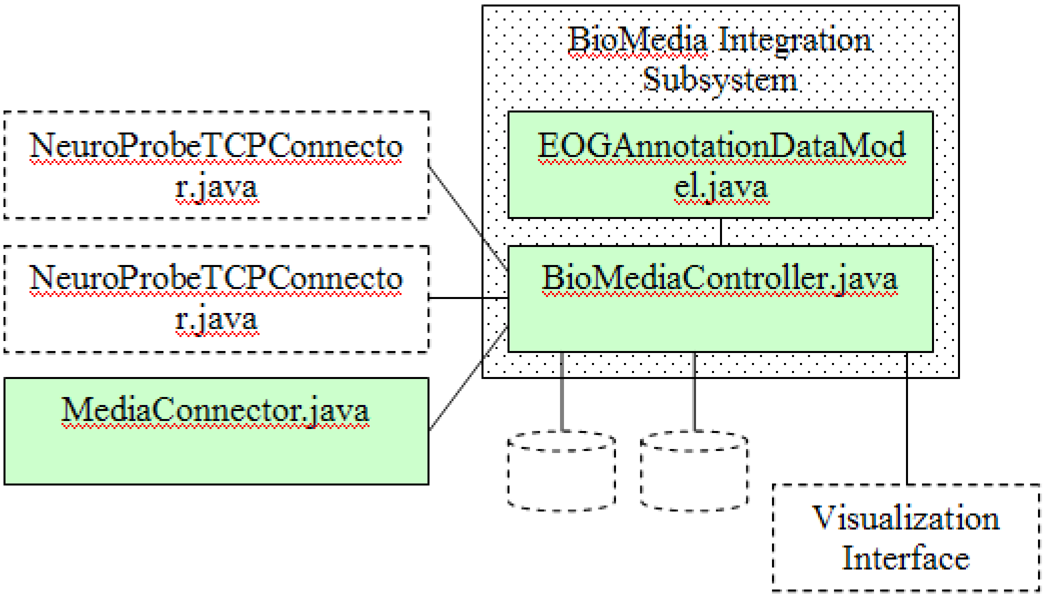
```
                    int noBytesRead = 0; // -1 if NeuroServer
stopped
                    byte[] tempBuffer = new
byte[TCP_PK_LEN*10]; // First read the bytes to this
                    while (running && socket.isConnected() &&
noBytesRead>=0) {
                         try {
                              noBytesRead = in.read(tempBuffer);

                              if (noBytesRead > 0) {
                                   // Copy data bytes to a
seperate buffer
                                   byte[] chBytes = new
byte[noBytesRead];

     System.arraycopy(tempBuffer,0,chBytes,0,noBytesRead);

                                   // Recover values
                                   recoverChannelValues(chBytes);

                              }
                         } catch (Exception e) {
                              e.printStackTrace();
                         }
                    }

                    // Disconnect from NeuroProbe
                    disconnect();
               }
          };
          th.start();
     }

     public void stopReceiver() {
          running = false;
          disconnect();
     }

     /********   INTERNAL FUNCTIONS *******/

     private boolean connect() {
          try {
               socket = new Socket(host,port);
               in = socket.getInputStream();

               // Clears the data buffer
               r = 0; w = 0;

               btnConnect.setEnabled(false);
               btnDisconnect.setEnabled(true);
               btnConfigure.setEnabled(false);
               return true;
          } catch (UnknownHostException e) {
               e.printStackTrace();
```

```
            } catch (IOException e) {
                 e.printStackTrace();
            }
            return false;
      }

      private void disconnect() {
            try {
                 btnConnect.setEnabled(true);
                 btnDisconnect.setEnabled(false);
                 btnConfigure.setEnabled(true);
                 in.close();
                 socket.close();
            } catch (Exception e) {
            }
      }

      private void recoverChannelValues(byte[] chBytes) throws
Exception {
            // size: number of TCP data lines * no of values in a
data line
            int[][] tempCHIntValues = new int[2]
[(chBytes.length/TCP_PK_LEN)*(TCP_PK_CH_LEN/4)];
            int tempCHIntIndex = 0;

            // This is used to convert bytes to their corresponding
int values
            ByteBuffer tempBBCh1 =
ByteBuffer.allocateDirect(TCP_PK_CH_LEN);
            tempBBCh1.order((ByteOrder.LITTLE_ENDIAN));
            ByteBuffer tempBBCh2 =
ByteBuffer.allocateDirect(TCP_PK_CH_LEN);
            tempBBCh2.order((ByteOrder.LITTLE_ENDIAN));

            int i = 0; // index for channel bytes
            byte[] tempCH1Values = new byte[TCP_PK_CH_LEN];
            byte[] tempCH2Values = new byte[TCP_PK_CH_LEN];
            while (i <= chBytes.length-TCP_PK_LEN) {

                 // TCP data line starts with "TCP DATA"
                 // Check whether the selected data line contains
channel data (2nd value empty?)
                 if ((char)chBytes[i]=='T' && (char)chBytes[i+1]=='C'
&& (char)chBytes[i+2]=='P' && chBytes[i+TCP_PK_CH1_OFFSET+4]!=0) {

                       // Corresponding bytes for channel values


System.arraycopy(chBytes,i+TCP_PK_CH1_OFFSET,tempCH1Values,0,tempCH1
Values.length);


System.arraycopy(chBytes,i+TCP_PK_CH2_OFFSET,tempCH2Values,0,tempCH2
Values.length);
```

```
                    tempBBCh1.put(tempCH1Values);
tempBBCh1.flip();
                    tempBBCh2.put(tempCH2Values);
tempBBCh2.flip();

                    // Now read the channel values as int
                    for (int j = 0; j < 16; j++) {
                         if (!OVERFLOW) {
                              chDataBuffer[0][w] =
(int)tempBBCh1.getFloat(j*4);
                              chDataBuffer[1][w] =
(int)tempBBCh2.getFloat(j*4);
                              w = ++w % buffSize;
                         }

                         if (w == r) { // OVERFLOW
                              OVERFLOW = true;
                              new Exception("Buffer Overflow!");
                         }
                    }

                    tempBBCh1.clear();
                    tempBBCh2.clear();

                    // Place the i near the next TCP data line
                    i = i+TCP_PK_LEN - 1;
               }
               i = i+1; // To scan the next byte
          }
     }

     private void setUIComponent() {
          // Code for GUI
     }

     public void actionPerformed(ActionEvent e) {
          if (e.getActionCommand().equals("Connect")) {
               startReceiver();
          } else if (e.getActionCommand().equals("Disconnect")) {
               stopReceiver();
          } else if (e.getActionCommand().equals("Configure")) {
               String inputValue = null;
               inputValue = JOptionPane.showInputDialog(this,"New
remote host:","NeuroProbe Connector
Settings",JOptionPane.QUESTION_MESSAGE);
               if (inputValue!=null)
                    host = inputValue;
               inputValue = JOptionPane.showInputDialog(this,"New
remote port:","NeuroProbe Connector
Settings",JOptionPane.QUESTION_MESSAGE);
               if (inputValue!=null)
                    port = Integer.parseInt(inputValue);
          }
```

```
        }
}
```

BioMedia Integration Subsystem



Selected code sections of MediaConnector.java

```
// Imported classes

public class MediaConnector extends JPanel implements ActionListener
{
        private int port = 2222;
        private ServerSocket serverSocket = null;
        private Socket socket = null;
        private PrintWriter out = null;
        private BufferedReader in = null;
        private boolean running = false; // To control the thread
        private boolean manual = false; // Manual media events

        private int value;
        private boolean DATAREADY; // Data ready?

        public MediaConnector() {
                setUIComponent();
        }

        public boolean isConnected() {
                return running;
        }
```

```
	public int getNextData() {
		return value;
	}

	private void disconnect() {
		running = false;
	}

	public void start() {
		Thread th = new Thread() {
			public void run() {
				btnConnect.setEnabled(false);
				btnDisconnect.setEnabled(true);
				btnConfigure.setEnabled(false);

				running = true;
				try {
					serverSocket = new ServerSocket(port);
					socket = serverSocket.accept();
					out = new
PrintWriter(socket.getOutputStream(), true);
					in = new BufferedReader(new
InputStreamReader(socket.getInputStream()));

					String inputLine;
					while(running && (inputLine =
in.readLine())!=null) {
						value = Integer.parseInt(inputLine);
						out.println(inputLine);
					}

					out.close();
					in.close();
					socket.close();

				} catch (IOException e) {
				}

				// Closing
				running = false;
				btnConnect.setEnabled(true);
				btnDisconnect.setEnabled(false);
				btnConfigure.setEnabled(true);
			}
		};
		th.start();
	}

	public void auto() {
		Thread th = new Thread() {
			public void run() {
				btnConnect.setEnabled(false);
				btnDisconnect.setEnabled(true);
				btnConfigure.setEnabled(false);
```

```
                    value = 0;
                    running = true;
                    try {
                         while (running) {
                              value = value + (int)
(Math.random()*2);
                              sleep(5000);
                         }
                    } catch (Exception e) {
                    }

                    // Closing
                    running = false;
                    btnConnect.setEnabled(true);
                    btnDisconnect.setEnabled(false);
                    btnConfigure.setEnabled(true);
               }
          };
          th.start();
     }

     public void manualRun() {
          Thread th = new Thread() {
               public void run() {
                    btnConnect.setEnabled(false);
                    btnDisconnect.setEnabled(true);
                    btnConfigure.setEnabled(true);

                    value = 0;
                    running = true;
                    try {
                         while (running) {
                              sleep(100);
                         }
                    } catch (Exception e) {
                    }

                    // Closing
                    running = false;
                    btnConnect.setEnabled(true);
                    btnDisconnect.setEnabled(false);
                    btnConfigure.setEnabled(true);
               }
          };
          th.start();
     }

     private void setUIComponent() {
          // GUI code
     }

     public void actionPerformed(ActionEvent e) {
          if (e.getActionCommand().equals("Connect")) {
```

```
                if (!running)
                    start();
            } else if (e.getActionCommand().equals("Disconnect")) {
                disconnect();
            } else if (e.getActionCommand().equals("Configure")) {
                if (!running)
                    manualRun();
                else
                    value++;

            }
        }
}
```

Selected code sections of EOGAnnotationDataModel.java

```
// Imported classes

public class EOGAnnotationDataModel {
      private String annoFile;
      private LineNumberReader annoReader; // Reader for annotation
file
      private int eogGraphBlockSize;

      Vector v;
      int Lcnt, Lseq, Rcnt, Rseq, RLdiff;

      // Recently read annotation from file
      int[] annoInfo;

      public EOGAnnotationDataModel(String annoFile, int
eogGraphBlockSize) {
            this.annoFile = annoFile;
            this.eogGraphBlockSize = eogGraphBlockSize;
            init();
      }

      public void init() {
            v = new Vector(); // Holder for annotations add/remove
            Lcnt = 0; // EOGLR counter from left
            Lseq = -1; // sequence number from left
            Rcnt = 0; // EOGLR counter from right
            Rseq = -1; // sequence number from right
            RLdiff = 0; // EOGLR count in the window

            try {
                  if (annoReader != null)
                        annoReader.close();
            } catch (Exception e) {
                  Support.message("Program error!");
                  e.printStackTrace();
            }
            annoReader = null;
```

```
            annoInfo = readNextAnnotationFromFile();
      }

      // Returns annotation type if exist
      public int[] nextToken(String token, int value) {
            if (token.equals("EOGLR")) {
                  Rcnt++;

                  // wait until fully plot the graph
                  if (RLdiff >= eogGraphBlockSize) {
                        Lcnt--;
                        if (Lcnt <= 0) {
                              Lseq++;
                              EOGAnnotationObject annoObj =
(EOGAnnotationObject)v.get(Lseq);
                              if (annoObj!=null) {
                                    Lcnt = annoObj.getEogCount();
                              }
                        }
                  } else {
                        RLdiff++;
                  }

            } else if (token.equals("S&TIME")) {
                  //System.out.println(value);
                  // Initial
                  if (Lseq==-1)
                        Lseq = value - 1;

                  // Add next sequence to the list
                  Rseq = value;
                  if (hasRegisteredAnnotation(Rseq)) {
                        v.add(new
EOGAnnotationObject(Rseq,Rcnt,getRegisteredAnnotation(Rseq)));


                        // To returng the annotation info
                        // p1,p2,annoType
                        int[] annoInfo = new int[3];
                        annoInfo[0] = eogGraphBlockSize - Rcnt;
                        annoInfo[1] = eogGraphBlockSize - 1;
                        annoInfo[2] = getRegisteredAnnotation(Rseq);

                        Rcnt = 0;

                        return annoInfo;
                  } else {
                        v.add(new EOGAnnotationObject(Rseq,Rcnt,-1));
                        Rcnt = 0;
                  }
            }

            return null;
      }
```

```
    public int[] nextAnnotation(boolean isAdd, int annoPoint, int
annoType) {
        if (RLdiff < eogGraphBlockSize) {
            Support.message("Graph not ready to add or remove
annotation");
            return null;
        }

        int p = annoPoint;
        p = p - Lcnt;
        int Aseq = Lseq;
        int[] annoInfo = new int[3];
        annoInfo[2] = annoType;

        while (p > 0) {
            Aseq++;
            if (Aseq >= v.size()-1) {
                Support.message("This region is not ready to
add or remove annotation");
                return null;
            }
            EOGAnnotationObject annoObj =
(EOGAnnotationObject)v.get(Aseq);
            if (annoObj != null) {
                p = p - annoObj.getEogCount();
                annoInfo[1] = annoPoint - p;
                annoInfo[0] = annoInfo[1] -
annoObj.getEogCount();
            }
        }

        if (p <= 0 && isAdd) {
            EOGAnnotationObject annoObj =
(EOGAnnotationObject)v.get(Aseq);
            if (annoObj!=null && annoObj.getAnnoType()==-1) {
                annoObj.setAnnoType(annoType);
                v.setElementAt(annoObj,Aseq);
                return annoInfo;
            } else
                Support.message("Annotation already exist");
        } else if (p <= 0 && !isAdd) {
            EOGAnnotationObject annoObj =
(EOGAnnotationObject)v.get(Aseq);
            if (annoObj!=null && annoObj.getAnnoType()!=-1) {
                annoObj.setAnnoType(-1);
                v.setElementAt(annoObj,Aseq);
                return annoInfo;
            } else
                Support.message("No annotation to remove");
        }
        return null;
    }
```

```
	public boolean saveAnnotations() {
		PrintWriter pw = null;
		try {
			annoReader.close();
			pw = new PrintWriter(new BufferedWriter(new
FileWriter(annoFile)));

			Enumeration e = v.elements();
		       while(e.hasMoreElements()) {
			EOGAnnotationObject annoObj =
(EOGAnnotationObject)e.nextElement();
			if (annoObj!=null && annoObj.getAnnoType()!=-1) {
				pw.println(annoObj.getSequence()+"
"+annoObj.getAnnoType());
			}
		       }
		       pw.close();
		       return true;

		} catch (Exception e) {
			Support.message("Program error!");
			e.printStackTrace();
		}
		return false;
	}

	private int[] readNextAnnotationFromFile() {
		try {
			if (annoReader==null)
				annoReader = new LineNumberReader(new
InputStreamReader(new FileInputStream(new File(annoFile))));

			String line;
			if ((line = annoReader.readLine())!=null) {
				String[] fields = line.split("\\s+");
				int[] annoInfo = new int[2];
				annoInfo[0] = Integer.parseInt(fields[0]);
				annoInfo[1] = Integer.parseInt(fields[1]);
				return annoInfo;
			}
		} catch (Exception e) {
			Support.message("Program error!");
			e.printStackTrace();
		}

		return null;
	}

	private boolean hasRegisteredAnnotation(int seq) {
		if (annoInfo == null)
			return false;
		if (seq==annoInfo[0]) { // current one matches
			return true;
		} else if (seq > annoInfo[0]) { // current one doesn't
```

```
match
                // search the file sequentially for maching
                while (annoInfo != null && annoInfo[0] < seq) {
                     annoInfo=readNextAnnotationFromFile();
                }
                if (annoInfo!= null && seq==annoInfo[0]) // if found
                     return true;
           }
           return false; // no match or seq has already passed
      }

      private int getRegisteredAnnotation(int seq) {
           if (annoInfo != null && annoInfo[0]==seq) {
                return annoInfo[1];
           }
           return -1;
      }
}
```

Selected code sections of BioMediaController.java

```
// Imported classes

public class BioMediaController extends JPanel implements
ActionListener {
      // Controllers
      private SimpleGraphEOGLR eogGraph;
      private SimpleGraphAnalysis analysisGraph;
      private NeuroProbeTCPConnector tcpConnector;
      private MediaConnector mediaConnector;
      private LEGOGSRConnector gsrConnector;
      private int eogGraphBlockSize = 800;
      private EOGAnnotationDataModel eogAnno;

      // Flags for actions
      private boolean PLAY;
      private boolean RECORD;
      private boolean REPLAY;
      private boolean PAUSE;
      private boolean FASTREPLAY;
      private boolean ANNOTATION; // True if Add; False if Remove
      private int annoDisplayOption;

      public BioMediaController() {
           init();
      }

      private void init() {
           eogGraph = new SimpleGraphEOGLR(eogGraphBlockSize, -2048,
2048, 1000, 100, Color.lightGray, Color.black);
           analysisGraph = new
SimpleGraphAnalysis(eogGraphBlockSize, 800, 1000, 1000, 200,
Color.lightGray, Color.black);
```

```
            tcpConnector = new NeuroProbeTCPConnector();
            gsrConnector = new LEGOGSRConnector();
            mediaConnector = new MediaConnector();
            eogAnno = new
EOGAnnotationDataModel("eogAnno.asm",eogGraphBlockSize);
            initUI();

            // Action flags
            PLAY = false;
            RECORD = false;
            REPLAY = false;
            PAUSE = false;
            FASTREPLAY = false;
            ANNOTATION = true; // Add annotation
            annoDisplayOption = -1;
      }

      private void initUI() {

            /*
             * EOG graph for both channels
             * EOG annotations | Media timeline | GSR
             * Button controls
             * NeuroProbe connector | LEGO GSR connector | Media
connector
             */
            // GUI code
      }

      private void start() {
            Thread th = new Thread() {
                  public void run() {
                        try {
                              if (PLAY || RECORD) {
                                    if (!tcpConnector.isConnected()) {
                                          message("Please connect to the
NeuroProbe");

                                          PLAY = false;
                                          RECORD = false;
                                    }
                                    if (!gsrConnector.isConnected()) {
                                          message("Please connect to the
LEGO RCX");

                                          PLAY = false;
                                          RECORD = false;
                                    }
                                    if (!mediaConnector.isConnected()) {
                                          message("Please connect to
Media");

                                          PLAY = false;
                                          RECORD = false;
                                    }

                                    int[] eegData;
```

```
                                int gsrData;
                                int mediaData;

                                FileChannel fc = null;
                                ByteBuffer bb = null;
                                String recordStr = "";
                                int seq = 0;
                                eogGraph.init();
                                analysisGraph.init();
                                tcpConnector.init(); // To retrive
fresh data

                                if (RECORD) {
                                     FileOutputStream fos = new
FileOutputStream(new File("outStream.asm"));
                                     fc = fos.getChannel();

                                     bb =
ByteBuffer.allocateDirect(128);

     bb.order((ByteOrder.LITTLE_ENDIAN));
                                }

                                while (PLAY || RECORD) {
                                     while (!
gsrConnector.isDataReady() && tcpConnector.getBuffStatus()>5) {
                                          eegData =
tcpConnector.getNextData();

     eogGraph.nextData(eegData[0],eegData[1]);

                                          if (RECORD) {
                                               recordStr = "EOGLR
"+eegData[0]+" "+eegData[1]+"\n";

     bb.put(recordStr.getBytes("US-ASCII"));
                                               bb.flip();

                                               fc.write(bb);
                                               bb.clear();
                                          }
                                     }
                                     eogGraph.repaint();

                                     if
(gsrConnector.isDataReady()) {
                                          gsrData =
gsrConnector.getNextData();
                                          // get media data
                                          mediaData =
mediaConnector.getNextData();

     analysisGraph.nextGSRData(gsrData);
```

```
      analysisGraph.setMediaInfo(mediaData);
                                          analysisGraph.repaint();

                                          if (RECORD) {
                                                recordStr = "GSR&M
"+gsrData+" "+mediaData+"\n";

      bb.put(recordStr.getBytes("US-ASCII"));
                                                bb.flip();
                                                fc.write(bb);
                                                bb.clear();

                                                recordStr = "S&TIME
"+seq+" "+Support.getTimeInMillis()+"\n";

      bb.put(recordStr.getBytes("US-ASCII"));
                                                bb.flip();
                                                fc.write(bb);
                                                bb.clear();

                                                seq++;
                                          }
                                    }

                                    sleep(100);
                              }
                        }


                        if (REPLAY) {
                              LineNumberReader lnr = new
LineNumberReader(new InputStreamReader(new FileInputStream(new
File("outStream.asm"))));

                              int count;
                              String line = null;
                              String[] fields;
                              int[] annoInfo;
                              eogAnno.init();
                              eogGraph.init();
                              analysisGraph.init();

                              int seq = 0, gsr = 0, mid = 0;
                              long millis = 0;

                              while (REPLAY) {
                                    count = 0;
                                    while (!PAUSE && count!=10 &&
(line = lnr.readLine())!=null) {

                                          fields =
line.split("\\s+");
```

```
annoInfo=eogAnno.nextToken(fields[0],Integer.parseInt(fields[1]));
                                            if (annoInfo != null &&
(annoDisplayOption == -1 || annoDisplayOption == annoInfo[2])) {

     eogGraph.addAnnotation(annoInfo);

     analysisGraph.setEOGFeature(annoInfo[2]);
                                            }

                                            if
(fields[0].equals("EOGLR")) {


eogGraph.nextData(Integer.parseInt(fields[1]),Integer.parseInt(field
s[2]));
                                                 count+=1;

                                            } else if
(fields[0].equals("GSR&M")) {
                                                 gsr =
Integer.parseInt(fields[1]);
                                                 mid =
Integer.parseInt(fields[2]);

     analysisGraph.nextGSRData(gsr);


     analysisGraph.setMediaInfo(mid);

     analysisGraph.repaint();
                                            } else if
(fields[0].equals("S&TIME")) {
                                                 seq =
Integer.parseInt(fields[1]);
                                                 millis =
Long.parseLong(fields[2]);

     System.out.println(seq+"\t"+Support.getTimeString(millis)
+"\t"+mid+"\t"+gsr);
                                            }

                                            // Handle add/rem
annotation
                                            int antP;
                                            if ((antP =
eogGraph.getAnnotationPoint())!=-1) {
                                                 int action =
annoUserInput(); // -1 if user cancelled
                                                 if (action != -1 &&
(annoInfo = eogAnno.nextAnnotation(ANNOTATION,antP,action)) != null)
{
                                                      if
(ANNOTATION)
```

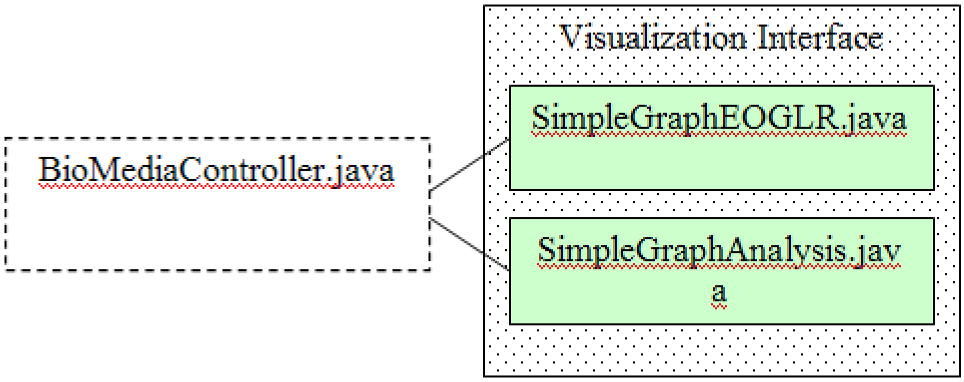
```
      eogGraph.addAnnotation(annoInfo);
                                                      else

      eogGraph.removeAnnotation(annoInfo);
                                                  }
                                             }
                                        }

                                        if (line == null) { // End of
file
                                             REPLAY = false;
                                             break;
                                        }

                                        eogGraph.repaint();

                                        if (FASTREPLAY)
                                             sleep(10);
                                        else
                                             sleep(100);
                                   }

                                   // Close opened files
                                   lnr.close();
                              }

                         } catch (Exception e) {
                              message("Program error!");
                              e.printStackTrace();
                         }

                         if (!PAUSE)
                              buttonEnablement(null);
                    }
               };
               th.start();
          }

          private int annoUserInput() {
               if (ANNOTATION) { // Add annotation
                    String s = (String)JOptionPane.showInputDialog(
                         this,
                         "Select the type:",
                         "Eye Activity Annotation",
                         JOptionPane.QUESTION_MESSAGE,
                         null,
                         EyeActivityFeatures.getLabels(),
                         null);
                    if ((s != null) && (s.length() > 0)) {
                        return EyeActivityFeatures.getID(s);
                    }
               } else { // Remove annotation
                    int n = JOptionPane.showConfirmDialog(
```

```
                        this,
                        "Are you sure you want to remove the
annotation?",
                        "Eye Activity Annotation",
                        JOptionPane.YES_NO_OPTION);
                if (n == 0) // Yes-0, No-1
                    return 1;
            }
            return -1;
        }

        //   Actions for buttons
        public void actionPerformed(ActionEvent e) {
            /*
             * Play: display data from streams
             * Record: display and record data from streams
             * Stop: stop Play or Recording
             * StopReplay: stop replay
             * PauseReplay: pause/resume replay
             * Replay: replay from beginning
             * FastReplay: switch between fast replay or normal
replay
             */
            if (e.getActionCommand().equals("Play")) {
                PLAY = true;
                buttonEnablement(new boolean[]
{false,false,true,false,false,false,false,true,false,false,false});

                start(); // Start playing

            } else if (e.getActionCommand().equals("Record")) {
                // Action flags
                RECORD = true;
                buttonEnablement(new boolean[]
{false,false,true,false,false,false,false,true,false,false,false});

                start(); // Start recording

            } else if (e.getActionCommand().equals("Stop")) {
                PLAY = false;
                RECORD = false;

                buttonEnablement(null);

            } else if (e.getActionCommand().equals("StopReplay")) {
                REPLAY = false;
                PAUSE = false;
                FASTREPLAY = false;

                buttonEnablement(null);

            } else if (e.getActionCommand().equals("PauseReplay")) {
                PAUSE = !PAUSE;
```

```
                if (PAUSE)
                     buttonEnablement(new boolean[]
{false,false,false,true,true,false,true,false,false,false,false});
                else
                     buttonEnablement(new boolean[]
{false,false,false,true,true,false,true,false,true,true,true});

           } else if (!REPLAY &&
e.getActionCommand().equals("Replay")) {
                REPLAY = true;
                buttonEnablement(new boolean[]
{false,false,false,true,true,false,true,false,true,true,true});

                start(); // Start replay

           } else if (REPLAY &&
e.getActionCommand().equals("FastReplay")) {
                FASTREPLAY = !FASTREPLAY;
                buttonEnablement(new boolean[]
{false,false,false,true,true,false,true,false,true,true,true});

           } else if (e.getActionCommand().equals("ConfigReplay")) {

                buttonEnablement(null);

                // Get the annotation display option
                String annoDisplayOptionLabel;
                if (annoDisplayOption == -1)
                     annoDisplayOptionLabel = "All";
                else
                     annoDisplayOptionLabel =
EyeActivityFeatures.getLabel(annoDisplayOption);
                String s = (String)JOptionPane.showInputDialog(
                     this,
                     "Which annotation category to display:",
                     "Annotation Display Option",
                     JOptionPane.QUESTION_MESSAGE,
                     null,
                     EyeActivityFeatures.getLabels("All"),
                     annoDisplayOptionLabel);
                if ((s != null) && (s.length() > 0))
                    annoDisplayOption =
EyeActivityFeatures.getID(s);

           } else if (e.getActionCommand().equals("AddAnnotation"))
{
                ANNOTATION = true;
                buttonEnablement(new boolean[]
{false,false,false,true,true,false,true,false,false,true,true});

           } else if
(e.getActionCommand().equals("RemoveAnnotation")) {
                ANNOTATION = false;
                buttonEnablement(new boolean[]
```

```
{false,false,false,true,true,false,true,false,true,false,true});

           } else if (e.getActionCommand().equals("SaveAnnotation"))
{
                REPLAY = false;
                PAUSE = false;
                FASTREPLAY = false;
                buttonEnablement(null);

                if (eogAnno.saveAnnotations())
                     message("Annotation data successfully saved");
           }
     }

     private void buttonEnablement(boolean[] s) {
           // Play Record Stop | StopReplay PauseReplay Replay
FastReplay | AddAnnotation RemoveAnnotation SaveAnnotation

           if (s==null)
                s = new boolean[]
{true,true,false,false,false,true,false,true,false,false,false};

           btnPlay.setEnabled(s[0]);
           btnRecord.setEnabled(s[1]);
           btnStop.setEnabled(s[2]);

           btnStopReplay.setEnabled(s[3]);
           btnPauseReplay.setEnabled(s[4]);
           btnReplay.setEnabled(s[5]);
           btnFastReplay.setEnabled(s[6]);
           btnConfigReplay.setEnabled(s[7]);

           btnAddAnnotation.setEnabled(s[8]);
           btnRemoveAnnotation.setEnabled(s[9]);
           btnSaveAnnotation.setEnabled(s[10]);
     }

     private void message(String msg) {


JOptionPane.showMessageDialog(this,msg,"Message",JOptionPane.INFORMA
TION_MESSAGE);
     }
}
```

BioMedia Visualization Interface



Selected code sections of SimpleGraphEOGLR.java

```
// Imported classes

public class SimpleGraphEOGLR extends JComponent implements
MouseListener {
      // Graph properties
      private int width;
      private int height;
      private Color backColor; // background color
      private Color lineColor; // line color

      // Handling data
      private int[][] dataBuffer;
      private int topIndex;
      private int points;
      private int yMin;
      private int yMax;
      private int antP; // annotation point

      // Uses
      BufferedImage I;
      Graphics2D G;
      double xstep, ystep;

      public SimpleGraphEOGLR(int points, int yMin, int yMax, int
width, int height, Color backColor, Color lineColor) {
            this.points = points;
            this.yMin = yMin;
            this.yMax = yMax;
            this.width = width;
            this.height = height;
            this.backColor = backColor;
            this.lineColor = lineColor;

            dataBuffer = new int[points][2];
```

```
            xstep = (double)width/(double)points;
            ystep = (double)height/(double)(2*(yMax-yMin)); // For
two graphs

            setBackground(backColor);
            setBounds(0,0,width,height);
            setPreferredSize(new Dimension(width,height));

            I  = new
BufferedImage(width,height,BufferedImage.TYPE_INT_RGB);
            G  = I.createGraphics();
            //G.setRenderingHint(RenderingHints.KEY_ANTIALIASING,Rend
eringHints.VALUE_ANTIALIAS_ON);
            addMouseListener(this);

            init();
      }

      public void init() {
            topIndex = 0;
            antP = -1;
            clear(0, width);

            G.setColor(Color.blue);
            // Channel 1
            G.drawString("EOG Channel 1 >>",(int)(width*0.8),(int)
(height*0.4));
            // Channel 2
            G.drawString("EOG Channel 2 >>",(int)(width*0.8),(int)
(height*0.8));
      }

      public void nextData(int val1, int val2) {
            val1 = val1>yMax?yMax:(val1<yMin?yMin:val1);
            val2 = val2>yMax?yMax:(val2<yMin?yMin:val2);
            dataBuffer[topIndex][0] = val1;
            dataBuffer[topIndex++][1] = val2;
      }

      private void move() {
            if (topIndex < 2) return; // not enough data

            int gWidth = (int)(xstep*(topIndex-1)); // how much to
move

            // move the previous image to the left
            G.drawImage(I,0,0,width-
gWidth,height,gWidth,0,width,height,null);

            // prepare the graw area space
            clear(width-gWidth, gWidth);

            // draw the line graph
            G.setColor(lineColor);
```

```
            double x1;
            for (int i=1; i<topIndex; i++) {
                  x1 = width - xstep*(topIndex-i);
                  G.drawLine((int)x1,height/2-(int)
(ystep*(dataBuffer[i-1][0]-yMin)),(int)(x1+xstep),height/2-(int)
(ystep*(dataBuffer[i][0]-yMin)));
                  G.drawLine((int)x1,height-(int)
(ystep*(dataBuffer[i-1][1]-yMin)),(int)(x1+xstep),height-(int)
(ystep*(dataBuffer[i][1]-yMin)));
            }

            // now we are ready to draw new data
            dataBuffer[0][0] = dataBuffer[topIndex-1][0];
            dataBuffer[0][1] = dataBuffer[topIndex-1][1];
            topIndex = 1;
      }

      private void clear(int x, int w) {
            G.setColor(backColor);
            G.fillRect(x,0,w,height);
      }

      public void paint(Graphics g) {
            move();
            g.drawImage(I,0,0,null);
      }

      public void mouseClicked(MouseEvent e) {
            antP = (int)(e.getX()/xstep);
      }

      // Point where Add/Remove annotation
      public int getAnnotationPoint() {
            int temp = antP;
            antP = -1;
            return temp;
      }

      public void addAnnotation(int[] annoInfo) {
            int x1 = (int)(xstep*annoInfo[0]);
            int x2 = (int)(xstep*annoInfo[1]);

            G.setColor(EyeActivityFeatures.getColor(annoInfo[2]));
            G.drawRect(x1,height/5,x2-x1,height/2);


G.drawString(EyeActivityFeatures.getLabel(annoInfo[2]),x1,height/2);
      }

      public void removeAnnotation(int[] annoInfo) {
            int x1 = (int)(xstep*annoInfo[0]);
            int x2 = (int)(xstep*annoInfo[1]);

            G.setColor(lineColor);
```

```
            G.drawRect(x1,height/5,x2-x1,height/2);
            G.drawString("XXXXXXXXXX",x1,height/2);
      }
}
```

Selected code sections of SimpleGraphAnalysis.java

```
// Imported classes

public class SimpleGraphAnalysis extends JComponent {
      // Graph properties
      private int width;
      private int height;
      private Color backColor; // background color
      private Color lineColor; // line color

      // Handling data
      private boolean newDataArrived;
      private int gsrNew, gsrPrv;
      private int points;
      private int yMin;
      private int yMax;

      private int eogType;
      private int mId, mIdPrv;
      private int mCount;

      // Uses
      BufferedImage I;
      Graphics2D G;
      double xstep, ystepGSR;

      public SimpleGraphAnalysis(int points, int yMin, int yMax, int
width, int height, Color backColor, Color lineColor) {
            this.points = points;
            this.yMin = yMin;
            this.yMax = yMax;
            this.width = width;
            this.height = height;
            this.backColor = backColor;
            this.lineColor = lineColor;

            xstep = (double)width/(double)points;
            ystepGSR = (double)(height*0.75)/(double)(yMax-yMin);

            setBackground(backColor);
            setBounds(0,0,width,height);
            this.setPreferredSize(new Dimension(width,height));
            I  = new
BufferedImage(width,height,BufferedImage.TYPE_INT_RGB);
            G  = I.createGraphics();
```

```
G.setRenderingHint(RenderingHints.KEY_ANTIALIASING,RenderingHints.VA
LUE_ANTIALIAS_ON);

            init();
      }

      public void init() {
            newDataArrived = false;
            eogType = -1;
            mId = -1;
            mIdPrv = -1;
            gsrNew = yMin;
            gsrPrv = yMin;

            clear(0, width);

            G.setColor(Color.blue);
            // Eye annotations
            G.drawString("Eye activity annotations >>",(int)
(width*0.8),(int)(height*0.1));
            // Media sequence ids
            G.drawString("Media sequence ids >>",(int)(width*0.8),
(int)(height*0.2));
            // GSR data
            G.drawString("GSR activity >>",(int)(width*0.8),(int)
(height*0.5));
      }

      public void nextGSRData(int val) {
            val = val>yMax?yMax:(val<yMin?yMin:val);
            gsrNew = val;
            newDataArrived = true;
      }

      public void setEOGFeature(int eogType) {
            this.eogType = eogType;
      }

      public void setMediaInfo(int mId) {
            this.mId = mId;
      }

      private void move() {
            if (!newDataArrived) return; // No new data to plot

            int gWidth = (int)xstep; // how much to move

            // move the previous image to the left
            G.drawImage(I,0,0,width-
gWidth,height,gWidth,0,width,height,null);

            // prepare the draw area space
            clear(width-gWidth, gWidth);
```

```
            int x1 = (int)(width - xstep); // where to draw

            // draw EOG feature if present
            if (eogType > -1) {
                  G.setColor(EyeActivityFeatures.getColor(eogType));
                  G.drawLine(x1,0,x1,(int)(height*0.15));
                  eogType = -1;
            }

            // draw media info if present
            // media bar
            G.setColor(Color.blue);
            G.drawLine(x1,(int)(height*0.15),x1,(int)(height*0.2));
            if (mId > -1 && mId != mIdPrv) { // Draw only if not
already drawn or not same media id
                  if (mCount <= 0) {
                        mCount = 10;
                        G.drawLine(x1,(int)(height*0.15),x1,(int)
(height*0.25));
                  } else {
                        mCount--;
                        if (mCount==1) {
                              G.setColor(Color.white);
                              G.drawString(mId+"",(int)(width -
xstep*10),(int)(height*0.2));
                              mIdPrv = mId;
                              mId = -1;
                        }
                  }
            }

            // draw GSR
            G.setColor(lineColor);
            G.drawLine(x1,height-(int)(ystepGSR*(gsrPrv-
yMin)),width,height-(int)(ystepGSR*(gsrNew-yMin)));
            gsrPrv = gsrNew;
            newDataArrived = false;
      }

      private void clear(int x, int w) {
            G.setColor(backColor);
            G.fillRect(x,0,w,height);
      }

      public void paint(Graphics g) {
            move();
            g.drawImage(I,0,0,null);

            // To draw a grid
            /*g.setColor(Color.orange);
            int dx = (int)(xstep * 8);
            for (int i=0; i < 100; i++)
g.drawRect(dx*i,0,dx*(i+1),height);*/
      }
```

```
    public void auto() {
        Thread th = new Thread() {
            public void run() {
                while (true) {
                    try {
                        nextGSRData((int)
(Math.random()*1000));
                        setEOGFeature((int)
(Math.random()*10)-8);
                        setMediaInfo((int)
(Math.random()*10)-4);
                        repaint();
                        Thread.sleep(100);
                    } catch (InterruptedException e) {}
                }
            }
        };
        th.start();
    }
}
```

* * *