Chapter 1

INTRODUCTION

This chapter introduces the problems discussed in this thesis, the motivation behind the present work, and the objectives of the thesis. It illustrates the various models and methodology of neuro-linguistics, emphasizing intelligent computing methods in the field. Finally, a comparative study of research going on aphasia and dyslexia has been done.

1.1 BRAIN ANATOMY OF LANGUAGE PROCESSING

The human brain is divided into two hemisphere-left hemispheres and the right hemisphere. In humans, the left hemisphere is a prominent part of language processing in the brain. About 97% of right-handed people and about 19% of left-handed people have a language processing area in the right hemisphere [1]. Broca and Wernicke first discovered language-specific brain areas by autopsies of patients suffering from various language-related problems before death. They found the damaged areas in

[1] http://webspace.ship.edu/cgboer/speechbrain.html

their brain were consistently located in the left hemisphere, and are named Broca and Wernicke areas named after them. Later, these discoveries were confirmed by Wilder Penfield and Herbert Jasper by brain surgery of patients giving local anesthesia while keeping them conscious and recording their experience [2]. Present-day research takes advantage of different brain imaging techniques like fMRI, PET-scan, and response recording techniques like EEG, and MEG. Also, the target community, previously only patients suffering from language difficulties, has been replaced by normal people, women, and children. It has been found that women use both hemispheres.

In contrast, children are found to be adaptive to brain injury. If the left hemisphere of the child is injured, the child may develop language capability in its right hemisphere. Neuro-imaging studies have been done on character, word, and syntax levels to explore a broader view of language processing regions [3]. The images of the brain areas have been recorded while subjects were involved in communication, reading, learning, and listening to explore this picture.

However, this is not the whole about regions involved in language processing; it is just a beginning. Based on the above discussion, the methodological trend and their findings in language processing by brain research can be summarised in the following Table 1.1.

Broca's [3],[4]- This was the first language area in the human brain that Paul Broca discovered (a French neurologist) through an autopsy of the patients. This area was named Broca's area after him. This is located in the brain's frontal lobe and is mainly responsible for speech production. Inability to speak is termed aphasia, and hence the inability to produce speech was termed Broca's aphasia. Broca's is also responsible for understanding complex aspects of grammar in communication. Wernicke's [3]- This brain language region was discovered by Carl Wernicke, a German

[2]http://webspace.ship.edu/cgboer/speechbrain.html
[3]http://webspace.ship.edu/cgboer/speechbrain.html

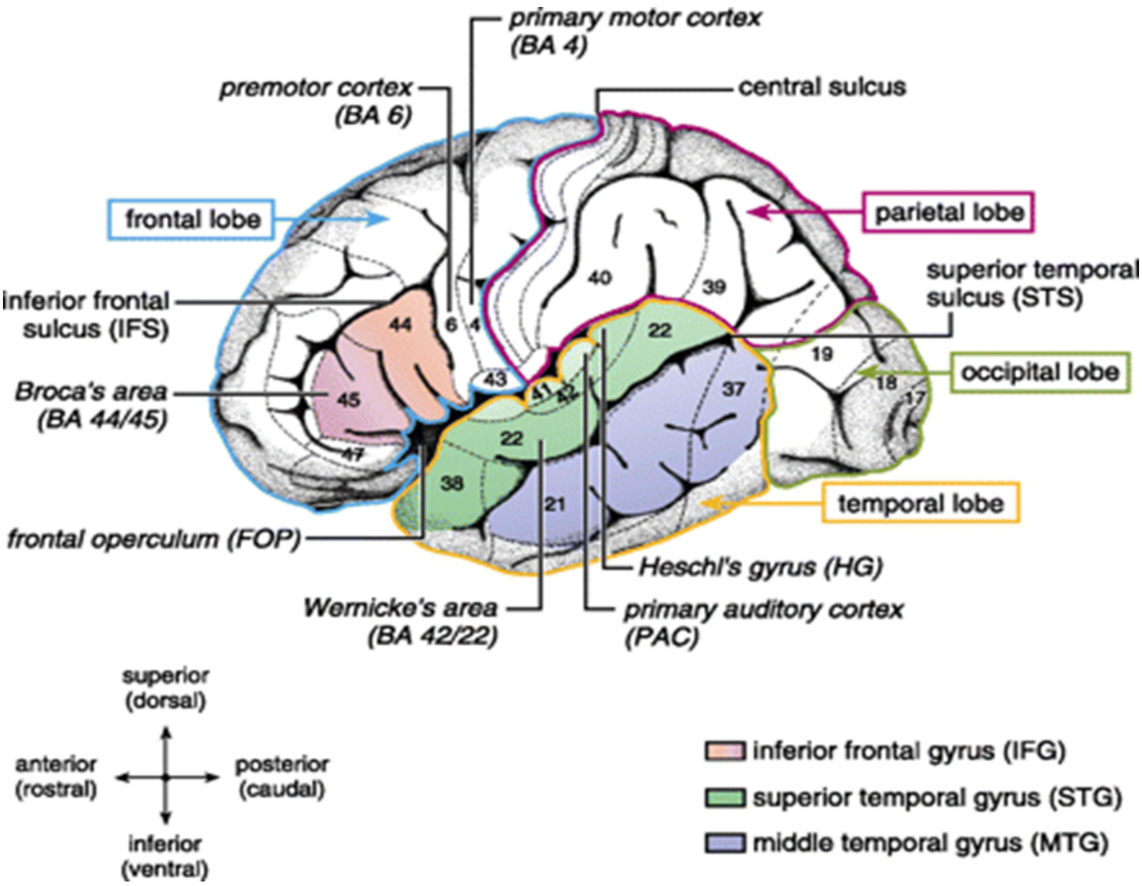

FIGURE 1.1: Brain anatomy for language processing [2]

TABLE 1.1: Trends in Neurolinguistics Research

Period	**The target group for research**	**Methods of Investigation**	**Result**
19th century	People having language-related disorders after their death	Autopsy	The language processing area is located in the left hemisphere
20th century	People with brain injury	Brain Surgery	Functioning module explored
Late 20th century to up to	Healthy people, including women and children	Neuroimaging techniques- FMRI, PET SCAN, Neuropsychological Techniques	Distributed processing area and distributed nature of processing for the same condition

neurologist, and named after him. This region was found by autopsy of a patient who can speak well but is unable to understand the speech of others. This is located in the upper portion of the temporal lobe, just behind the auditory cortex. This area is related to speech comprehension and naming things, i.e., mental dictionary. The problem of not understanding speech is known as Wernicke's aphasia or receptive aphasia. Arcuate fasciculus [4]- Broca's and Wernicke's are connected by tracts of nerves called the arcuate fasciculus. Damage to arcuate fasciculus results in aphasia reaching conduction aphasia. People suffering from conduction aphasia can understand and produce speech but cannot repeat words or sentences they hear. Angular Gyrus [5] is located near the parietal and occipital lobes. It enables us to associate multiple types of language-related information, visual, auditory, or sensory. Perceived words are only associated with different images, sensations, and ideas due to this part. Inactive angular gyrus can result in problems like alexia (inability to read), dyslexia (difficulty with reading), and agraphia (inability to write). However, dyslexia can involve other regions of the brain. The visual cortex [6]- is the area of the cerebral cortex involved in processing visual information.

1.2 EXPERIMENTAL METHODS FOR LANGUAGE PROCESSING IN THE BRAIN

1.2.1 HISTORICAL METHODS

I AUTOPSY[7] – The classical investigations of brain lesion analysis by Broca, Wernicke, and others in the 19th century were based on post-mortem autopsies of patients with language disorders, particularly aphasia.

[4] Anatomy of Speech & Language: http://memory.ucsf.edu/brain/language/anatomy
[5] Anatomy of Speech & Language: http://memory.ucsf.edu/brain/language/anatomy
[6] Anatomy of Speech & Language: http://memory.ucsf.edu/brain/language/anatomy
[7] http://webspace.ship.edu/cgboer/speechbrain.html

II WADA TEST[8] (Intracarotid sodium amytal test)- This method was used to study inter and intra-hemispheric differences in handling language function. In this method, using anesthesia, carotid arteries were made non-functioning, and hemispheric functions were recorded before surgery. This method was primarily used in the case of epilepsy.

III CEREBRAL ANGIOGRAPHY [9] is a radiological technique to explore vascular structure by injecting a contrast substance into the carotid artery to make blood vessels visible in an angiogram. This was mainly used to find out the blockage in blood vessels. This method was risky as it involved the chances of stroke.

1.2.2 RECENT METHODS

1.2.2.1 STATIC RECORDING

I COMPUTED TOMOGRAPHY (CT)[10] is a radiographic method in which a narrow X-ray beam examines the brain in skinny slices. The X-ray beam is rotated around the head and passed into it. On the other side, the quality and quantity of beam are recorded from which the image of black, white, and grey shade is obtained.

II MAGNETIC RESONANCE IMAGING (MRI)[5] - This measures the magnetic activity of hydrogen atom nuclei. An external magnetic field is applied around the brain, making the hydrogen nuclei align in a single plane. With external radio frequency, transmitter signals are transmitted to make them align on different patterns, and soon after the signal, they return to their original way releasing an electromagnetic signal. The computer records these signals, and converts them into images of grey, black, and white shade.

[8] http://webspace.ship.edu/cgboer/speechbrain.html
[9] Cerebral Angiography: http://www.radiologyinfo.org/en/info.cfm?pg=angiocerebral
[10] C.T Scan Wikipedia: https://en.wikipedia.org/wiki/CT_scan

III fMRI[6]- Functional magnetic resonance imaging is one the most commonly used techniques for studying language processing in the brain. This method analyzes a functional MR image of blood oxygenation level to account for the local neuronal activity. With the increased local neuronal activity, blood flow also increases, increasing oxygenated blood disproportionate to the high need for oxygen for neuronal activity. Due to this, the paramagnetic deoxygenated hemoglobin-generated susceptibility effect is reduced. This improves signal intensity on T2*-weighted MR images in active brain areas. fMRI technique is used in patient care suffering from different neurological diseases and in both types of research. This is because the classical model of language processing is oversimplified. Recent studies, based on fMRI imaging techniques and PET scans, have revealed no unequivocal association between types of aphasia and lesion location[7]. The problems related to the lesion in specific parts are not constant and vary from patient to patient.

IV PET[7]- Positron emission tomography is an isotopic technique that records the physiological changes in the brain by inserting glucose tagged with radioactive sodium positron in the body. The positron collides with an electron, and both get annihilated, releasing two photons (gamma rays) which move in opposite directions. The brain's detector detects the photon, and an image is produced. The active area of the brain uses more energy, i.e., more glucose, so more photons are released, and computers translate these as warmer colours such as green or blue. This methodology produces a three-dimensional map of brain activities in different regions.

V MEG-[11]Magnetoencephalography is a functional neuroimaging technique that records small changes in the magnetic field produced by electric current naturally occurring in the brain in response to a particular activity. Arrays of SQUIDs (superconducting quantum interference devices) are currently the most

[11]Magnetoencephalography:Wikipedia, https://en.wikipedia.org/wiki/Magnetoencephalography

common magnetometer, while the SERF (spin-exchange relaxation-free) magnetometer is being investigated for future machines. This measures neural transmission more directly than blood flow or metabolism data.

1.2.2.2 DYNAMIC RECORDING: ELECTRICAL ACTIVITY

I EEG-[8]Electroencephalogram tracks and records electrical activity brain wave patterns. In this method, small electrodes of thin wire are placed on the scalp, sending a signal to the computer to record. The normal electrical activity makes a recognizable pattern, while abnormal indicates seizures or other problems. Altered consciousness levels can be easily detected, and EEG is a handy diagnostic tool for this case. It is a specialized mechanism to record second language processing. The time resolution of the EEG technique captures the rapidly changing electrical response to individual words, morphemes, or speech sounds. Generally, it is used to measure how a second language has been understood based on average response.

II ERP[9]- Evoked or event-related potential is electrical activity resulting from the central nervous system's reaction to sensory stimulation. Electrodes record them in the same manner as EEG. It adopts an averaging technique to remove disturbances and reveals the acute response. The ERP is a typical series of positive and negative peaks representing earlier and later stages of information processing. The advantage of using ERP is that it is very inexpensive and allows acceptable temporal measurement of cognitive processing.

1.2.3 NEURO-LINGUISTIC COMPUTATIONAL MODELS[1]

Current neuro-linguistic computational models are built upon artificial intelligence's core idea, which believes that the brain is like a digital computer. However, the processing in the brain is massively parallel, and there is no specific memory module to access information. But the assumption of modularity in brain functioning is a critical element of all these models. Despite many constraints in modelling brain processing, there are two views of brain modelling: structured modelling and unstructured modelling or emergent modelling.

1.2.3.1 STRUCTURED MODELS

I MODULE-LEVEL STRUCTURED MODELS- This model attempts to localize the processing area in the brain. A familiar example of this type of model is the Geschwind model[10], which suggests that language comprehension begins with receipt of the signal by the auditory cortex in the temporal lobe and passed to Wernicke's area for lexical processing and then over arcuate fasciculus to Broca's area where the reply is planned, and output is sent to motor cortex for articulation. However, this model is problematic as there is little evidence that Wernicke's area functions as an association cortex with any specific linkage to lexical or linguistic processing. The Broca area also has problems, although it is well defined anatomically. But it is not possible to locate a particular area for specific aphasia. However, the recent fMRI technique supports the cluster-based functionality module in a specific area that supports the module-level structured models. Also, studies on children and development disorders in which a specific language disorder is explained as the particular link to a specific area is damaged.

II NEURON-LEVEL STRUCTURED MODEL- Morton's logogen model [11] was the most successful model of this type. There was a master neuron devoted to a particular word in this model. This central unit was activated, further triggering the subsequent units in phonology, orthography, meaning, and syntax. McClelland and Rumelhart [12] developed the IA model. IA model account for context effect in letter perception. This model successfully explained speech production, reading, lexical-semantic, and second language learning. The problem with this model is that it is far from reality. It is impossible to associate a particular neuron with a specific word in practice.

1.2.3.2 EMERGENT MODELS

I SELF-ORGANIZING MAP-To overcomes the limitations of the IA model, a PDP (Parallel Distributed Processing) model was proposed by Rumelhart[13], which relies on back-propagation and successfully deals with the distributed nature of memory in the brain. MacWhinny showed that the PDP model could not represent words' localist representation, leading to complicated morphological and syntactic processing. Kohonen [14] proposed a Self-Organizing Feature Map (SOFM) to handle all these problems. SOFM is difficult for language processing, but its extension and further research are impressive. It has been used by Mikkulainen [15] for the visual system. The devLex-II word learning model of Li [16] illustrates the operation of this model. This model has three local maps: a concept map and an articulatory map to represent learning in children. There is a possibility of extending the map based on the addition of neurons or overlaying new features.

II SYNTACTIC EMERGENCE- Elman [17] proposed a simple recurrent back-propagation connection to predict the next word. This model assumes comprehension is highly constructive, and the goal is to find the next term. MacDonald [18] has presented a model for ambiguity resolution. This model has excellently modelled the temporal properties of sentence processing. Macwhinny [19] proposed a construction grammar. This framework emphasises the role of the individual lexical item in early grammatical learning.

III LESIONING EMERGENT Model: After the syntactic model has been built, lesioning models are constructed to study the aphasic symptoms of the brain.

In this model, lesioning is done by removing the hidden units, removing connections, rescaling weight, removing inputs, or addicting noise to the system. It has been shown that various lesioning networks produce similar effects [20]. Plaut and Shallice [21] developed a model of deep dyslexia using a lesioning technique.

1.3 MATHEMATICAL METHODS

I ANN- An artificial neural network is an essential electronic model that mimics the brain's structure and function. A neural network consists of processing neurons as nodes, and information flows via the proper channels. Each node can have one or more inputs associated with some weight. Each neuron does some computation on its input. The output may be input to some other neuron or may be the system's output. The primary sources of brain learning experiences and neural networks work similarly. Neural network-based models can explain language acquisition in children and the second language learning paradigm. The self-organising map model of Kohenen [14] and the SRN model of Elman [22] are neural network-based models to explain language acquisition.

II SVM- The use of support vector machines in brain image analysis is increasing day by day due to its capability of capturing multivariate relationships in the data. Brain image analysis based on univariate voxel-wise analysis fails in cases where statistical tests upon registered stereotaxic space result in spatially complex differences and involve a combination of different voxels or brain structures [23]. The support vector methods have solved these problems to a significant level [24],[25]. These approaches allow capturing complex multivariate relationships in data and are successfully applied to a variety of neurological conditions in classification [26],[27]. In image segmentation and classification problems, SVM is frequently used.

III BAYESIAN APPROACH TO BRAIN FUNCTION: In the fields of behavioural science and neuroscience, cognitive ability based on statistical principles is explained by the Bayesian approach. It assumes that the internal probabilistic model of the nervous system is maintained by processing sensory information using Bayesian probability. It explains and investigates the nervous system's capacity in an uncertain situation. Human perceptual and motor behaviour is modelled with Bayesian statistics. Landy [28], Jacobs [29], and Goldreich [30] had used Bayesian decision theory. Hawkins' [31] work on cortical information processing, also called hierarchical temporal memory, is based on the Bayesian network of the Markov chain.

1.4 RECENT RESEARCHES ON APHASIA AND DYSLEXIA

Analysing different literature research works, we can also find the importance of behavioural results. Table 1.2 shows a comparative study of behavioural data vs. experimental data for aphasia and dyslexia.

1.5 MOTIVATION

Language is a unique feature of human beings which enables them to communicate ideas and emotions. We speak and understand speech signals. How do we understand these signals? Is there any representation in the brain which can be analysed? What is the relationship between speech signals and the corresponding brain representation? Many such questions inspired me to analyse the processing of language in the brain. There are a number of findings in the literature which explore these questions. But, none of them discovered the entire phenomenon of language in one

Table 1.2: Recent Research on Aphasia and Dyslexia

Author name	**Work**	**Disease**	**Methodology**
Warren et al.[32]	Structural prediction	Aphasia	Behavioural
Hanne et al.[33]	Sentence comprehension and morphological study	Aphasia	Behavioural
Cruice et.al [34]	Verb use study by different group	Aphasia	Behavioural
Della Rosaet al.[35]	Functional recovery in aphasia	Aphasia	fMRI
Toumiranta et al.[36]	Vocabulary acquisition Functional deficit in clause and nominal phrases	Aphasia	Behavioural
Wang et al.[37]	Argument effect in action verb naming	Aphasia	Behavioural
Bart den Ouden et al. [38]	Semantic processing in English-Spanish bilingual	Aphasia	fMRI
Sebastian et al. [39]	Differential effect of word presentation rate	Aphasia	Behavioural
Karni et al.[40]	Bilingual Reading comparison	Dyslexia	fMRI
Oren et al.[41]	Recall range and information processing	Dyslexia	ERP
Shiran et al. [42]	Reading Speed	Dyslexia	ERP
Richard et al.[43]	Morphological spelling treatment in children	Dyslexia	fMRI
Leeuwan et al.[44]	Brain mapping study of two-month infant	Dyslexia	fMRI
Dandache, S. et al. [45]	Reading and phonological skill of children	Dyslexia	Behavioural

place. Our aim is to explore the different aspects of language and its representation in the brain, like word level, sentence level, and discourse level analysis. One question remains unanswered: One more question remains unanswered: can we model brain images in any way to determine what they represent in terms of languages? We developed models that can figure out what kind of word, sentence, or emotion the subject is reading the symbols for just by analysing the fMRI data.

1.6 PROBLEM STATEMENT AND THESIS OBJECTIVES

This thesis is related to developing a technique that can read the brain just by analysing the data of the brain. We have analysed fMRI data for nouns, sentences, and discourse. Our proposed model can identify the thought with a reasonable degree of accuracy.

The objective of the proposed work in this thesis is to apply machine learning approaches to analyse language processing in the brain with different feature selection and classification techniques to investigate the processing of words, sentences, and discourse in the brain.

The brief contribution and objectives of this thesis are as follows:

1. To study and compare the performances of the various conventional and state-of-the-art methods for Neurolinguistics.
2. Design, develop, and implement efficient algorithms for language processing in the brain.
3. Design, develop, and implement an effective classification cum retrieval system for concrete noun classification in the brain.
4. Design, development, and implementation of sentence polarity detection method for the brain.
5. Design, develop, and implement the automated algorithms using Random Forest to classify moods and emotions.

All the proposed methods have been implemented using MATLAB R 2014 and Python software on a standard Intel Core i7 PC with 8 GB of RAM and tested for standard datasets. Their performances were evaluated using various performance measures, and the performances of each of the proposed methods were compared against state-of-the-art methods available in the literature. The obtained results and their performance analyses justify the applicability of the proposed approaches.

1.7 OUTLINE OF THE THESIS

This thesis consists of six chapters. The outline of the thesis is as follows:
CHAPTER 1 presents a brief introduction of language processing in the brain, methods, models, and techniques for investigation of the brain, followed by the motivation and objectives of the thesis.

CHAPTER 2 discusses the theoretical background of language and the brain. This chapter also discusses an overview of language comprehension and language acquisition. Further, this chapter presents a comprehensive literature review and comparative study of various traditional and state-of-the-art language processing methods in the brain.

CHAPTER 3 presents the computational model of concrete noun representation in the brain using fMRI data. It gives a cascading feature selection method to select the prominent features of the brain, which are fed to the classifier to classify the brain signals.

CHAPTER 4 presents sentence polarity detection using correlation-based feature selection and random forest. In this affirmative and negative sentence, brain images are classified using random forest, k-NN, and MLP.

CHAPTER 5 presents a discourse-level analysis of fMRI data of the brain. This gives a word-level analysis of the brain and the localization of different POS tags in story reading. Different basic emotions as described by Paul Ekmann are analysed in the story, and corresponding fMRI data is classified. Also, the locations in the brain for emotion-laden words are investigated, and finally, a brain model is proposed that can identify the reader's mood in story reading.

CHAPTER 6 presents the conclusions of the thesis and summarises the main findings of this thesis work. This chapter also proposes possible future perspectives for this thesis.