APHASIADX: AN EXPERT DIAGNOSTIC SYSTEM FOR APHASIA

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ABSTRACT

AphasiaDx is an expert system that has been created to assist with the diagnosis of aphasia. It has been developed using Common Lisp, Common Lisp Object System, and a logic programming system Prolisp. As part of a larger neurodiagnostic system, Neurobridge, AphasiaDx has been programmed to diagnose Broca's aphasia, Wernicke's Aphasia, global aphasia, mixed transcortical aphasia, transcortical sensory aphasia, transcortical motor aphasia, and conduction aphasia. Benchmarks were developed and tested against our programmed rule base and confidence factors (CF) were accurately produced for the correct diagnosis. This expert diagnostic system can be utilized for medical problem solving as well as well as for educational purposes.

KEY WORDS:

Artificial Intelligence, Expert Systems, Aphasia, Diagnostics, Stroke

1. Introduction

Aphasia is a language disorder that affects a person's ability to communicate in both the spoken and written form. Aphasia is most often caused by a stroke or brain injury, but may also be caused by tumors or other progressive or degenerative brain diseases. The two language centers in the brain are Broca's area and Wernicke's area. Broca's area is located in the frontal region of the left hemisphere just anterior to the motor cortex and is comprised of the neurons which control speech [19]. Wernicke's area is also located in the left hemisphere, posterior to the auditory cortex, and is responsible for comprehending speech sounds [20]. The major components of aphasia, which vary between conditions, are fluency of speech, comprehension of written or spoken language, and intact repetition. Depending on the affected area, a person may suffer from different forms of aphasia. The most common types are Wernicke's aphasia, Broca's aphasia, or global aphasia. Other categories of aphasia include mixed transcortical aphasia, transcortical sensory aphasia, transcortical motor aphasia, and conduction aphasia [8].

Wernicke's aphasia, also known as fluent aphasia, is characterized by the person's ability to create long, complex sentences that are incoherent, including words that are unrecognizable or out of place. Affected individuals are unable to repeat even simple words correctly. People with this type of aphasia are often unable to understand spoken language and are typically unaware that they are not being understood [10]. The person with fluent aphasia has an impaired ability to comprehend the meaning of words and his/her ability to read and write can also be severely affected. Wernicke's aphasia is due to lesions in the temporal lobe, where Brodmann's Areas 21 and 42 are affected, sometimes extending into the parietal lobe and area 39 [15].

Broca's aphasia, or nonfluent aphasia, affects the output of language rather than the comprehension. A person with this form of aphasia will usually be able to understand written and spoken language, maintaining the ability to read, but they are unable to produce grammatical sentences [7]. Repetition is difficult for them. The person affected with Broca's aphasia has preserved comprehension, but is nonfluent, with fragmented, effortful speech. Broca's aphasia is due to damage in the left frontal lobe, Brodmann's Area 44 and 45 [15].

Global aphasia is the instance where areas of the brain controlling both comprehension and expression of language are damaged. This is the most severe form of aphasia. People with global aphasia are unable to speak or repeat using real words and are unable to understand spoken or written language at all. They can neither read nor write [1]. Depending on the extent of damage this form of aphasia can sometimes improve, but is otherwise a lasting condition. Global aphasia occurs from both anterior and posterior legions [15].

Mixed transcortical aphasia (MTcA), also known as isolation syndrome, is similar to global aphasia in that both speech comprehension and expression are severely impaired, however, there is preserved repetition [18]. A person with this form of aphasia is able to repeat short phrases, and if only the first half of a common phrase is given they will be able to complete the rest of the phrase. There is little to no comprehension, and the ability to read is no longer present or severely hindered. MTcA is the result of areas surrounding both Broca's and Wernicke's being damaged, while the language area itself remains preserved [22].

Transcortical sensory aphasia is similar to Wernicke's in that there is little preserved comprehension, and although fluent, their words are nonsensical jargon. However, people affected with this form of aphasia are able to repeat phrases. If this person is asked a question they are

more likely to repeat the question than to answer it [8]. In one study lesions are shown to localize in the posterior parieto-occipital area [13]. Damage is believed to occur in the watershed areas of the blood supply. Broca's and Wernicke's area are often preserved but have no connection to the brain, and lesions can be found in Brodmann's areas 37, 22, and 39 [15].

Transcortical motor aphasia (TcMA) results from damage near Broca's area. Unlike classic Broca's aphasia, this person is able to repeat complex words and phrases [2]. Comprehension is mostly maintained but not the ability to fluently produce difficult conversational speech. In a study on classic TcMA patients, lesions were found in the left frontal lobe, most commonly in the white matter anterolateral to the left frontal horn [11], below Broca's area in Brodmann's Area 6 [15].

Conduction aphasia takes place when there is damage to the pathway connecting Broca's and Wernicke area, the arcuate fasciculus [3]. This person maintains comprehension and fluency of speech, but is unable to repeat phrases. Difficulty with repetition increases as length and complexity of the phrase increases.

2. Background

Neurological conditions are complex to diagnose. Experts who are skilled at diagnosing aphasia include neurologists, neuropsychologists, and speech therapists. Aphasia syndromes are diverse and have areas of overlap that can be overlooked by healthcare providers who do not have a specialty in that area. Many different interpretations and definitions of aphasia exist amongst providers [5] and higher level providers are not always available when primary care physicians need support with diagnostic specialties. We have used artificial intelligence to attempt simulation of a neurologist for diagnostic support and educational purposes.

This report presents AphasiaDx, a program that will analyze aphasia syndromes and populate a diagnosis with confidence factors for each category of aphasia. This is part of a much larger software program, Neurobridge, which is an expert system we are designing to emulate the behavior of the neurologist with expedience and efficiency. The overall system will automatically analyze patient symptoms, signs, laboratory values, imaging studies, and pathologies results, compute a neuroanatomic localization of one or more central nervous system lesions, and determine a set of diagnoses that might account for the input data. The software product from this effort will become a valuable tool to assist the health care professional in medical problem solving.

Neurobridge includes an object oriented neuroanatomical atlas (NAA), which is a digital atlas that exists as a knowledge base (objects and relationships). The NAA will contain objects such as nuclei, ganglia, dermatomes, arteries, spinal cord structures, areas (i.e. Brodmann's areas), and so on. Relationships between these objects will be defined and will include cell to cell connections, arterial branching descriptions, functional behavior (such as proprioception), and spatial relationships. This knowledge base with images will be a comprehensive resource for the expert system software, neuroscientists, remote physicians, and students in the biological sciences.

AphasiaDx is a newly developed system. Upon literature review we found other aphasia diagnostic systems that function differently than ours. The Aphasia Diagnostic System was created as a computer based assistance program for analyzing aphasia syndromes [4]. A hierarchical fuzzy rule based approach has also been developed [6], which uses statistical analysis to determine diagnosis of Aphasia. Other AI systems exist which are intended for treatment and therapeutic purposes but are not diagnostic [12] [21].

AphasiaDX will be added to our comprehensive library of neurodiagnostic tools called the Neurobridge.

3. Methods and Materials

The language Common Lisp [16], Common Lisp Object System (CLOS) [17], and the logic programming language Prolisp [9] were used in programming AphasiaDx.

3.1 Rules

The rules for this set of diagnoses were encoded using PROLISP, an object-oriented logic proving system modeled on Prolog and encoded in Common Lisp Object System. The rules are processed using hypothesis driven backward chaining depth-first search technology. Each rule has qualitative elements such as "repetition is intact" and a statistical element (the confidence factor). Patient benchmark files were manually created and contain symptoms that correspond specifically to a given diagnosis. For example, the Wernicke's aphasia benchmark specifies that fluency is intact but comprehension is impaired. The benchmark files were created to provide a mechanism for software diagnostic validation (e.g., does the program compute the correct diagnosis given a set of symptoms?).

We describe the modules of the system below. See figure 1 for architecture.

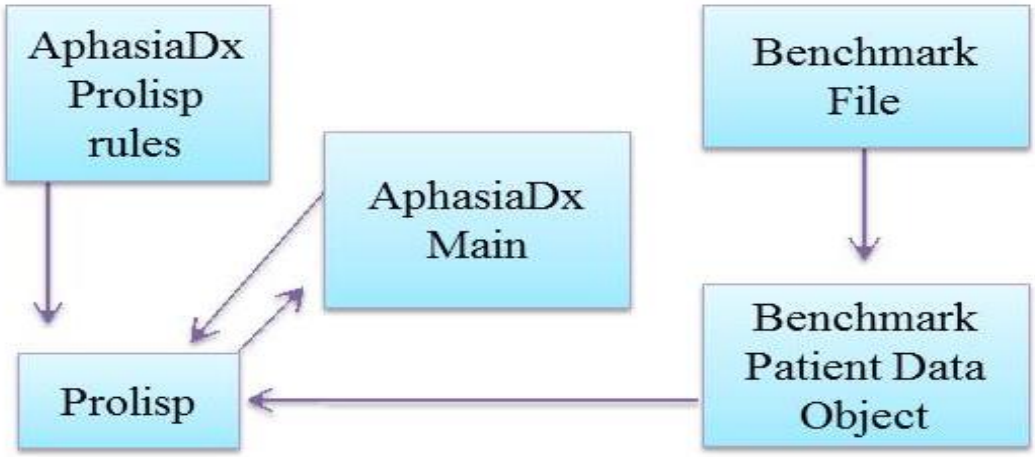

Figure 1. AphasiaDx Architecture

PROLISP: This module is the logic prover, supports rules and facts, and is based on Prolog. To prove a theorem, "proof" operator processes the rules for a specific diagnosis such as Wernicke's Aphasia.

Benchmark Database: This module is file storage for the benchmarks. Each benchmark file was manually created. When a benchmark file is loaded the data is stored in a large patient-data class object. Access to the patient-data object is via Lisp generic functions.

Benchmark to Prolisp Facts: This module converts patient data to asserted Prolisp fact patterns such as "(language comprehension good 1.0)" or "(language fluency poor 1.0)" where this is an n-tuple with qualitative factors (e.g. fluency is poor) and a confidence fact (e.g. 1.0). AphasiaDx rules match on the fact base by standard logic programming technology (unification and resolution).

AphasiaDX Rule base: This set of rules is specific to aphasia syndromes and include these hypotheses: Wernicke's Aphasia, Broca's Aphasia, Transcortical Sensory Aphasia, and so on.

A Prolisp rule has this syntax: (define-rule *head clauses*) where head is the main rule pattern and clauses are multiple sub-rules. Clauses are processed in order and "and" logic is applied. In Prolisp, a variable begins with a question mark (e.g., ?fluency-cf).

An example rule is below:

```
(define-rule '(wernickes-aphasia ?cf)
 '((comprehension-is-poor ?comp-cf)
  (fluency-is-preserved ?fluency-cf)
  (repetition-is-impaired ?rep-cf)
  (average ?comp-cf ?fluency-cf ?rep-cf ?cf)))
```

When all clauses succeed ("and" logic) and confidence factors are unified, the rule succeeds and the final diagnostic CF ?cf is returned.

AphasiaDX main algorithm: With rules and facts loaded into memory, loop over all aphasia diagnoses. For each diagnosis, process rules and compute a diagnostic confidence factor. Sort on confidence factors and present all results. The diagnosis with the high confidence factor is the most probable diagnosis.

3.2 Database of Rules

Rules have been encoded for aphasia in which we address Broca's aphasia, Wernicke's aphasia, global aphasia, mixed transcortical aphasia, transcortical sensory aphasia, transcortical motor aphasia, and conduction aphasia. The major components of the condition, which vary between types, are fluency, comprehension, and intact repetition. In the data base, each condition is coded yes or no for each of these three categories (table 1). For example, if symptoms are entered into the system as non-fluent, no comprehension, and no repetition, the case will be diagnosed as global aphasia, with a confidence factor of 1.0. Confidence factors (CF) will be produced for each individual aphasia diagnosis and it will populate how likely the patient is to have each of the outcomes.

For numerical representation of truth this system uses the confidence factor. The standard convention for a CF is zero represents false, 0.5 represents unknown, and 1.0 represents true. A mathematical operator, alpha, is employed in this system. Applied to confidence factors, alpha combines values synergistically.

Table 1. **Aphasia Rules.** Rules have been encoded for each of the 7 types of aphasia. Rules include Comprehension, Fluency and repetition (across the top) and results are shown here for the variation among diagnosis (on the left).

	Comprehension	Fluency	Repetition
Wernicke's Aphasia (Fluent Aphasia)	no	yes	no
Broca's Aphasia (nonfluent Aphasia)	yes	no	no
Global Aphasia	no	no	no
Mixed Transcortical Aphasia (MTcA)	no	no	yes
Transcortical Sensory Aphasia	no	yes	yes
Transcortical Motor Aphasia (TcMA)	yes	no	yes
Conduction Aphasia	yes	yes	no

Table 2. **AphasiaDx Confidence Factors.** Displayed are the system generated confidence factors (CF) for each of the benchmarks against the rules for the possible diagnoses. AphasiaDx correctly diagnosed each of the benchmarks giving a CF of 1.0 at the appropriate diagnosis.

Benchmark vs. Dx Rule	WA	BA	GA	MTcA	TcSA	TcMA	CA
Wernicke's Aphasia (Fluent Aphasia- WA)	1.00	0.33	0.66	0.33	0.66	0.00	0.66
Broca's Aphasia (nonfluent Aphasia)	0.33	1.00	0.66	0.33	0.00	0.66	0.66
Global Aphasia	0.66	0.66	1.00	0.66	0.33	0.33	0.33
Mixed Transcortical Aphasia (MTcA)	0.33	0.33	0.66	1.00	0.66	0.66	0.00
Transcortical Sensory Aphasia	0.66	0.00	0.33	0.66	1.00	0.33	0.33
Transcortical Motor Aphasia (TcMA)	0.00	0.66	0.33	0.66	0.33	1.00	0.33
Conduction Aphasia	0.66	0.66	0.33	0.00	0.33	0.33	1.00

WA= Wernicke's Aphasia, BA= Broca's Aphasia, GA= Global Aphasia, MTcA= Mixed Transcortical Aphasia, TcSA= Transcortical Sensory Aphasia, TcMA=Transcortical Motor Aphasia, CA= Conduction Aphasia

3.3 Benchmarks

Benchmarks have been created to be used as non-ambiguous patient files for the various aphasia diagnostic tests. Each benchmark is a set of patient findings that are characteristic of a specific aphasia syndrome. The benchmarks encode patient symptoms such as fluency of speech, comprehension of spoken or written language, and ability to produce repetition. Neuroanatomical localizations for each syndrome are also included.

The first step involves processing the benchmark dataset (a CLOS object) and for each attribute a Prolisp fact is created. As with Prolog, facts are patterns on which the theorem prover applies rules in a depth-first search.

3 steps to testing the benchmarks

1. Load benchmark file ex: Broca's aphasia

2. Benchmark facts are tested against each AphasiaDx diagnosis

3. Confidence factors are produced and the correct syndrome for the benchmark should give the highest CF, thus the diagnosis is made by the system. 0 means no confidence, 1 means complete confidence, 0.5 means unknown confidence

The rules and the inference engine then return an explanation for the deductions. This cycle repeats over each benchmark file.

4. Results

Results are seen in the tables above. Table 1 describes the qualities of the aphasia syndromes. Table 2 summarizes the confidence factors for each diagnosis as found by the system. Each benchmark file was correctly diagnosed by the system with a confidence factor of 1.0.

5. Discussion, Conclusion and Future Work

The current diagnostic capability of the system is sufficient for giving the proper aphasia diagnosis. We have shown that our rules are correct in diagnosis based on our benchmarks.

Artificial intelligence and expert systems can be employed to assist healthcare professionals and medical students in the assessment of complex neurological diagnoses. Aphasia is one such diagnosis in which an automated system will assist by evaluating facts unbiasedly and producing accurate, standardized diagnostic results.

We plan to add more knowledge rules, especially anatomical knowledge. These anatomical rules would then process CT or MRI information about where lesions are found. We plan to create a suite of actual patient files and to test the system to see if the system maintains accuracy in diagnosis. Other plans include drawing patient data from our medical records and doing a large scale diagnostic process and to record and publish the results. We also plan to present a 3 dimensional brain model that locates the stroke lesion associated with each aphasia syndrome. This AphasiaDx system is part of a much larger neurodiagnostic system called NeuroDx and we plan to continue growing the knowledge base incrementally.

We have created this expert system to be a part of a Neurobridge, along with StrokeDx and Brachial PlexusDx, and it will continue to be further extended. The extensions will include HeadacheDx, SeizuresDx, Movement DisorderDx, Multiple SclerosisDx, Peripheral Nerve DiseaseDx, TremorDx, Spine DiseaseDx, and Muscle DiseaseDx. We will continue to enlarge the library of neurodiagnostic tools.

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