PLEXUSDX: AN EXPERT SYSTEM WITH THREE DIMENSIONAL LOCALIZATION MODELLING FOR THE BRACHIAL PLEXUS

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ABSTRACT

The brachial plexus is a complex anatomical structure that links the cervical spine with muscles and dermatomes of the arm. An expert neurodiagnostic system, PlexusDx, has been developed to assist in the diagnosis of brachial plexus legions. This is part of a larger neuro-diagnostic system called Neurobridge. Benchmarks for lesions of the plexus were created and tested against diagnoses of various plexus lesions. Confidence factors were computed at nearly 100% accuracy for the benchmark against the correct diagnosis. A Lisp front end to the 3 dimensional drawing program POV-Ray has been developed and named Povlisp. Povlisp was used to define and draw a representation of the brachial plexus with a highlighted lesion to accompany a plexus diagnosis. PlexusDx may be a useful resource in medical offices as well as medical schools and other educational settings.

KEY WORDS:

Artificial Intelligence, Expert Systems, Brachial Plexus, Three Dimensional Modeling

1. Introduction

The brachial plexus (BP) is a nerve complex formed by anterior rami of spinal nerves C5 to T1 [4]. It is described as having three trunks - the superior trunk, middle trunk, and inferior trunk. The next distal components are called divisions, anterior and posterior. Each division has a superior, middle, and inferior subdivision. Then, distally, are the components termed cords which include posterior, medial, and lateral cords. The final substructures are branches (nerves) and these include the musculocutaneous nerve, the axillary nerve, the median nerve, and the ulnar nerve. There are several smaller branches from the plexus. The plexus includes sensory axons and motor axons. The motor axons carry action potentials from the ventral horn cells of the spinal cord to the neuromuscular junction of target muscles [7]. The brachial plexus maintains the motor connection to all of the muscles in the arm with the exception of the trapezius and levator scapula [4]. The sensory components of the brachial plexus are complex. Sensory action potentials travel from cutaneous receptors to the spinal cord dorsal horn. The pseudo-unipolar neurons (in the dorsal root ganglia) project axons to the dorsal horn and to the corresponding dermatome via the brachial plexus.

With the multitude of muscles and nerve connections in the arm, making a brachial plexus diagnosis is very complicated.

Expert systems have long since been identified as key elements in computer systems of the future [2]; we have created an expert system for the assistance of diagnosing BP lesions using artificial intelligence. For the model to be complete, all such connections have been described in the knowledge code. The system, PlexusDx, is part of a larger neuro-diagnostic system called Neurobridge. Not only is PlexusDx an expert diagnostic system, but it also includes a Neuro Anatomical Atlas (NAA) which provides a localization to go with the diagnosis. In the NAA we have modeled the brachial plexus using object oriented technology.

The creation of PlexusDx also involved the software development of POVLISP, which is a Lisp front end to POV-Ray, which is described later in this paper.

This system will allow users to run a set of symptoms in the system for which it will return a set of diagnoses with confidence factors. Additionally, it will populate a visual model of the brachial plexus with the corresponding lesion indicated by a contrasting color. This is an AI tool that will be employed for research and development in neuroscience, assisting with difficult BP diagnoses.

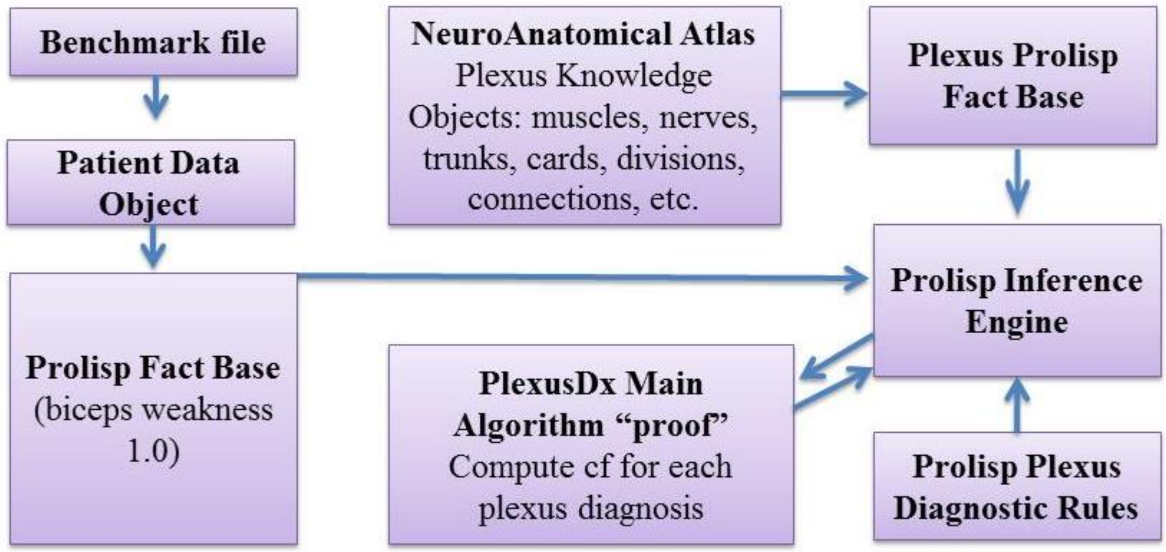

Figure 1. PlexusDx Architecture

2. Methods and Materials

2.1 PlexusDx Architecture and Modules

See Figure 1 for the architecture of PlexusDx.

Benchmark File: A benchmark file contains about 100 data elements that describe patient attributes for a specific diagnosis. **Patient Data Object:** When a benchmark file is loaded, the patient attributes are stored in a CLOS object. **Prolisp Fact Base:** A function reads the patient data object and stores Prolisp facts into memory. An example is (biceps weakness 1.0). **NeuroAnatomical Atlas:** This is a very large neurological knowledge base and contains entries for nerves, arteries, brain lobes, major pathways, and of course the brachial plexus. This knowledge base contains thousands of entries and thousands of interconnections. **Plexus Prolisp Fact Base:** The plexus knowledge is written into the Prolisp fact memory for logic processing. **Prolisp Plexus Diagnostic Rules:** Stored in a file, these rules describe each diagnosis contained in PlexusDx. When loaded, the rules are entered into Prolisp memory. **Prolisp Inference Engine:** This module uses depth-first search, unification, and resolution to process rules and produce proof conclusions. **PlexusDx Main Algorithm:** Prolisp rules are processing using the proof operator. The results of a search when successful include variable bindings and confident factor computations.

2.2 PlexusDx

We created PlexusDx using the logic programming tools Common Lisp [9], Common Lisp Object System (CLOS) [3], and the logic programming language Prolisp [7]. The rule base is encoded in Prolisp and employs hypothesis driven depth first search. Rules have been encoded for superior trunk lesions, middle trunk lesions, inferior trunk lesions, radial nerve lesions, median nerve lesions, and ulnar nerve lesions.

There is a comprehensive library of knowledge specifications for the plexus. This library (part of the NAA) includes muscles, nerves, trunks, cords, divisions, and a novel structure that we call *connection*. The connection explicitly describes the path of an axon through the plexus. For example, one connection is (C5 → superior-trunk → anterior-division → lateral-cord → musculocutaneous nerve → biceps).

We have written these diagnostic rule sets: superior trunk, inferior trunk, median nerve, ulnar nerve, and radial nerve. The diagnostic rules contain knowledge about muscle function and sensory function. For example, the radial nerve provides motor input to the flexors of the forearm (such as flexor digitorum). For example, if one or more of the flexors of the forearm are weak this supports the diagnosis of radial nerve lesion.

For each of the nerve lesion rules (median, radial, and ulnar) we have added in exclusionary clauses. Many of the nerves and muscle connections have similar muscle groups (e.g. the ulnar nerve and inferior trunk muscles are almost identical). By including exclusionary rules, we can focus the rules and eliminate confidence factor ties when the muscle sets overlap. For example, with the ulnar nerve lesion diagnosis, there are three major clauses: weakness of ulnar nerve muscles, strength of median nerve muscles, and strength of radial nerve muscles. If the median nerve muscles are all strong then this supports ulnar nerve lesion. If the median nerve muscles are weak then the lesion is more proximal in the plexus. We also include a clause to test the strength of the radial nerve muscles. If the radial nerve muscles are all strong then this supports ulnar nerve lesion. If the radial nerve muscles are weak then the lesion is more proximal in the plexus. The knowledge mechanism produced the desired confidence factors to differentiate the ulnar nerve lesion from the inferior trunk lesion.

2.3 Brachial Plexus Knowledge Base

Two classes, *motor-connection* and *sensory-connection*, are defined to support PLEXBASE.

A motor-connection transmits efferent signals from the spinal cord to a muscle and contains attributes as follows. The connection *source* is where the neuron cell body lies (e.g., ventral-horn-c5-right), *trunk* (superior-trunk-right), *division* (anterior-division-superior-right), *cord* (lateral-cord-right), *nerve* (musculocutaneous-nerve-right), and *destination* (biceps-brachii-right). For the motor connection between C5 and biceps, the following fact is generated:

(MOTOR-CONNECTION VENTRAL-HORN-C5-RIGHT SUPERIOR-TRUNK-RIGHT ANTERIOR-DIVISION-SUPERIOR-RIGHT LATERAL-CORD-RIGHT MUSCULOCUTANEOUS-NERVE-RIGHT BICEPS-BRACHII-RIGHT)

The second key concept (and class) is the *sensory-connection*. A sensory-connection transmits afferent signals from a cutaneous receptor to the dorsal horn of the spinal cord. A sensory connection contains attributes as follows: The connection *source* is where the neuron cell body lies (e.g., spinal-ganglion-c5-right), *trunk* (superior-trunk-right), *division* (anterior-division-superior-right), *cord* (lateral-cord-right), *nerve* (musculocutaneous-nerve-right), and *destination* (dermatome-c5-right). The pseudo-unipolar neurons of the spinal ganglia project to the ipsilateral dorsal horn and through the ipsilateral brachial plexus.

All named structures of the plexus, peripheral nerves, muscles, spinal cord structures, and nerve roots are defined and instantiated as objects in the knowledge base and can then be accessed. The roots and ventral horn associate in a one-to-one relationship and so root identifiers are prefixed with “ventral-horn” in this application.

The system is designed to convert knowledge from PLEXBASE to Prolisp facts. Each object is converted to a Prolisp fact and stored as a Prolisp fact. PLEXBASE knowledge network can also be accessed by a library of Lisp functions. Prolisp rewrite-rules are used to access PLEXBASE knowledge; an example rewrite-rule *muscles-for-trunk ?trunk* obtains all muscles for a specific trunk. In the following section, we describe a few of the knowledge base commands. A Prolisp rewrite-rule, when processed, runs a Lisp function to derive the data to unify with the variable.

2.4 PLEXBASE Query Rules

In this section, the library of rules to access and do elementary reasoning about the brachial plexus is described. In some examples, a query history ?hx variable is shown.

MOTOR-CONNECTION

Using the Prolisp proof operator, a search of the fact base for a motor-connection from spine to deltoid muscle can be done. The variable bindings yield knowledge of the plexus components of this connection. In the following example, the proof unifies the variables (such as ?root1) and returns the bindings. A successful proof means that the proof (applied to rules and facts) succeeded.

```
(proof '(motor-connection ?root1 ?trunk1 ?division1
?cord1 ?nerve1 deltoid-right))
?ROOT1 = VENTRAL-HORN-C5-RIGHT
?TRUNK1 = SUPERIOR-TRUNK-RIGHT
?DIVISION1 = POSTERIOR-DIVISION-SUPERIOR-
RIGHT
?CORD1 = POSTERIOR-CORD-RIGHT
?NERVE1 = AXILLARY-NERVE-RIGHT
```

To find the motor connection to the biceps:

```
(proof '(motor-connection ?root1 ?trunk1 ?division1
?cord1 ?nerve1 biceps-brachii-right))
?ROOT1 = VENTRAL-HORN-C5-RIGHT
?TRUNK1 = SUPERIOR-TRUNK-RIGHT
?DIVISION1 = ANTERIOR-DIVISION-SUPERIOR-
RIGHT
?CORD1 = LATERAL-CORD-RIGHT
?NERVE1 = MUSCULOCUTANEOUS-NERVE-RIGHT
```

The proof variable bindings are displayed above. Note that the division, cord, and nerve are different for biceps and deltoid muscles.

HAS-SAME-ROOT (?muscle1 ?muscle2 ?root)

The *has-same-root* rule queries PLEXBASE, obtains roots for ?muscle1 and ?muscle2 and runs an intersection operator producing the ?root answer. If there are no common nerve roots, the proof will fail. Clinical relevance: An injury to a nerve root could produce weakness in the muscles sharing the root.

(proof '(has-same-root deltoid-right biceps-brachii-right ?root))
?ROOT = VENTRAL-HORN-C5-RIGHT

HAS-SAME-TRUNK (?muscle1 ?muscle2 ?trunk)

The *has-same-trunk* rule queries the BP knowledge base, obtains trunks for both muscles, applies intersection, and binds the result variable ?trunk.

(proof '(has-same-trunk deltoid-right biceps-brachii-right ?trunk))
?TRUNK = SUPERIOR-TRUNK-RIGHT

ALL-ROOTS (?muscle ?roots)

The *all-roots* rule queries the PLEXBASE facts to find all roots that include motor fibers innervating the muscle. This is done by using a rewrite-rule that references Lisp function *get-all-roots* (that returns a list). Clinical relevance: weakness in the named muscle might reveal damage to the list of roots returned by this query.
(proof '(all-roots biceps-brachii-right ?roots))

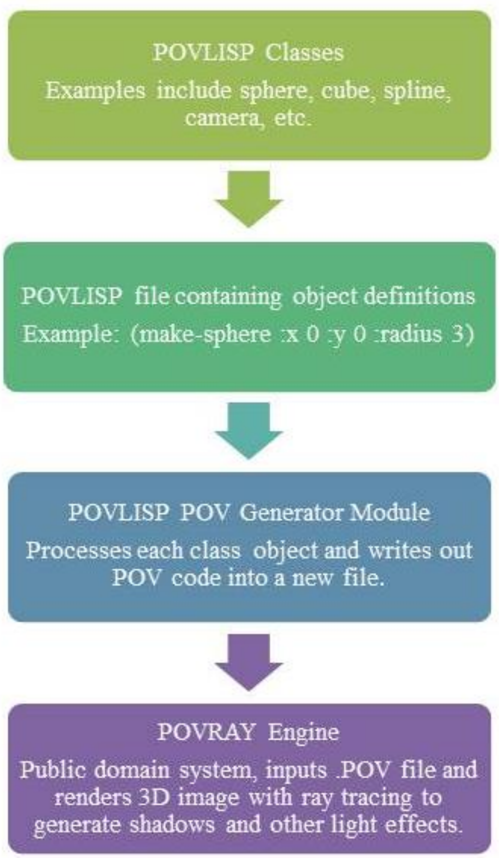

Figure 2. Flow Diagram. POVLISP 3D drawing system

?ROOTS = (VENTRAL-HORN-C5-RIGHT VENTRAL-HORN-C6-RIGHT)

ALL-MUSCLES-OF-NERVE (?nerve ?muscles)

The *all-muscles-of-nerve* rule is defined as a rewrite-rule using Lisp function get-all-muscles-of-nerve and binds *?muscles* to a list of muscles that are innervated by axons passing through the named nerve. Clinical relevance: Damage to this nerve might produce weakness in the list of muscles produced by this query.

(proof '(all-muscles-of-nerve median-nerve-right ?muscles))
?MUSCLES = (OPPONENS-POLLICIS-RIGHT SECOND-LUMBRICAL-RIGHT FIRST-LUMBRICAL-RIGHT FLEXOR-POLLICIS-BREVIS-RIGHT ABDUCTOR-POLLICIS-BREVIS-RIGHT PRONATOR-QUADRATUS-RIGHT PALMARIS-LONGUS-RIGHT FLEXOR-POLLICIS-LONGUS-RIGHT ...)

SHARE-THESE-ROOTS (?root1 ?root2 ?muscles)

This rule obtains muscles that have efferent fibers from the two different nerve roots. Clinical relevance: Weakness in the listed muscles suggests problems with the named roots. This rule could easily be modified to support three roots.

(proof '(share-these-roots ventral-horn-c7-right ventral-horn-c6-right ?m))

?M = (ANCONIUS-RIGHT CORACOBRACHIALIS-RIGHT TRICEPS-LATERAL-HEAD-RIGHT EXTENSOR-CARPI-RADIALIS-BREVIS-RIGHT FLEXOR-CARPI-RADIALIS-RIGHT TRICEPS-MEDIAL-HEAD-RIGHT TRICEPS-LONG-HEAD-RIGHT EXTENSOR-CARPI-RADIALIS-LONGUS-RIGHT)

Another example finds the muscles that share C7 and C5 roots:

(proof '(share-these-roots ventral-horn-c7-right ventral-horn-c5-right ?m))
?M = (CORACOBRACHIALIS-RIGHT EXTENSOR-CARPI-RADIALIS-BREVIS-RIGHT EXTENSOR-CARPI-RADIALIS-LONGUS-RIGHT)

SENSORY-CONNECTION (?ganglion ?trunk ?division ?cord ?nerve ?dermatome)

The *sensory connection* is a fundamental knowledge element. Using the proof operator, the sensory connection fact base can be queried to bind variables. This example finds the connection between C7 and C7 dermatome.
(proof '(sensory-connection spinal-ganglion-c7 ?trunk ?division ?cord median nerve dermatome-c7)
?TRUNK = MIDDLE-TRUNK

?DIVISION = ANTERIOR-DIVISION-MIDDLE
?CORD = LATERAL-CORD

2.5 Brachial Plexus Diagnostic Rules

A set of rules were developed for inclusion in the diagnostic suite of PlexusDx. Rules were specified using Prolisp syntax. The syntax has this form: (predicate arg1 arg2 argN). Rules may have sub-clauses that are processed using "and" logic. This rule, when processing, will testing each clause. If a clause succeeds, a CF is returned. The confidence factors are averaged giving final CF ?cf that is returned as a unified variable.

A very simple example follows:

```
(define-rule (superior-trunk-lesion ?cf)
  '((weakness deltoid muscle ?deltoid-cf)
   (weakness biceps muscle ?biceps-cf)
   (average ?deltoid-cf ?biceps-cf ?cf)))
```

Examples of diagnostic rules being processed (using the proof operator) follow.

LOSS-OF-SENSATION (?dermatome ?side ?cf ?hx)

This rule queries the patient facts to find if the ?dermatome has loss of sensation. Sub-goals include four of the sensory modalities. The ?hx variable reports on the data that allows the query to succeed. Clinical relevance: Loss of sensation may represent brachial plexus injury, nerve injury, or stroke.

```
(proof '(loss-of-sensation dermatome-c5 :right ?cf ?hx))
?CF = 1.0
?HX = (LOSS-OF-SENSATION DERMATOME-C5
:RIGHT 1.0 (LOSS-OF-TOUCH DERMATOME-C5
:RIGHT 1.0) (LOSS-OF-VIBRATION DERMATOME-
C5 :RIGHT 1.0) (LOSS-OF-PAIN DERMATOME-C5
:RIGHT 1.0) (LOSS-OF-TEMPERATURE
DERMATOME-C5 :RIGHT 1.0))
```

STRENGTH-OF-MUSCLES (?trunk ?side ?cf ?hx)

This rule queries first the PLEXBASE to map from ?trunk to associated muscles. The muscle strength is converted by sub-rules to a CF. Muscle strength ranges from 0, weak, to 5, strong. In this example there is good confidence that superior trunk muscles are strong.

```
USER(21): (proof '(strength-of-muscles superior-trunk
:left ?cf ?hx))
CF = 0.9
?HX = (STRENGTH-OF-MUSCLES SUPERIOR-
TRUNK :LEFT (STRENGTH CF 0.9) (STRENGTH-
DATA ((BICEPS-BRACHII-LEFT 5) (BRACHIALIS-
LEFT 5) (BRACHIORADIALIS-LEFT 5) … )))
```

Prolisp rules (for inclusion in StrokeDx) were created for decision support system for brachial plexus lesions. These rules are discussed below.

Rule Superior Trunk Lesion

The rule for a superior trunk lesion was developed and the rule tests benchmark information for superior trunk lesion. The rule searches for weakness in biceps, deltoids, brachioradialis muscles and C5 dermatome sensory loss and C6 dermatome sensory loss. This rule was tested against the right superior trunk benchmark and was a near perfect match. In competition with other rules in the

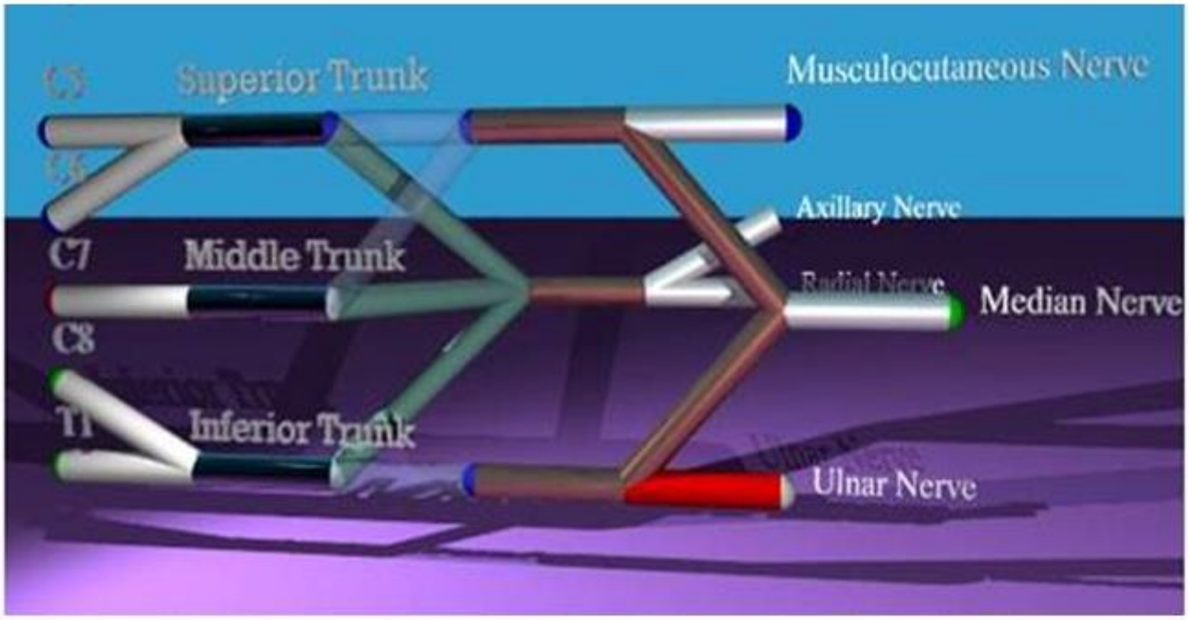

Figure 3. 3D Blachial Plexus model. PlexusDx employs a 3 dimensional model of the brachial plexus with the highlighted legion corresponding to the diagnosis. Ulnar Nerve lesion seen here highlighted in red.

stroke set, the superior trunk diagnosis yielded the highest CF (1.0). The proof for the left superior trunk yielded CF of 0.37 (essentially “no”). The proof for *right inferior trunk lesion* against right superior trunk benchmark yielded CF of 0.07. The rules can differentiate between the two trunks. The ?HX variable is bound to the search path that produced the successful proof and represents an explanation for the proof.

```
(proof '(superior-trunk-lesion :right ?cf ?hx))
?CF = 1.0
?HX = (SUPERIOR-TRUNK-LESION :RIGHT 1.0
(WEAKNESS-OF-MUSCLES SUPERIOR-TRUNK
:RIGHT 0 (WEAKNESS-CF 1) (STRENGTH-OF-
MUSCLES SUPERIOR-TRUNK :RIGHT (STRENGTH
CF 0) (STRENGTH-DATA ((BICEPS-BRACHII-RIGHT
0) (BRACHIALIS-RIGHT 0) (BRACHIORADIALIS-
RIGHT 0) (CORACOBRACHIALIS-RIGHT 0)
(DELTOID-RIGHT 0) … (TERES-MINOR-RIGHT 0)
(ANCONIUS-RIGHT 0) (FLEXOR-CARPI-RADIALIS-
RIGHT 0) (LATISSIMUS-DORSI-RIGHT 0) (TRICEPS-
LATERAL-HEAD-RIGHT 0) (TRICEPS-LONG-HEAD-
RIGHT 0) (TRICEPS-MEDIAL-HEAD-RIGHT 0)))))
(LOSS-OF-SENSATION DERMATOME-C5 :RIGHT
1.0 (LOSS-OF-TOUCH DERMATOME-C5 :RIGHT 1.0)
… )
```

Rules for middle trunk lesion and inferior trunk lesion were also encoded and tested against the benchmark files.

2.6 Benchmarks

Standard benchmark files were created using a word processor to test the decision support system rules for brachial plexus lesions. Benchmark files are discussed below. The benchmark file for a *superior trunk lesion* was developed and encoded patient information consistent with a superior trunk lesion. The benchmark codes weakness in biceps, deltoids, brachioradialis muscles and encodes C5 dermatome sensory loss and C6 dermatome sensory loss. This benchmark was tested against the superior trunk diagnostic rule and was a near perfect match (as is expected).

The benchmark file for an *inferior trunk lesion* is completed and encodes patient information consistent with a inferior trunk lesion. The benchmark codes weakness in muscles including flexor digitorum profundus, abductor pollicis brevis, and first dorsal interosseous, and encodes C8 dermatome sensory loss and T1 dermatome sensory loss.

Benchmark data files were manually created to test the diagnostic system. Each benchmark encodes the typical motor and sensory findings for a brachial plexus lesion. For example, the superior trunk lesion benchmark is programmed to show weakness in biceps and deltoid muscles and show sensory deficits in the C5 dermatome (lateral arm and thumb). Upon running benchmarks against the rules, confidence factors (CF) are produced for each potential brachial plexus lesion (Table 1). The confidence factor is a numerical representation of truth for this system. The standard convention for a CF is zero represents false, 0.5 represents unknown, and 1.0 represents true. This system uses either average or alpha as mathematical operator [5]. Applied to confidence factors, alpha combines values synergistically.

2.7 POVLISP and 3D Localization

A software system called POV-Ray is a ray tracing three dimensional drawing package [6]. To support our research work, we have written a Common Lisp front-end to POV, called POVLISP which supports object oriented specifications for drawing primitives such as sphere, lathe, text, and so on.

POVLISP supports object oriented programming and interfaces with the evolving Neurobridge systems that are encoded in Lisp. See figure 2 for flow logic. Once a drawing specification has been written in POVLISP, the software generates POV-Ray code. The POV-Ray code can be loaded and rendered by POV-Ray creating the 3D drawings. We have created POVLISP object specification for the brachial plexus and can generate and manipulate a 3D plexus image. We can change the parameters of the specification and mark "lesions" (such as superior trunk lesion) and present the plexus lesion to the viewer (Figure 1). Using object class inheritance (in CLOS), we can define a hierarchy of object and methods.

For a subset of the POV-Ray commands we have implemented a corresponding POVLISP function. The POVLISP function when interpreted will first create an object in the Lisp memory space and this object will be stored in a library. The next step is to process each of the library objects and to generate the POV-Ray code into a .pov file. The .pov file is then processed by the POV-Ray system in the usual manner and rendered into an image file.

For example, the function **pov:make-camera** will generate a camera primitive in POV-RAY.

```
(pov:make-camera :location (pov:make-vector 80 40 -80)
  :look-at (pov:make-vector 5 30 0) :angle 60)
```

generates this POV-Ray code

```
camera {
  location <80, 40, -80>
 look_at <5, 30, 0>
  angle 60
}
```

Benchmark

Diagnosis	Superior Trunk	Inferior Trunk	Radial Nerve	Median Nerve	Ulnar Nerve
Superior Trunk	1.00	0.10	0.10	0.33	0.00
Middle Trunk	0.35	0.45	0.90	0.15	0.00
Inferior Trunk	0.07	1.00	0.77	0.77	0.90
Radial Nerve	0.35	0.40	1.00	0.00	0.00
Median Nerve	0.28	0.62	0.58	0.98	0.62
Ulnar Nerve	0.24	0.66	0.62	0.62	1.00

Table 1: **Diagnosis chart**. Benchmarks have been run across rule sets in the PlexusDx expert system, and confidence factors have been populated for each benchmark against each of the brachial plexus diagnosis. PlexusDx produced accurate confidence factors for each benchmark against their rule sets.

Another example shown here is the POVLISP function **pov:make-sphere**. This function creates a variable SPHERE1 and assigns a sphere object to that variable.

```
(pov:make-sphere :id 'sphere1
 :declare "SPHERE1"
 :location (pov:make-vector 0 0 0)
 :scale (pov:make-vector 1.5 1.5 1.5))
```

generates POV-Ray code

```
#declare SPHERE1 =

sphere {
    <0, 0, 0>
    , 1
     scale <1.5, 1.5, 1.5>
}
```

A third example demonstrates the POVLISP function **pov:make-cylinder** that causes a POV variable CYLINDER1 to be created and assigned a cylinder object.

```
(pov:make-cylinder :id 'cylinder1
 :comment "Connects sphere1 to sphere2"
 :declare "CYLINDER1"
 :base-point (pov:make-vector 0 0 0)
 :cap-point (pov:make-vector 0 1 0)
 :open-flag t :radius 1)
```

generates POV-Ray code

```
// Connects sphere1 to sphere2

#declare CYLINDER1 =
cylinder {
  <0, 0, 0>
  <0, 1, 0>
  1
  Open
}
```

3. Results

Our experimental results are summarized in Table 1 and present the confidence in each diagnosis/benchmark pair.

For example, for superior trunk benchmark, the superior trunk diagnosis CF is 1.00 which is the expected result (the program computed the correct diagnosis given the specific symptoms for each benchmark).

4. Discussion

The inferior trunk and the ulnar nerves nearly have the same set of muscles. For this reason, the inferior trunk diagnosis/ulnar nerve benchmark analysis yields confidence of 0.9. The CF is 0.9 (and not 1.0) because the inferior trunk does send axons to the median nerve. The ulnar nerve and median share one muscle, the flexor pollicis brevis (FPB). Since the exclusionary rule for median neuropathy is the ulnar muscle strength and this would include FPB, this would pull the CF down very slightly and thus the median CF for the median benchmark is less than 1.0.

The ulnar nerve lesion rule tests 5 clauses. The most important is *weakness of muscles of ulnar nerve*. The idea is if the muscles of this nerve are weak then the nerve has a lesion. If the confidence factor of this clause is computed to be zero then there is no evidence to support the ulnar nerve lesion because all of its muscles are strong. The clause *strength of muscles* of median nerve is new and it is important because if any of those muscles (innervated by median nerve) are weak then there must be a more proximal lesion in the plexus, in a cord or a trunk for example. This is the same idea with clause *strength of muscles of radial nerve*. There are also sensory analysis clauses by dermatome. The ulnar nerve is a C8/T1 nerve so we can test those dermatomes.

In the future, PlexusDx will be further expanded to include rules for the axillary nerve, the musculocutaneous nerve, and rules for cords and divisions.

5. Conclusion and Future Work

No recent work was found, but older systems such as PLEXXUS [10] and Computer-Assisted Localization of Peripheral Nervous System Legions [1], have previously employed artificial intelligence to create a basic diagnostic system for brachial plexus lesions. Three dimensional models of the brachial plexus have also been created [9], but PlexusDx is a novel system in that it combines the two.

By implementing POVLISP (Lisp interface between our AI system and POV-Ray) we can quickly present our computed results as a visual model. In the future we will extend our diagnostic system with 3D brachial plexus model to the public on a web interface that allows users to access the model and populate potential lesions for their desired purpose at any time via the web.

The brachial plexus innervates every muscle in the arm. Memorizing the entire brachial plexus, along with pathways and connections, is challenging. PlexusDx is an expert diagnostic system that evaluates all of these connections with precision, and could be employed to do so in doctors' offices as well as medical schools or other educational settings.

We have created this expert system to be a part of Neurobridge, along with StrokeDx and AphasiaDx, which have already been coded. Neurobridge will continue to be further extended to 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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