# Video EEG Expert System: Software to compute seizure focus lateralization and localization prior to epilepsy surgery

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### Abstract

OBJECTIVE: To develop the Video EEG Expert System (VES), a program to analyze patient data with the goal of finding anatomic seizure focus in the context of epilepsy pre-surgical evaluation. BACKGROUND: Numerous systems have been created to analyze electroencephalogram (EEG) data with the goal of searching for epileptiform discharges. Literature review does not reveal software dedicated to evaluation of data for a patient under consideration for temporal lobectomy surgery. METHODS: Patient data included MRI, PET, SPECT, and video EEG. The system is in Lisp and a logic programming module, Prolisp, that supports hypothesis-driven rules. Benchmark files (controls) and corresponding anatomic localization hypothesis trees were created. 23 experimental files were used to test correctness in localizing seizure focus. The principle developer was blind to these files. RESULTS: The system selected the correct localization for 100% of benchmark files. For the experimental files, the correct localization was selected in 78%, first place ties were computed in 13%, and incorrect localizations were found in 9%. Analysis of incorrect results yielded minor software problems and some incomplete knowledge concerning temporal lobe localization. CONCLUSIONS: VES performed well at identifying seizure focus. The tools developed for VES, especially Prolisp, should serve future neurological expert system development.

### Keywords

Expert system, neurology, temporal lobe epilepsy, logic programming.

## 1. Introduction

For temporal lobe epilepsy, surgical resection is associated with 70-80% rate of one-year remission [1]. At our institution, a team of neurologists, neurosurgeons, neuroradiologists, neuropsychologists, and technical staff analyze information for a patient being evaluated for seizure surgery. The information includes magnetic resonance imaging (MRI), positron emission tomography (PET), single photon emission computed tomography (SPECT), interictal electroencephalography (EEG), video EEG (VEEG), and neuropsychological testing. VEEG studies record details of the ictal (seizure) event. The goal of analysis is to identify anatomic lateralization and localization of seizure focus. We have written software called the Video EEG Expert System (VES) to automate such analysis.

## 2. Background

Liu [2] used artificial neural networks for 90% detection rate of epileptic activity in EEGs. A neural network was used for classification of EEGs [3] with 80% of analytical comments of good quality. Real-time detection of epileptiform activity in EEG records yielded sensitivity of 76% and selectivity of 41% [4]. Smeets [5] reports on software for monitoring antiepileptic drug treatment. The correctness of the system was consistently higher than that of individual neurologists, when the majority decision of the remaining neurologists constituted the standard. Artificial neural networks were used for analysis of long term EEG records with 97% sensitivity and 89.5% selectivity [6]. Siregar [7] reports on software to analyze temporal and spatial EEG data and produce different scenarios of seizure spread.

The early MYCIN system automated bacterial species identification [8]. Fuzzy logic was described [9] and is an important contribution to decision support technology. The PROSPECTOR program used hypothesis analysis to discover mineral deposits [10].

Research work integrating AI and neurology includes a medically-oriented natural language parsing system [11], a prototype Neuro-Anatomic Atlas [12], and development of a stroke diagnosis expert system called the System for Neurologic Analysis of Patient Symptoms (unpublished in our laboratory). Our literature review finds no expert system software for localization of seizure focus given clinical description, imaging, and EEG data.

## 3. Methods

The fundamental technology used in VES is rule-based hypothesis-driven diagnosis. Common Lisp [13] was the development language, the Common Lisp Object System [14] was used for database development, and a logic-programming module, Prolisp, was used to build a library of rules encoding knowledge of the epilepsy surgery evaluation team. The localization hypotheses for which we wrote rules included: mesial temporal lobe, temporal neocortex, occipital lobe, frontal lobe, and parietal lobe. Seizure lateralization can be *left*, *right*, or *unknown*.

### 3.1. Confidence Factors

VES employs the *confidence factor* (CF) for representing a continuum from *false* (0.0) to *true* (1.0). The CF 0.5 represents *unknown*. The numeric representation of truth, falseness, and uncertainty has been investigated extensively [9]. The early MYCIN system employed confidence factors [8]. Scheduling software for the Hubble Space Telescope used numeric values to represent time-specific scheduling suitability [15, 16].

Use of numeric confidence factors supports uncertainty and data quality in our inputs. Operators on confidence factors include *alpha*, *minimum*, *maximum*, and *average*. The alpha function is compensatory and amplifies factors that are close to zero or one [17]. For example, evaluation of (alpha 0.8 0.8) yields 0.94. Alpha, in Lisp, is:

```
 (defun ALPHA (x y)
    (/ (* x y)   (+ (* x y) (* (- 1 x)  (- 1 y)))))
```

### 3.2. Prolog In Lisp (PROLISP)

A logic programming module called *Prolog In Lisp* (PROLISP) has been written by our team in Common Lisp. Based on *Prolog* [18] and *SRI's New Automated Reasoning Kit* [19], Prolisp is a logic programming language that supports rules, facts, unification, and resolution [20]. Prolisp supports the function `(define-rule goal clauses)` where *goal* is the tested hypothesis and *clauses* are sub-goals to be tested in support of the goal. Prolisp supports a *rewrite* mechanism whereby predicates are associated with Lisp functions. The arithmetic function alpha is evaluated using this rewrite facility. A reference to alpha within a rule causes the associated Lisp function alpha-function to be evaluated and the resulting number is substituted for the alpha reference. In Prolisp, rule-resident lexically scoped variables begin with the "?" character. The Prolisp function `(proof goal)` causes the goal to be tested.

Another mechanism supported by Prolisp for accessing Lisp is the *satisfier* mechanism wherein, for a specific predicate, a Lisp function is called that returns a list of patterns for the predicate. The form `(define-satisfier predicate function)` specifies that the `predicate` is associated with a Lisp `function`. For example, given the specification `(define-satisfier 'MRI 'mri-data) and` a reference to the term `(mri ?lobe ?region ?side ?confidence)`, the function `mri-data` is called returning a list `((temporal-lobe mesial right 0.9) (frontal-lobe anterior left 0.3))`. The list provides patterns that can then be targets for unification.

An example Prolisp rule with goal *imaging-locus* is shown here:

```
(define-rule
 '(IMAGING-LOCUS
    ?lobe ?region ?side ?cf)
 '((mri ?lobe ?region ?side ?cf1)
   (pet ?lobe ?region ?side ?cf2)
   (average ?cf1 ?cf2 ?cf))))
```

Running the Prolisp *proof* function yields a proof flag and variable bindings.

```
(proof
 '(IMAGING-LOCUS ?lobe ?region
    ?side ?image-cf))
:PROOF
?LOBE = TEMPORAL-LOBE
?REGION = MESIAL
?SIDE = RIGHT
?CF = 0.9
```

### 3.3. The Database Findings Important For Seizure Surgery

Patient data is stored in files that are loaded thereby creating an object oriented database in memory. The findings that are employed for patient evaluation and seizure focus include MRI findings, PET findings, SPECT findings, clinical seizure semiology, interictal EEG findings, and video electroencephalogram (VEEG) findings. Each of these is described below.

The MRI and SPECT findings are derived from a radiology report and include the anatomic locus, the side, and a confidence factor. The PET finding is derived from a radiologist’s report and includes the anatomic locus, the side, and a confidence factor. In the case of a neoplasm, the PET study may demonstrate hypermetabolism in the area of interest.

Clinical Seizure Semiology. The VEEG long term monitoring evaluation will typically record seizure events and are analyzed by a neurologist. Clinical findings that are important to localization include, but are not limited to, clonic motor [21], head version, paraphasia [22], ictal laughter, focal numbness, and abnormal epigastric sensation [1].

VEEG data. VEEG analysis of seizure events may reveal electrographic abnormalities that are localizing and lateralizing. Key elements from the EEG record are interictal spikes and electrographic seizures (rhythmic abnormalities that are focal and that evolve). The *VEEG onset* and *interictal eeg* findings include lobe, side, frequency, electrode, and amplitude.

Neuropsychological findings are not included in the initial phase of VES.

### 3.4. Explanation Mechanism

Each VES rule includes a clause for accumulating an *explanation tree* that reflects the depth-first deductive pathway of the inference engine. The explanation tree structure can be displayed to clarify the analysis of each anatomic localization hypothesis (ALH). An example is shown below. The label *branch* marks each intermediate sub-goal, the label *leaf* marks each patient finding, CF represents *confidence factor*, and (n) denotes search depth. The function *alpha* is the default combiner for all branches.

```
LOCATION: RIGHT MESIAL TEMPORAL, SCORE: 0.99
 LOBE: TEMPORAL-LOBE
 REGION: MESIAL, SIDE: RIGHT
 CF: 0.99
(1) Branch: IMAGING-LOCATION
    LOBE: TEMPORAL-LOBE
    REGION: MESIAL, SIDE: RIGHT
    CF: 0.84
(2) Leaf: MRI
    LOBE: TEMPORAL-LOBE
    REGION: MESIAL, SIDE: RIGHT
    CF: 0.7
(2) Leaf: PET
    LOBE: TEMPORAL-LOBE
    REGION: MESIAL, SIDE: RIGHT
    CF: 0.7
(1) Leaf: VEEG-ONSET
    ELECTRODE: SP2
    LOBE: TEMPORAL-LOBE
    SIDE: RIGHT
    CF: 0.7
(1) Branch: CLINICAL-FOCUS
    SIDE: RIGHT, CF: 0.99
(2) Branch: ICTAL-FINDINGS
    SIDE: RIGHT, CF: 0.98
(3) Leaf: VERSION
    LOCUS: HEAD, SIDE: LEFT
    CF: 0.8
(3) Leaf: EPIGASTRIC-SENSATION
    CF: 0.9
(2) Branch: POST-ICTAL-LANGUAGE
    SIDE: RIGHT, CF: 0.95
(3) Branch: POST-ICTAL-LANG-RT
```

```
    CF: 0.05, COMBINER: INVERSE
    INVERSE-CF: 0.95
(4) Leaf: PARAPHASIA
    CF: 0.1
(4) Leaf: DYSNOMIA
    CF: 0.3
```

In this explanation tree, the following semantics are represented in the branch labeled "post-ictal-language": The branch represents the sub-hypothesis "after a right hemispheric seizure language is normal." A seizure with right temporal lobe onset may not disturb left sided language areas (e.g., Wernicke's area). The patient finding *paraphasia* has CF of 0.1 (i.e. language abnormalities were not seen). The rule *post-ictal-lang-rt* applies *alpha* to its findings (paraphasia and dysnomia) giving CF 0.05. This rule also contains a logical not (represented by mathematical *inverse*) producing an *inverse-cf* of 0.95. The hypothesis of post-ictal-lang-rt is supported and semantically represents "the absence of language abnormalities supports a right sided seizure." The higher level goal of post-ictal language normality is also, therefore, supported.

### 3.5. Benchmark Files

For the set of anatomic localization hypotheses (ALH's) that have been listed above, benchmark files have been created. Each such file contains a full suite of finding definitions with high certainty confidence factors. The file's definitions will instantiate a findings database from which the VES inference engine may obtain data via the satisfier function definitions. The definitions in each benchmark file should unequivocally lead VES to a specific anatomic locus (e.g., frontal lobe) and lateralization (e.g., left) with an associated strongly positive confidence factor. The benchmark files have guided rule development and are data for system testing. In such testing, each benchmark file should exercise the software as to robustness and yield the same result hypothesis.

### 3.6. Default Values

In the situation wherein a finding is missing, a default finding module is employed. For example, the default finding value for MRI data is computed as follows: If the database query was for a specific anatomic location (e.g., frontal-lobe) and there is no MRI data, then a default MRI finding is provided. The finding will include the same location and side, the data source attribute is set to *default*, and the confidence factor is set to 0.5 (i.e., unknown). A rule that uses this finding will therefore be satisfied and the hypothesis in question will be computed completely. The explanation tree will contain the information that this finding is a default value. The default confidence can be changed to any value (0.0 representing false, for example) to explore different expert system behaviors.

### 3.7. Organization of Video EEG Data

The clinical portion of a seizure is temporally represented in VES as either pre-ictal (before the seizure), ictal (during the seizure), or post-ictal (after the seizure). The ictal portion is defined as starting when the patient's behavior is noted to be different from the baseline. This change may include cessation of prior activity, repetitive grasping, head version (i.e. turning), dystonic posturing, automatisms, lip smacking, etc. The seizure end is marked (by an observer) as the time point when seizure behaviors cease. This point varies in character and may include the patient becoming quiet, the patient becoming responsive to stimuli or questioning, or cessation of convulsion activity.

Correspondingly, VES rules divide the clinical seizure activity into the three segments mentioned above. This representation converts continuous video data into discrete data. This conversion is a first-phase design decision and later phases of this software may be implemented using actual real-time data points. Algorithms and/or rules would then be required to reason over these time associated events and would necessarily be more complex.

In a similar manner to the video data, EEG data (derived from the VEEG recordings) is placed into one of three discrete time regions. These segments are interictal (between seizure events), ictal, and post-ictal. The ictal data is classified as ictal-onset or ictal-evolution. The ictal-onset defines the electrode (e.g., SP2), the frequency (e.g., 6 Hz), and the amplitude (e.g., high) where the electroencephalographer has noted the first electrographic signs of the seizure. Onset data is considered highly important to seizure analysis. Ictal-evolution defines the same parameters for a set of electrodes which later demonstrate seizure activity. Evolution usually occurs a few seconds after onset and represents a transition from onset to the next component of the seizure.

### 3.8. General Purpose Rule Strategy

Development of an AI programming environment (including an object-oriented database, Prolisp, benchmark files, rule encoding techniques, confidence factor use, and explanation facility) has provided a basic structure for VES. Additionally, this software environment will provide tools for other neurological decision support software. These utilities will be used for on-going development of a stroke syndrome expert system, SYNAPS, in our laboratory. Application to other areas of epilepsy research (e.g., seizure classification) is also planned.

### 3.9. VES Rule Library

A library of eight anatomic localization hypothesis (ALH) trees was created using the benchmark files as guiding input data. Fifteen common rules (for processing MRI, PET, SPECT, and EEG data), eight arithmetic rules, six frontal seizure rules, six temporal seizure rules, five parietal seizure rules, and thirteen occipital seizure rules (54 total rules) were written to support this expert system. The VES testing algorithm analyzes inputs (a data file and an anatomic localization hypothesis) and produces outputs (a confidence factor and an explanation tree). Sorting all hypotheses by CF produces the highest scoring ALH.

## 4. Testing

Three data file types (*benchmark*, *control*, and *experimental*) were used for testing. Benchmark files containing data associated with anatomic localization hypotheses for temporal, frontal, parietal, and occipital seizures were written. Five control patient files were tested during rule evolution. Five unblinded patient *control* files were processed using VES.

Twenty three experimental case files were converted to standard file format. The person converting the files was “blind” to the localization associated with each file. No experimental file contains information about the identity or geographical location of the patient. These files were processed by VES software.

## 5. Results

VES selected the correct anatomic localization hypothesis (ALH) for each benchmark file 100% of the time. VES selected the correct diagnosis in 5/5 (100%) control patient files. For experimental files, VES selected the correct lateralization in 23/23 (100%), the correct localization in 18/23 (78%), and localization and lateralization in 18/23 (78%). The results included 3/23 (13%) ties for top score. Correct localization plus ties yields 91%. Incorrect localization occurred in 2/23 (9%). Total run-time was 30 seconds.

In case #3, the expert consensus was left peri-sylvian (frontal/temporal) brain and the plan was to test further with intracranial grid electrodes. VES chooses only one diagnosis (left frontal) which is correct given the two-lobe localization. In case #16 where the diagnosis was parietal lobe, VES produced an incorrect top selection and a 3-way tie for second place that included parietal lobe as one of the localizations. Clinical findings were sparse, EEG data were non-localizing, SPECT data were of low quality, and interictal EEG supported the temporal lobe (the VES selection). The expert opinion on this case was of parietal lobe but further patient studies were required. In case #18, the localization was correct but the temporal lobe regions (mesial vs superior) were tied for first place. In case #22, the experts diagnosed multiple seizure foci and VES selected right mesial temporal. Analysis reveals this selection was based on SPECT data of low confidence. In case #23, VES produced an incorrect answer (frontal lobe). Analysis revealed that a key combination function was *alpha* for the frontal rules and *average* for the temporal rules. Correction (by changing the frontal combiner to average) yielded the correct diagnosis.

## 6. Conclusions

VES was able to process all test files completely and to produce correct results in most cases. The case files contain a high proportion of temporal lobe diagnoses (82%) and this reflects the actual case distribution seen in practice. The software demonstrated lower accuracy of analysis in cases involving parietal and occipital lobes. VES does not support cases where multiple seizure foci are seen. Improvement of rules pertaining to these localizations can improve software behavior.

One case showed that new rules differentiating between mesial and non-mesial temporal localizations are required. Gil-Nagel [23] reports that epigastric aura, early oral automatisms, and aura with experiential content are associated with hippocampal seizures but not extra-hippocampal temporal lobe seizures.

Future development plans include a graphical user interface to enter findings, an interface to display hypotheses and associated confidence factors, an interface to graphically display a selected explanation tree, and an interface to display the brain region selected by the software as a seizure focus. Integration of Bayes’ Rule [24] is also being studied.

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