Development of an Expert System for Distinguishing Headaches from Migraines

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Abstract. We created a program, written in the CLIPS language for expert systems, to distinguish migraines from headaches. The system can be web-based, takes seconds to input data and quickly converges to the correct diagnosis. Over time such an application can result in enormous savings to doctors, patients, and health care institutions.

1. Introduction

1.1 Purpose of the Study

We design and develop a prototype expert system to aid physicians in the diagnosis of migraine headaches. We have included the essential questions and rules that are necessary for building an expert system for distinguishing migraines from other types of headaches. The knowledge acquisition process was facilitated by a physician who served as our domain expert to identify the application's key elements. This application utilizes a data collection form, the C Language Integrated Production System (CLIPS), and a program with the appropriate rules, which are written in the CLIPS language. The front end and middle tier is built, and the connection between the HTML front end and the expert system shell CLIPS is established. We also create an XML representation of the International Classification of Diseases, 9th Revision Clinical Modification (ICD-9-CM), including the disease category 346 (Migraine), and publish it on the Web.

In addition, we make recommendations for a specific configuration based upon the prototype's capabilities and performance, summarize our findings, and identify opportunities for future work.

1.2 Background and Significance/Justification

Headaches in a variety of forms are one of the most common areas of complaint presented to the clinician. The International Headache Society has proposed a classification scheme for headaches; but the rules to diagnose migraines seem to be oversimplified [1, 2]. A web-enabled application to distinguish between migraines and headaches, using more sophisticated rules, could provide physicians and patients with a powerful diagnostic tool. Access to a well-established knowledge base could help to reduce potential errors in migraine diagnoses.

The CLIPS expert system shell provides a cohesive tool for handling a wide variety of knowledge with support for three different programming paradigms: rule-based, object-oriented and procedural. Rule-based programming allows knowledge to be represented as heuristics, or "rules of thumb," which specify a set of actions to be performed for a given situation. CLIPS can be embedded within procedural code, called as a subroutine, and integrated with languages such as C and Java. CLIPS can easily be extended by a user

through the use of several well-defined protocols, and it can be implemented in web-based applications using the Common Gateway Interface (CGI) bin or Java servlets.

1.3 Hypothesis

This application involves the design and development of an expert system to aid physicians in the diagnosis of migraine headaches. This study will explore the potential of such a system to reduce the incidence of diagnostic errors that can occur in this domain.

1.4 Programming

The research application prototypes were developed on both UNIX and Windows platforms using the following techniques: data mining, on-line transaction and analytical processing. Open source and freeware tools such as Java, MySQL database, Apache Web server, C Language Integrated Production System (CLIPS) Expert System shell were used in the development process.

The Migraines / Headaches Application: We created the program, written in the CLIPS language for expert systems, and studied the execution time depending on the number of questions and migraine types. A Java extraction transformation loading (ETL) procedure was used to transform the source text file into an XML file. It was then utilized to build the XML representation of the original International Classification of Diseases, 9th Revision, Clinical Modification (ICD-9-CM). The Migraines and Headaches Application Form Revision 1.1.3 was developed and published on the Web. The Perl script *simple-form.cgi* takes the input from a form, sends it to a specified email address, appends information to the XML file and returns a confirmation page. An example of CLIPS-to-HTML connection written in the C language was developed and published on the Web. An example of the interaction between Java and CLIPS that utilizes Java Native Interface (JNI) is presented in Appendix B.

2. Requirements Analysis and System Design

2.1 Introduction and Preliminary Investigation Phase

The prototype application for classification should be web-enabled, and designed separately for physicians and patients. These were identified as fundamental requirements. It was also decided that users should be able to insert and retrieve information in a simple way. The future integration of this application to another system, such as a medical errors database or another expert system, was also identified in the requirements discovery phase.

2.2 Software Requirements Analysis Phase

An expert system can be considered as an environment for the construction of the application's middle tier and back end. The system should be able to handle a wide variety of knowledge, preferably, with support for different programming paradigms: rule-based, object-oriented and procedural. Rule-based programming allows knowledge to be represented as heuristics, which specify a set of actions to be performed for a given situation. Object-

oriented programming allows complex systems to be modeled as modular components, which can be easily reused later. The procedural programming capabilities are similar to capabilities found in languages such as C.

An Expert System Shell should include a number of features to support the verification and validation of expert systems, including support for modular design and partitioning of a knowledge base, static and dynamic constraint checking of slot values and function arguments, and semantic analysis of rule patterns to determine if inconsistencies could prevent a rule from firing or generate an error. The application should have an option to be embedded within procedural code, called as a subroutine, and integrated with languages such as C or Java.

The software should provide an interactive, text oriented development environment, including debugging aids, on-line help, and an integrated editor. The tool should provide a short response time even for robust pattern matching capabilities.

We prefer the software to be portable, i.e., having the ability to be installed on many different operating systems without code changes. Low maintenance cost, availability of training classes and companies providing consulting services, should also be considered for the long-term project.

2.3 Decision Analysis Phase

We decided to create an application to distinguish between migraines and other headaches using more sophisticated rules. These rules were represented in the CLIPS expert system shell. CLIPS is a product development and delivery expert system tool which provides a complete environment for the construction of rule and/or object based expert systems [3].

3. Methodology

3.1 Migraines / Headaches Application

We designed and developed a prototype expert system to aid physicians in the diagnosis of a migraine. The web-enabled XML files were created as a repository of International Classification of Diseases, 9th Revision, Clinical Modification (ICD-9-CM). A fragment of the ICD-9-CM for the disease category 346 (Migraine) classifications is available in Appendix B, Figure B.2. The complete ICD-9-CM List of Three Digit Categories (Financial Year 2004) is also available on the Web (http://acc4.its.brooklyn.cuny.edu/~gshagas/).

CLIPS is a productive development and delivery expert system tool that provides a complete environment for the construction of rule and/or object-based expert systems [3]. We started from a simple rules implementation in the CLIPS language (see Appendix B, Section 1(a)). However, the strategic goal is to create a self-learning program, based on an expert system, which can collect and analyze all patient data.

The application is intended primarily for physicians, but patients could use a modified version. This could be both an online and stand-alone application. Once the point of a "self-learning program" is achieved, the online approach is better for new data collection and updating rules. The program itself can dynamically generate the forms. The graphic user interface (GUI) and presentation layer are written in HTML and JavaScript, while the Application and data manipulation layers are written in Common Gateway Interface (CGI) Perl script (see Appendix B, Figure B.1.) In our present implementation, data is collected in

the XML format as a file for future analysis and sent by e-mail (see Appendix B, Figures B.1, B.3 and B.4).

Paper forms are not required, but this could be an option for people without access to a computer. First, data should be validated and corrected, if necessary.

We identified a total of 23 questions (see Appendix B) for the Migraines form. We dealt with a total of 20 types of migraines, identified by ICD-9-CM classification. The answers from six patients, diagnosed with migraines, were obtained by interviewing. The data was entered directly using an existing CLIPS interface (see Appendix B).

4. Findings

4.1 Results: The Migraines / Headaches Application

The Migraines Applications latest form, revision 1.1.5, is available in Appendix B (Figures B.2, B.3). The Perl script *simple-form.cgi* takes the input from a form, formats it and sends it to a specified email address, appending information to the XML file and returning a confirmation page.

We would expect to deal with a total of 20 types of migraines, identified by ICD-9-CM classification. Part of our research was performed on a subset of questions and types of migraines. These simplifications are necessary to create a prototype of the expert system for migraines, test the rules and performance, and extend it later. We also introduced additional complexity into the CLIPS rules to increase accuracy of migraine diagnosis. By increasing the number of questions to 50 (expected in the future) we can further check the performance of a web-based application.

We selected only 10 of these questions for our research, and created the appropriate program. From the 20 known types of migraines we randomly selected 14 types. The rules we created are based on existing criteria [1, 2]; however, we introduced additional artificial dependencies for the purpose of testing system performance. The certainty of each diagnosis is calculated by three parameters; these parameters are chosen by the program according to certain rules related to the answers given (see Appendix B, Section 1(a)).

Some of the questions could be omitted according to the rules. The questions and the patients' answers are presented in Table 1. For example, question 3 will appear only if the answers to question 1 "Age (in years)?" is "0-29" and to question 2 "Your gender?" is "female." Question 3 "Does your headache occur during menstruation, ovulation, menopause or oral contraceptives?" is relevant for certain age and gender only. In the same way, question 8 "Does nausea accompany your headache?" will not be asked if the answer to Question 7 "Does vomiting accompany your headache?" is "yes." According to the IHCC rules, the presence of "either vomiting or nausea," which may accompany headache, is essential for diagnosis [4]. That is to say, if the answer to Question 7 is "yes" (there is vomiting) then there's no need to ask question 8 "Does nausea accompany your headache?" These rules are not comprehensive, but comprise a minimal set with which we hope will illustrate the prototype's functionality. For example, question 6 "Pain interferes significantly with school activity" is unlikely to be answered "yes" by patient number 4, who is at least 70 years old. The user's dialog with the CLIPS application is presented in Appendix B, Section 3. Here we presented only ten questions, and we are currently working on the comprehensive program containing the set of all available questions and rules. For example, the question "Does your headache BEGIN on left side?" does not appear.

Table 1 Migraine Expert System Questions and Answers (cases 1… 6)

#	Question	Answers for case					
		#1	**# 2**	**# 3**	**# 4**	**# 5**	**# 6**
1	Age (in years)?	0-29	30-49	50-69	70-up	0-29	50-69
2	Gender?	female	male	female	male	male	female
3	Does your headache occur during menstruation, ovulation, menopause or oral contraceptives?	yes	-	-	-	-	-
4	Does your headache BEGIN on right side?	yes	yes	no	yes	no	no
5	How does your headache feel?	dull	aching	throbbing	unknown	aching	dull
6	Does pain interfere significantly with school activity*	yes	no	no	no	no	no
7	Does vomiting accompany the headache?	no	yes	no	yes	yes	no
8	Does nausea accompany the headache?	yes	-	no	-	-	no
9	The number of headaches per month?	0-2	6-9	10-19	0-2	3-5	6-9
10	Can your headache be triggered by certain foods, odors, stress or weather changes?	yes	no	yes	no	no	yes

***Note:** School would apply to an adolescent or young adult in graduate school.

Another example of this is patient number 1, who is diagnosed with three types of migraines (see Table 2). The certainty of Horton's neuralgia is highest (88%), and for the atypical migraine is lowest (40%). Missing values for the other 11 types of migraines indicate that the certainty of such types is negligible. We narrowed 14 * 6 = 84 possible diagnoses for six patients down to 3+11+8+13+7+4 = 48 possible diagnoses, for a reduction of (84-48) / 84 = 43%.

The results from the CLIPS system are presented below:

Table 2 Certainty of a Specific Diagnosis for Various Cases

#	ICD-9 Code	Migraine description	Certainty for each Case Number (%)					
			#1	**# 2**	**# 3**	**# 4**	**# 5**	**# 6**
1	346.0.1	Migraine preceded by ...	-	40	92	36	-	40
2	346.0.2	Migraine with aura	-	-	-	20	20	-
3	346.1.1	Atypical migraine	40	-	-	20	20	-
4	346.1.2	Sick Headache	-	36	36	59	20	-
5	346.2.1	Cluster headache	64	20	-	36	-	-
6	346.2.2	Histamine cephardia	-	36	36	59	-	40
7	346.2.3	Horton's neuralgia	88	20	20	20	-	80
8	346.2.4.1	Migraine abdominal	-	20	-	36	-	-
9	346.2.4.2	Migraine basilar	-	76	-	76	76	-
10	346.2.4.3	Migraine lower half	-	40	40	68	40	-
11	346.2.4.4	Migraine retinal	-	40	-	68	40	-
12	346.2.5	Neuralgia	-	40	40	20	-	-
13	346.2.8.1	Migraine hemiplegics	-	-	97	-	-	80
14	346.9	Migraine, unspecified	-	40	40	68	40	-

Another aspect of our research was related to the performance of the application. We identified 23 questions necessary to build the expert system. We expect to improve the precision of the system by adding finer questions, leading to a total for about 50. We also

analyzed the execution time as a function of the number of additional questions and migraine types. Additional complexity was added to the CLIPS rules, by increasing the number of questions to 25 (close to the current number 23) and 50 (the expected number in the future). The number of migraine types also varied from 5 (the most common migraine cases) to 20 (the comprehensive migraine classification). These questions and rules were randomly chosen from existing ones and were included in the artificial rules file. We learned that the execution time depends on the number of Migraine types embedded into the expert system, and ranges from 3 to 17 seconds (see Figure 1).

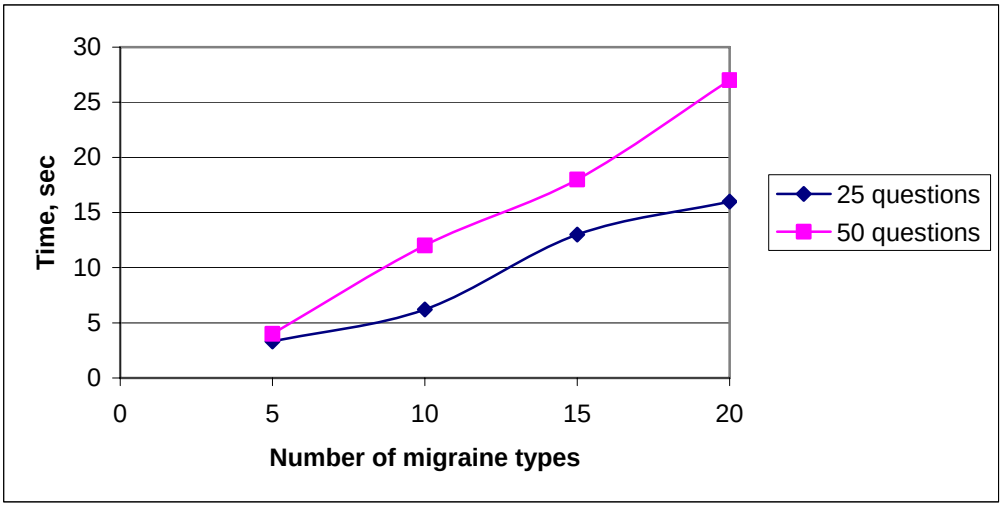

Figure 1 Time of CLIPS procedure

We could evaluate the benefits of the Migraine application by the following estimation. Let's consider that the typical physician can perform one patient assessment over 30 minutes. A physician could select multiple symptoms and then reduce by 43 % (see Table 2) the possible number of diagnoses generated by the expert system according to the symptoms selected. This procedure would require about 1 minute entering the data and executing the expert system. We estimate that such procedure could save (a) 5 minutes for the doctor, (b) more than 5 minutes for the patient, and (c) reduce the time spent on physical exam and laboratory tests. We can then estimate that such procedures, given today's medical cost and given the liklihood that this approach can help to reduce medical errors, the savings, when cumulated over time and millions of patients, could be enormous.

4.2 Discussion and Recommendations: The Migraines / Headaches Application

We designed and developed a prototype expert system to aid physicians in the diagnosis of a migraine. Our research in the area shows that the data can be analyzed using Perl, C, or Java methods and procedures. However, once rules become complicated, an Expert System Shell should be considered.

Physician could select multiple symptoms and then narrow down by 50 % (see Table 4.4) the possible diagnoses made by the expert system according to the symptoms selected. This procedure required 1 minute to enter the data and execute. We estimate, that such improvements in efficiency could save (a) 5 minutes for the doctor, (b) more than 5 minutes for the patient, and (c) reduce time spent on physical exam and laboratory tests. The execution time could be decreased by using other expert shells, such as Gensym

Corporation's G2 expert system, GENESYS, EXSYS, XpertRule from Attar Software Limited, Fair Isaac Blaze Decision System etc.

The German Migraine and Headache Society (DMKG) estimated, that a headache could be caused by more than 110 diseases [5]. This fact indicates the inherent complexity of the comprehensive Migraines / Headaches Application.

5. Summary

We created a program, written in the CLIPS language for expert systems, to distinguish migraines from headaches. We have identified 23 essential questions that are necessary for building an expert system that distinguishes migraines from headaches. The execution time depends on the number of migraine types embedded in the expert system. The time varies from 3 seconds for the five most common migraine cases to 17 seconds for the entire set of 20 types of migraine according to the ICD-9-CM classification. We also created an XML representation of the International Classification of Diseases, 9th Revision Clinical Modification (ICD-9-CM), including disease category 346 (Migraines), and published it on the Web.

References

[1] Olesen, J. *Classification and diagnostic criteria for headache disorders, cranial neuralgia, and facial pain.* Cephalalgia Headache Classification Committee of the International Headache Society. (1988); 8 (suppl 7):1-96. Available: http://www.i-h-s.org.

[2] Troost, T. M.D. *Migraine and other Headaches,* Wake Forest University School of Medicine (2002). Available: http://imigraine.net/migraine/intro.html

[3] GHG Internet Services, *CLIPS, A Tool for Building Expert Systems,* Available: http://www.ghg.net/clips/CLIPS.html [June 2003].

[4] International Headache Classification Committee (IHCC*). ICD-10 guide for headaches.* International Headache Classification Committee. Cephalalgia 1997; 17(suppl 19): 1-82 .

]5] Deutsche Migräne- und Kopfschmerz-Gesellschaft e.V. / DMKG. *ICD 10 Liste aller klassifizierten Kopfschmerzsyndrome.* (February 2002). Available: http://www.dmkg.de/fortbild/icd.htm.

Appendices

Appendix B. Migraines and Headaches Application.

Section 1. Migraine Application Schema and GUI

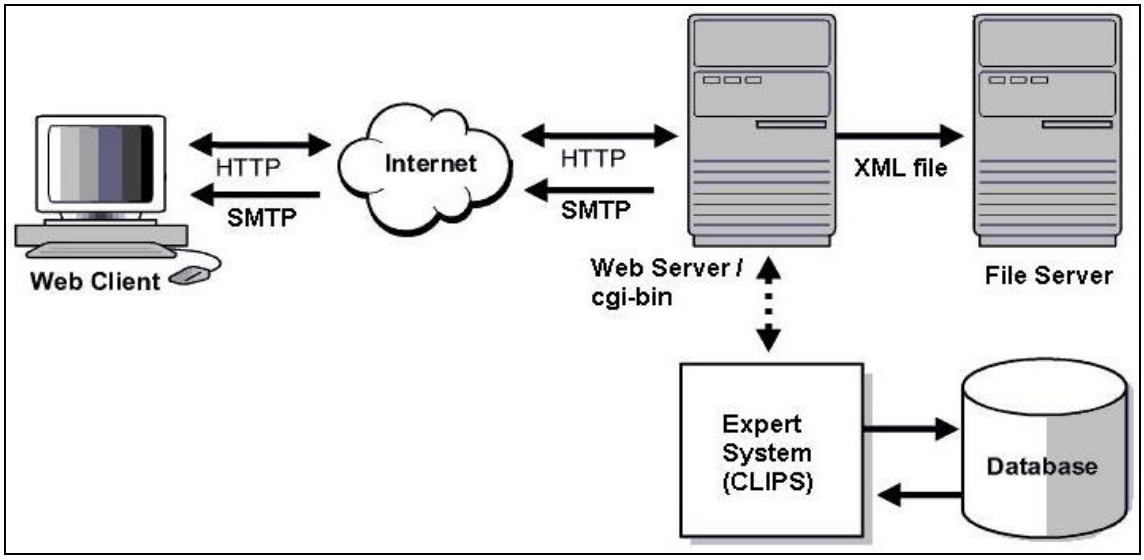

Figure B.1. The Migraine / Headaches Application Schema

```
<?xml version="1.0" encoding="UTF-8" ?>
- <ICD-9-CM>
  - <topic name="Classification of Diseases and Injuries">
      <group number="1">Infectious and Parasitic Diseases</group>
      <group number="2">Neoplasms</group>
      <group number="3">Endocrine, Nutritional, and Metabolic Diseases and Immunity
        Disorders</group>
      <group number="4">Diseases of the Blood and Blood-Forming Organs</group>
      <group number="5">Mental Disorders</group>
    - <group number="6">
        Diseases of the Nervous System and Sense Organs
      - <diseases numbers="340-349">
          <diseasesclass>Other disorders of the central nervous system (340-349)
            </diseasesclass>
        - <category id="346">
            <categoryname>Migraine</categoryname>
          - <subcode id="346.0">
              <subcodename>Classical migraine</subcodename>
              <disease id="346.0.1">Migraine preceded or accompanied by transient focal
                neurological phenomena</disease>
              <disease id="346.0.2">Migraine with aura</disease>
            </subcode>
          - <subcode id="346.1">
              <subcodename>Common migraine</subcodename>
              <disease id="346.1.1">Atypical migraine</disease>
              <disease id="346.1.2">Sick headache</disease>
```

Figure B.2. International Classification of Diseases (ICD-9-CM) (Fragment)

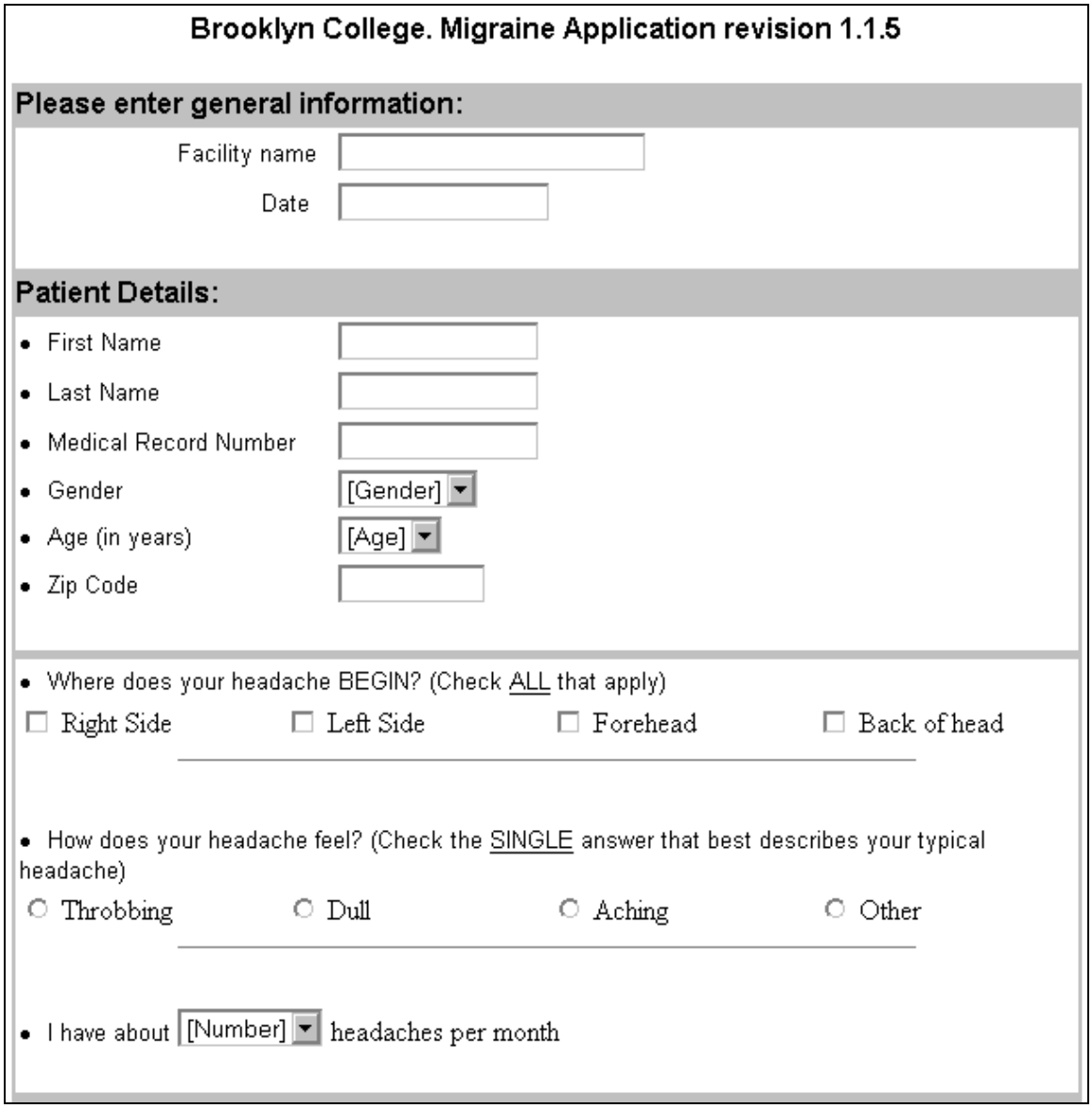

Figure B.3. Migraine Application HTML Form (Fragment – upper part)

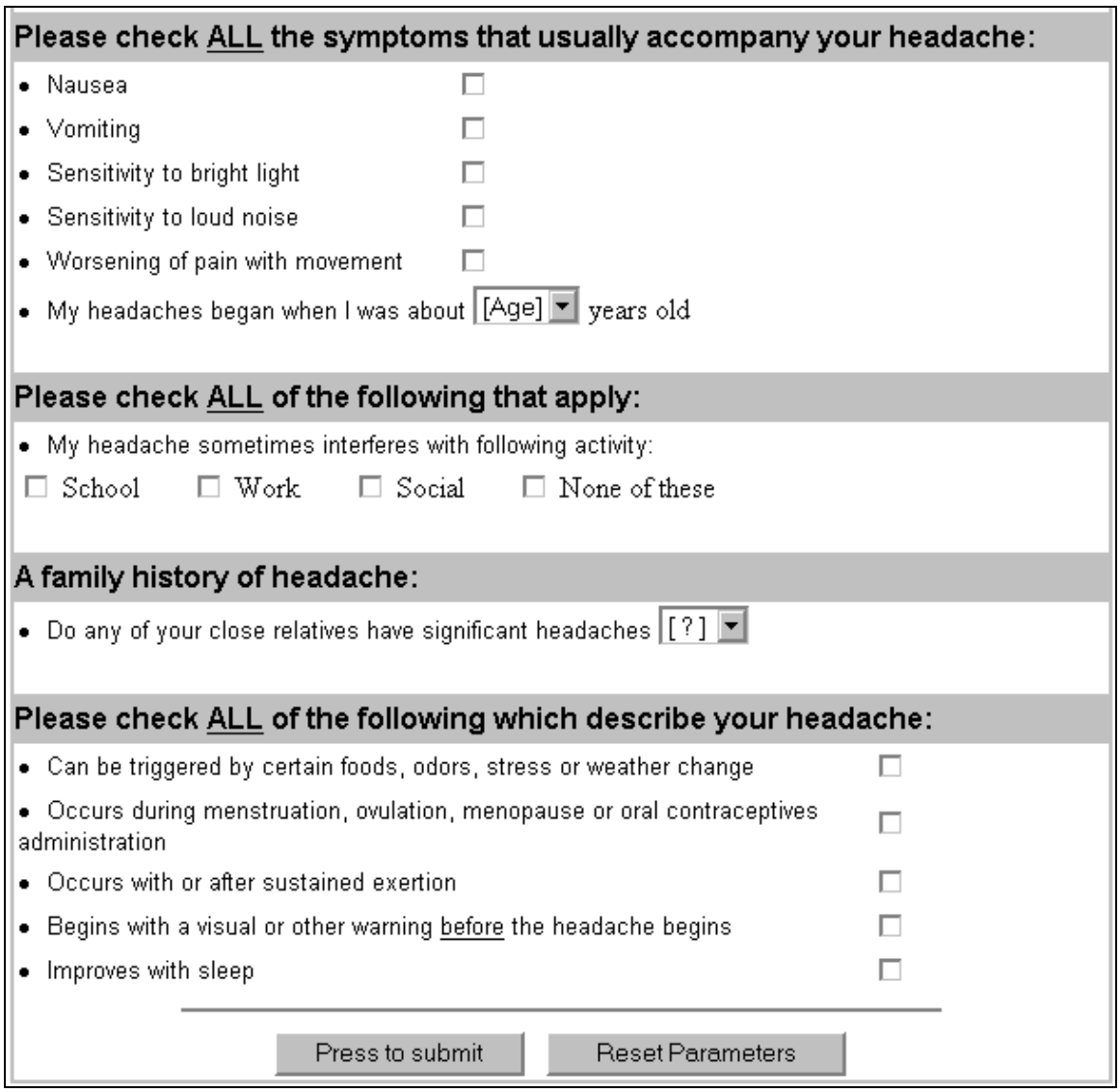

Figure B.4. Migraine Application HTML Form (Fragment – lower part)

Note 1. Most of the questions are based on the identification of headache syndromes in accordance with the International Headache Society (HIS) or the World Health Organization's International Classification of Diseases (ICD-10).
Note 2. School would apply to an adolescent or young adult in graduate school.

Section 3. Patients' interaction with CLIPS system

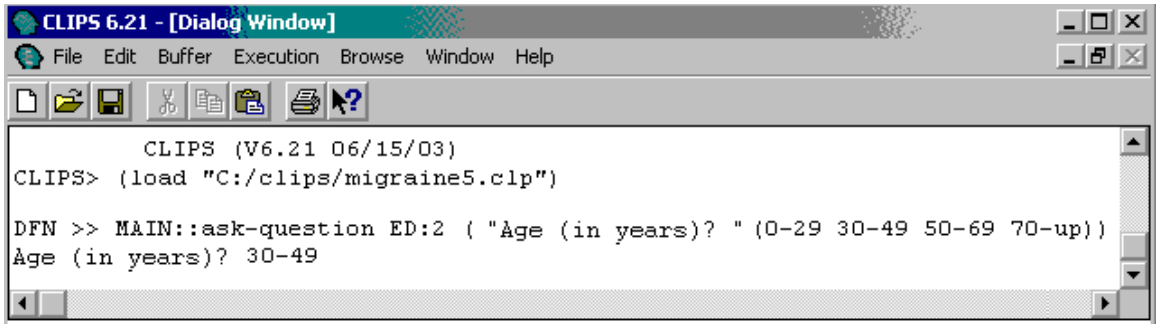

Figure B.5. User's dialog with CLIPS application (fragment)

The answers from six patients, diagnosed with migraine, were obtained by interviewing. The data was entered directly using an existing CLIPS interface. Patients' potential diagnoses are presented in Chapter 4.1.2, Table 4.4.

Patient # 1 dialog with CLIPS system:

"Age (in years)?" (0-29 30-49 50-69 70-up)) /* valid answers, see Figure B.5 */
Age (in years)? 0-29

Gender? (male female)
Gender? female

Does your headache occur during menstruation, ovulation, menopause or oral contraceptives? (yes no)
Does your headache occur during menstruation, ovulation, menopause or oral contraceptives? yes

Does your headache BEGIN on right side? (yes no)
Does your headache BEGIN on right side? yes

How does your headache feel? (throbbing dull aching other unknown)
How does your headache feel? dull

Does pain interfere significantly with school activity? (yes no)
Does pain interfere significantly with school activity? yes

Does vomiting accompany your headache? (yes no)
Does vomiting accompany your headache? no

Does nausea accompany your headache? (yes no)
Does nausea accompany your headache? yes

The number of headaches per month? (0-2 3-5 6-9 10-19 20-up)
The number of headaches per month? 0-2

Can your headache be triggered by certain foods, odors, stress or weather changes? (yes no)
Can your headache be triggered by certain foods, odors, stress or weather changes? yes

Patient # 2:
Age (in years)? 30-49
Gender? male
Does your headache BEGIN on right side? yes
How does your headache feel? aching
Does pain interfere significantly with school activity? no
Does vomiting accompany your headache? yes
The number of headaches per month? 6-9
Can your headache be triggered by certain foods, odors, stress or weather changes? no

Patient # 3:
Age (in years)? 50-69
Gender? female
Does your headache BEGIN on right side? no
How does your headache feel? throbbing
Does pain interfere significantly with school activity? no
Does vomiting accompany your headache? no
Does nausea accompany your headache? no
The number of headaches per month? 10-19
Can your headache be triggered by certain foods, odors, stress or weather changes? yes

Patient # 4:
Age (in years)? 70-up
Gender? male
Does your headache BEGIN on right side? yes
How does your headache feel? unknown
Does pain interfere significantly with school activity? no
Does vomiting accompany your headache? yes
The number of headaches per month? 0-2
Can your headache be triggered by certain foods, odors, stress or weather changes? no

Patient # 5:
Age (in years)? 0-29
Gender? male
Does your headache BEGIN on right side? no
How does your headache feel? aching
Does pain interfere significantly with school activity? no
Does vomiting accompany your headache? yes
The number of headaches per month? 3-5
Can your headache be triggered by certain foods, odors, stress or weather changes? no

Patient # 6:
Age (in years)? 50-69
Gender? female
Does your headache BEGIN on right side? no
How does your headache feel? dull
Does pain interfere significantly with school activity? no
Does vomiting accompany your headache? no
Does nausea accompany your headache? no
The number of headaches per month? 6-9
Can your headache be triggered by certain foods, odors, stress or weather changes? yes